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2017 TOC and Index

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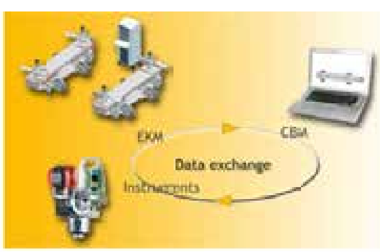

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Phone: +49 351 44 55 491 Fax: +49 351 44 55 540

Contact: sales@ast.de

2016 LMOA MVP RECIPIENTS

The executive board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable People of their respective committees in 2016.

NAME	COMMITTEE
Jason Fox	Diesel Electrical Maintenance
Brady Calvert	New Technologies
Greg Wilson	Diesel Mechanical Maintenance
Joshua Soles	Fuel, Lubricants and Environmental
Michael Hartung	Diesel Material Control

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

LMOA EXECUTIVE COMMITTEE

The LMOA Executive Board wishes to thank the CSX for hosting our annual joint technical committee meeting in Jacksonville, Florida on May 8 and 9, 2017.

They provided meeting rooms and AV equipment to facilitate our meetings. Special thanks to Brian Barr, Yousef Abdel Moty and Shanette Crennel for making all the arrangements and for providing lunch. We greatly appreciate their support. We also wish to thank our 2nd Vice President and retired CSX, Mike Drylie, for being such an important liaison in ensuring that these meetings went off without a hitch.

LMOA would also like to extend their appreciation to Larry Biess and Reliable Rail for setting up a tour of the facility in Green Cove Springs, FL where CSX locomotives are undergoing extensive work.

The Executive Board of the Locomotive Maintenance Officers Association would like to express their deep and sincere gratitude and appreciation to LMOA 1st Vice President Dwight Beebe of Temple Engineering for sponsoring an Executive Committee meeting and luncheon at the Omaha Hilton on Tuesday, October 4, 2016.

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

PAST PRESIDENTS

1939 & 1949	F.B. DOWLEY (Deceased) Shop Supt., C. & O. Ry.
1941	J.C. MILLER (Deceased) MM, N.Y.C. & St. L.R.R.
1942-1946, Inc.	J.E. GOODWINN (Deceased) Exec. Vice President, C. & N.W. Ry.
1947	S.O. RENTSCHILLER (Deceased) Chief Mechanical Officer, Bessemer and Lake Erie R.R.
1948	C.D. ALLEN (Deceased) Asst. C.M.O. - Locomotive, C. & O. Ry. & B. & O. R.R.
1949	J. W. HAWTHORNE (Deceased) Vice-Pres.- Equipment, Seabord Coast Line R.R.
1950	G.E. BENNET (Deceased) Vice-Pres.- Gen, Purchasing Agent, C. & E. I. Ry.
1951	P.H. VERD (Deceased) Vice-Pres.- Personnel, E. J. & E. Ry.
1952	H.H. MAGILL (Deceased) Master Mechanic, C. & N. W. Ry.
1953	S.M. HOUSTON (Deceased) Gen. Supt. Mech. Dept. Southern Pacific Co.
1954 & 1955	F.D. SINEATH, Retired Chief of Motive Power, Seabord Coast Line R.R.
1956	T.T. BLICKLE (Deceased) General Manager-Mechanical, A.T. & S.F. Ry.
1957	J.T. DAILEY (Deceased) Asst. to Pres.-Mech., Alton & Southern R.R.
1958	F.E. MOLLOR (Deceased) Supt. Motive Power, Southen Pacific Co.
1958	F.R. DENNY (Deceased) Mechanical Supt., New Orleans Union Passenger Terminal
1959	E.V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry.
1960	W.E. LEHR (Deceased) Chief Mechanical Officer, Pennsylvania R.R.
1961	O.L. HOPE (Deceased) Asst. Chief Mechanical Officer, Missouri Pacific R.R.
1962	R.E. HARRISON (Deceased) Manager-Maintenance Planning & Control, Southern Pacific Co.
1963	C.A. LOVE (Deceased) Chief Mechanical Officer, Louisville & Nashville R.R.
1964	H.N. CHASTAIN (Deceased) General Manager-Mechanical, A.T. & S.F. Ry.
1965	J.J. EKIN, JR. (Deceased) Supt. Marine & Pier Maintenance, B. & O. R.R.
1966	F.A. UPTON II (Deceased) Asst. Vice-President-Mechanical, C.M. St. P. & P. R.R.
1967	G.M. Beischer, Retired Chief Mechanical Officer, National Railroad Passenger Corp. Washington, D.C. 20024
1968	G.F. BACHMAN (Deceased) Chief Mechanical Officer, Elgin Joliet & Eastern Ry.
1968	T.W. BELLHOUSE (Deceased) Supt. Mechanical Dept., S. P. Co., - St. L. S.W. Ry.
1970	G.R. WEAVER (Deceased) Director Equipment Engineering, Penn Central Co.
1971	G.W. NEIMEYER (Deceased) Mechanical Superintendent, Texas & Pacific Railway
1972	K.Y. PRUCHNICKI (Deceased) General Supervisor Locomotive Maintenance, Southern Pacific Transportation Company
1973	W.F. DADD (Deceased) Chief Mechanical Officer, Chessie System
1974	C.P. STENDAHL, Retired General Manager, M.P.-Electrical, Burlinton Northern Railroad
1975	L.H. BOOTH (Deceased) Retired Assistant C.M.O.-Locomotive, Chessie System
1976	J.D. SCHROEDER, Retired Assistant C.M.O.-Locomotive, Burlinton Northern Railroad, 244 Carrie Drive, Grass Valley, CA 95942
1977	T.A. TENNYSON (Deceased) Asst, Manager Engineering-Technical, Southern Pacific Transportation Co.
1978	E.E. DENT (Deceased) Superintendent Motive Power, Missouri Pacific Railroad
1979	E.T. HARLEY, Retired Senior Vice President Equipment, Trailer Train Company, 289 Belmont Road, King of Prussia, PA 19406
1980	J.H.LONG (Deceased) Manager-Locomotive Department, Chessie Systems
1981	R.G.CLEVENGER, Retired, General Electrical Foreman, Atchison, Topeka & Santa Fe Rwy

1982 N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
1983 F.D. BRUNER (Deceased), Asst. Chief Mechanical Officer, R&D, Union Pacific RR
1984 R.R.HOLMES (Deceased), Director Chemical Labs & Environment, 600 Brookestone Meadows Place, Omaha, NE 68022
1985 D.M.WALKER, Retired, Asst. Shop Manager, Norfolk Southern Corp, 793 Windsor St, Atlanta, GA 30315
1986 D.H.PROPP, Retired, Burlington Northern RR, 10501 W. 153rd St, Overland Park, KS 66221
1987 D.L.WARD (Deceased), Coordinated-Quality Safety & Tech Trng, Burlington Northern RR
1988 D.G. GOEHRING, Retired, Supt. Locomotive Maintenance, National RR Passenger Corp, 1408 Monroe, Lewisburg, PA 17837
1989 W.A.BROWN, Retired, I&M Rail Link, 9047 NE 109th St. Kansas City, MO 64157
1990 P.F.HOERATH, Retired, Sr. Mech. Engr. Shop, Conrail 1534 Frankstown Rd, Hollidaysburg, PA 16648
1991 D.D.HUDGENS, Retired, Sr Mgr R&D, Union Pacific, 16711 Pine St., Omaha, NE 68130
1992 K.A.KELLER, Retired, Supt. Locomotive Maint, Reading RR, 241 E. Chestnut, Cleona, PA 17042
1993 W.R.DOYLE, Commuter Rail Transportation Superintendent, Sound Transit, Seattle, WA 98104
1994 M.A.COLES, Retired, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
1995 C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
1996 G.J.BRUNO, Retired, Supt.-Mechanical, Amtrak 14142 S.E. 154th Pl, Renton, WA
1997 D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
1998 H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
1999 JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak, 25531 NE 138th St., Salt Springs, FL 32134
2000 RON LODOWSKI, Retired Production Mgr, CSX Transportation, Selkirk, NY 12158
2001 LOU CALA, Retired, Duncansville, PA 16635
2002 BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
2003 BRIAN HATHAWAY, Consultant, Port Orange, FL 32129
2004 BILL LECHNER, Retired, Sr Genl Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp, Altoona, PA 16601
2005 TAD VOLKMANN, Director-Mech. Engrg., Union Pacific RR, Omaha, NE 68179
2006 BRUCE KEHE, Retired, CMO, CSS&SB, Michigan City, IN 46360
2007 LES WHITE, Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
2008 MIKE SCARINGE (Deceased), Director-Locomotives, Amtrak, Beech Grove, IN 46109
2009 DENNIS NOTT, Northwestern Consulting, Boise, ID 83703
2010 BOB REYNOLDS, Sales Manager, Amglo Kemlite Laboratories, Calgary, Alberta T24 2V8
2011 JACK KUHNS, 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
2015 BOB HARVILLA, VP-Sales, PowerRail Distribution, Duryea, PA
2016 STUART OLSON, Sales Director-Infrastructure, Wabtec Corporation, Alpharetta, GA

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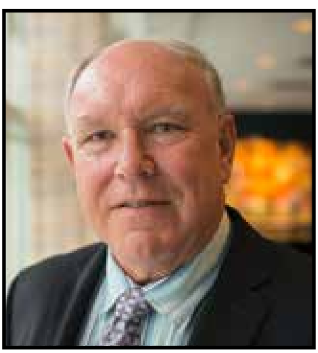
Manager-Locomotive Engineering-RETIRED
Norfolk Southern Corporation
Roanoke, VA

1st Vice President
DWIGHT BEEBE
Temple Engineering
Liberty, MO



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CSX Transportation
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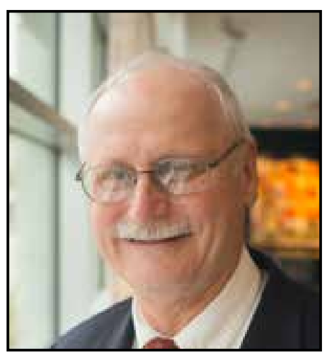

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Boise, ID

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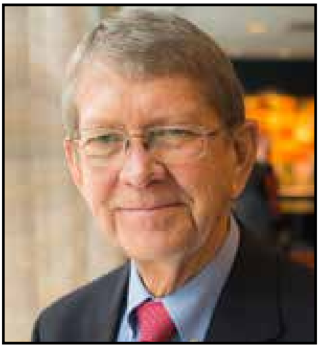

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Wabtec Corporation
Alpharetta, GA

BOB REYNOLDS
Sales Representative
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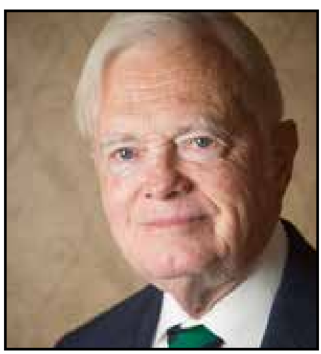
Largo, Florida



ROBERT RUNYON
Norfolk Southern Corporation-RETIRED
Engineering Consultant
Roanoke, VA

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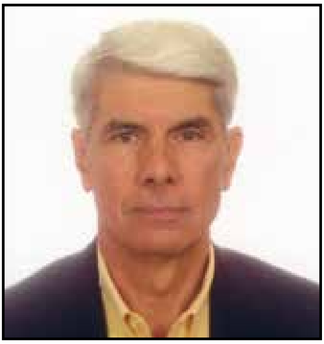
President
JAB Rail Services
East Wakefield, NH

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

LES WHITE
Application Specialist
Bach Simpson
London, Ontario

Our Regional Executives



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Morgan Advanced Materials/National
Greenville, SC

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Global Railroad Technical Liaison
Chevron Oronite
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Omaha, NE

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Manager-Training & Development
ZTR Control Systems
London, Ontario Canada

BILL PETERMAN
DIRECTOR-RAIL OPERATIONS
BP Railway Services
Pierre Fonds, Quebec Canada

2016 State of the Union Address

T. Stuart Olson
Monday, October 3, 2016
1:30 P.M.

Ladies and Gentlemen, members of the Executive Committee, Mr. Secretary, all Committee Members, and fellow LMOA members, I thank you for the privilege and honor of serving as President of this Association for the 2015 – 2016 term. It has been humbling to follow in the footsteps of so many.

Welcome to the RSI/CMA 2016 Rail Expo & Technical Conference. In particular, welcome to the 2016 LMOA Technical Sessions here in Omaha. Thank you all for attending this morning and this afternoon. We think you will find all the technical presentations interesting and most of all useful to you in your career as railroader or supplier. We trust you have found the morning sessions by New Technologies, Diesel Electrical Maintenance and Shop Safety, Practices and Equipment Committees both interesting and useful.

I will now take a few minutes to give you my perspective on the current state of our organization.

We have 216 people registered for this session – 49 Railroad; 18 Foreign and 149 Associates - not too bad for a year with no outside exhibits and the current economic conditions. As a comparison, at the last Convention we had a total of 209. As always we want to grow our membership and our value to the industry. An interesting thing to note is that the Coordinated Mechanical Associations has five member organizations. All five are meeting here in Omaha at this time. LMOA represents about 40% of all participants that were preregistered.

When accepting the office of President last year I felt a need to remind all of us of the stated objectives of LMOA. I want to do that again and now paraphrase from our current constitution and by-laws: **"The purpose of the Association shall be to improve the interest of its members through education, to supply locomotive maintenance information to employers, to exchange knowledge and information with members of the Association, and to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad Industry."**

We all have many challenges we must meet each day. Those challenges are often complicated by the people we work with; the industry we serve and the world in which we live. LMOA is no different. We have been challenged to provide information on a timelier basis; to become more aligned with railroad Mechanical and Supply Chain Management concerns and to be sure we bring real value to our constituents. We have been challenged to change as our world changes.

We discussed these challenges briefly at our closing executive meeting last October in Minneapolis. One of our first opportunities to hear more about these concerns came in early 2016. A group of us attended a meeting at CSX with their three Chief Mechanical Officers and was generally advised that they found it difficult to support LMOA due to other demands on their personnel and the value received from Committee participation. That meeting further elevated our concern. So, we conducted a Survey Monkey questionnaire of all members to get feedback – we had good responses and it became even more apparent that we must do something with our organization to bring greater value to members and our industry. Shortly after the Survey Monkey exercise we began to openly discuss these challenges at our 2016 Joint Technical Committee sessions held in Roanoke, VA. At that time we talked with each committee about the concerns we had heard from various Class 1 and Short Line RR's regarding their participation and the value received. Soon after we were asked to attend a Joint CMO meeting in Omaha in mid-May. Their objective for inviting us was to initiate a dialogue with LMOA regarding how to better serve the railroad community. Bob Harvilla and Dwight Beebe attended and represented LMOA interests. We gained considerable insight from that CMO meeting and with that insight and guidance we did two things. We established an LMOA lunch and learn (spear headed by Dwight Beebe) and we established an organizational steering committee (spear headed by Tom Mack) using direction from the CMO's.

The LMOA Lunch and Learn has been extremely successful – Dwight Beebe has made contact with multiple Class 1 CMO's and conducted five of these sessions – the focus of each session has been current issues and how LMOA can help. We have plans to continue this type interface into the future. We expect these sessions to help us better align the topics and issues we address with our railroad constituents.

Tom Mack, chairing the organizational steering committee, has conducted calls regarding the overall Technical Committee structure and many of you in this room have participated. The steering committee was asked to address several things– the most important was Committee Realignment. During each of the Technical Committees final review on Sunday we have outlined the proposed Technical Committee structure of LMOA as follows:

- Combine the Diesel Material Control Committee with the Shop Safety, Practices and Equipment Committees – the Shop Processes

Committee has been suggested as the committee name
- Next - establish a Software, Electronics and Communications Committee
- Finally - dissolve the New Technologies Committee anticipating that members will migrate to a newly formed committee or find a home in an existing committee
- Other committees will remain intact
- We will emphasize the need for all committees to include appropriate new technology topics in their technical report line up

We met with each of the technical committees on Sunday and presented this lineup. We received additional feedback and proposed names along with ways to transition to the new lineup. We expect to review these recommendations and finalize an appropriate lineup by the end of the convention.

We have had other suggestions such as using LMOA committees to support the AAR Locomotive Committee and the various Technical Advisory Group (TAGs) that support it. We believe this will be a way for us to further highlight the value each of our committees can bring to the industry. We intend to make sure we maintain a constant communication stream with the AAR Locomotive Committee and support their efforts. We are pleased to note that the Fuel, Lubricants and Environmental Committee under the direction of Virginia Wiszniewski has already initiated support for the AAR Locomotive Committee on an issue.

Now let's hit another topic. Our Constitution and Bylaws were last revised in 2003. When you received your convention credentials every member was provided a proposed revision to the document. Our Bylaws require any changes to be approved by a 2/3 vote of those members present. The changes are generally minor in nature and have been made to clarify uncertainties. We will vote on this revision tomorrow between 8:30 and 8:45 AM. We look forward to acceptance of the changes by the membership. Our thanks to Bob Runyon, Dwight Beebe and Tom Mack for working on these revisions.

We thank Jeff Cutright and Norfolk Southern for providing meeting rooms, shop tours, and hosting our joint meetings in Roanoke. We also thank Jack Kuhns and Graham White for opening your doors to our group and providing an enlightening tour of your facility during the Joint meetings. While I do not have the details of all your technical committee meetings that were held throughout the year I will say that those meetings coupled with shop tours are key components of the overall LMOA experience.

So to summarize: our Association is healthy; overall we have good member activity; we are sensitive to the needs of our constituents; we are responding to the challenges that we know about; and we are ready to make changes that support our stated objectives and meet the needs of our industry.

I thank all of you for your

support and dedication to this Association. As the gavel moves on to Jeff Cutright of NS, I want to wish him the best. There is a fantastic and committed group in place that will provide support as you navigate the coming year. It has been an honor to serve. Thank you.

Acceptance speech

Jeff Cutright
Tuesday, October 4, 2016
8:30 A.M.

Thank you Stuart…

Ladies, Gentlemen, Executive Committee, Mr. Secretary, Past President, Fellow LMOA members and guests of the LMOA.

I am honored to be your President of the Locomotive Maintenance Officers Association for the upcoming year. I am humbled to stand in the company of the past presidents who have guided this organization over the years. **MAKE LMOA GREAT AGAIN.**

Stuart I appreciate your leadership and guidance over the last year. The executive committee has been encouraged this year after a meeting with railroads management to make some changes. The same group has made a commitment to support the association with more oversight and continue to participate in our proceedings.This should increase RR participation and strengthen our future.

Dwight Beebe I want to thank you for your continued support and active participation to take the CMO guidance to the next level, responding immediately to the request and making visits to many of the RR's staff with the Lunch and Learn initiative. And as we will see in a little bit, Dwight worked on some needed bylaw changes.

Tom Mack, thank your for you help in leading the reorganization task force, chairing a committee and delivering a paper. That is a very real example of the type of leadership in the group.

I want to thank each of our technical committee members for their hard work and hope you continue your participation, growth and networking in our organization. What you get out of this experience should be very valuable to you and your employer. As you learned yesterday, LMOA brought 40% of the folks here from the Coordinated Association.

I want to take a moment and recognize the supplier community that supports this organization through participation, advertising in our book, booth rental, membership and support at our meetings. Without you we would not be here.

The next year will be one of change and challenge as we work hard to align ourselves with the desires of the industry Chief Mechanical Officers. Stuart was tasked with a re-alignment and it will be our charge to take this challenge and turn the LMOA into a more understood organization, working to support the industry with work and insight into issues requested by the

CMOS. Dwight Beebe has met with many Class I organizations and their management and brought back to the Executive committee challenges that need to be incorporated into our future papers and organization.

I can personally say that the LMOA has meant a lot to me and my career. My eyes have been opened and many conversations and changes have started due to information exchanged at these presentations. Thank you LMOA for the opportunity to grow and learn.

I remember two events early in the LMOA association that I'll share. My first meeting in August of 1994 with the Shop Equipment Committee. Darlene Kisko, Mike Scaringe, Lou Cala, Bill Peterman, Tom Stefanski, and Ron Yartin were at this meeting in Altoona. What a great group to be with and many of them had quite an impact on me. The first time I presented a paper was a disaster. Luckily, it was a co-presentation and I learned from these and many, many other experiences all due to my involvement with LMOA.Please take advantage of these experiences. One advantage of the LMOA is relationships. Meet folks, join a committee, write a paper. You will not regret it.

I was able to move to the Mechanical Committee about halfway in my LMOA experience and was shaped and learned from a strong group of industry leaders on that committee, too…

I have had great support in recent years from Norfolk Southern. I have been able to go to many meetings and RSIs in the last 15 years and that exposure and experience has helped my growth.

There are so many challenges in the future and for LMOA. The latest challenge we are seeing is the relentless change in software. I know we thought we had a good process in place in order to manage software, but the ever increasing changes in emissions credits categories, PTC and the never ending number of boxes added to the locomotive is making software management and cost a major challenge in our industry.

The LMOA has seen an ever increasing need for the exchange of ideas and information. Our biggest challenge is to get this information to a greater number of our teammate's hands. There have been some ideas kicked around and that will continue as we discuss the future of the LMOA and the different technologies that exist in order to share our work more quickly and to a broader audience.

One of the changes that will further the LMOA is the association with the AAR locomotive committee. The Fuel and Lubes committee will be the first committee that will be more associated with the work and needs of this committee.

The Mechanical and Electrical Committees may look more at reliability issues and mods that have successfully made locomotives operate more reliably. The industry is challenged with fewer car loads and greater pressure to perform. Knowledgeable and informed people, armed with data will be the way to make informed fleet decisions.

We are in this together. The changes, the challenges, the growth. they all depend on us and how we contribute to our employers and what we can gain from the LMOA and our associates.

At this point I want to recognize Ron Pondel our Secretary/Treasurer and a tireless supporter of LMOA… I am so glad Ron will be with us through this transitional year.

As for me… I'm here to help. The executive committee will continue to support the organization and help further the evolution needed to move forward.

I want to take a moment and thank my wife Leonita and our two grown children Sarah and Haley for their continued support over the years. Without them, the LMOA experience I know would not be as enjoyable. My youngest daughter was born on September 23. and for years, I was gone on that date due to the LMOA meetings. Today is a better day as it is Leonita's birthday and we can celebrate it together today.

Thank you for your time today and your commitment to the LMOA.

Please attend the rest of the proceedings with the Diesel Mechanical committee and Fuels and Lubes.

Thank you for your support….


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Newly elected President Jeff Cutright calling executive committee meeting to order.

LMOA executive committee meeting, Tuesday, October 4, 2016, at 12:30 PM.

Newly elected President Jeff Cutright assisting newly elected 3rd VP Ian Bradbury with his LMOA blazer.

Outgoing President Stuart Olson handing gavel to newly elected President Jeff Cutright with Past President Bob Harvilla in attendance.

Past President Bob Reynolds, center, presenting Past President's watch to outgoing President Stuart Olson. Ceremony was witnessed by Past President Tad Volkmann.

Past President Lex White pointing to Past President's Pin worn by outgoing President Stuart Olson.

Report on the Committee on Mechanical Maintenance

Monday, September 17, 2017 at 10:00 A.M.

Chairman

Tim Standish

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

Vice Chairman

Mark Duve

System Manager-Loco. Reliability, Norfolk Southern Corp.
Atlanta, GA

Commitee Members

M. Abbott	Product Design Engineer	HotStart	Spokane, WA
J. Bink	National Sales Manager	JMA Rwy Supply	Carol Stream, IL
J. Brunson	Sales Manager	Link Up International	Roanoke, TX
S. Bumra	Assistant Superintendent	Amtrak	Chicago, IL
D. Cannon	PTC Project Manager	BNSF Railway	Fort Worth, TX
T. Casper	Vice President-Operations	PowerRail Distribution	Duryea, PA
E. Dillen	Engine Platform Leader	GE Transportation	Erie, PA
D. Freestone	Chief Mech. Officer	Alaska RR	Anchorage, AK
J. Hedrick	Principal Scientist	Southwest Research Institute	San Antonio, TX
F. Jalili	President	Chromium Corp	Dallas, TX
J. Kincaid	AVP Mechanical-Midwest Reg	Genesee & Wyoming	Springfield, IL
A, Meek	Manager-Rail Business Dev	Cummins, Inc	Broomfield, CO
D. Nott	Consultant	Northwestern Consulting	Boise, ID
A. Reid	Chief Mechanical Officer-Locos	Iowa Interstate RR	Cedar Rapids, IA
M. Ritchey	President	Curry Supply	Hollidaysburg, PA
D. Rutkowski	President	JAB Rail Svcs	East Wakefield, NH
C. Shepherd	Chief Mechanical Officer	Arkansas & Missouri RR	Springdale, AR
B. Singleton	Vice President-Sales	Transpar Corp	Fort Edward, NY
K. Ulbick	Sales Manager	Peaker Services	Brighton, MI
G. Wilson	Superintendent of Cars	Iowa Interstate RR	Cedar Rapids, IA
R. Wullschleger	Chief Mechanical Officer	New York & Atlantic Rwy	Glendale, NY

Note: Dennis Nott and Dave Rutkowski are Past Presidents of LMOA.

PERSONAL HISTORY

Tim Standish

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

Tim was born and raised in South Suburban Illinois, and obtained a Bachelor of Science degree in Mechanical Engineering from the Illinois Institute of Technology in Chicago, IL. He joined Electro-Motive Division of General Motors in LaGrange, IL as a manufacturing engineering intern and later hired on full time as a gage control supervisor. Over the last 25 plus years at Electro-Motive Tim has held other roles in quality including quality assurance supervisor, quality engineer and quality manager. During that time, Tim was instrumental in launching a pilot program called Built in Quality that resulted in quality improvements in both product and processes. Tim has been an ASQ certified quality engineer since 1997.

Tim also held other positions over the years including customer engineer which helped understand various locomotive mechanical issues and help with resolution to those problems through problem solving and troubleshooting methodology. Later he became supervisor of that group. Also, during his employment, Tim attended DePaul University obtaining a Master's in Business in 2003 with a Marketing concentration in which he put to good use marketing engine components and emission kits. Later positions included production manager overseeing crankcase, turbocharger and engine manufacturing.

Tim and his beautiful wife of 24 years, Michelle, live in Orland Park, Illinois along with their wonderful children, Melanie, Victoria and Evan. Tim enjoys biking, running and coaching soccer in his spare time.

The Diesel Mechanical Maintenance Committee would like to express their sincere gratitude to Southwest Research Institute and John Hedrick for hosting/ supporting our spring committee meeting on March 19-20, 2017 in San Antonio, Texas.

The Mechanical Committee also had two WebEx meetings that were set up by Progress Rail for which we want to say thank you.

The meeting and WebEx meetings could not be held without the support of companies such as Southwest Research and Progress Rail.

Locomotive Emission Kits

Prepared by:
Tim Standish, Progress Rail, Inc

Technical Support & Editing by:
LMOA Mechanical Committee

Introduction

The following is an overview of engine remanufacturing emission kits that will provide basic information about emission standards, kit contents, idle reduction requirements and emission labels. The reason this topic is being covered is because emission kits are generally not applied by the certificate holder (the company who certifies the kit with the EPA) but by the end user so various questions come up as to when kits should be applied, label application and post kit application requirements such as registration, audits, maintenance and record keeping. This paper will also review definitions of remanufacturing, repowering, refurbishing and upgrading.

Please note that this paper is only an overview of the EPA CFR Part 1033 rule along with various issues noted through LMOA Mechanical Committee. It is the responsibility of the manufacturer, remanufacturer and/or the owner/operator to fully understand the rules and to ensure compliance to those rules. This paper does not represent an official interpretation of the rules or legal advice but is to be used to help provide a basic understanding of some of the general requirements. Please consult your own legal counsel for advice and guidance.

Emission Standards and Remanufacture Kits

History of the final emission standards from locomotives is summarized in EPA document EPA420-F-97-048: Since locomotive emissions have not been regulated before, it was necessary for EPA to create a comprehensive program, including not only emission standards, but also test procedures and a full compliance program. This rulemaking, which took effect in 2000, will affect railroads, locomotive manufacturers, and locomotive remanufacturers. In general terms, the overall program is similar to previously established programs for heavy-duty highway engines and other nonroad engines. <u>One unique feature</u> included for locomotives, however, is the regulation of the engine remanufacturing process, including the remanufacture of locomotives originally manufactured prior to the effective date of this rulemaking. Regulation of the remanufacturing process is critical because locomotives are generally remanufactured 5 to 10 times during their total service lives (typically 40

years or more). Standards that only applied to locomotives originally manufactured after the effective date of the rule would not achieve significant emissions reductions in the near term, as those locomotives slowly replaced the existing fleet.

The first EPA standards on locomotive emissions (40 CFR Parts 85, 89 and 92) were adopted in 1998 and covered new locomotives establishing the Tier 0, 1 and 2 emission limits. The rule also established remanufacturing standards for locomotives built in 1973 or later. In 2008 EPA adopted new regulations (40 CFR 1033) requiring new line-haul locomotives to meet Tier 3 (2012-2014) and Tier 4 (2015-) emission limits and remanufactured/refurbished locomotives, including switch locomotives, to meet revised Tier 0, 1 and 2 limits. Idle control requirements were added for all new and remanufactured locomotives. To distinguish the revised standards in the 1033 rule from the previous part 92 rule the emission levels are often referred to "+". As an example, locomotives originally manufactured to Tier 1 standards under part 92 and overhauled in 2017 that would need to meet the revised Tier 1 rules under 1033 are often noted as Tier 1+ or needing a Tier 1+ emission kit. Emission limits are shown below in Tables 1 and 2 from 40 CFR 1033.101.

TABLE 1 TO § 1033.101—LINE-HAUL LOCOMOTIVE EMISSION STANDARDS

Year of original manufacture	Tier of standards	Standards (g/bhp-hr)			
		NO_X	PM	HC	CO
1973–1992 [a]	Tier 0 [b]	8.0	0.22	1.00	5.0
1993 [a]–2004	Tier 1 [b]	7.4	0.22	0.55	2.2
2005–2011	Tier 2 [b]	5.5	[e]0.10	0.30	1.5
2012–2014	Tier 3 [c]	5.5	0.10	0.30	1.5
2015 or later	Tier 4 [d]	1.3	0.03	0.14	1.5

[a] 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.
[b] Line-haul locomotives subject to the Tier 0 through Tier 2 emission standards must also meet switch standards of the same tier.
[c] Tier 3 line-haul locomotives must also meet Tier 2 switch standards.
[d] Manufacturers may elect to meet a combined NO_X+HC standard of 1.4 g/bhp-hr instead of the otherwise applicable Tier 4 NO_X and HC standards, as described in paragraph (j) of this section.
[e] The PM standard for newly remanufactured Tier 2 line-haul locomotives is 0.20 g/bhp-hr until January 1, 2013, except as specified in § 1033.150(a).

TABLE 2 TO § 1033.101—SWITCH LOCOMOTIVE EMISSION STANDARDS

Year of original manufacture	Tier of standards	Standards (g/bhp-hr)			
		NO_X	PM	HC	CO
1973-2001	Tier 0	11.8	0.26	2.10	8.0
2002-2004	Tier 1 [a]	11.0	0.26	1.20	2.5
2005-2010	Tier 2 [a]	8.1	[b]0.13	0.60	2.4
2011-2014	Tier 3	5.0	0.10	0.60	2.4
2015 or later	Tier 4	[c]1.3	0.03	[c]0.14	2.4

[a] Switch locomotives subject to the Tier 1 through Tier 2 emission standards must also meet line-haul standards of the same tier.
[b] The PM standard for new Tier 2 switch locomotives is 0.24 g/bhp-hr until January 1, 2013.
[c] Manufacturers may elect to meet a combined NO_X+HC standard of 1.4 g/bhp-hr instead of the otherwise applicable Tier 4 NO_X and HC standards, as described in paragraph (j) of this section.

As you can see from these tables, there are different emission limits for new line haul and switch locomotives over their useful life. 40 CFR 1033.901 defines locomotives to be new when originally manufactured and when remanufactured (see excerpts, below). The applicable standards are based on the year of original manufacture, which is also defined in 40 CFR 1033.901. The distinction between switch and line haul locomotives is that switch locomotives can only have a maximum rated power of 2300 hp or less. If there are multiple engines (not including anti-idling auxiliary engines) it is the total of hp of all engines. (See Switch Locomotive Definition in 40 CFR 1033.901). There are other requirements that will not be covered in this paper including smoke standards and when it is required to use ultra-low sulfur diesel fuel (ULSD).

There are special provisions for small railroads as defined in 40 CFR 1033.901 and 1033.601. For example, locomotives owned and operated by small railroads are not considered to be "new" when remanufactured, unless they were previously certified to EPA emissions standards. Class I and II are not small railroads. (See 40 CFR 1033.610) Intercity passenger and commuter RR are excluded from this definition of small railroad. (See 40 CFR 1033.901)

Useful life is the period which the engine is designed to properly function in terms of reliability and fuel consumption without being remanufactured and comply with applicable emission standards. (See 40 CFR 1033.901). It is generally specified in MW-hrs and years and is equal to the rated HP x 7.5 or 10 years, whichever is reached first. For additional details and requirements related to useful life, see 40 CFR 1033.101(g).

Definitions

There are a number of definitions that apply to the regulations in 40 CFR Part 1033. These definitions are found in 40 CFR 1033.901 and some are explained further in 40 CFR 1033.640.

Remanufacture

- To replace, or inspect and qualify, each and every power assembly of a locomotive or locomotive engine whether during a single maintenance event or cumulatively within a five-year period
- To upgrade a locomotive or locomotive engine (see definition of upgrade below)
- To convert a locomotive or locomotive engine to enable it to operate using a fuel other than it was originally manufactured to use
- To install a remanufactured engine or a freshly manufactured engine into a previously used locomotive
- To repair a locomotive engine that does not contain power assemblies to a condition that is equivalent to or better than its original condition with respect to reliability and fuel consumption

Repower

- Means replacement of the engine in a previously used locomotive with a freshly manufactured locomotive engine.
- Per 1033.640, a repowered locomotive is deemed to be either remanufactured or freshly manufactured, depending on the total amount of unused parts on the locomotive. It may also be deemed to be a refurbished locomotive (see definition of refurbished below).

Refurbished

- Locomotives that contain more unused parts than previously used parts.
- Per 1033.640 a locomotive containing more unused parts than previously used parts may be deemed to be either remanufactured or freshly manufactured, depending on the total amount of unused parts on the locomotive.

Upgrade

- Repowering a locomotive that was originally manufactured prior to January 1, 1973.
- Refurbishing a locomotive that was originally manufactured prior to January 1, 1973 in a manner that is not freshly manufacturing.
- Modifying a locomotive that was originally manufactured prior to January 1, 1973 (or a locomotive that was originally manufactured on or after January 1, 1973, and that is not subject to the emission standards of this part), such that it is intended to comply with the Tier 0 standards.
- Upon upgrading, it will now be subject to the standard and any future remanufacture of this locomotive.

To determine whether a repowered or refurbished locomotive qualifies as freshly manufactured or remanufactured (which, in turn, determines which emission limits apply), one must carefully read and apply the requirements of 40 CFR 1033.640. 1033.640 also includes how to determine the relative amount of previously used parts.

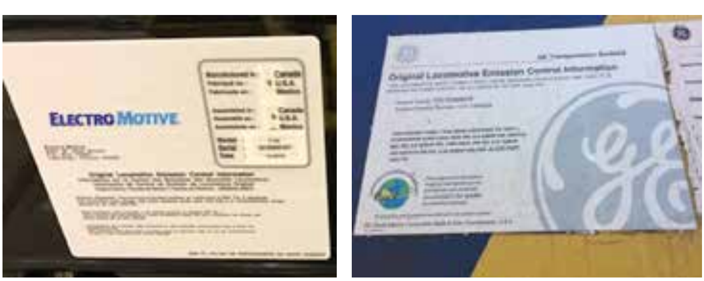
Emission Labels

There is often confusion regarding emission labels. Labeling is governed by 40 CFR 1033.135, which requires that each locomotive have a label on the locomotive and a separate label on the engine. The label on the locomotive stays on the locomotive throughout its service life and identifies the original certification of the locomotive (see further information below). Manufacturers must apply a locomotive label at the point of original manufacture. The remanufacturer must apply a locomotive label at the point of original remanufacture, unless the locomotive was labeled by the original manufacturer. An engine label must be applied by the manufacturer at the point of original manufacture; and the remanufacturer at the point of each remanufacture. The regulation requires that the engine label always be replaced as part of remanufacture, but the locomotive label may or may not be replaced. If the Family Emissions Level ("FEL") or standard to which the remanufacturer is certifying the locomotive is different than the original FEL or standard to which it was certified, then the remanufacturer must apply a locomotive label. See 40 CFR 1033.135(b) & (c). Per 1033.150, locomotive labels for transition to new standards applies when you remanufacture a locomotive that was previously certified under 40 CFR part 92. You must remove the old locomotive label and replace it with the locomotive label specified in 1033.135.

From 40 CFR 1033.135(b)(2)(i): The label must be permanent and legible and affixed to the locomotive in a position in which it will remain readily visible. Attach it to a locomotive chassis part necessary for normal operation and not normally requiring replacement during the service life of the locomotive. You may not attach this label to the engine or to any equipment that is easily detached from the locomotive. Attach the label so that it cannot be removed without destroying or defacing the label. Before applying the label, be sure that the surface is clean and free of oil, dirt, loose paint, scale, or weld spatter. Follow the installation instructions for any other requirements for label application. These labels must have the heading "ORIGINAL LOCOMOTIVE EMISSION CONTROL INFORMATION", include the date of original manufacture of the locomotive and the standard/FELs to which the locomotive was certified, along with the following statement: THIS LOCOMOTIVE MUST COMPLY WITH THESE EMISSION LEVELS EACH TIME THAT IT IS REMANUFACTURED, EXEPT AS ALLOWED BY 40 CFR 1033.750. See 1033.135(b)(2)(iii). Label locations are typically spelled out in the installation instructions that are provided with the emission kit by the certificate holder.

Label diesel-fueled locomotives near the fuel inlet to identify the allowable fuels, consistent with 1033.101. For example, Tier 4 locomotives with sulfur-sensitive technology (or that otherwise require ULSD for compliance) should be labeled "ULTRA LOW SULFUR DIESEL FUEL ONLY". You do not need to label Tier 3 and earlier locomotives certified for use with both LSD and ULSD.

Examples of Emission Labels:



Original Locomotive Label from Manufacturer

Original Engine Label from Manufacturer

EMD Kit Label Application in Cab per Installation Instructions

In addition to the labels described above, remanufacturers that refurbish a locomotive must add a secondary locomotive label that includes the following heading: “REFURBISHED LOCOMOTIVE EMISSION CONTROL INFORMATION”, as well as the following statement: “THIS LOCOMOTIVE WAS REFURBISHED IN [year of refurbishment] AND MUST COMPLY WITH THE TIER [applicable standard level] EACH TIME THAT IT IS REMANUFACTURED, EXCEPT AS ALLOWED BY 40 CFR 1033.750”. (See 40 CFF 1033.640(f)(3).

There are often questions about keeping the labels correct for the model year. Labels are associated with a particular kit, which is covered by a certificate of conformity from the EPA for the model year. The kit should reflect the model year of the family corresponding to the year in which the kit is produced. Thus, a kit produced in 2016 will have labels that indicate a 2016 model year family. These labels should be applied when the kit is installed, independently of when the kit is assembled. To be clear, it is okay and normal to apply a kit in 2017 or 2018 that and been assembled and shipped in 2016, so long as the kit meets the standards applicable to the locomotive being remanufactured. (See 40 CFR 1033.640). The railroad may have purchased that kit in 2016 and not needed to use it until 2018. The label would not need to be changed to reflect 2017 or 2018. With that said, depending on individual railroad’s policies and locomotive maintenance tracking, a railroad may elect to request updated labels to match the year of kit installation from the kit provider. The

label(s) originally sent with the kit will have to be returned to the kit provider to ensure that those labels are not improperly applied to other applications. Labels are required to be designed such that they last for the entire service life of the locomotive. The label should be designed to withstand sun, rain, wind, and any chemicals that would typically be present around a locomotive – diesel fuel, oil, coolant and cleanser. Should the label be damaged or otherwise unreadable, it must be replaced. Labels are probably an area where standardization of label locations would help railroads easily locate and read when performing maintenance.

Kit Application

As noted in the introduction of this paper, remanufacture kits are generally not applied by the certificate holder, the company who certifies the kit with the EPA. Thus, instructions must be provided by the kit manufacturer to ensure proper application of the kit. It is required that the remanufacturer exactly follow the instructions provided by the certificate holder. (See 40 CFR 1033.805(d)(1). The rules require the following statement be part of the installation instructions: "Failing to follow these instructions when remanufacturing a locomotive or locomotive engine violates federal law (40 CFR 1068.105(b)) and may subject you to fines or other penalties as described in the Clean Air Act." (See 40 CFR 1033.130(b)(4)(i)). This includes making sure that the locomotive configuration is correct for the remanufacture kit, the specified parts are used, and other components not included in the kit, but specified in the manufacturer's instructions, are installed on the locomotive. This also includes the proper labeling of the engine and locomotive as described above, and providing the certificate holder the information it identifies as necessary to comply with the regulations. Kit contents will vary based on the certificate holder, the locomotive model, and the year originally manufactured. Generally, though, the kit will contain installation instructions, labels (engine and, depending on the kit, locomotive), parts and a registration card/identification of information that must be provided to the certificate holder.

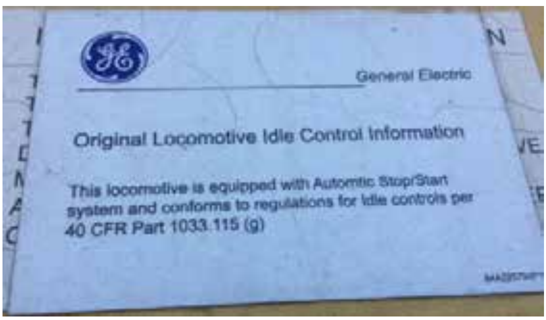
Idle Controls

Idle controls are another requirement under 40 CFR 1033.115. All locomotives that qualify as "new" under Part 1033 must be equipped with automatic engine stop/start. This system must be designed to start at least 6 times per day without causing engine damage and, except as outlined below, shut down the main locomotive engine after 30 min or less of idling. The engine may restart or continue idling for the following reasons:

- Prevent engine damage such as freezing
- Maintain air pressure for brakes, starting system or to recharge battery
- Perform maintenance
- Comply with federal regulations
- Heat or cool cab if necessary

EPA may be asked to approve an alternate stop/start system that will achieve equivalent idle control. (See 40 CFR 1033.115).

40 CFR 1033.201 sets forth provisions that allow a certificate holder to obtain a separate certificate for idle controls. If there are separate certifications, one for emissions and one for idle control system, then two separate labels are required. A locomotive may already be equipped with an auto start/stop system prior to remanufacture, in which case, you will have to find out from the OEM or start/stop system supplier if they have a certificate and a label for the system which will be required upon remanufacture. If the locomotive's certification includes an idle control system, a separate idle control system label is not required.



Idle Control Label

Audits

Certifying remanufacturers are required by 40 CFR 1033.335 to conduct installation audits for remanufacture of locomotives covered by their certificates of conformity. The certificate holder is to audit for proper components, component settings and component installations on randomly selected locomotives in an engine family. The certificate holder can submit audits performed by the owner/operator if they are done according to the standard, but EPA may require an affidavit. The requirement is to audit at least 5% of annual production per model year per installer or 10 per engine family per installer, whichever is less. Certificate holders are not required to audit installers that remanufacturer less than 10 locomotives per year. Audits are to be conducted as soon as practical after remanufacture is complete, but not later than 45,000 accumulated miles. If a locomotive fails an audit, 2 additional locomotives from the next 10 must be audited. Additional details and requirements can be found in 40 CFR 1033.335.

Even if you are not the certificate holder, it is recommended that remanufacturers audit their own processes to ensure compliance. Audits are often based on the returned registration cards so these need to be returned on a timely basis so that the 45,000 mile requirement can be met.

Operator Responsibilities

Part 1033 subpart I sets forth requirements that apply to owners and operators of locomotives. These responsibilities include remanufacturing requirements, in-use testing, maintenance, operation and repair, and refueling requirements. If another entity is doing the remanufacture, you are still responsible for making sure the certificate is applicable to your locomotive prior to placing into service. (See 40 CFR 1033.805) The owner must also make sure all emission related maintenance is performed per instructions provided by the certifying manufacturer or remanufacturer, which includes performing unscheduled maintenance in a timely manner, and keep records of all emissions-related maintenance and repairs. (See 40 CFR 1033.815). Railroads also have to comply with the in use testing requirements when ordered by the EPA. (See 40 CFR 1033.820).

Other Items

Section 1033.645 details a Non-OEM program which is a voluntary program to get EPA approval of non-OEM components for use during remanufacturing. This is for components that are commonly replaced during remanufacturing. It does not apply for other types of components that are replaced during a locomotive's useful life, but not typically replaced during remanufacture. Certified components may be used for remanufacturing or other maintenance. There are liabilities if an approved component causes a certified locomotive to not meet standards during an in use test.

40 CFR 1033.120 requires the manufacturers and remanufacturers provide a specific emission-related warranty. The warranty from the manufacturer or remanufacturers must warrant that the locomotive, including all parts of the emission control system is designed, built, and equipped so it conforms at the time of sale to the ultimate purchaser to the requirements in Part 1033, and it is free from defects in materials and workmanship that may keep it from meeting those requirements. With some exception, the minimum warranty period is one-third of the useful life (remember the useful life definition), MW-hrs or years, whatever comes first (miles if no MW-hr meter). The emission-related warranty for any component may not be shorter than any basic mechanical warranty you offer without charge for that component. If extended warranties are provided at additional charge to individual owners for components covered by 40 CFR 1033.120, then emission-related warranty must also cover the components to the same degree. The warranty period for a remanufactured locomotive begins when the locomotive is placed back into service after remanufacture. The emission related warranty covers all components whose failure would increase a locomotive's emissions of any regulated pollutant (reference 40 CFR part 1068, Appendix I). For remanufactured locomotives, the emission-related warranty is required to cover only those parts that supplied by the certificate holder or for which the certificate holder specify allowable part manufacturers. It does not need to cover used parts that are not replaced during the remanufacture. Warranty can be denied if the operator caused the problem through improper maintenance or use. (See 40 CFR 1033.120).

Conclusion

US locomotive emission standards are complex and stringent. They impose specific legal obligations on manufacturers, remanufacturers, installers, owners, operators and others. . This paper provided only a synopsis of some of the requirements under 40 CFR Part1033, and is not intended to be a thorough review of the applicable regulations; indeed, regulations in other parts of the Code of Federal Regulations (such as 40 CFR Part 1068) may apply, but have not been covered here. It should be noted that if the EPA determines that a party has violated the Clean Air Act or implementing regulations (such as those under Part 1033), it may seek civil penalties against that party. Operators, manufacturers, suppliers and remanufacturers need to read the rules themselves and consult their own legal counsel for assistance with understanding and applying the regulations.

DC To AC Locomotive Conversion

Prepared by:
Mark Duve, Norfolk Southern Corporation

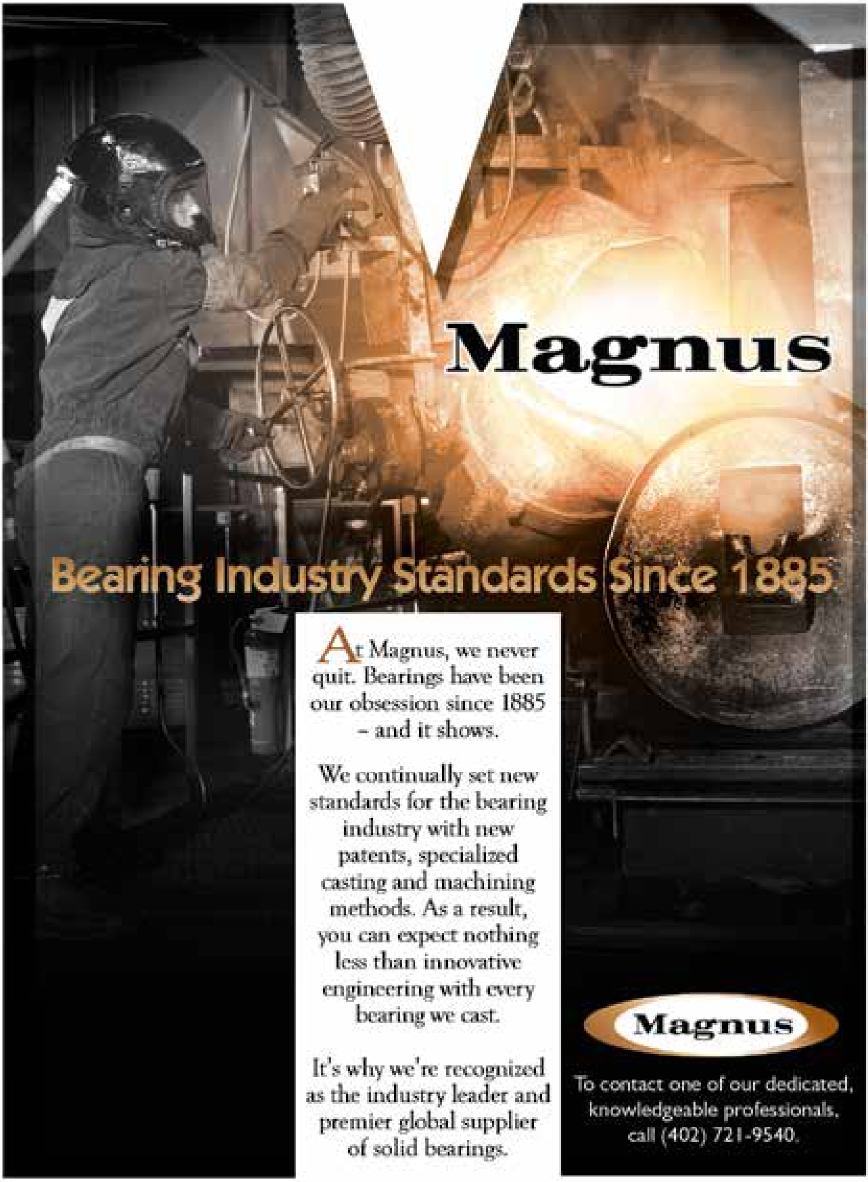
Introduction

Even though the first production ready AC locomotive was available in 1994, AC locomotives did not completely take over the North American rail market until late 2010 when the last new DC locomotive was delivered. Some railroads did not want to commit at the time to AC due to uncertainty about the longevity, maintenance and the premium cost of AC power. Since a diesel locomotive can easily last 30 to 40 years, there is still quite a bit of life in those DC locomotives that have been delivered in the last two decades. This paper describes Norfolk Southern's conversion of the Dash 9 locomotives from DC to AC including the reasons for conversion and detailing the conversion process. The new locomotive model designation after conversion is the AC44C6M.

Reasons for Conversion

The Dash 9 locomotive makes up the largest fleet of the entire Norfolk Southern Fleet with 1287 locomotives. As a typical locomotive ages, there are issues with technology obsolescence and reliability, and some components are well worn. However, many components on a locomotive that are often rebuilt are re-used in a conversion.

Dash 9 Locomotive



Magnus, LLC ■ P.O. Box 1029, Fremont, Nebraska 68026 ■ www.magnus-bearings.com

Technological Obsolescence and Reliability:

Locomotives that were built in the 1990s contain microprocessors of that era. As time progresses it gets more difficult to procure electronic components that were designed 20 years ago. The EVO CCA microprocessor control system produced today is considerably faster and has greater capability in fault prediction and control. Even providing enhancements to the older Dash 9 CAB/EXC/AUX computer system does not bring it up the ability of the latest EVO locomotive. Essentially there are limitations of the old Dash 9 computer system due to its age.

Worn Components:

The oldest Dash 9s of the NS fleet were built in 1995 with narrow cabs. Over the past 20 years, these cabs have seen quite a lot of wear. Typically, NS will put a locomotive through cab upgrade in the midlife of the locomotive. This midlife upgrade usually includes replacing the floor, ceiling, seats, toilet, air conditioner and control stand. The upgrade also includes any cab and battery box rust repair. As part of the conversion these materials are included. Thus, instead of performing a cab upgrade on an old Dash 9, the cab upgrade became part of the conversion.

Reliability and Performance

The major reliability issue of any DC locomotive fleet is the traction motor. The AC traction motor has proven to be more robust than the DC motor. On Norfolk Southern's DC fleet, the traction motor is the number one cause of road failures. There has been some thought that in mixed consists of AC and DC locomotives, the DC units are working as hard as the AC units and taking the life out of the DC motors.

Overall, it has been proven that an AC locomotive can also deliver more tractive effort at much slower speeds for longer periods of time. The Dash 9 conversion to the AC44C6M has demonstrated the starting tractive effort of 200,000 pound which is significantly greater than the 130,000 pounds of the Dash 9.

Reusable Locomotive Components

The Dash 9 locomotive has many components that with an overhaul or a little rework have more life in them. These components include the platform, engine, alternator, engine support systems, air compressor, radiators and car body. By keeping these components there is a benefit in that the shops crafts know these components and there is a supply of parts already set up.

Economic Benefits of Conversion

The re-use of many components in a conversion allows the conversion alternative to cost less than a new locomotive. In converting a locomotive fleet from DC to AC, the locomotive conversion solution can provide a greater number of AC locomotives than buying new replacement locomotives.

Emissions Considerations in the Conversion of Locomotives

When converting a locomotive a railroad must consider the emissions regulations as stated in 40CFR1033.640. Care must be taken such that the greater than 50% of existing components by dollar value are re-used. If less than 50% of existing components are re-used, then the locomotive must meet the current Tier 4 emissions regulations. For calculation purposes, the cost of existing components can be estimated as equivalent to the new component cost. It is best for each railroad to consult their legal staff in evaluating the overall project and component costs before commencing a locomotive conversion project.

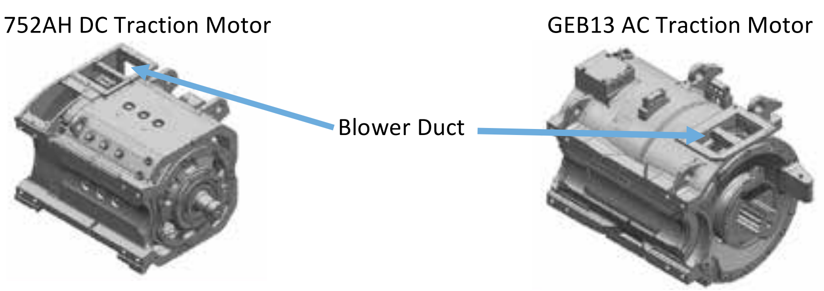
Conversion Process

The conversion process is based upon disassembling the locomotive, modifying some of the components and re-assembling the locomotives with both new and modified components.

Modified Components

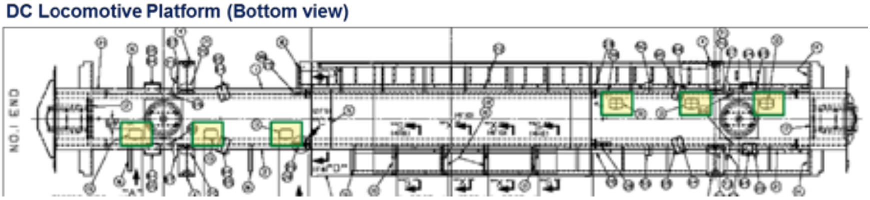
Platform: After being completely cleared the platform is modified as follows:

1) Traction motor plenum ducts relocated to the opposite side for the AC traction motor. (Note the GE AC traction motor has the air ducts on the opposite side than the DC motor)



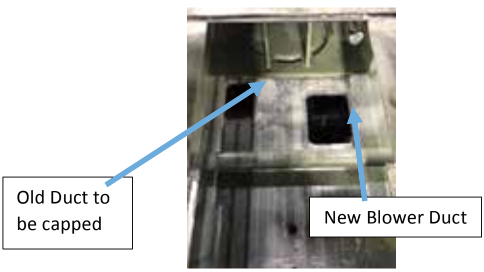
Traction Motors

DC Locomotive Platform (Bottom view)



AC Locomotive Platform (Bottom view)

Platform Front (Under the Operator Cab)



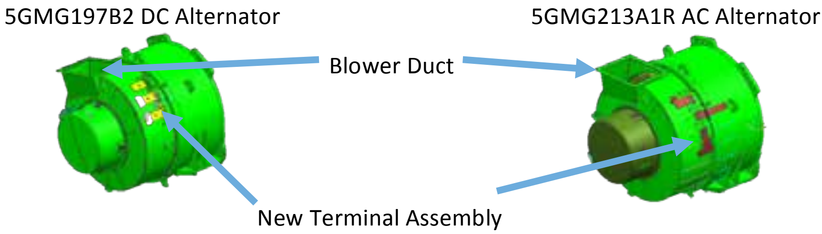
Rear Platform (Under the Rad Cab)

Platform Modifications

2) Ballast is added such that the total finished locomotive weight with full supplies is 432,000 pounds.

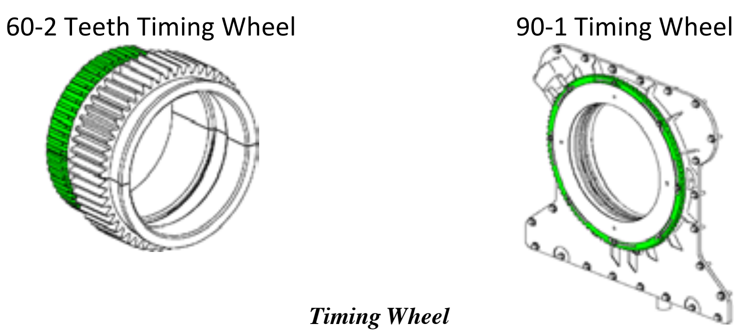
Alternator: The output of the alternator is designed for the characteristics of the locomotive. AC locomotives need a different voltage schedule than provided by an alternator built for a DC locomotive. The existing alternator is rebuilt for the AC locomotive requirements and is additionally modified to fit on the reconfigured locomotive.

1) The alternator is rebuilt to provide optimum performance for an AC locomotive.
2) The blower duct is modified for ventilation alignment with new blower cab.
3) The main terminal assembly is modified for cable changes and an improved connection process.



Alternator

Engine: On the Dash 9 some of the engine sensors such as the manifold air pressure, barometric pressure, lube oil, water temperature, and engine speed sensors were wired directly into the EXC/AUX computer; whereas, the CCA control system has these sensors wired directly to the ECU controller. As part of the rebuild the EGU is replaced with ECU as the ECU is designed to communicate with CCA computer system. Therefore, as part of the conversion all the engine sensors must be changed. The engine timing wheel must also be changed from the 60-2 teeth to the 90-1 teeth wheel.



Timing Wheel

Re-Used Components

Radiator Cab: The radiator, cooling fan, piping and air compressor in the radiator cab are re-used. The fan motor and air compressor are rebuilt. NS did add an electric assist parking brake

Radiator Cab

Engine Cab: The engine cab is used as is with just a blast and paint.

Engine Cab

New Components

The following new components were provided as part of the conversion:

1) Operator Cab: A new operator cab is included as part of the conversion. The cab is a new structure that is fully equipped with the following new components: control stand, cab seats, underfloor HVAC, fully equipped toilet compartment and PTC equipment (including JEM antenna farm).

Operator Cab

2) Aux Cab: The aux cab comes fully wired and includes the AC inverters, blower cycle skippers, and the EGU engine control modules.

3) Blower Cab: A new blower cab is provided that fits over the alternator and provides new blowers for the alternator and the lead truck traction motors.

4) Trucks: New fully jeweled truck frames and AC combos are provided as the Dash 9 truck was made for DC traction motors with a nose pack instead of a dog bone link. Due to the increased tractive effort provided by AC traction, the traditional traction motor nose pack is not sufficient. In addition, the cast frames of the original DC Dash 9 are not strong enough for the increased traction effort, the new truck frames are strengthened for 200,000 pound of tractive effort.

Nose Pack on Dash 9 DC Truck Frame

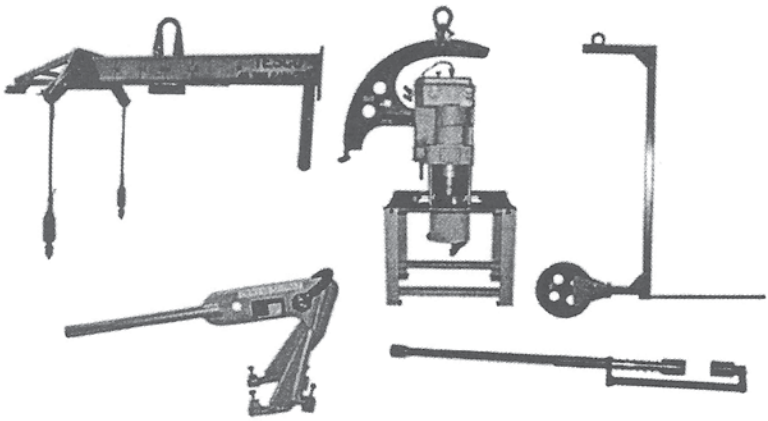
Dog Bone on AC Truck Frame

Trucks

Converted Locomotive prior to Paint

Completed Locomotives: Once completed the final locomotive goes through paint and is ready for another 25 years of service. The New AC traction system together with the new CCA EVO computer architecture provides a highly reliable modern locomotive.

Completed Locomotive



Water Treatment of Cooling Systems

Written by:
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Tim Standish, Progress Rail

Contributor:
Tim Koziatek, ISC Water Solutions

Coolant solutions are composed of water, corrosion inhibitor and if necessary, antifreeze. The selection and maintenance of a proper coolant solution is necessary for efficient cooling system operation. Failure to recognize the importance of these factors can result in cooling system damage, increased maintenance costs, and unnecessary equipment down time. Water treatment of locomotive cooling systems is often an overlooked component of maintenance in which improperly treated systems can lead to system corrosion and leaks, component failures and cooling capacity loss leading to inefficient operation of engine or air compressor. This paper will cover base water requirements, what water treatment corrosion inhibitors do, what are the components of inhibitors, how to check inhibitors, what happens if not maintained and recommendations. As a side note, antifreeze will not be covered in this paper but it should be noted that the thermal conductivity of an antifreeze solution is lower than that of an inhibited water coolant. Thus, antifreeze should not be used without prior consultation with the engine manufacturer regarding the specific installation and possible engine derating requirements.

A coolant suitable for use in cooling systems must meet five basic requirements. It shall adequately transfer heat energy through the cooling system. It shall not form scale or sludge deposits in the cooling system. It shall not cause corrosion within the cooling system. It shall not deteriorate cooling system seal materials. It should be environmentally acceptable. These requirements are normally satisfied by combining suitable water with a quality corrosion inhibitor.

Water quality is the key element to acceptable coolant performance. Coolant water should be of such quality that it does not contain excessive solids, hardness salts, or corrosive elements such as chlorides. Water containing these constituents in undesirable amounts can either be softened or deionized to make it suitable for use. Water quality should be evaluated whenever a new water source is to be used, or when changes in existing water sources occur. Adding a reliable corrosion inhibitor product to an acceptable quality water source will produce a coolant formula that will prevent scale build-up, sludge formation and prevent corrosion of the multiple metals present in the engine cooling system.

Locomotive cooling system inhibitors maintain heat transfer and prolong equipment life by:

- Inhibiting corrosion on all of the metals that are in contact with the cooling water
- Inhibiting scale formation due to minerals in the water
- Minimizing vibrational erosion of cylinders due to cavitation
- Neutralizing carbonic acid formed from the carbon dioxide present in the exhaust gas blow-by (acids destroy the inhibitor)
- Keeping any water-borne particulates in suspension rather than depositing.
- Preventing foaming

Inhibitors generally have been described as “Nitrite”, “Borate” and sometimes “Nitrate” inhibitors, or “Borate-Nitrite”. Properly formulated inhibitors contain all of the above plus many other ingredients including azoles, thiazoles, controlled low silicate, organic corrosion inhibitors, inorganics and organic polymers. Defoamers along with organic color indicators (dyes) are also included. There are no heavy metals (no chromium, no molybdenum). Safety and hygienic precautions should always be exercised when handling corrosion inhibitors to avoid possible irritation of eyes, nose, and skin.

Borate-Nitrite type inhibitors are furnished in the form of powder, pellets, and liquids. The pH of these inhibitors, when mixed with water, ranges from 8.5 to 10.0. They also contain a dye that is distinctive in color and stable at a temperature of 190o F. It is recommended that a pellet or powder inhibitor first be dissolved in water and then added to the cooling system.

The water treatment supplier should recommend a dose amount of the qualified inhibitor product. EMD requires a minimum level of 1200 to 1400 ppm nitrite as (NO_2). GE’s requirement is for $NaNO_2$ to be greater than 1400 ppm. Please consult latest locomotive maintenance instructions to verify proper levels as they may vary by model. Only products that have been qualified acceptable by the OEM’s should be considered for use in the cooling system. The above inhibitor usage concentrations have been found suitable for most corrosion inhibitors; however, customers should always contact their inhibitor supplier for recommendations as to the proper concentration level for their application

The cooling water corrosion inhibitor is depleted slowly over time and can vary based upon the condition of the engine and hours of operation. When to drain and recharge is related to the condition of the coolant in terms of nitrite level, pH and insoluble solids present in the sample. Nitrite level is the most indicative. Further (more elaborate) testing for specific metals dissolved in the water can be done. Engine coolant samples should be taken per OEM maintenance instructions (typically every 92 days or 184 days) to ensure that the quality of the solution is maintained. As a general rule, coolant solution should be serviced at least annually. Cooling systems that have been maintained with a quality inhibitor and suitable water should not require cleaning. Field history has shown that EMD cooling systems are rarely cleaned.

Most inhibitor suppliers have test kits to determine the concentration of their respective inhibitors/ trace elements. It is important that the concentration of a specific inhibitor be determined with the proper test kit as recommended by the supplier. Inhibitor concentration checks can be done by various methods. A dissolved solid meter is easy and fast to conduct and uses the electrical conductivity of the solution to determine the amount of dissolved solids. This test can be impacted by usage of hard water which would give a higher reading.

Example of a dissolved solid meter

Application Table For Liquid Type Rust Inhibitor

Locomotive Model	Water Capacity Gallons	Gallons Required if System is Drained or Existing TDS is:					
		Drained	1000	2000	3000	4000	5000-7000
MP15	230	7	7	5	5	2	OK
SW1500	230	7	7	5	5	2	OK
GP15	230	7	7	5	5	2	OK
GP38	240	7	7	5	5	2	OK
GP39	240	7	7	5	5	2	OK
GP40	240	7	7	5	5	2	OK
GP50	240	7	7	5	5	2	OK
GP60	240	7	7	5	5	2	OK
SD38	254	8	8	5	5	3	OK
SD39	254	8	8	5	5	3	OK
SD40-2	254	8	8	5	5	3	OK
SD70	270	8	8	5	5	3	OK
SD70M	270	8	8	5	5	3	OK
SD60	276	8	8	6	6	3	OK
SD60M	276	8	8	6	6	3	OK
SD45T	288	9	9	6	6	3	OK
DD40X	300	9	9	6	6	3	OK
SD70M Tier 1	320	10	10	6	6	3	OK
SD70ACe	325	10	10	7	7	3	OK
B23-7	350	11	11	7	7	4	OK
B30-7	366	11	11	7	7	4	OK
SD9043AC	380	11	11	8	8	4	OK
B39/40-8	380	11	11	8	8	4	OK
C40-8	380	11	11	8	8	4	OK
C44-9W	380	11	11	8	8	4	OK
C44AC	380	11	11	8	8	4	OK
C44/60AC	380	11	11	8	8	4	OK
C45 (03)	380	11	11	8	8	4	OK
C45 (05-07)	410	12	12	8	8	4	OK
C45 (08-14)	450	14	14	9	9	5	OK
C60AC	560	17	17	11	11	6	OK

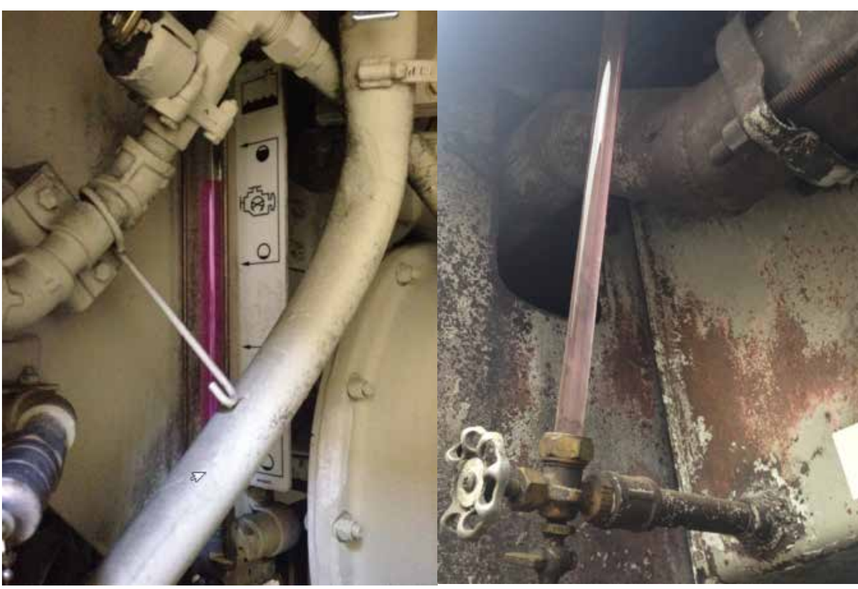
Note: C45 locomotives have different cooling system capacities by build year.

Example of a Dissolved Solid Meter Reading and Inhibitor Requirements

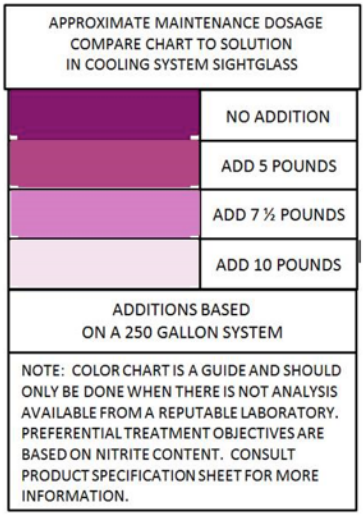
Conducting a direct nitrite test is the most accurate way to check cooling system concentration. There are many test kit suppliers that offer inexpensive nitrite test kits. See example of a kit below.

Example of a nitrite test kit

A quick check of the coolant color is the fastest way but not as accurate as the above tests due to lighting or color dissipation. Work with coolant supplier for proper color charts.



Sight glass color checks



Example of a color chart

To check the water treatment, first make sure you follow all applicable locomotive shop safety practices. Take engine water sample in clean container with engine running and warm. Take sample where water flow is normally turbulent and allow water to flow out of sampling point for several seconds before taking sample in order to expel any accumulated dirt or sediment. This practice helps prevent contaminated samples.

Improperly treated systems will cause metals in the cooling system to pit and rust. The most sensitive metals will fail first: solder, aluminum and brass. Excessive coolant and/or oil temperatures may be due to dirty radiator fins, fouled radiator coolant screens or plugged radiator tubes. Radiator fins and coolant screens should be cleaned as per OEM instructions. Plugged radiator tubes are difficult to clean by chemical treatment. Chemical solutions that are capable of dissolving the debris may also, to some degree, attack the radiator metal. The only practical method of cleaning the radiator is to rod out the tubes. The radiator should be pressure-tested to insure that the rodding operation did not damage the tubes. Excessive oil temperature may be due to the oil cooler having dirty fins or tubes coated with water hardness salts. To remove carbonaceous deposits from the fin side, the cooler may be cleaned in a vapor degreaser or a water soluble cleaner. Do not use a strong alkaline cleaner to clean the aluminum fins. Strong alkaline cleaners will attack and/or dissolve aluminum. The deposits in the tubes should be cleaned by mechanical rodding. Excessive temperatures may also be due to hard water salts. The hardness salts of magnesium and calcium will coat the hot surfaces of the fire face side of the cylinder head. To a lesser extent, the hardness salts will coat the oil cooler tubes.

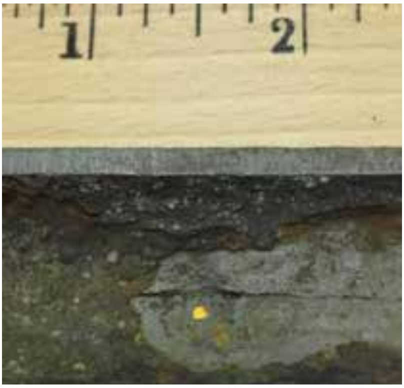
Generally the only indication of excessive scale on the coolant side of the fire face is failure (cracking) of the cylinder head. To determine the severity of the scale coating, the failed cylinder head may be sectioned (cut) approximately one inch from the fire face (valve) seat side. Scale thickness greater than 1/64 inch (0.0156 inch) is considered detrimental to efficient heat transfer. If the other cylinder heads have been in the engine for a similar period of time as the failed head, it can be assumed that the scale thickness is also similar. The most efficient method, with the least damage to the engine, is to remove the cylinder head for cleaning.

Buildup of scale on a cylinder head fireface.

Rust is an obvious sign of active corrosion in the cooling system. Generally the area most susceptible to corrosive attack is the coolant jumper lines. The coolant jumper lines should be inspected for pitting corrosion. Evidence of pitting corrosion indicates the jumper line has been weakened to some degree. Rather than cleaning the jumper lines, it is recommended that they be replaced. Rust may also plug the cylinder liner coolant ports. Past experience has shown that acid cleaners are not effective in dissolving rust in a blocked port. Further, the acid may damage the base metal. The only effective way of opening a blocked port is rodding.

Erosion/corrosion of a water jumper

Rust/ Sludge in air compressor



Erosion/corrosion to perforation of a steel pipe

Corrosion on a water pump

Oil contamination of the coolant will adversely affect the heat transfer. Determination of where the oil is entering the cooling system must be made. Oil may be removed by flushing the cooling system with a mild automatic dishwashing detergent. Before flushing the cooling system with dishwashing detergent, the whole system should be flushed thoroughly with plain water to physically remove as much residual oil as possible before introducing a detergent or chemical cleaning. The cleaner concentrations must be decided on an individual basis. Generally, the customer should contact the cleaner representative with information as to the type of scale to be removed. Cleaner concentration, time and temperature should be decided by the representative. The detergent cleaning procedure is intended to remove oil residues in these circumstances, but not for removal of bulk amounts of lube oil. If bulk amounts of oil are present, multiple flushings and drainings using plain water and small amounts of detergent or chemical should be performed. Use of large amounts of detergent in a single flushing operation can leave detergent residues in the engine, radiator and oil cooler and is not recommended.

It is not recommended to mix different brands of water treatment. Most manufacturers advise against mixing of different brands of corrosion inhibitors. This restriction recognizes the fact that some corrosion inhibitor brands may not be compatible with other brands which incompatibility may lead to foaming, precipitations, or accelerated corrosion. Draining an inhibited coolant from one engine and reusing in another is a poor practice that can cause corrosion. The reuse of inhibited coolant that has been drained from an engine is not recommended. If a customer does reuse the coolant, particular attention should be given to piping and holding tanks to ensure they are free of dirt and oil. Follow railroad policies for proper draining of cooling systems. Federal, state, and local pollution restrictions should be investigated before discharging borate-containing inhibitors.

In order to properly maintain your cooling system, set up a prescribed sampling interval based on OEM recommendations along with your fleet experience (usage, operating conditions, etc.) to monitor coolant condition. Train personnel on how to safely collect a sample of cooling system and test it for corrosion inhibitor. Based on the results of the sample tested, personnel will need to know what the next steps are to bring the system into proper condition. This may include adding inhibitor, dumping the coolant and if other maintenance should be conducted due to oil, excessive sediment, rust or gelation. Keeping accessible records of the cooling system service history will go a long way in understanding next steps. Historical fact: close to 50% of locomotives entering a diesel shop are not serviced for cooling system corrosion inhibitor condition. With the information above, hopefully that number can change and fleet performance will improve.

Overview of Locomotive Starter Abutment & Fail-to-Start Issues

Prepared by:
Tom Casper, PowerRail, Inc. &
Keith Mellin, Peaker Services, Inc.

Technical Support & Editing by:
Tom Kennedy, Union Pacific Railroad &
Mike Abbott, HOTSTART

Introduction

The definition of locomotive starter abutment is when the starter pinion gear does not line up and engage properly with the teeth in the ring gear. Starter abutment issues are generally believed to be "system" related issues and all internal components must come together and work properly to avoid abutment. For the purpose of this paper, we will focus on the known issues or problems with the mechanical and electrical systems and offer possible solutions or preventative maintenance options to avoid abutment issues. The interrelated components as defined in this paper are the ring gear, brackets, pinion, motor, batteries, contactors, and start related issues. The team of LMOA committee members who have worked on this paper have not been able to pinpoint a single predominant cause of abutment.

Causes

Several causes have been discovered throughout our research related to the subcomponents of each system.

Ring Gear Related Problems:

If the Total indicated Runout (TIR) is out of specification or the ring gear is not centered on the crankshaft centerline, it will bind against the starter pinion. This can happen on a new flywheel or if the ring gear is bent or mounted incorrectly.

A three-piece ring gear has special keys and can also cause the binding issue if improperly mounted.

See picture below of ring gear with special key:

Rust or paint on the ring gear teeth can also create binding. The rust or paint tightens the tolerances and adds "real estate" between the pinion and the ring gear. This problem may be resolved over time once the build-up wears away.

Missing or damaged gear teeth caused by over use and lack of maintenance can cause binding or misalignment. Improper or worn ring gear chamfer or lack of chamfer due to improper manufacturing processes can also cause binding and misalignment.

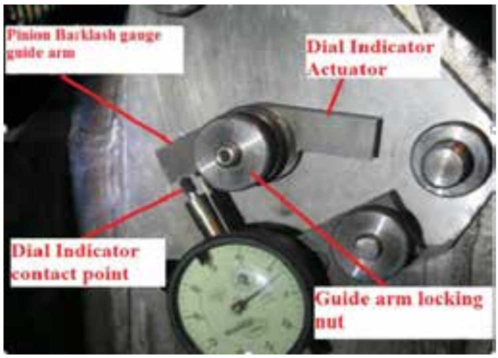
Proper pinion and ring gear alignment is shown below. Although, the pinion gear is not fully engaged and the ring gear teeth show no signs of chamfer.

Picture of chamfered ring gear teeth below:

Bracket Related Problems:

Improper mounting of brackets can cause misalignment (see alignment MI BP06-065). Brackets can be mounted incorrectly and interfere with necessary tolerances and mating of pinion to ring gear. Even though the brackets are doweled, the dowel pins can wear and the bracket may result in misalignment.

It is important to note, when transporting engines; do not use a bracket as a tie down. The weight shift in transport can easily misalign the brackets and contribute to abutment. Proper bracket mounting and alignment shown below:



The allowable starter pinion backlash is 0.020" to 0.040". The mounting bracket must be replaced if the backlash does not fall within these specifications. There may also be dimensional issues on the bracket causing binding or misalignment. Some brackets can be machined improperly and allow for misalignment.

Pinion Related Problems:

Pinions can sometimes be too hard. The pinion needs to be "softer" than the ring gear by three points Rockwell C Hardness (HRC). For example, if the ring gear is at a hardness of 55HRC, the pinion needs to be 52HRC. If the HRC is correct, the desired outcome results in the pinion being "sacrificed" before the ring gear if a problem occurs. This is preferred because the pinion is easily replaced when compared to ring gear replacement. Additionally, if the hardness is identical between the pinion and ring gear, the steel tends to gall and can cause the pinion to slip and contribute to abutment.

Too much greasing may also not allow the pinion to index properly, particularly with spray grease. Dirt or metal can collect in certain grease types and can reduce tolerances and affect clearances between pinion and ring gear. Spray grease will compound the problem more than dry grease. It can cause the pinion and ring gear to become "sticky", causing the pinion to cake up and contribute to abutment by not allowing the pinion to align properly with the ring gear. As a note of caution (unrelated to abutment), if you spray grease on the ring gear, when it spins it will "dirty up" the car body due to grease flinging off the ring gear.

Improper chamfer of the pinion or other manufacturing defects can cause binding at the ring gear mating surface. Poor quality of the pinion and missing teeth can cause issues if the teeth are not machined within tolerances or if they wear prematurely. One example that may contribute to premature wear would be the use of improper material for the pinion casting.

Without proper preventative maintenance and regular inspections, there may be unnoticed damage to the pinion caused by wear and tear. Wear and tear may also result in a bent pinion shaft which will restrict shaft travel and not allow the pinion to engage or travel properly.

Motor Related Problems:

Pinion end cap bushing misalignment can result if the original bushings are sintered bronze. It has been discovered, due to the heavy load on gears, that the sintered bronze can smear and result in sealing the pores (spooning), not allowing for proper lubrication at application by reduction in the oil flow to the gears.

Measuring the amperage draw of the starter motor is a good practice because if the draw is in excess of the manufacturer's specifications, it usually means the motor is faulty and may also indicate the bushings are worn.

Wick and pre-oiling with straight 30 or 40 weight oil may cause issues in cold weather conditions (too thick).

Poor quality solenoids or incorrect solenoid part number can cause failure to engage the pinion completely by introducing a poor contact connection.

Proper setting of the pinion throw is necessary. If pinion throw is not correct, pinion failure may occur. If not engaged all the way, it will result in high gear tooth loads to the pinion and ring gear. The pinion needs to be fully engaged with full insertion into the ring gear or the excessive load can damage the teeth on the pinion and ring gear.

Battery Related Problems:

If a no start condition occurs, it could be due to the EMDEC not reading greater than 30 RPM on speed input. On an EMD engine, EMDEC will not start to inject fuel until 30 revolutions per minute (RPM). If the batteries are below 60 VDC, you will not have enough current to reach 30 RPM at the end of 20 seconds. This condition can be magnified and become more of a problem with AESS starters because there is no person in the loop. On manual starts using the governor, it is less of an issue because the lay shaft can be pushed in to inject fuel manually. Overall poor battery condition can also contribute to abutments. Battery condition and charge level play an important role in starting the engine. Once battery state of charge (SOC) level reaches 2.02 Volts per Cell (VPC), restarting an electronic fuel injected locomotive is not likely. There will not be enough energy left in a 64 volt battery (or less) to achieve minimum 30 RPM to start the injection cycle. Less than 30 RPM condition can also be affected by low engine oil temperature and battery age. A general rule of thumb for the oil temperature lower limit with a good set of batteries is 50 degrees. Battery temperature also has an effect on the ability of the battery to start the engine. The starter will not reach 30 RPM with sticky cold oil or if the battery is too cold.

On an EUI (Electronic Unit Injection), EM2000 controlled engine, or EMDEC (EMD Electronically Controlled), there will be a 20-second crank limit and 2 minute cool-down imposed. This does not apply to mechanically injected units. If the computer breaker is cycled, the 20-second limit can be circumvented and another start may be attempted. This is not advised due to starter overheat potential. This can result in shorter starter life, which will burn up starters more quickly and may also contribute to abutment. The number of start attempts needs to be limited (uncertain number). The battery voltage should be checked again after a certain number of start attempts and possibly the temperature of the starter should also be checked.

Electrical and Start Related Problems:

STA contactor relay may not be operational and can result in abutment. When making the connection, a backing wrench should be used. If a backing wrench is not used, the nut where the starter cable connects can be overtightened and twist the stud internally, resulting in a cracked insulator.

Abutments may also occur due to damaged contactors. There may be loose connections on starters, contactors, and/or solenoids. Using arc welders to start the engine can damage the starter can also contribute to abutments.

Multiple start attempts (4 or more) in a row with 20-second rolls will damage motors. Repeated re-starts over a short time period of time can cause the starter armatures to overheat, causing nose bearing temps to rise and smearing of the bronze bearing material may result. This can contribute to abutment by causing the starter to wallow out the bearing, causing improper pinion alignment. As the bearing wears, it will wallow out towards the opposite end of the ring gear. If significant wallowing occurs, it may result in “hogging” out of the ring gear if the pinion spins before engagement.

Suggested Solutions and PM

Mechanical

- Chamfers on pinions and ring gear need to be proper.
- Sintered bronze bushings should be replaced by machined brass bushings. The machined brass bushings use an oil path, similar to a con-rod, grooved to the hole using boundary flow lubrication wicking oil to the reservoir, thereby improving bearing life.
- Dust extractor boot on starter can prevent dust from entering the starter. It is important to re-apply the boot when changing starter to prevent foreign object damage to the ring gear and starter interface.
- It is important to follow rebuild specifications and ensure proper distance between pinion and pinion stop, which must be maintained, and should be 23/64” +/- 1/32”.

Electrical

- The pinion must be held in the cranking position electrically, using the solenoid hold-in coil to achieve proper relationship of pinion, solenoid shaft, and contact disc.
- When one starter fails, change both out.
- Electrical starter maintenance – annual change outs.
- During inspection, wiggle plugs while checking for opens to simulate engine vibration. Plug 1A pin K on PD4 is a frequent source of faults.
- Use 6 brushes; harder and wider – softer brushes can cause internal shorts.

Preventative Maintenance

- Pneumatic starter maintenance:
    - Grease pinion at 184 days.
    - Change pinion every 3 years.
- Another preventative measure may be the use of a "super cap" or super capacitor. The "super cap" eases up load on the battery by potentially reducing the inrush load on the batteries during a start.
- 20W40 oil is advantageous over straight weight 30 in cold weather starting.
- Proper lubrication to pinion and ring gear. Dry lube like graphite is better for lubricating the pinion and ring gear.
- It is important to place tie downs when transporting engines under the bracket.

Report on the Committee on Fuel, Lubricants and Environmental

Monday, September 18, 2017 at 1:30 P.M.

Chairman

Virginia Wiszniewski

Researcher, Exxon Mobil Research & Engineering
Paulsboro, NY

Vice Chairman

Pete Whallon

Director Railroad & Industrial Sales, Clark Filter Parker Hannifin
Lancaster, PA

Commitee Members

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R. Chapman	OEM & Industry Liaison Manager	Innospec Fuel Specialties	Newark, DE
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S. Fenwick	Technical Director Chief	National Biodiesel Board	Jefferson City, MO
S. Fritz, P.E.	Manager-Research & Development	Southwest Research Institute	San Antonio, TX
J. George	Engineering Manager	Parker Filtration, Canada	Laval, Quebec Canada
F. Girshick	Technologist	Infineum USA, L.P.	Linden, NJ
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S. Koshy	Mechanical Engineer	Amtrak	Wilmington, DE
N. Kuzhiyil	Senior Lube & Fuel Technologist	GE Transportation	Fort Worth, TX
C. Leftwich	Senior CTS Technologist	Afton Chemical Corporation	Richmond, VA
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H. Parker	Director-Fuel Infrastructure	Union Pacific RR	Omaha, NE
C. Ruch	Asstistant Director-Technical Research & Development	BNSF Railway	Topeka, KS
M. Torrance	Senior Reliability Specialist	Canaiian National Railway	Edmonton, Alberta, Cannada
D. Tuttle	Director-Raiilroad & Marine Sales	American Refining	Atlanta, GA
J. Walkup	Technical Business Development	Dingo Maintenance Systems	Centennial, CO
K. Wazney	Chemist/Testing Specialist	Canadian Pacific	Winnipeg, Manitoba

PERSONAL HISTORY

Virginia Wiszniewski

Researcher, Exxon Mobil Research & Engineering
Paulsboro, NY

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

The Fuel, Lubricants and Environmental Committee would like to express their sincere appreciation to Chevron Oronite and particularly Tom Gallagher and his team for hosting meetings on February 22 and 23, 2017 at the Chevron Oronite facility in Richmond, California. They provided a tour, lunch, transportation and interface discussions.

We also had an opportunity to meet with the Chevron Oronite railroad team.

The committee would also like to thank ExxonMobil for their support which included hosting teleconferences.

One Size Fits All? Clarifying Standards for Locomotive Fueling Infrastructure – Storage Tank Overfill Protection

Prepared by:
Hillary Parker, Director, Fuel Infrastructure Reliability, Union Pacific Railroad

Introduction

Diesel fuel storage guidelines and standards have evolved through lessons learned and the consensus of subject matter experts. Governing agencies offer diverse perspectives and interests on environmental, fire, and overall safety issues. The Environmental Protection Agency (EPA), National Fire Protection Association (NFPA), ASTM International, and American Petroleum Institute (API) are the leaders in this area. Each of these groups publishes a series of standards that address fuel quality and storage issues.

The EPA established compliance statutes for operations that store oil or oil products[1]. The EPA Clean Water Act of 1973 led to oil pollution prevention regulations mandating the prevention of, preparedness for, and response to oil discharges. The goal of these regulations was to prevent oil from reaching navigable waters and adjoining shorelines, and to contain discharges of oil. The regulations require applicable facilities to develop and implement Spill Prevention, Control, and Countermeasure (SPCC) Plans and establishes procedures, methods, and equipment requirements that ensure compliance.

The goal of the most widely accepted document for overfill protection, API 2350, Overfill Protection for Storage Tanks in Petroleum Facilities, is to reduce the chance of oil spills and overfills by developing practical and safe operating procedures for storage facilities[2]. Product spills during delivery, or due to containment overfills, can result in severe safety, environmental, monetary and/or violation consequences to operators. Data compiled by a reputable operator in the United States estimated that overfills occurred once in every 3,300 filling operations[3] demonstrating the need for process and controls standards. Adapting and implementing clearly defined activities through standardized equipment and step by step procedures, can have an enormous impact on safety, the environment, and cost savings to fuel infrastructure maintenance and operational productivity.

Defining Moments

In 2005, API 2350 3rd Edition was released; a safety standard for a specific use-case (overfill prevention) in a specific application (non-pressurized aboveground large petroleum storage tanks) was issued. The standard covers atmospheric tanks storing Class I (flammable) and Class II (combustible) petroleum liquids. While the newly released standard focused on tank overfill prevention it allowed for increased operational efficiency and higher tank utilization.[4] This standard initiated the division of facilities into attended and unattended operations. For attended facilities, there were no requirements for level detectors for tanks, while unattended facilities required continuous monitoring during transfers, alarms and an automatic shutdown if the operator response time was not adequate, or the operation was fully automatic.

The release of the updated API edition in 2005 coincided with a significant tank overfill failure bringing added attention to worldwide standards related to the safety of petroleum storage tanks. In December 2005, the Hertfordshire Oil Storage Terminal (Buncefield), located 25 miles Northwest of London, England, experienced catastrophic losses contributed to multiple process and facility failures. Safeguards on a tank at the terminal failed and the staff on duty did not realize its capacity had been reached. Vapor from the tank overfill ignited and engulfed 20 tanks within the facility resulting in 45 injuries.[5]

Challenges

Fuel infrastructure management encompasses overfill protection, system corrosion mitigation, rotating equipment, power and mechanical process safety controls, fire protection, walking and working surfaces/fall protection, and industrial waste containment; each presenting its own set of unique specifications and priorities. Geographic location, commodity (oil) type(s), composition, proximity to water, transportation method(s), plus a hierarchy of governing bodies and jurisdictional regulations contribute to the dynamics of oversight and present conflicting challenges and perpetually evolving requirements to developing standards.

Mapping a Solution

The Toyota Way[6] continuous improvement practice offers standard work that can be used in any industry to develop processes, equipment, and inspection uniformity profiles to improve quality and reduce costs for system infrastructure equipment. An example of success in this area is Southwest Airlines that adopted a "One Plane Fits All" single fleet strategy. Through standardization Southwest was able to increase its effectiveness in maintaining and improving efficiency of operations while reducing risk, maintenance and training costs[7].

Mapping a solution for an overfill compliance standard requires a comprehensive database of tank inventory. Tanks must be physically inspected for current configurations and a risk assessment completed for compliance and initial gap baseline. Understanding the complexities of geography and jurisdictional regulations is key to successful execution and establishing standards that avoid significant difference; incorporating similarities and charting differences allows for standards development (Appendix 1 – offers an abbreviated example of tank overfill requirements for select municipalities).

Once the gap assessment is complete programs are established for gap closure with the result being tank systems that are compliant with API 2350 and utilize similar equipment, inspection, and testing methods. A sample data set of tanks, the requirements for liquid high level alarms varied from 85 to 95 percent of tank volume depending on their geographic location. Driving a uniform standard may force the most conservative position to be selected however unintended consequences may need to be considered (reduced system inventory in this scenario). The information gleaned from the jurisdictional codes will allow for a clearly defined set of requirements by commodity tank (Appendix 2).

Conclusion

The data set analyzed included twenty-two states; Texas was the only state identified to require tank overfill to initiate at 85%; in this example to avoid impact to multi-state system inventories, a one size fits all standard may not be a solution 100% of the time. Even with slight adjustments in standards to address the one-off exceptions, clarifying standards and procedures for fuel infrastructure will streamline equipment maintenance, inspections and reduce operational expense and mandated compliance exceptions.

1 *Code of Federal Regulations, Title 40 Protection of the Environment, Chapter 1, Subchapter D, Part 112, Oil Pollution Prevention; SPCC limited to facilities with a total aboveground storage capacity of greater than 1,320 gallons; or a total underground storage capacity of greater than 42,000 gallons.*

2 *Tank Overfill Protection - API 2350 and IEC 1511Safety Considerations; Authors: Don Newell, Shamrock Gulf Gene Cammack, Siemens Industry Inc., Praveen Muniyappi, Siemens Industry Inc., 2009. http://leadwise.mediadroit.com/files/10756WP3.pdf*

3 *Atmospheric Storage Tanks, Risk Engineering Position Paper 01, Marsh Ltd. www.marsh.com/uk*

4 *The Complete Guide to API 2350, Phil E. Myers, API 2350 Committee*
Chairman

5 *BBC News, How Buncefield fire unfolded, July 16 2010*

6 *The Toyota Way : 14 Management Principles from the World's Greatest Manufacturer, Jeffrey K. Liker, McGraw Hill , 2003.*

7 *Wired – Southwest Airlines' Seven Secrets for Success, Joe Brancatelli, Portfolio.com; "Southwest flies just one plane type, the Boeing 737 series. That saves Southwest millions in maintenance costs—spare-parts inventories, mechanic training and other nuts-and-bolts airline issues. It also gives the airline unique flexibility to move its 527 aircraft throughout the route network without costly disruptions and reconfigurations."*

Appendix 1 - A
bbreviated example of tank overfill requirements for select municipalities

Overfill Protection - State Specific Guidelines	
Arizona	Automatic-closing emergency shutoff valves required by IFC Section 2206.7.4 (approved emergency shutoff valve designed to close automatically in the event of a fire or impact) shall be checked not less than once per year by manually tripping the hold-open linkage.
California	Storage tanks in refineries, bulk plants or terminals regulated by Sections 5706.4 or 5706.7 shall have overfill protection in accordance with API 2350 (Applicable to Diesel/Oil Tanks @ 1,320 gallons or more).
	For tank located inside buildings, see CA Fire Code 5704.2.9.5.1.
Colorado	Specific overfill protection requirements include ensuring great enough volume is available in tanks prior to transfers, constant monitoring during transfers, and annual gauge calibration with maintained documentation. Means shall be provided for determining the liquid level in each tank and be accessible to the delivery operator. Spill and overfill prevention equipment is required for all ASTs installed after September 30, 1994. Specifically, for all ASTs installed after September 30, 1994 at service stations, and for all secondary containment type tanks without diking or impounding protection, equipment shall be present to automatically stop the delivery of liquid to the tank when the liquid level in the tank reaches 95 percent of capacity or sound an audible alarm when the liquid level in the tank reaches 90 percent of capacity.
Idaho	As it pertains to truck delivery, specifically in Pocatello, transfer operations must be supervised at all times with the tank fill opening/connection in full view, and personnel must be within 15 feet of the delivery vehicle and emergency shutoff device.
Minnesota	Per Minnesota Pollution Control Agency (MPCA) requirements, all regulated aboveground storage tanks (ASTs) with a capacity greater than 1,100 gallons must have overfill protection if the tanks are filled by transfers of more than 55 gallons at one time.
	1. A high-level alarm that can be seen or heard by the person controlling the transfer, set at no greater than 95 percent of the tank capacity (UPRR Standard of 90% will apply).
	2. A system that automatically shuts off flow into the tank, set at no greater than 95 percent of capacity.
	3. A permanently mounted sight glass or gauge that is visible to the person controlling the transfer that accurately shows the tank's level.
	4. A manual gauge with a level stick that is monitored during the transfer by the person controlling the transfer or by someone in contact with the person controlling the transfer.
	Double-walled tanks must use either the high-level alarm or automatic shut-off device. If any level stick, sight glass, or gauge does not read in volumetric measurements and requires conversion, a clearly labeled conversion chart indicating maximum working capacity of the tank must be mounted on the tank or the tank's delivery manifold and visible to the person controlling the substance transfer.

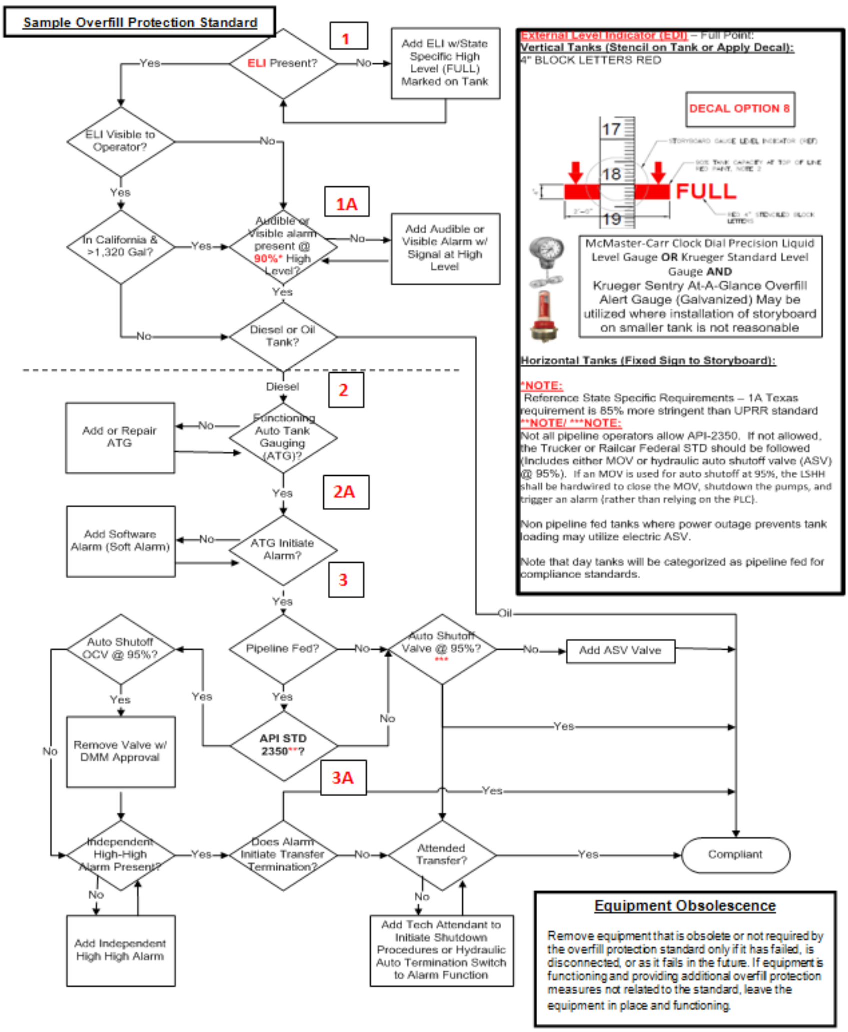
Appendix 1 (Continued)

Overfill Protection - State Specific Guidelines	
Missouri	ASTs installed and connected together utilizing a common piping system or manifold shall be installed with each tank top level with all other tank tops to prevent overfilled tank conditions.
New Mexico	Effective Aug. 15, 2004, ASTs must be equipped with spill prevention equipment that will prevent a release of regulated substances to the environment when the transfer hose is detached from the fill pipe. By the same date, they also must have overfill prevention equipment that will automatically shut off flow into a tank when it is 95 percent full, and alert the transfer operator when the tank is no more than 90 percent full by restricting the flow into the tank or triggering a high-level audible and visual alarm. Owners and operators may be exempted from these requirements if they use approved alternative equipment, if the AST is filled by transfers of no more than 25 gallons at once, or if the fill port is located within a secondary containment system.
Oklahoma	One of the following methods must be used to prevent overfilling: high liquid level alarms with an audible or visual signal at a constantly attended operation of surveillance station, high liquid level pump cutoff devices set to stop flow at a predetermined container content level, direct audible or code signal communication between the container gauger and the pumping station, or a fast response system for determining the liquid level of each bulk storage container such as digital computers, telepulse, or direct vision gauge. Liquid level sensing devices must be tested at least annually. Means must be provided for determining the liquid level in each tank, accessible to the delivery operator.
Texas	Houston has specific overfill protection requirements including:
	Protected aboveground tanks shall not be filled in excess of 90 percent of their capacity. An overfill prevention system shall be provided for each tank. During tank filling operations, the system shall:
	1. Provide an independent means of notifying the person filling the tank that the fluid level has reached 85 percent of tank capacity by providing an audible or visual signal, providing a tank level gauge marked at 85 percent of tank capacity or other app
	2. Automatically shut off the flow of fuel to the tank when the quantity of liquid in the tank reaches 90 percent of tank capacity.
	For rigid hose fuel-delivery systems, an approved means shall be provided to empty the contents of the filler hose into the tank after the automatic shutoff device is activated.
	A permanent sign shall be provided at the fill point for the tank to document the filling procedure and the tank calibration chart.
	The filling procedure shall require the person filling the tank to determine the gallonage required to fill it to 90 percent of capacity before commencing the filling operation.
Washington	Seattle Fire Code – Chapter 57 adopts the API 2350 standard for ASTs located within Seattle.

Appendix 1 (Continued)

Overfill Protection - State Specific Guidelines	
Wisconsin	Sufficient volume available in a tank must be ensured prior to transfers. Transfer operations must be monitored constantly. Visual and audible warning signals must be clearly marked to be recognizable. Spill and overflow prevention equipment shall be maintained to work as originally designed and installed.
	Tanks filled via hand-held nozzles shall be constantly attended during product delivery with a vent whistle or other overfill prevention equipment which provides a visual signal at 90% of the tank's capacity. Tanks located remote from the fill point, that are filled only with a manual-shutoff nozzle without a latching mechanism shall be provided with overfill prevention equipment which notifies the person filling the tank, with both an audible and a visual signal, that the liquid level has reached 90 percent of
	The following new and existing tanks that have a fill point not located within a diked area shall be provided with overfill prevention equipment which notifies the person filling the tank, with both an audible and a visual signal, that the liquid level has reached 90 percent of the tank's capacity, and which automatically shuts off flow when the quantity of liquid in the tank reaches 95 percent of the tank's capacity:
	1. Tanks using tight-connect delivery.
	2. Tanks located remote from the fill point that use delivery nozzles with latch-open devices.
	Existing tank systems shall comply with this subsection within 2 years after August 1, 2009.
	Operators shall utilize the procedures and equipment as specified in PEI RP600 for preventing overfilling of new and existing shop-built aboveground tanks. Fuel-delivery persons shall utilize the procedures in PEI RP600 for preventing overfilling of new and existing shop-built aboveground tanks, and may not interfere with equipment that is intended to prevent overfilling.
Wyoming	Aboveground storage tanks are further mentioned in Part I of Chapter 17, Section 34-37.
	Overfill protection. All ASTs regulated under this section shall have overfill protection as follows:
	1. Systems shall sound an audible or visible alarm at the filling rack when the AST is 90% full;
	2. Systems shall close valves and prevent overfilling the tank before the AST is 95% full; and
	3. For tanks larger than 100,000 gallons, the following shall also be provided: a system shall sound a second audible and visible alarm at the filling rack when the AST is 95% full.

Appendix 2



Sample Overfill Protection Standard
1
ELI Present?
Yes
No
Add ELI w/State Specific High Level (FULL) Marked on Tank
ELI Visible to Operator?
Yes
No
1A
In California & >1,320 Gal?
Audible or Visible alarm present @ 90%* High Level?
Add Audible or Visible Alarm w/ Signal at High Level
Diesel or Oil Tank?
Diesel
Oil
2
Functioning Auto Tank Gauging (ATG)?
Add or Repair ATG
2A
ATG Initiate Alarm?
Add Software Alarm (Soft Alarm)
3
Pipeline Fed?
Auto Shutoff Valve @ 95%? ***
Add ASV Valve
Auto Shutoff OCV @ 95%?
Remove Valve w/ DMM Approval
API STD 2350**?
3A
Independent High-High Alarm Present?
Does Alarm Initiate Transfer Termination?
Attended Transfer?
Compliant
Add Independent High High Alarm
Add Tech Attendant to Initiate Shutdown Procedures or Hydraulic Auto Termination Switch to Alarm Function
External Level Indicator (ELI) – Full Point:
Vertical Tanks (Stencil on Tank or Apply Decal):
4" BLOCK LETTERS RED
DECAL OPTION 8
17
18
19
FULL
McMaster-Carr Clock Dial Precision Liquid Level Gauge OR Krueger Standard Level Gauge AND
Krueger Sentry At-A-Glance Overfill Alert Gauge (Galvanized) May be utilized where installation of storyboard on smaller tank is not reasonable
Horizontal Tanks (Fixed Sign to Storyboard):
*NOTE:
Reference State Specific Requirements – 1A Texas requirement is 85% more stringent than UPRR standard
**NOTE/ ***NOTE:
Not all pipeline operators allow API-2350. If not allowed, the Trucker or Railcar Federal STD should be followed (Includes either MOV or hydraulic auto shutoff valve (ASV) @ 95%). If an MOV is used for auto shutoff at 95%, the LSHH shall be hardwired to close the MOV, shutdown the pumps, and trigger an alarm (rather than relying on the PLC).
Non pipeline fed tanks where power outage prevents tank loading may utilize electric ASV.
Note that day tanks will be categorized as pipeline fed for compliance standards.
Equipment Obsolescence
Remove equipment that is obsolete or not required by the overfill protection standard only if it has failed, is disconnected, or as it fails in the future. If equipment is functioning and providing additional overfill protection measures not related to the standard, leave the equipment in place and functioning.

Statistical Evaluation of Lube Oil Analysis as a Potential Predictive Maintenance Tool

Prepared by:
Dwight Beebe Temple Engineering and
Dennis W. McAndrew Consultant

Overview: Railroads have been leaders in used lubricating oil analysis and interpreting the data as an indication of an engine's health. Recent advances in statistical data analysis are being used to predict mechanical problems far in advance of actual catastrophic failures. This predictive analysis can allow railroads to schedule maintenance days, weeks, or even months before the failure occurs. There have been several advances in this technology over the past 10 plus years with participation from railroads, third party vendors, and at least one Original Equipment Manufacturer (OEM). There are many challenges implicit in implementing such a program. A myriad of variables can affect the predictions and make the conclusions invalid.

How does it work?

Railroads have been participating in used oil analysis programs for over 50 years and have been at the forefront of this technology. Traditionally, analytical results were compared to operational limits for oil condition and for specific contaminants. When limits were exceeded, the locomotive was shopped prior to the scheduled maintenance date to investigate and fix the issue. A further refinement is to evaluate the used oil analysis data for a statistically significant trend. This trend can be recognized far in advance of a potential failure versus traditional limits (which are set to prevent imminent catastrophic failures).

Statistical analysis requires the development of scenarios. The individual scenario is the most likely reason for possible detection and trending of contaminants given the engines' history, age, metallurgy, operating conditions, and crankcase oil. These scenarios, in general, are worked up by teams that should include; mechanics, engineers, chemists, laboratory personnel, and statisticians. Generally, both OEM and railroaders are contributors to the development of the analytical tool. Each scenario that is developed must be validated by comparing the used oil data to the actual engine conditions and failures.

The validation process usually involves evaluating used oil test data and identifying trends. The trend is compared to the scenario suspected to have caused the change. Inspections are ordered for the locomotive based on that suspected cause. Once the suggested scenario is validated by engine inspection, it can be written into the software tool and used for predictive maintenance. If the field results do not support this scenario, it will have to be adjusted or discarded and a new scenario will have to begin the validation process

What is the status quo?

Currently several class I railroads share used oil analysis data with an OEM that evaluates the figures with their patented system. Another railroad has developed their own in-house system, and two other railroads are using third party vendors' proprietary systems.

One Railroad which recently implemented a third party vendor's system is reporting favorable results. They attribute the system to saving approximately 40 to 50 engines over the past year from catastrophic failure. They define a "saved" engine as an engine in which the software tool predicted an impending catastrophic failure and field engine inspections confirmed the scenario.

This system has undergone a rigorous validation process over the past year and will continue into the future. Payback on invested time and money is ongoing as scenarios are validated. Consequently, the railroad can reduce the amount of inspection required at preventive maintenance intervals.

Comparison of Three Systems

In-House system: There are several systems available which differ on functionality, capability, operational experience, and cost. Perhaps the lowest cost method is to develop an in-house system or purchase off-the-shelf statistical process control or analysis software. One railroad has developed a system using a *Microsoft Access* Database. Older locomotives still have limits for oil parameters but newer engines have been set up for trending. This system is integrated into the existing maintenance scheduling software to generate work orders.

The system is working well but requires a chemist that is proficient with database software and statistical analysis. An advantage of this system is its responsiveness to changes and the ability to mine data quickly. Most changes can be made by the chemist directly and if needed worked through the company's Information Technology (IT) department to make changes to the interface with the maintenance scheduling software.

At the request of management, the chemist can make queries to investigate specific issues. This capability is present on all three systems, but having the database available for direct access by railroad personnel is an advantage.

All systems require "quality control" with a direct review of trending analysis. The in-house system may have the most extensive need for review and may not be as intuitive as other systems. Also, this system does not have the customized screens and interface that vendor systems have.

Before taking on development of an in-house system, a thorough study of the requirements needs to be conducted. Downfalls of this approach include: a heavy reliance upon a single individual, no guarantee of the operability of the finished product, a significant investment in manpower and training, and finally a system that may not be as robust as systems available from other sources.

OEM Developed: At least one locomotive OEM has developed a patented system with a track record. The development of their system software tool took over five years. Their development team included their oil specialists, engineers, statisticians, and field service engineers. They evaluated four years of crankcase oil data from multiple railroads, locomotive downloads, utilization history, data validation (check for outliers), engine failure history, field engine inspection, and engine overhaul inspections. From all this input they were able to link failures to changes in oil condition and/or contamination. They were also able to determine that not all the railroads' oil data was of the quality to be used as a predictor. That was in part due to insufficient specimen collection frequency, too many outliers, or poor analytical data. This system was presented in a LMOA 2012 paper. "*Diesel Engine Health Prediction with integrated Lube Oil Analysis*", also known as incipient engine failure detection. This 2012 LMOA paper gives a good overview of the OEM developed system and its capabilities.

Third Party Systems: At least two third party vendors are operating systems in the class I community and are developing a track record. Of the two, one railroad was willing to comment on the status. They were happy with the implementation and the results. The vendor was responsive to the railroad, and had frequent meetings to liaison and update the software. Ongoing support and open communications are keys to a successful program.

Challenges Implementing Statistical Analysis Systems.

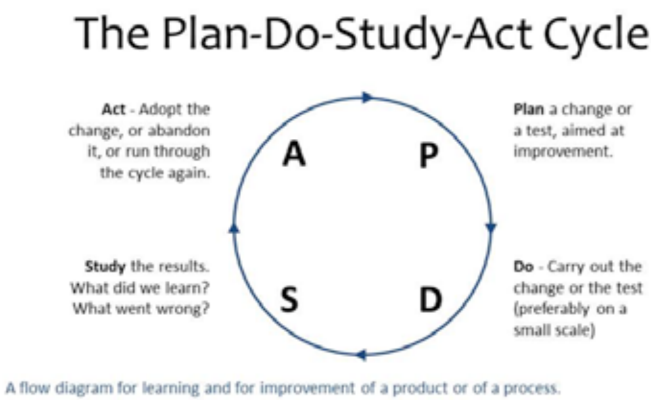
Commitment: Changing from preventive to predictive maintenance is a huge undertaking with incredible potential. The change will require continued perseverance and commitment. "Other [quality] programs have failed because they lacked leadership commitment" (Marash). The rail industry has seen various quality programs come and go over the years. If predictive maintenance is to succeed it will take a complete change in culture for railroads.

One of the biggest impediments to implementing statistical quality control (SQC) for industrial managers in mid-1900's was the lack of a working example. The rail industry faces this same impediment. Industry leaders have to ask themselves, "will predictive maintenance work, what will it be like, and will it be worth the investment?"

Variation: Statistical quality programs are best known in manufacturing where large fixed machinery is tracked for quality and performance. The equipment is generally operated by a small number of individuals and maintained by a team within the plant where the equipment is located.

Implementation in the rail industry is daunting. Instead of tracking fixed machinery in known conditions, we are attempting to track moving equipment. Locomotive maintenance can be done by various teams at different locations, contract mechanical shops or even another railroad's mechanics. Different crankcase oil formulations may be used provided they are compatible and meet specifications, but these oils will not have identical properties or performance. There are myriads of other variations that are introduced to a moving system as compared to a fixed system.

Validation: The validation process is long and arduous. As scenarios are validated, preventive maintenance procedures can be eliminated one by one. This process was actually conceived by a pioneer in statistical quality control W. Edwards Deming which he called The Shewhart Cycle for Learning and Improvement or The PDSA cycle:



(Deming)

An initial challenge to implementing a statistical program arises when the system first goes live and a large number of issues are immediately identified. These issues must be worked through which may be disruptive to existing shop flow. Maintenance and inspections will need to be carefully prioritized as these issues are addressed. The end result is an upgrade of the entire fleet. Data collected from resolving these issues is used to validate the scenarios. The upfront man hours for implementation are relatively high, but should diminish over time.

Integration: Integration of predictive maintenance into the existing preventive maintenance software can be a challenge. In general, existing systems are designed to schedule preventive maintenance tasks on a regular interval. One railroad reported that they were inputting predictive maintenance tasks on a case by case basis. This allows for close review of data and monitoring the system but can be time consuming for an engineering staff that is already pressed for time. Long term plans should include integrating the statistical evaluation system directly into the existing maintenance software and requiring only a simple approval on maintenance protocol.

Data Quality: With statistical programs there are always concerns about having correct data. Some of these concerns are addressed in another 2017 LMOA paper: *Failures Result from Misunderstanding Used Oil Data, Locomotives, and the Trouble with Trending*, Dennis W. McAndrew (Consultant), Dwight Beebe (Temple Engineering).

A diligent effort should be made to ensure data integrity before embarking on a statistical program that will be based on said data. This effort must be comprehensive from collecting the sample on the locomotive to final entry of the laboratory data and all steps in between. With predictive maintenance, the oil analysis becomes a key facet of the maintenance program, just as important or perhaps more important than turning a wrench.

Some programs have built-in data tests that detect outliers and report them. These outliers may be indicative of a systemic failure in the oil analysis system and should also be monitored and quickly resolved. If the suspect oil sample is available it should be retested. If necessary a resample and retest should be performed. Operators should beware of testing the samples until the expected result is achieved.

Communication: Maintaining communications between OEMs, railroads, laboratories and those supporting the statistical analysis program is key to developing a reliable predictive analysis program. Recent changes in oil and bearings have highlighted the need for this coordination. In early 2017, several railroads had to investigate high boron in oil in what appeared to be a problem with an entire fleet. The problem was resolved when it was found that boron is part of a new oil additive package and the change had not been adequately communicated.

Problems like these can lead to false positives and make maintenance crews question the entire program.

Top management should be updated regularly during the implementation process. The changes to railroad maintenance infrastructure will be far-reaching. Since predictive analysis has the potential to identify problems far in advance, locomotives can be moved to shops that can specialize in maintenance procedures making shops more efficient.

Recommendations

1. Railroads should review their oil analysis program to ensure it is producing quality data. Refer to 2017 LMOA paper *Failures Result from Misunderstanding Used Oil Data, Locomotives, and the Trouble with Trending* Prepared by: Dennis W. McAndrew and Dwight Beebe
2. Before proceeding, ensure that there is long term commitment within the company and support throughout the organization. Similar programs have failed in other industries because of lack of long term support.

As these programs move forward it will take patience and diligence to reach the vision of true predictive maintenance.

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Failures Resulting from Misunderstanding Used Oil Data, Locomotives, and the Trouble with Trending

Prepared by:
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Dwight Beebe Temple Engineering

Executive Summary:

The goal of the paper was to prevent engine failures resulting from laboratories' misinterpretation of lubricating oils conditions, trends, and incorrect analytical methods. The paper gives seven real examples to clearly show how catastrophic engine failures, increased oil drains frequency, and increased cost were in part a result from contract laboratories that were not fully vetted when selected. The paper discusses how the systemic errors were discovered from data lacking proper trending, or after engine failures, and the corrective actions. All the problems discussed in the paper were corrected. However, without constant monitoring by knowledgeable railroad personnel, or other experts, what will be the next systematic system errors resulting in engine failures?

Introduction: Lubricating oils quality and condition are critical to locomotive engines reliability, durability, availability, and performance. The railroad industry has been a leader in developing oil analysis technology and depends on accurate determination, reporting and interpretation of used crankcase oil quality and condition. Typical or recommended analysis include the following: oil specimens collected once every 10 to 15 days, specimens are sent to a central laboratory. Analyses consist of the following; viscosity 100˚C, viscosity 40˚C, base number (BN), acid number (AN), pentane insolubles (PI, soot), concentration of 18 or more elements, oxidation, nitration, sulfation, soot/insolubles, and fuel, water and dirt ingress contamination.

History: By the late 1990s, most railroads closed their railroad owned and managed oil testing laboratories. This trend continued for another 10 plus years until all class 1 railroads in the US and Canada relied on outside commercial laboratories for their analysis. Early in the transition to outside laboratories, there was a stipulation by some railroads to keep their railroad oil experts on to oversee and manage the outside laboratories. However, as those experts started to retire, some railroads did not replace those experts.

Commercial Laboratories (CL) Overview: The result was those railroads became dependent on the commercial laboratories, not only for running the required laboratory tests, but much more, e.g., data interpretation, and selection of analytical methods. To maintain profits some of the commercial test laboratories replaced several of the OEMs or railroads required tests with their own in-house tests. Reasons being, they did not have the capability to run the required OEMs or railroads tests, and or theirs were faster. Some testing laboratories implemented their in-house surrogate tests without ever running correlation studies to the existing test!

Currently there are several different used oil testing laboratories employed by the North American railroads. They should be providing a valuable service to the railroads in helping maintenance scheduling, failure prevention, oil condition determination, and more. Some of those laboratories are of high quality with knowledge of standard laboratory practices, railroad requirements, and OEMs requirements. However, there are some testing laboratories that fall short on providing the necessary quality data and interpretation of the data.

The commercial laboratories are not often kept abreast of industry changes such as locomotive fluid temperatures changes, lubricating oil formulation changes, and engine and locomotive components' alloy changes. Locomotives and oil additive packages are not static designs, they are dynamic. The limits and condition used by the commercial laboratories need to be constantly reviewed and modified when required.

Example of major failures: The following seven real examples are of systemic errors from a lack of understanding on the part of the testing laboratories. The fifth example is from a lack of response by a railroad to the oil parameters that exceeded the OEMs condemning limits. These examples will be followed with some general items that if not applied correctly can result in fleet wide problems/failures.

1. ***Test results not changing with time, i.e., flat trend lines.*** After railroad "A" transitioned to an outside commercial laboratory the number of locomotives being flagged as having one of more oil parameters exceeding condemning limits dropped to near zero. Although this railroad was exceeding 400 MWHr per month, and on a 184 day oil drain, the oils' base number (BN) only dropped from new 17 mg KOH/g to a range from 14 to 16 mg KOH/g, and the pentane insoluble (PI, soot) new only increased from nil to a range of to 0.2 to a maximum of 1% by weight. Under similar conditions expectations were that the base should have fallen to 4, 5, or 6 mg KOH/g and the PI increased to 3, 4, 5 weight percent.

   After there was a major increase in crankshaft failures at a significant cost, the railroad contacted the OEM for support. The railroad called a meeting at their facility that included themselves, the locomotive OEM and the test laboratory.

The laboratory was using the latest technology in their laboratory, a Fast Fourier Transform Infrared (FTIR). It was suggested by the OEM chemist to run a blind study on multiple oil specimens. Those specimens were sent to 5 different laboratories. The tests results were provided to the OEMs chemist in a code format, i.e., the chemist did not know which laboratory matched up with which data set. The results were evaluated for both repeatability and reproducibility. Although the new laboratory did have a high degree of repeatability (close to the same results) in their own laboratory there was a reproducibility issue. In other words, the reproducibility results from the laboratory were significantly different from the results reported by the other 4 laboratories, an outlier.

The outcome was the railroad chose a different laboratory. After inspecting locomotive engines crankshafts for damage, and taking the proper corrective actions, the failure rate went back to what was typical for that railroad. With the new laboratory the number/occurrences of "flags" being reported were similar to the historical numbers.

2. ***Using wrong frequency in surrogate test method.*** Railroad "B" implemented the use of FTIR spectrometer for BN and PI (soot) determination rather that the classical method of titration and weight percent respectfully. However, wanting to do due diligence, the railroad's statistician and commercial laboratory did run a correlation study between the OEMs method and the FTIR surrogate method. They determined there was a higher correlation (r^2) if they did not use the established frequency of 2000 cm^{-1} for PI (soot) but a frequency of 1735 cm^{-1}. Although they did have a better mathematical correlation using a different frequency with the locomotive fleets that were in-service, there was a problem looming. That frequency (1735 cm^{-1}) is the carbonyl frequency, i.e., oxidation frequency.

   When the railroad received new Tier 2 locomotives, the PI FTIR trend results were flat for the new units. The reason being the newer locomotives oil temperatures were 15 to 20 degree cooler than the older locomotives. Thus the carbonyl rates of increase on the new units were considerably reduced compared to the older units. This is important because soot is known to be a major contaminant leading to crankshaft failures! Therefore using the oxidation frequency, the PI (soot) was under reported, thereby increasing the risk of engine failures.

   Correlation study of the data failed to account for the chemical and physical reality, i.e., it was misapplied. Changes to procedures or methods of analysis should be reviewed by a chemist, OEM and railroad representatives. Statistics

can be used to validate scientifically sound changes. This is an example of non-chemist (statistician) and outside laboratory not understanding chemistry and/or the locomotives' operating conditions. The Tier II locomotive's oils soot contamination rate and oxidation rate are lower than the older locomotives, so there was no apparent increase in failures. However, under other conditions, changes in analytical methods, without complete knowledge of the differences between locomotives, could result in significant numbers of failures.

3. ***Laboratory not calibrating analytical instrument correctly.*** Railroad "C" changed crankcase oil additive package and used oil analysis laboratory. This major laboratory, with many laboratory accreditations, reported major loss of BN in the fleets within the first 4 to 6 weeks. Rather than risk engine failures, the railroads implemented a plan to drain crankcase oils every 4 to 6 weeks based on oil flags, rather than the expected 184 day oil drain cycle. The railroad (believing the problem was from a weak additive package) threatened to change additive package if drain cycles of 4 to 6 weeks was not improved.

   This very rapid drop in the BN was not typical for this additive package. Other railroads were using this package, successful achieving 184 drain cycle. An outside chemist (consultant) was brought in to evaluate the issue. Upon auditing the laboratory, the problem was quickly discovered. Although this laboratory did have several laboratory accreditations, copies of the ASTM methods, with statements they did follow the written method, they did not follow standard laboratory practices. In this case, they only used one aqueous pH 10 standard to calibrate their electrodes. Furthermore, they did not know about the organic buffer end point standard discussed in the ASTM method. At the consultant's recommendation, the laboratory purchased two additional aqueous standards with pH of 7 and 4. This was to calibrate the electrodes for a linear response.

   After a week of testing oil specimens if was soon apparent the oils were in fact not out of base and in acceptable base condition for 184 days. However, the laboratory did continue to use a fixed millivolt (pH) as the endpoint rather that an inflection point established with the organic buffer end point. This was a documented increase in oil cost and lost availability of the locomotives.

4. ***Laboratory used oil condemning limits for one locomotive manufacture and applied the same limits to the other OEMs locomotives.*** Railroad "D"'s laboratory was using EMD condemning limits for GE locomotive. The EMD elemental and oil limits are higher or different than GE limits. The results were a failure to set flags on GE units at the correct values.

Once the laboratory was informed they could not use the same limits, with some reluctance, they did change their software to have separate limits for the two different manufacturers.

5. ***Railroad not responding to oil flags.*** Railroad "E" did have an oil test program, but failed to take corrective actions when condemning limits were exceeded. As a result, there were significantly more failures on this railroad when compared to another railroad with very similar operating environment. A major investigation was undertaken to explain to the railroad that the failures were a result of extremely high soot loading, some two times above condemning limits, and base number close to being nil. After six months for evaluating oil history followed with a presentation to the railroad, they did start to respond to the oil flags. This relatively smaller non North American railroad experienced approximately four percent engine failures of its fleet after 20 MWHrs, all within 2 to 3 months. Inspection of the balance of the fleet discovered an additional six percent of the fleet had some crankshaft damage. To prevent further damage, and possible road failures, those six locomotives were pulled for early engine overhaul. The cost is not only the locomotive engine failures, but the lost availability of the locomotives and the impact on the business operation. This was an extremely costly lesson on the importance of taking corrective actions when one or more of the used oil parameters condemning limits are exceeded.

   Given time the engine failure rate did drop to typical low levels.

6. ***Oil specimen collection/identification problem: Although they knew what occurred, railroad "F" called asking for an opinion on the following.*** Upon reviewing water leak flags on multiple units (approximately 10), it was noted that not only were the concentration of sodium and boron (elements in water treatment) the same, but so were all the other measured oil parameters. Furthermore it was noted that all the oil specimens were collected at the same service center on the same day.

   It was very likely that someone collected several oil specimens from one unit and identified the specimens as being collected from different locomotives. This lack of integrity resulted in additional expenses to the railroad. All the locomotives identified with leaks had to be shopped to have new oil specimens collected, and all locomotives inspected for potential coolant leaks. In addition to the cost associated with the extra shopping, the reverse scenario could have been more costly. That is, if the locomotive that had the oil specimens collected did not have a leak, and one of the others did, it could have resulted in a catastrophic failure on the locomotive with the leak.

One suggestion that has been implemented on one or more railroads is to scan the bar code on the locomotive followed with scanning the bar code on the specimen bottle.

7. ***Viscosity measurement error:*** Railroad "F" contracted their oil testing program to an outside laboratory without a review of the analytical methods selected by the outside laboratory. This testing laboratory used an instrument for paint's viscosity (similar to a Zahn Cup) for the determination of oil viscosity. It is basically a cup with a hole in the bottom and the viscosity is determined by the amount of time it takes for the oil to flow out of the cup. The OEM's field service engineer contacted their oil specialist for assistance in determining why the oil's viscosity ranged from a high being over 25 cSt at 100 C to values as low as 2 cSt at 100 C. The high value would be for a much more viscous fluid, and the low value would be the viscosity for diesel fuel, not crankcase oil. Additional other parameters, e.g., wear metal elements, insoluble/soot, and BN were not typical.

   Oil's specimens were collected and forwarded to the OEMs oil test laboratory facility. All the required oil parameters were determined for those specimens. The results were significantly different than the contract laboratory's results. After several calls between the laboratory, railroad, and OEM, it was determined this laboratory could not obtain the precision on several of the required methods. Furthermore they did not want to invest into new equipment. Therefore the railroad chose another laboratory. That choice was made after screening multiple laboratories.

   This major inability to precisely and accurately determine oil condition could have resulted in very high failure rates similar to those in example 5. Fortunately, the railroad selected a different laboratory before third body wear or corrosion could start.

Discussion: The below are a few Items to consider, understand, and be concerned about with outside commercial test laboratories.

- Laboratory selection process
- Engine alloys used
    - o Wear elements detected in crankcase oil influenced by Tier, alloys used, e.g., bearings
- Condemning limits could be different
    - o Example: Elements to consider being important, e.g., older GE and EMD units used tri-metal alloy bearings, the alloy on the bearing surface was a lead (Pb) alloy, copper alloy (Cu) mid layer, and steel back, these bearing and alloys are not used on the newer Tier locomotives, therefore, the

laboratory should not be looking for Pb and Cu for bearing wear in newer locomotives

- Engine fluid temperatures changes
- Analytical method chosen
- Correlation studies
- Response to oil condemning flags
- Laboratory overstating their capabilities
- Laboratory personnel education
- Turnover of person
- Instrumentation
- Knowledge of OEMs limits (change or can be different for new generation (Tier) locomotives)
- Knowledge of railroad's requirements

Recommendations:

1. Laboratory selection process using the recommendations in a LMOA 2001 paper
   - Evaluation of Locomotive Engine Oil Analytical Laboratories
2. Round robin oil testing with other railroads
3. Use correct condemning limits per locomotive OEM
4. Obtain current limits for all locomotives
5. Review used oil data trends, railroad personnel or help from:
   - Additive company
   - Oil company
   - OEM's
   - Testing laboratory
   - Outside consultants
6. Monthly review e.g., pull one year of data from 20 locomotives of each type
   - Tier 1, 2, 3,and 4
   - GE and EMD
7. If possible issue discovered, review additional data sets
8. Take proper corrective actions

Round robins check laboratories:

Were round robins run to help select a quality laboratory?

- Accuracy
- Precision
- Interpretation
- Able to perform required tests
- Apply correct limits
- Turnaround time
- Reporting methods

Summary:

- Major errors discovered in laboratories test results
- Major errors discovered in used oil trend lines
- Lack of understanding existed at some locations
- Resulted in catastrophic locomotive engine failures
- Those errors discussed above were corrected

Without quality laboratories and data interpretation you are only guessing. Failures will be prevented with knowledgeable accurate use of used oil data. **Without the quality and understanding what will be the next problem?**

Why is this important? Increased reliability, durability, availability, and reduced failures/costs.

High Pressure Common Rail Engines in Locomotive Service: Symptoms, Causes and Cures for HPCR Deposits

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Executive Summary

In recent years new locomotive engines with High Pressure Common Rail (HPCR) fuel injection systems are increasingly being placed into service. Advantages of using HPCR technology are many:

- Fuel injection pressure independent of engine speed
- Low operating noise
- Reduced fuel consumption/ improved fuel economy
- Improved emissions and compliance with strict emissions limits
- Adaption for exhaust gas treatment
- Long service life

HPCR systems are a significant improvement over previous technology such as pump-line-nozzle and unit Injectors. High common rail pressure to all injectors allows for better fuel atomization, improved combustion and improved emissions. Higher pressures are obtained by minimizing the metal to metal sliding clearances within the injectors—clearances often as small as 2 microns. Unfortunately, this also makes HPCR injectors vulnerable to sticking and malfunction due to particulates, deposits and other contaminants which can impede the sliding nature of the injectors. Thus, extra care is needed to ensure that fuel is clean, requiring significant improvement in on-board

filtration systems. The switch to HPCR technology also coincided with significant changes to diesel fuel (i.e. industry move to Ultra Low Sulfur Diesel, especially in the on/off road industry). Drastically lowering fuel sulfur brought about compositional and solubility changes to diesel fuel which inadvertently led to problems with the storage, distribution and use of diesel fuel. These combined events led to significant problems such as Internal Diesel Injector Deposits (i.e. IDID) and increased filter plugging in on-highway and non-road diesel engines. The objective of this paper is to present a general overview of HPCR injection system deposits and cures for the same based on on-highway and non-road diesel experience, with the intent of providing the locomotive community with an awareness of potential problems and solutions.

Introduction

Many older, legacy locomotive diesel fuel injection systems still exist in the railroad industry today. In recent years however, many newer technology locomotive engines with High Pressure Common Rail (HPCR) fuel injection systems have been placed into service such as: GE Tier 2+, Tier 3 and Tier 4; Cummins gensets with QSK19 engines, and Progress Rail/EMD Tier 4.

HPCR technology utilizes a system in which fuel in a reservoir—common to all injectors—is pressurized by a pump to very high pressures (e.g. 1500 bar or higher) and then electronically injected into individual cylinders at the proper time. The fuel reservoir in the high-pressure pump and injectors ensure a constant injection pressure at the nozzle, and enable multiple injections with increased flexibility. The system can also be flexibly adapted to a variety of engine types. Advantages of HPCR technology are:

- Fuel injection pressure independent of engine speed
- Low operating noise
- Reduced fuel consumption/improved fuel economy
- Improved emissions and compliance with strict emissions limits
- Adaption for exhaust gas treatment
- Long service life

HPCR systems are a significant improvement over previous technology such as pump-line-nozzle and unit Injectors. High common rail pressure to all injectors allows for better fuel atomization, improved combustion and lower emissions. The higher pressures realized in an HPCR system are obtained by minimizing metal to metal sliding clearances within the injectors—clearances often as small as 2 microns. Unfortunately, this also makes HPCR injectors vulnerable to sticking and malfunction due to particulates, deposits and other contaminants which can impede the sliding nature of the injectors. Thus, extra care is needed to ensure that fuel is clean, requiring significant improvement in on-board filtration systems.

The switch to HPCR technology also coincided with significant changes to diesel fuel (i.e. industry move to Ultra Low Sulfur Diesel, especially in the on/off road industry, as well as increased use of biofuels). Drastically lowering fuel sulfur brought about compositional and solubility changes to diesel fuel which inadvertently led to problems with the storage, distribution and use of diesel fuel. These combined events led to significant problems such as Internal Diesel Injector Deposits (i.e. IDID) and increased filter plugging in on-highway and non-road diesel engines. In the succeeding discussion, an overview of the on-highway and non-road diesel experience is given with the intent of providing the locomotive community with an awareness of potential problems and solutions related to HPCR deposits. For a more detailed discussion on why HPCR systems are needed for modern diesel engines, please see the 2016 Locomotive Maintenance Officers Association (LMOA) paper, "High Pressure Common Rail Fuel Injection System and Potential Issues" by Fritz and Hedrick of Southwest Research Institute[1].

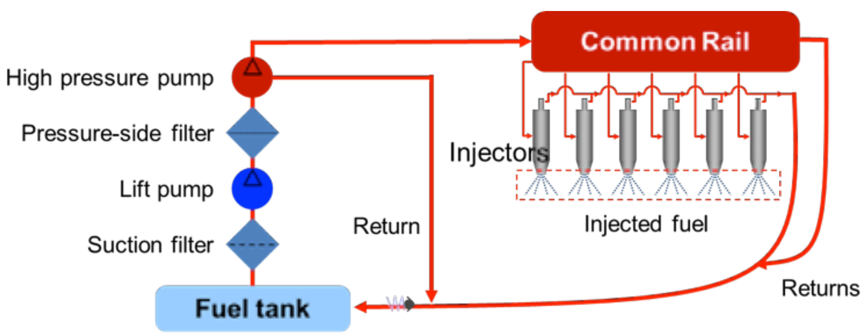

Figure 1—High Pressure Common Rail System

Background—Why the need for High Pressure Common Rail (HPCR) engines?

Improved emissions as mandated by US EPA Tier 3 and 4 requirements are the main reason why engines with HPCR fuel injection are needed. The United States Congress amended the Clean Air Act in 1990, part of which was designed to improve air quality by lowering emissions from internal combustion engines, including locomotives, in a step-wise fashion. Non-road diesel engines faced significant demands in pollutants such as hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) and oxides of nitrogen (NO_x). To allow the engines to meet the requirements, Low Sulfur Diesel (or LSD), with sulfur levels below 500 ppm, was required for non-road diesel engines starting on June 1, 2007. Three years later, on June 1, 2010, almost all of the diesel fuel sold into the US and Canadian on and non-road diesel markets became what's known as ULSD—15 ppm maximum sulfur diesel. Railroads had a two year reprieve and were still allowed to use LSD until June 1, 2012, and then switched to ULSD. Later revisions to EPA's fuel regulations permit non-Tier 4 locomotives without sulfur-sensitive engine technology to use transmix diesel fuel with higher sulfur levels, up to 500 ppm. The demand on locomotives to reduce emissions is on-going, especially in places like California[2].

To obtain these low emissions levels, fuel atomization, mixing and combustion all had to be greatly improved. This could only be done by drastically increasing fuel injection system pressures which in turn could only be achieved by significantly decreasing metal to metal clearances in injection systems. Along with these higher pressures also came higher temperatures which can also affect fuel stability.

The fuel changes—mostly related to drastically lowering fuel sulfur—also brought about additional fuel compositional and solubility changes. These changes inadvertently led to other problems with the storage and distribution of diesel fuel, and some issues in HPCR engines. Lowering sulfur also necessitated the use of, or increased the use of some fuel additives.

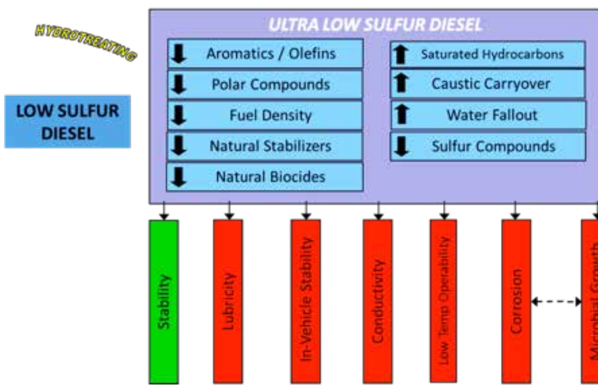

Figure 2—Diesel fuel compositional changes caused by sulfur lowering process (Innospec Fuel Specialties)

Types of HPCR Deposits

The heavy-duty diesel (HDD) On/Off-road experience is vast—how and if this correlates to the railroad community is not yet fully understood, but the On/Off road experience has shown that there are three basic types of internal injector deposits affecting HPCR systems: carbonaceous, metal carboxylates or other salts, and lacquers.

- Carbonaceous Deposits—These deposits are mostly carbon and result from the degradation of otherwise good fuel under the extremely high temperatures and pressures seen in HPCR systems. Though external, fuel injector tip deposits are often high in carbon content as well. The deposits under discussion are usually internal deposits formed by dehydrogenation whereby the fuel basically turns graphitic by the abstraction of hydrogen atoms as shown in Figure 3.

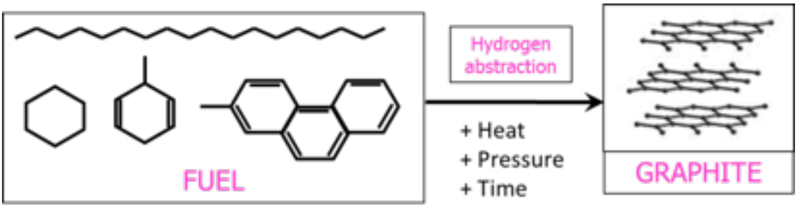

Figure 3—Carbonaceous deposit formation (Innospec Fuel Specialties)

  - These deposits are typically black and may occur either alone or with other types of deposits. If multiple types of deposit are involved, carbonaceous ones are usually found on or closest to the metal surface while salt, soap and lacquer type deposit are typically found on top of them[3]. There has been much good research done and reported on this topic[4]. Carbonaceous deposits are also usually exacerbated by higher fuel return flow, especially if the return temperatures are high and not controlled. These deposits are also found in fuel filters and indeed are often the leading indicator of a problem, with on-board filters often turning black prematurely (see below)

- Metal Carboxylate "Soaps" and Salt Deposits—This type of deposit usually is the result of fuel refining and other manufacturing system contaminants (such as biodiesel manufacture) and is typically due to inadequate process control or poor fuel housekeeping. Examples are caustic carryover, inadequate neutralization processes and failure to drain water off of storage tanks. These deposits are usually composed of a metal ion such as sodium coming in contact with acidic species such as that from degraded fuel, biodiesel ageing or hydrolysis or even some additives. Pure inorganic salts such as NaCl can often be found as well.

  - These deposits are typically whitish or tan though they can be a variety of colors. The soaps tend to be stickier type deposits and can occur along with carbonaceous deposits and are often found within the injector along the injector pin or on the diesel metering valve (DMV). This type of deposit can lead to injector sticking or seizing as is described later in this paper.

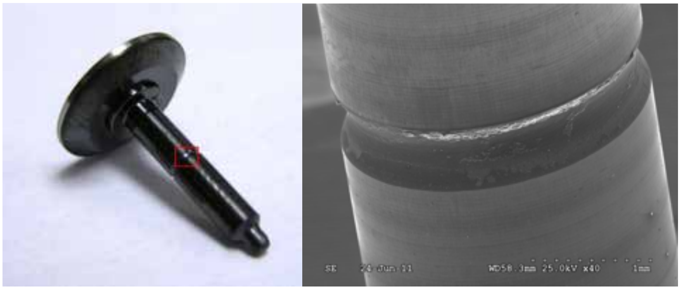

Figure 4—Diesel Metering Valve with deposits (Courtesy BNSF)

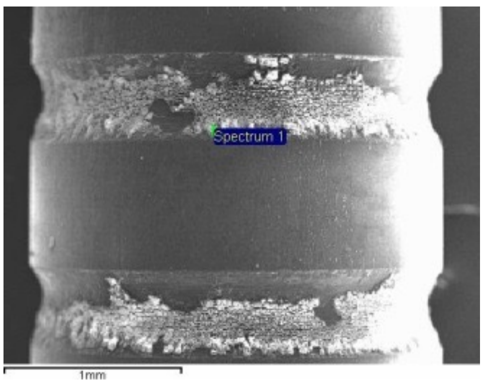

Figure 5—Diesel Metering Valve (DMW) with NaCl Deposits

- Organic Deposits (lacquers and other deposits)—These types of deposits are usually found less frequently than the other two and are usually the result of combinations of two or more organic materials—either unstable bio-diesel, degraded fuel, poor quality additives, etc. in combination with other contaminants.

Figure 6—Lacquer Type Injector Deposit (Innospec Fuel Specialties)

Sources of Injector Deposits

Injector deposits—whether Internal Diesel Injector Deposits (i.e. IDID) or external tip nozzle clogging deposits, originate from a wide variety of sources. Some deposits (e.g. carbonaceous type) are mostly due to the high pressures and temperatures of the HPCR engine "cooking" the fuel (i.e. the "dehydrogenation" process described above), but a significant amount of deposits originate from impurities in the fuel.

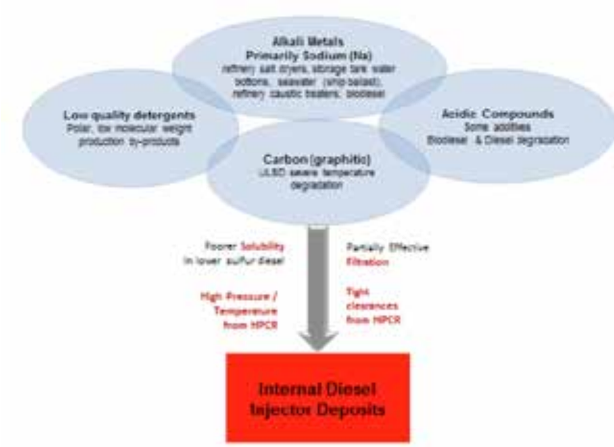

Figure 7—How Injector Deposits are Formed (Afton Chemical Corporation)

Injector Deposit Symptoms

Internal injector deposits in heavy-duty diesel (HDD) engines with HPCR systems typically cause injector pins or diesel metering valves to stick open or closed or move sluggishly. Hard particulates tend to lead to wear and erosion while soft particles usually lead to sliding parts "gumming up" along with premature filter plugging. When injectors stick in the closed position, engines typically fail to start. Longer crank times are common for stuck or partially stuck injectors. In the stuck open position, the ECM (Electronic Control Module) may fail to signal the solenoid if there's not enough rail pressure being built up because of the open position. The open position may be more dangerous than the stuck-closed position, as it can cause engine run-on or over-fueling. Some Original Equipment Manufacturers (OEM's) have shown disastrous results from stuck open injectors such as pistons thrown through cylinder walls, etc. Partial sticking of injectors usually results in engines running rough and causing erratic performance, increased emissions, and decreased fuel economy. There can also be excessive smoking, and rough idle that may clear up with increased engine run time. Lastly, turbocharger surge and "coking" and

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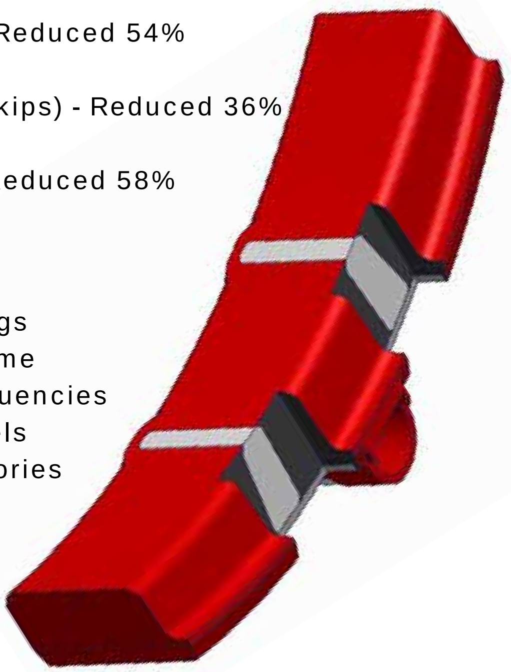

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more frequent after-treatment regenerations (e.g. of Diesel Particulate Filters or DPF's) can also result from improperly operating fuel injectors.

Impact of HPCR Deposits on Long-life Fuel Filters—Filtration

HPCR fuel systems have very small clearances and use very high pressures. Hence they require very high fuel cleanliness that calls for the use of fine filtration. A fuel cleanliness requirement of 18/16/13 by ISO 4406 as supplied from dispensers and 11/9/7 as supplied to the injection system is common, and is recommended by fuel injection system manufacturers[9]. Several studies in recent years (both on/off road and locomotive) have shown that much of the diesel fuel available as dispensed does not meet the World Wide Fuel Charter recommendation of 18/16/13 by ISO 4406[8]. A pending study by the Coordinating Research Council (CRC) will examine roughly 200 nationwide samples to determine the state of diesel fuel cleanliness and how it might relate to diesel engine operation[11]. Improved filtration systems have been developed for these requirements by filter manufacturers.

Examples of increased filter plugging are known to be caused by the high pressure and temperature generated in HPCR systems which can cause fuel to "crack" and degrade thereby producing particulates that lead to increased filter plugging. Fuel returned from injectors and the pump to the fuel tank contains these degradation products which then pass through the filter in turn. In a field test carried out by a railroad OEM[7], it was found that finer filters worked well without reaching the maximum allowable pressure drop on locomotives with unit injection system for 184 days while the same filters failed on units with an HPCR system in less than 184 days. The deposits were not thick, but did plug the filter media pores (See Figure 8 below). This problem can be overcome by increasing the area of the filter media, yet it is important to consider the sensitivity of the HPCR system to fuel quality.

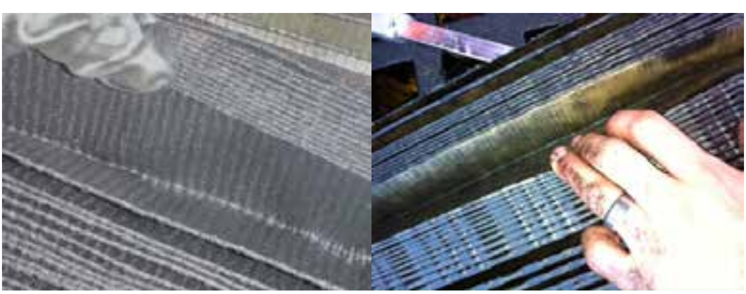

Figure 8—Locomotive fuel filter with black carbonaceous deposits (left) vs. a relatively clean one (right)

HPCR Systems Drives Fuel System Cleanliness

HPCR systems are a significant improvement over previous technology such as pump-line-nozzle and unit Injectors. High common rail pressure to all injectors allows for better fuel atomization, improved combustion and improved emissions. The higher pressures are obtained by minimizing metal to metal sliding clearances within the injectors—clearances often as small as 2 microns. Unfortunately, this also makes HPCR injectors vulnerable to sticking and malfunction due to particulates, deposits and other contaminants which can impede the sliding nature of the injectors. Thus, extra care is needed to ensure that fuel is clean, requiring significant improvement in on-board filtration systems. As mentioned above, organic and inorganic deposits and contaminants can result in sticking or sluggish behavior of the injector sliding parts. In addition hard, inorganic impurities such as sand, dust, or dirt can also impact the injection system causing metal wear or erosion. To prevent these particles from causing injector sticking and metal damage, certain levels of diesel fuel cleanliness must be maintained in order to prevent injection system problems. ASTM D975-17 diesel fuel standard requires that diesel fuel contain no more than 0.05 vol. % water and particulate as per D2709 and the Workmanship requirements specified within that standard. This limit is virtually always met at the point of manufacture (i.e. refining), however it is not typically checked at further points downstream and can on occasion be higher than the 0.05 vol. % limit due to picking up water in the distribution system. Another standard, ASTM D4176, Procedure 2—commonly known as the Colonial Haze test—is typically used in pipelines and terminals instead, specifying a fuel haze limit of "2" maximum. Fuel injection equipment manufacturers (FIE's) of HPCR systems don't believe that ASTM D2709 goes far enough however and specify additional cleanliness levels (as per ISO 4406), requiring that an 11/9/7 be delivered to the high pressure pump and the injectors. Additionally and as a minimum, the non-mandatory Appendix of ASTM D975-17 advises in Section X8, "Water and Sediment Guidelines", that an ISO 4406 level of 18/16/13 for dispensed fuel is considered relatively "clean" diesel fuel (specifically section X8.3.1.1). This same level of cleanliness is also specified in the World Wide Fuel Charter[8] as well as FIE and OEM fuel recommendations[9].

The reason that this extra measure of cleanliness is now required is because large particles and small particles have different effects on HPCR systems. Larger particles can immediately harm components or create catastrophic failure conditions (i.e. blocking injectors, scoring, etc.). However, the presence of small particles promotes erosion and wear, which can lead to longer term issues such as lower fuel combustion efficiency or general reduced performance. When wear occurs within the injector, at the injector tips or in the high pressure pump, higher maintenance costs generally result.

Minimizing water content of locomotive diesel fuel is also critically important. The use of coalescing fuel filters or combination coalescing/particulate filters should always be used as damage from high levels of water is fairly common. Water is also a great solvent and will dissolve many undesirable contaminants from fuel processing and distribution. If water is drained off of fuel tanks religiously many problems will be avoided. Most OEM's (e.g. Cummins, GE, etc.) recognize that there are geographic areas where fuel quality is poor and may offer a severe fuel filtration option in order to provide sufficiently clean and low water content fuel for HPCR applications[12]. One major downside of this improved filtration is that use of such fine filters may lead to increased instances of fuel filter plugging. This appears to be an accepted fact of using HPCR systems.

Figure 9—Mopar Severe Fuel Filter System Mounted on Fuel Tank Bottom

Fuel Quality, Specifications and Control Challenges

Ensuring good fuel quality through improved housekeeping, good filtration and preventative maintenance are keys to preventing fuel system problems. Many of these problems emanate from high entrained or free water and particulate levels such as that from dirt, rust and other hard particles. Water and dirt will cause problems in all diesel fuel injection systems due to metal scoring and erosion. Unfortunately, these contaminants (as well as those leading to injector deposits) may not always be adequately controlled by fuel specifications such as ASTM D2709 within the US. Diesel fuel for heavy duty diesel engine use and locomotives is generally specified by ASTM D975—some purchasing contracts even specify requirements more stringent than ASTM D975, though cost considerations may over rule this. In the opinion of many, this specification is arguably outdated when compared to the advances of modern engines and HPCR injection systems (though it should be noted that an ISO code particulate level of 18/16/13 is now recommended in the ASTM D975 Appendix). Though there are many useful individual parameters within ASTM D975, it's generally those aspects that aren't in the specification that can cause problems (e.g. entrained water, sodium and other dissolved metals, particulates, etc.). ASTM D975 is often only applied at the end user sale, and not to the many individual parties that may be involved in the manufacturing and downstream transportation of it (e.g. refineries, pipelines, terminals, end user tanks, etc.). This can present a problem as there is often no verification that fuel is still "fit for purpose" between the changing of hands.

Mitigation of HPCR Related Injection System Deposits—What Can Be Done?

What can a diesel fuel user do to prevent problems on a high pressure common rail system? Ensuring good fuel quality from the supplier can be one of the keys—periodic checking of the fuel to make sure that it is clear and bright (not hazy), without water or dirt is a good place to start. Simple tests to make sure that diesel fuel samples are on specification are also essential. Regularly draining accumulated water off of storage tanks, wayside and on-board locomotive tanks will help eliminate water and many particulate problems. Water is the world's greatest solvent and often dissolves many different contaminants as fuel passes through the distribution system—eliminating it not only prevents damage caused by water itself, but also helps eliminate potential injector and filter clogging salts, soaps and other contaminants. Fuel filters, both particulate and coalescing (water removing) types should be checked regularly, well before scheduled change-outs—increased differential pressure across filters is a sure sign that filters are beginning to plug and need to be replaced. It's also important that the engine/injection system manufacturer's advice be followed concerning filter micron/beta ratio sizes to ensure that fuel systems are protected. Many of these recommendations and more can be found in recent reports from the Coordinating Research Council (CRC). Report 667 "Diesel Fuel Storage & Handling Guide" and Report 672 "Preventative Maintenance Guide for Diesel Storage & Dispensing Systems"[13]. Another resource that some have found useful is the 2014 LMOA report "Diesel Fuel Troubleshooting Guide"[6]. The CRC reports can be downloaded from http://www.crcao.org while the Diesel Fuel Troubleshooting Guide can be obtained from the LMOA.

Fuel Economy Implications

Diesel fuel is possibly the single most important commodity to railroads in terms of costs, profits, and operations[6]. Excellent fuel economy along with minimization of downtime are therefore of key importance to railroads. Improving these parameters should therefore be a high priority. The guidance found above in relation to fuel injection system problem prevention should help to minimize downtime and equipment maintenance costs. Improving fuel system optimization through better atomization and combustion, while also reducing harmful emissions at the same time, is also of critical importance. Indeed, injection system manufacturers are constantly looking to make a better, more efficient injector to improve durability and efficiency. An increasing amount of injector internal sliding parts today are coated with DLC (diamond-like coating) to help prevent deposits from forming and to make metal surfaces more durable against particulate contaminants. To that end, many diesel fuel users have found that detergent additives can also be beneficial in preventing HPCR injection system deposit problems as well as cleaning up old deposits. Substantiated data from the On/Off road industry showing significant improvement in fuel economy from reputable fuel and additive suppliers are available and are fairly commonplace[14,15,16]. Several additive companies along with major oil companies have shown detergent induced fuel economy benefits in many heavy-duty diesel trials. One such trial[16] showed that deposits created in test engines and vehicles responded well to detergent additive clean up. A majority of lost power from a "dirty-up phase was restored by detergent action, showing lost power being returned in all cases in short clean up test durations". This shows that high quality fuels can overcome deposit formation both in severe industry standard tests as well as in real vehicles running more realistic driving cycles. There are more examples of improved fuel economy as shown listed in the reference section[14, 15]. Locomotive trials evaluating the effect of detergent additives have been relatively few, but several trials involving older locomotives with dirty engines have shown significant improvement in fuel economy once the engines were cleaned up by detergent[17]. It is unknown whether this level of improvement is sustainable once the engine is cleaned however.

Absence of HPCR Problems in Locomotives Compared to On/Off Road Heavy Duty Vehicles

Up until the present, HPCR injector deposit problems haven't been as prevalent in medium-speed locomotive engines as those experienced in the On/Off Road Heavy Duty market. Some possible explanations for this are:

1. HPCR injection systems in locomotive engines are relatively new as these locomotive systems have only been in place for a few years. GE introduced HPCR with Tier 3 in 2012. The On/Off Road HDD (Heavy Duty Diesel) systems with HPCR have been in place since 2007 or earlier so there's been much greater opportunity for deposit problems to manifest themselves in that market. It is estimated that there are about 3500 GE Locomotives with HPCR units in service today, but there haven't been any significant injector deposit problems reported.
2. Locomotive fuel injectors are much larger than On/Off-Road ones, so the clearances are greater. In addition, the fact that larger parts use more force to move the sliding parts may allow the injectors to overcome minor deposits.
3. Locomotive engine fuel injectors are typically changed out at 18 months (or about 150K miles). This proactive maintenance is very favorable compared to the On/Off Road engines which are generally not proactively changed out, instead being used continuously for 500,000—1,000,000 miles or more[18].
4. Better fuel handling is likely involved as well—railroads are typically very systematic in the way fuel is handled with better housekeeping in general.

They're usually very faithful about removing water which can be a great solvent for contaminants that lead to deposits. One of the ways in which this is shown is in the dedicated use of fuel-water separators by locomotive HPCR injection systems.

5. Locomotive engines usually have multiple fuel return lines from the injectors and high pressure pumps—this likely keeps fuel cooler which has been shown to lead to less deposit.
6. Fuel Delivery may also be different or at least fuel may be received with more care. Additionally, some terminals are directly supplied from pipelines—having a dedicated source is often preferable from a fuel quality standpoint.

Conclusion

The use of clean diesel fuel is imperative in HPCR fuel injection systems to prevent operational and durability problems. All efforts to improve fuel cleanliness through better housekeeping and improved filtration should lead to less problems and increased engine performance. An important adage to remember is "Keep it clean and dry" in regards to diesel fuel. Preventative maintenance and use of additives as appropriate will help reduce and/or prevent instances of injector deposit problems and thus ensure good engine operability. The good practices of the railroad industry in regards to locomotive preventative maintenance such as limiting filters to 184 days and changing out injectors every 18 months likely goes a long way in preventing the HPCR injection system deposits as seen in the On/Off-road industry. The railroad industry is to be commended for these practices—it will likely result in a continued absence of injection system deposit problems in the future as more and more HPCR systems are rolled out in the industry.

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Acknowledgement

The author would like to thank all members of the LMOA Fuels, Lubes and Environment Committee for their invaluable help in reviewing this document and making good suggestions for improving it.

Diesel Fuel Cleanliness- Application of the ISO 4406 Particulate Contamination Codes

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Abstract

Diesel fuel cleanliness has become increasingly important since the introduction of high pressure fuel injection (aka High Pressure Common Rail or "HPCR") systems in locomotives. Due to the tight tolerances, small amounts of particulate contaminants can be detrimental or even catastrophic to the fuel system. The International Standard ISO 4406:1999 describes a method of quantifying particulate contamination levels in hydraulic fluid systems and is increasingly applied to diesel fuel. This paper will give an overview of the ISO 4406:1999 standard and how it can be applied to diesel fuel cleanliness in railroad applications.

Particle Characterization

Particulate contamination in diesel fuel can be characterized as either hard or soft particles. Dust, sediment, and rust are typical types of hard particulate contamination that find their way in diesel fuel and are generally metallic or mineral in nature. These hard particles are either the result of equipment corrosion over time, sediment or dirt in the distribution system, or dust that comes through vents or openings in the system. Soft particles typically have an organic component and are more often generated due to physical or chemical processes occurring in the diesel fuel itself or contaminants from the manufacturing process. Oxidized hydrocarbons, salts, soaps, and bacterial growth are good examples of soft particles. Soft particles are often sticky in nature and can agglomerate together to form larger particles. Due to their nature, soft particles are often the most difficult to characterize. They also can be a challenging contaminant to eliminate.

Traditionally, gravimetric methods have been the most common method of quantifying the amount of particulate contamination in diesel fuel. Filtering a known volume of fluid through a filter paper and then drying and weighing the amount of contamination collected, the amount of contamination can be expressed as a concentration (e.g. mg/l) or as a percentage of the total weight of fluid. However, other than a general amount of contamination present in a system, gravimetric methods do not provide any information or characterization of the contaminants.

Particle counters provide additional information on the nature of the contaminants by determining the size or range of sizes of the particles. There are different methods used to count particles but they can be described in two general categories: Mechanical and Optical.

Mechanical methods use sieves, meshes, or membranes to separate and classify particles into different size segments. Contaminants that have been classified can be weighed to provide a gravimetric size distribution. The process of separating and classifying the contaminants can also provide information to characterize the fluid, such as pressure drop between the different size mesh. The advantages of mechanical methods compared to optical methods are that opaque fluids can also be analyzed. However, the results are still typically based on the weight of the contaminants so the actual number of particles at different sizes is not known.

Optical methods can vary depending on the needs of the end user. Direct imaging methods exist such as ASTM D8049, where hi-resolution cameras or microscopic techniques take pictures of filtered samples and then the pictures are analyzed visually or by computer to count the captured particles. This type of analysis is often used to determine the cleanliness of a component where a solvent is used to flush out any contamination that may be present in or on the component. Light scattering and light blocking techniques such as ASTM D7619, are more predominantly used to count particles present in a fluid stream. Particles pass in front of a light source in a sample chamber and the amount of light scattering or light blockage is measured. These measurements are then converted to calculate the size of the individual particles. As a result, the number of particles at different sizes can be determined independent of their weight or density. Being able to determine the number of particles at different sizes represents the main advantage of optical methods. The one downfall of light scattering particle counters is that it may also count water droplets as particles. Adding a small amount of a solvent such as ResolverTM or Iso-propyl alcohol are methods to negate this problem however.

ISO 4406:1999
(Hydraulic fluid power - Fluids – Method for coding the level of contamination by solid particles)

ISO 4406:1999 uses particle counters to determine the number of particles in one milliliter of fluid, at 3 different sizes: equal or greater than (≥) 4, ≥6, and ≥14 microns (μm). The 4 and 6 μm particles represent “silt” and fine particles that are difficult to remove and more easily kept in suspension. The number of ≥14 μm particles represents the larger particles that could lead to a more catastrophic failure event.

The specification also defines an “ISO 4406 code” (aka “the code”) which is based on the number of particles for each of the three size ranges counted in one milliliter of fluid (See Table I). A higher code number corresponds to more particles found in the fluid which means dirtier fluid. The code numbers are provided in the format 4μm/6μm/14μm.

Table I. ISO 4406:1999 Codes

Code number	Number of particles in one ml of fluid	
	More than	Up and including
24	80,000	160,000
23	40,000	80,000
22	20,000	40,000
21	10,000	20,000
20	5,000	10,000
19	2,500	5,000
18	1,300	2,500
17	640	1,300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.5	5
8	1.3	2.5
7	0.64	1.3
6	0.32	0.64
5	0.16	0.32

The specification is normalized to "particles per ml", however in practice, particles are counted in a known volume of fluid (for example 100ml) and then the number of particles found at each size is divided by the total volume. This provides the average number of particles per milliliter of fluid. For example, particle counters could provide the following results in 100 ml of diesel fuel:

Table II. Example of particle counts in 100ml of fluid.

Particle Size	Total # of Particles	# of Particles/ml	ISO 4406 Range
≥4µm	1,823,319	18,233	21
≥6µm	305,601	3,056	19
≥14µm	52,022	520	16

The resulting ISO 4406 code is 21/19/16.

When is Diesel Fuel Dirty?

ISO 4406 provides a convenient way of characterizing fluid cleanliness but does not say if the cleanliness level is acceptable or not. Acceptable levels of cleanliness depend on the systems and their requirements for proper functioning. In 1998, the Worldwide Fuel Charter was first established by the World-Wide Fuel Charter Committee consisting of representatives of Auto Manufacturers from Europe (ACEA), the USA (AAM), Japan (JAMA), and Truck & Engine Manufacturers Association (EMA). The purpose of the committee was to promote the need to harmonize global fuel quality, especially considering modern engines equipped with high pressure fuel injection and exhaust after-treatment. In their standard, an ISO 4406 code of 18/16/13 is recommended as the desired level of cleanliness for diesel fuel at the fuel station nozzle. Recently, the ASTM D975 specification for Diesel Fuel has included this recommendation in its Appendix.

Although an ISO code of 18/16/13 is recommended at the fuel station nozzle, is the fuel clean enough for the modern Tier 4 locomotive diesel engine? The short answer is no, diesel fuel at the recommended fueling cleanliness of 18/16/13 is not clean enough for any engine using a high pressure fuel injection system. The manufacturers of fuel injection equipment require that diesel fuel has a cleanliness code of 12/9/6, which means that any fuel going into the locomotive fuel tank must be further purified to reach an acceptable cleanliness to meet the fuel injector manufacturers requirements. The main drivers are the very tight tolerances and dimensions of the high pressure fuel pump and injectors.

Are locomotives in North America being fueled with diesel fuel at 18/16/13 today? Yes and no. While some fuel going onboard locomotives is achieving 18/16/13 or better, not all fuel is reaching the recommended level. There are many potential reasons for this: age and corrosion of fueling equipment, failure to follow recommended maintenance practices, or general poor fuel handling. However, very little testing is performed today and so data is not readily available.

Diesel Fuel Cleanliness Survey

As part of this paper, an informal fuel cleanliness survey was carried out in various locomotive fueling locations. Routine diesel fuel samples from the storage and handling network taken by a Class 1 railroad were forwarded to a laboratory where they were tested for the ISO 4406 cleanliness code. No samples were taken from a locomotive fuel tank or onboard a locomotive. It is important to note that no special precautions for cleanliness were taken for the samples in this survey which may have resulted in some additional contamination present. Typically, special sampling techniques such as using ultraclean sample bottles are required for fuel cleanliness surveys. For this survey, intent was to introduce the possibility of including an ISO 4406 test as part of a routine diesel fuel analysis.

In total, 83 different samples were tested to determine the ISO 4406 cleanliness code. The results indicate that only 18% of the diesel fuel met the recommended cleanliness level of 18/16/13, as shown in Figure 1. The dirtiest fuels were determined to have an ISO code of 23/21/14 and the cleanest fuels at 16/15/12 which meets the recommended cleanliness level.

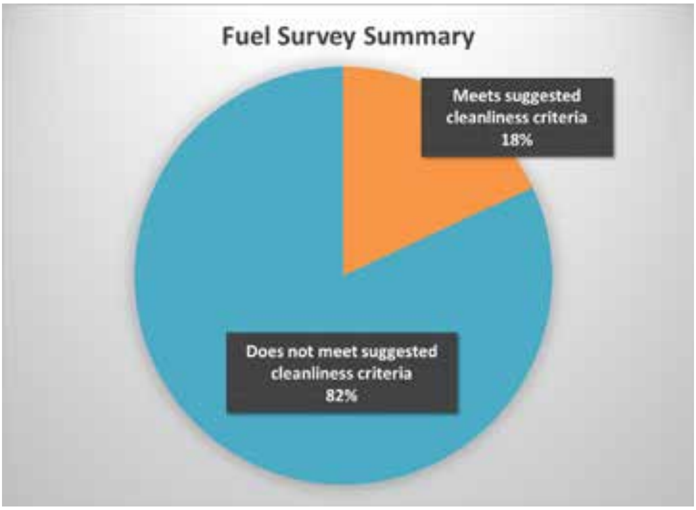

Figure 1. Fuel survey results overview. Percentage of samples measured meeting and not meeting recommended cleanliness ISO code 18/16/13.

The geographical location, the source, and the date were noted for each sample. The samples came from 18 different states and the sample locations on-site included those listed in Table III.

Table III. On-Site Sample Locations

Hose	Fueling hose to the locomotive
Tank	Diesel storage tank
Truck	Delivery to storage
Tank car	Delivery to storage
Pipeline	Delivery to storage
Direct to Loco	Fueling truck service direct to locomotive

Due to the limited sample size, it was not possible to determine any correlations or relationships between the sample location. However, Figure 2 shows that all samples together seems to exhibit a standard distribution.

While not a comprehensive scientific study, these results show that the majority of diesel fuel being put into locomotives at one class 1 railroad does not meet the recommended cleanliness level expectation for the fuel system onboard. It should be stressed that any fuel not meeting the recommended cleanliness levels is putting extra burden on the onboard filtration system which increases the risk of damage to the engine or failure to meet the locomotive on-board fuel filtration service interval. These results are not unusual or specific to rail as other fuel surveys for diesel fuel cleanliness in other diesel engine markets (on-road, off-road) have also shown that a large percentage of diesel fuel does not meet the recommended cleanliness levels.

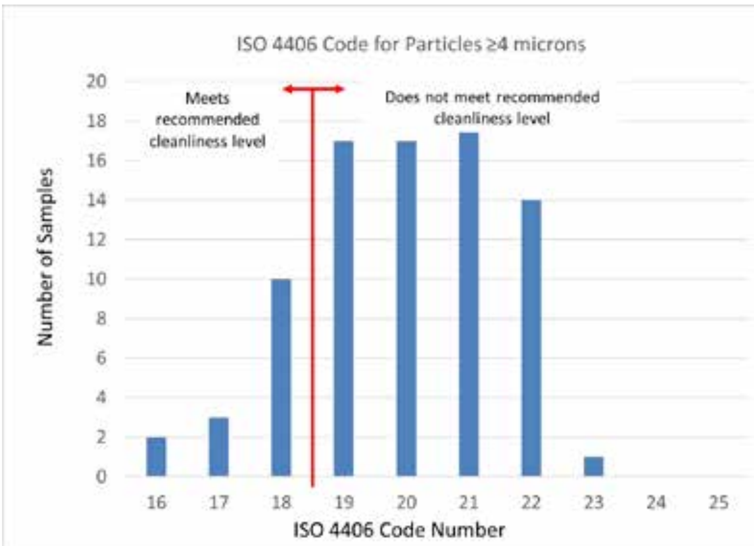

Figure 2. Fuel survey results overview.
Number of samples at given ISO code for particles ≥4 microns.

Practical Use of ISO 4406

Now that we know what our diesel fuel cleanliness is, and what it should be, ISO 4406 also provides guidance to understanding what level of filtration is needed for a given system. When looking at the particle ranges relative to the ISO code provided in Table I, we note that the number of particles doubles for each step from a lower code to a higher code, or conversely is halved for each step from a higher code to a lower code. This aspect of the ISO 4406 definition is very useful and can be used to give an approximation of the particulate removal efficiency required.

By knowing the number of ISO code improvements needed to achieve the appropriate cleanliness for the system, an estimate of the particle removal efficiency can be calculated. Table IV contains an example of the calculation for filtration efficiency and beta ratios depending on the change of ISO code numbers. Considering that each ISO code is a range of a number of particles, it is good practice to add 1 ISO code to the improvement needed and then consider the results as the minimum level of filtration required.

Table IV. ISO 4406 Practical Guide for Filtration

Code number drop	Minimum Filtration Efficiency	Minimum Beta Ratio
2	75.0%	4
3	87.5%	8
4	93.8%	16
5	96.88%	32
6	98.44%	64
7	99.22%	128
8	99.61%	256
9	99.80%	512
10	99.90%	1024
11	99.95%	2048
12	99.98%	4096

ISO Code Drop Example 1

The fuel in the locomotive fuel tank meets the recommended 18/16/13 minimum and needs to reach a required ISO code 12/9/6 for the high pressure fuel injection system. What level of filtration is needed?

Looking only at the 4 µm particle size, we see that the fuel must go from ISO code 18 down to 12, or an improvement of 6 ISO codes. To take into account the full range in each code range, we add 1 ISO code and come up with a minimum requirement of improving 7 ISO codes. This is equivalent to saying that we must halve the number of 4 µm particles 7 times to achieve the desired cleanliness. Either mathematically or by looking at Table III, we see that we need to achieve a minimum efficiency of 99.22% at 4 µm in order to get to the cleanliness required.

ISO Code Drop Example 2

The informal fuel survey has shown that it is difficult to meet 18/16/13 in real life. For this reason, what level of filtration is needed to achieve 12/9/6 when starting with a diesel fuel that might be at 21/19/15?

Performing the same exercise as above, the minimum number of ISO code improvements at 4 µm is 21-12 = 9, plus 1 to cover the range gives a total of 10. Either by calculation or by referring to Table III, we see that a minimum of 99.90% filtration efficiency at 4 µm is required. It is interesting to note that the corresponding beta ratio in this case is over 1000, which is a filtration ratio commonly referred to as an absolute filter. So, in this example we see that an absolute 4 µm filter is needed as a minimum to achieve the required fuel filter cleanliness, and the North American railroad expectation for locomotive applications is that the filter element will provide this level of protection over 6 months.

Both examples above demonstrate the difficulty to achieve the required fuel cleanliness for high pressure fuel injection systems. At the same time, the difficulty is further increased if we consider that fuel must be cleaned and delivered to the engine over the entire fuel filter element service life, which today is mainly 184 days.

What can be done?

The risks of excessive wear, catastrophic failure, and not reaching the required service intervals are increased with dirty fuel. We have seen that real life conditions with current fuel handling practices make it difficult to meet the industry recommended levels of fuel cleanliness. There are some actions that can be taken to improve the situation:

- Train the employees to understand the importance of clean fuel.
- Maintain the fuel distribution system and equipment.
- Use recommended filtration and fueling equipment.
- Ensure that filters and equipment are serviced at recommended intervals.
- Create clean maintenance practices.

Conclusions

Diesel fuel cleanliness has become an important characteristic in overall diesel fuel quality. The ISO 4406 standard is a tool that can provide valuable information on fuel cleanliness which can be applied to maintaining locomotive engine performance and longevity.

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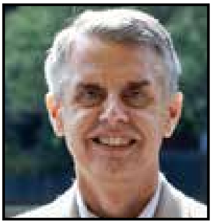
Report on the Committee on Locomotive Software and Systems

Monday, September 18, 2017 at 3:30 P.M.



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PERSONAL HISTORY

Tom Mack

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

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

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

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

The Locomotive Software and Systems Committee held a number of web conference calls in 2017.

The committee wishes to express their sincere appreciation to ZTR Control Systems for hosting and arranging these web calls which enabled the committee to discuss the technical papers that were prepared by committee personnel.

Thank you ZTR.

Connected Locomotives

Prepared by:
Viktor Gvelesiani, ZTR Control Systems

The topic of locomotive connectivity isn't new. Initial prototypes and demonstrations date back to the days of analog modems. For the most part they worked but didn't get past the development stage, leading to question whether locomotives were too unique to benefit from the advancements of digital technologies.

New technologies and communication systems applied to locomotives in recent years bring the idea of locomotive connectivity back into the spotlight. However, the big question regarding the viability of a 'connected locomotive' comes back with it.

The recent emergence of the Internet of Things (IoT) has changed the context in which the idea of locomotive connectivity is now viewed. In the past, locomotive connectivity assumed remote connection to a person asking for specific data using a computer. This proved too cumbersome and time consuming. IoT removes the burden of data collection, transmission and aggregation from people and moves it to software and systems. Is this enough to make connected locomotives a reality, or will "connected locomotive" become just another hot topic of the day that will fade away like it did many times before?

The answer to that question largely lies with the way a digital strategy is developed and implemented by individual railroads.

The Internet of Things

Connected locomotives, just like all other connected devices, fall under the definition of the Internet of Things:

The Internet of things (IoT) is the inter-networking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings, and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data[1].

The key element of this definition is the ability of intelligent devices, such as locomotives, to exchange data: with each other, or with other intelligent devices. The Internet of Things no longer requires human involvement, but is expected to provide significant benefits to people through its outcome.

The outcome of this technology, just like any other complex technology, has to be carefully and diligently crafted in the form of a digital strategy.

1. https://en.wikipedia.org/wiki/Internet_of_things

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Digital Strategy

Digital strategy carries many similarities with IT strategy, but they are not interchangeable. The two strategies are highly complementary to each other, but ultimately are focused on achievement of different goals.

IT strategy is focused on application of digital technologies to the existing business processes. Its main focus is to achieve greater efficiency by introducing more efficient methods of operation within pre-defined processes.

Digital strategy is about changes in processes enabled by the digital technologies. Its main focus is to elevate human performance through changes in business processes enabled by information and digital technologies.

Connected locomotives are a critical element of the digital strategy and should be a primary source of information. However, important as they are, they only represent a piece of the overall puzzle of digital strategy. Other elements of digital strategy are just as equally important; only together they can help to unlock and materialize the true potential of IoT technology.

Creating the digital strategy typically follows four steps (or stages) shown in Figure 1.

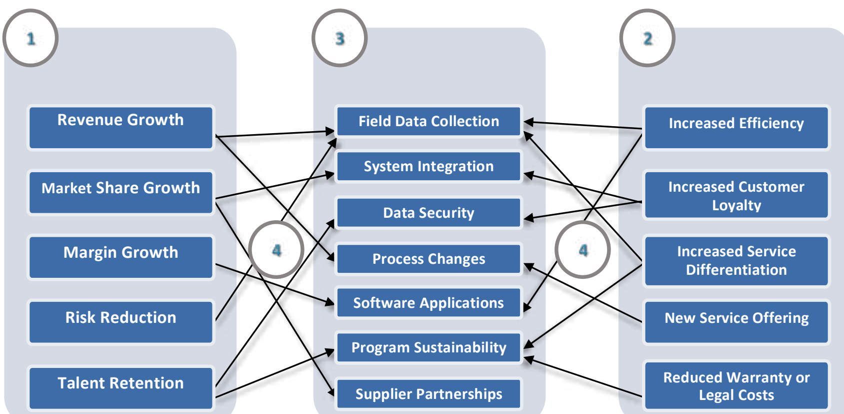

Figure 1: Digital Strategy Process

Step 1: Business priorities define strategic direction of the railroad. Examples of business priorities are:

- Revenue growth
- Market share growth
- Profitability improvements
- Talent retention
- Risk reduction

Step 2: Competitive advantages are the means by which business priorities are achieved. Examples of competitive advantages are:

- Increased efficiency
- Increased customer loyalty
- Service differentiation
- Reduced warranty
- Reduced legal costs

Step 3: Business elements are the specific areas of business processes that enable achievement of business priorities and competitive advantages. Examples of business elements are:

- Field data collection
- System integration
- Supply chain management
- Customer service
- Software development

Step 4: Digital strategy can then be developed as a link between these components, and a method to deliver information necessary to process changes in the business elements that would lead to the achievement of business priorities and competitive advantage.

Digital Elements of IoT Strategy

The main elements of digital or IoT strategy are usually considered as in a data flow diagram, from source to destination, as shown in Figure 2.

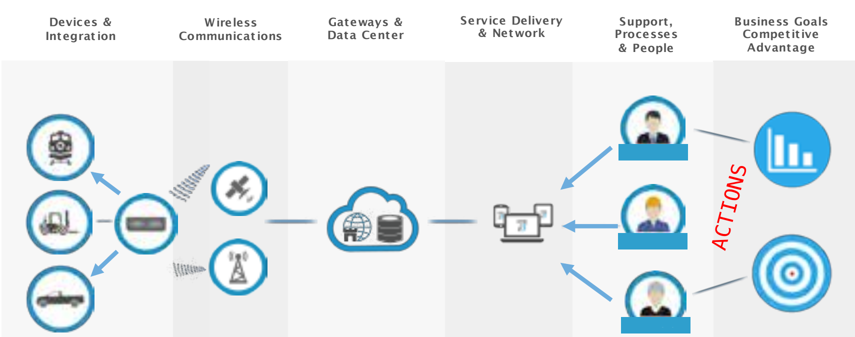

Figure 2: Digital Elements

The destination (human actions based on the information) is the most critical and the most commonly overlooked part of the data flow. The elements of the digital strategy are defined by the desired human actions (changes in the processes). This means that during the development of digital elements the flow is reversed: human actions are defined first and devices and integration systems are considered last.

The desired human actions may require new information and new means of delivery of this information to people. New information may impose additional data requirements, which will affect data collection systems on locomotive and wireless data off-boarding systems.

Scalability and Expandability

Another critical element in development of digital strategy is its ability to accommodate the ever increasing volume of data. Business needs and priorities are constantly changing. When additional assets come online, they bring quantum increases in data. The data center designed for today's needs may very quickly become inadequate, facing an increase in number of assets communicating data simultaneously or users attempting to use the information.

Data accumulation over time poses another threat to infrastructure. Historical data is usually important if data trend analysis is required. Keeping all data in one data store will inevitably slow down analytics as it will require more time to sift through a larger amount of data.

New information available to users may trigger new innovative ways of changing business processes, which may require new information. The system of data collection, transmission, storage, analytics and distribution of information to the users must be able to accommodate these future needs. Because these future needs are largely unknown at the time of initial development, it is crucial to assure flexibility of the digital platform, as shown in Figure 3:

- Telematics, the data collection system including sensors, communication interfaces, audio/video recordings and etc.
- Transmission devices and carriers, including cellular, satellite and WiFi communications and networks supporting them
- Business integration systems allowing collected data and information to be directly injected into the business systems, such as ERP systems, quality systems, work order systems, parts management and etc.
- User interfaces, providing the right information to the right people at the right time when human decisions are required

Data Security and Integrity

A successful digital strategy will connect and integrate data from locomotives and other assets into business systems and processes. Data security and integrity is another critical element of the digital strategy.

Data security has to be capable of quickly identifying and adapting to new threats and have a sufficient amount of redundancy and backup systems to ensure near uninterrupted functionality.

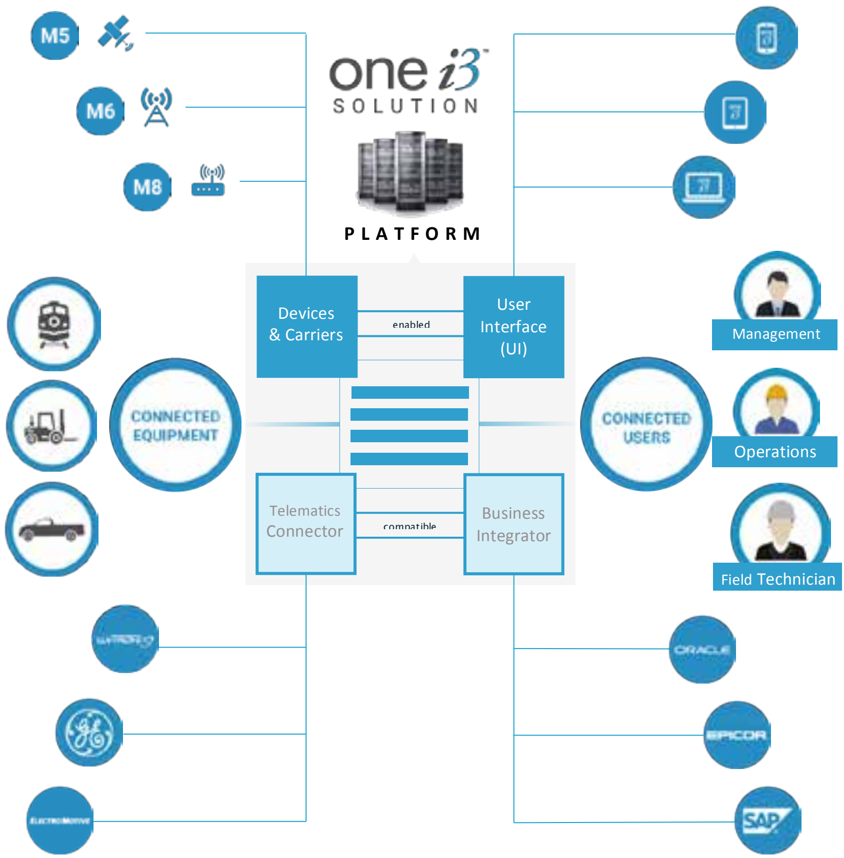

Figure 3: Scalable And Expandable Digital Platform

The good news is that there is a multi-billion dollar data security industry making it possible for even small IT groups to maintain high levels of security and integrity of digital systems. Recent increase in popularity of cloud-based systems is a testament to that. Large cloud service providers are able to invest far more resources than individual users into providing instantaneous scalability of services (literally requiring a few clicks of a mouse from the user), superior backup and data recovery capabilities as well as data security options.

Conclusions

It is difficult to imagine that in the world of "smart" phones, cars, televisions and refrigerators, something as significant and expensive as a locomotive cannot be successfully connected to other smart devices and business systems. However, our experience shows that such connectivity can only be successful when implemented as part of a larger digital IoT strategy focused on driving change, elevating human performance, and adopting new processes.

Digital IoT strategy cannot be only about locomotives. It has to consider other assets and devices, as well as their integration into business systems and processes. These systems must be designed with flexibility and scalability to allow continuous and successful evolution.

Successful digital strategy cannot be developed in isolation. Best practices and technologies from other industries, as well as leveraging significant investment in technologies by larger companies, are crucial in assuring future compatibility of new technologies and relatively smooth ongoing evolution of digital systems.

Sensors and Instrumentations on Locomotives-A Railroad Case Study

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Intro

CSX Transportation, Inc. ("CSXT") is, by its very nature, an asset-intensive company. On any given day, CSXT manages multiple trains, over thousands of miles of mainline track, with a large inventory of freight cars and locomotives, on track that is equipped with switches, signal equipment, and wayside equipment utilized to manage, monitor, and control train and car movements in an effort to safely and reliably move goods to its customers.

In addition, numerous other assets both mobile and fixed are used by CSXT to maintain facilities and move trains. Examples include but are not limited to:

- Rubber Tired Vehicles (RTV)
- On track work equipment
- Environmental facilities
- Shop Facilities
- Air Compressor Plants
- Turntables

- Drop Tables
- Communications systems
- Signal systems
- Positive Train Control Equipment
- Yard Systems

In its current state, CSXT relies primarily on periodic inspection and repair activities to identify equipment conditions that require corrective actions in order to maintain desirable service levels. In spite of the massive efforts to maintain facilities and the myriad assets that run on it using the periodic approach, CSXT continues to explore alternatives that continue to improve safety, service and availability.

Recently, CSXT performed extensive benchmarking with companies inside and outside of the rail industry. The goal of this exercise was to find out what other companies were doing to improve reliability, asset availability, and productivity.

Benchmarking

The overall results of the benchmarking feedback were very consistent. All of the companies that benchmarked in one way or another were either providing or adopting technologies to collect operational data that could then be analyzed and used to create actionable information. In more recent terms, this strategy is called the Industrial Internet of Things ("IIoT").

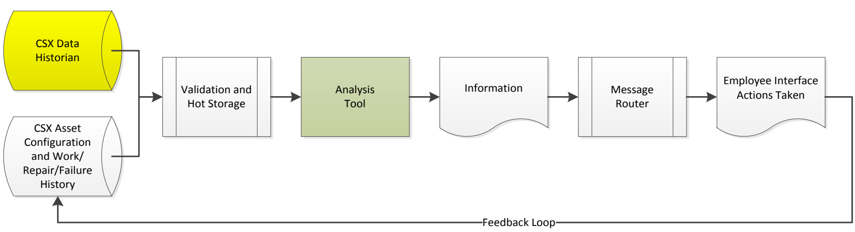
Image Source: MIT Sloan/CISR Research Briefing Volume XII, Number 2, February 2012. Ross & Beath; "Working Smarter: The Digital Economy Is All About Your People"

At the heart of this message was the need for an analytics package - one that could be easily used by business experts to identify trends, conditions, and situations that could be evaluated and prioritized for specific actions. The theme was pretty clear: Commoditize data, find an analytics package and use it to create information so people can work smarter.

Need for predictive analytics and machine learning

CSXT has had some success in recent years with regard to acquiring asset data, most notably in the area of wayside monitoring. CSXT currently utilizes more than 1,000 wayside detectors that are integrated with CSX data systems (the "Yellow Box") that then poll the data to provide car/train health information to Mechanical and Transportation personnel. The technology developed and implemented to network these assets and the knowledge gained have contributed to a reduction in train accidents, and are the basis for condition-based maintenance activities for both the Mechanical (Cars) and Signals (Detectors).

Currently, this data is processed using a legacy rules engine that is effective in creating pass/fail indications, but which was not developed to process myriad sources of data off of a single asset. CSXT previously benchmarked and piloted analytics tools, and as a result selected an analytics tool that is currently applied across the locomotive fleet.



Locomotives and Data

An area of opportunity for CSXT that has not been cultivated is the acquisition of locomotive data. Today, the only sources of hosted performance data on CSX locomotives is either from the wayside network (wheel and truck performance data) or through locomotive oil sampling (lube oil analysis). Local/manual acquisition of fault logs are also performed, but these are not currently collected.

Through benchmarking, CSXT has met companies that are either successfully acquiring locomotive data or have expertise that may provide locomotive data. On board locomotive data is seen as an untapped opportunity to monitor and maintain the locomotive fleet. Available data streams include but are not limited to:

- Road Number/Asset ID
- Traction Motor Status
- Traction Motor Operational Data
- Main Alternator Operational Data
- Main Engine KwHr/Operational Control Data

- EAB (if equipped) Operational Data
- Head of Train Defect/Operational Data
- Fuel Level
- APU status (if equipped)
- Trip Optimizer Status (if equipped)
- Horn Actuation
- Bell Actuation
- Computer related problems/faults (If loco equipped with electronic/solid state control system)
- PTC equipment operational data
- PTC equipment problems/faults
- Equipment Duty Cycle/Operating data
- Fuel consumption (mass flow rate)

In addition to these data sources, CSXT sees an opportunity to acquire other native sources of data on locomotives with electronically controlled engines. These native sources include:

- Lube oil pressures
- Lube oil temperatures
- Cooling water pressures
- Cooling water temperatures
- Fuel Oil Pressures
- Injector Timing Information
- Exhaust temperatures
- Cylinder pressures
- Auxiliary equipment operational data
- Auxiliary equipment status
- Additional data tags that may be identified as useful for equipment monitoring
- Local/on board reporting (inspection reports)
- Potential: Locomotive Digital Video Recorders
- Potential: Locomotive ride quality/track condition data, both discrete and continuous.
- Potential: Locomotive Acoustic Detectors/Microphones

Architecturally, CSXT sees an opportunity to leverage the on-board systems installed on its locomotives as part of the Positive Train Control ("PTC") initiative. These systems can be leveraged to consolidate and synchronize the data points to ensure accurate chronological time stamps. Where possible and where it does not affect mission reliability, an integrated approach to data acquisition and transmission is the desired end state.

Locomotive configurations are broadly categorized as follows:

1. Locomotives equipped with existing information gateways and communications managers.
   a. See Figure 1

2. Locomotives NOT equipped existing information gateways and communications managers.
   a. See Figure 2

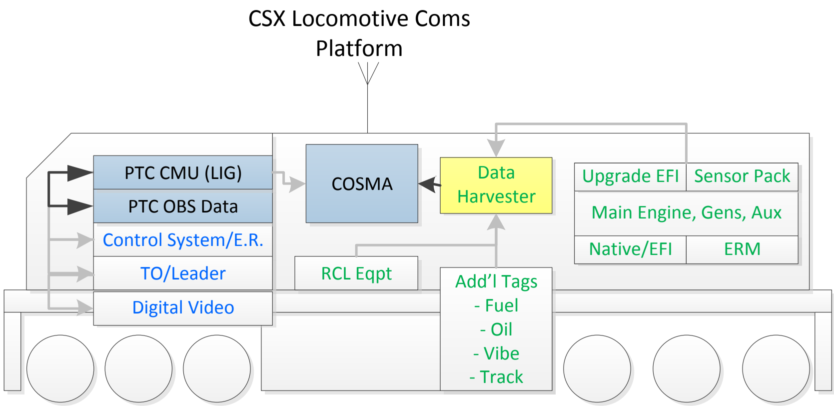


Figure 1: Architectural overview of on-board systems, PTC Equipped

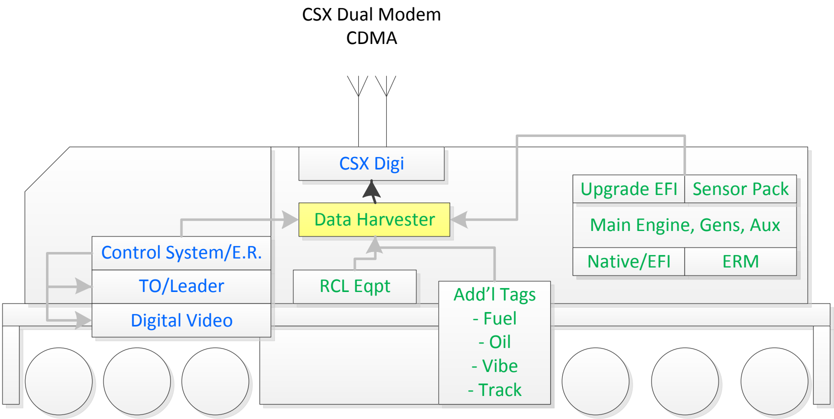


Figure 2: Architectural overview of on-board systems, Non-PTC Equipped

Harvesting existing data

Joint Wayside Detector System (JWDS)

As stated above, CSXT has a complex network of wayside systems that assist in monitoring rolling stock. There are a variety of threshold rules for the different detectors. To start, we focused on improving the accuracy of these rules. Focusing on the Wheel Impact Load Detector ("WILD") and the Optical Geometry detector ("OGD") initially, we began employing machine learning techniques.

Our WILD sites measure the vertical impact force on the rail by utilizing a series of strain gauges. This detector can determine the condition of the wheel in relation to flat spots or built up tread. It can also help identify applied handbrakes. An algorithm was created by looking at vertical peak force, lateral peak force, speed, tonnage and various other predictors. This algorithm can detect whether a particular wheel on a locomotive will reach an impact level of 90 kips within 1 month.

The OGD looks at the position of the trucks and wheelset relative to the centerline and angle of the rail. See Figure 3.

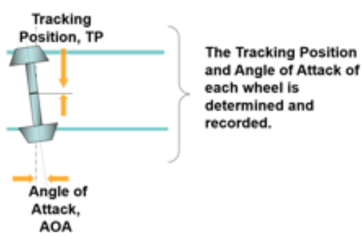


Figure 3: OGD Primary Wheel Measurements

We were able to find a correlation between the tracking position measurement and thin flange conditions. The tracking position measurement measures the deviation of the of the axle centerline to the centerline of the track (FIGURE 3). The rule flags locomotives at risk and instructions are applied to measure the wheels at the next servicing. If a defect is noted, it must be repaired in accordance with CSXT's operating protocols.

Machine Learning

There were many lessons learned during the development process. As with any data science exercise, a majority of the time is spent pre-processing the data. Careful attention must be paid to the quality of the data. Secondly, predictors must be developed. We began with the basic principles of a normal distribution, focusing on mean, median, mode, max, min and standard deviation for specific time frames. More creative predictors were developed later on in the project. The data was then ready to be analyzed. We utilized a Data Mining software to visualize and build algorithms. We experimented with logistic regression, decision trees, neural networks and clustering algorithms. From our experience, decision trees proved to be the most accurate. When we score our models, we pay close attention to the misclassification percentage. This ensures that we take in to consideration the entire decision table, true positives, false positives, true negatives and false negatives. We also found that decision trees are easy to explain and implement. The result lends itself to easily be programmed in to our legacy system. Both algorithms calculated with an accuracy of over 90% on locomotives that were flagged. After performing these two ad-hoc projects we knew that this was the direction we wanted to move in, but needed a solution that was automated and could handle large amounts of data.

Oil sample

A first pass at analyzing high volumes of information began with our locomotive diesel engine oil sample data. Historically, we applied threshold rules to the results of the lab analysis. Our goal was to implement a process that would provide instructions to our field employees based on the severity of the oil sample. We partnered with Mtelligence, Inc. (“Mtell”), a prescriptive analytics software provider to assist in analyzing our locomotive oil sample data. This proved to be an excellent pilot project due to the fact that each sample had 22 variables associated with it, and the frequency of each sample was approximately 14 days.

Algorithms were created utilizing supervised and unsupervised learning. For example, specific catastrophic failures were modeled by looking back at the oil sample history. In addition, algorithms were also created by anomaly detection and clustering the input data.

CSXT created rules based on wear metals (lead, copper, iron, tin, aluminum, chromium and silver), internal water leaks (boron and sodium), and internal fuel leaks. Depending on which rule flagged, a specific work order was assigned to that locomotive in our work order management system. For example, a wear metals work order will contain a detailed head, liner, piston and main bearing inspection. In the first year we were able to prevent locomotive line of road failures.

Control system data

The locomotive oil sample pilot was an excellent example of multivariable analysis with time series data. The next phase collected existing control system data and transmitted it to CSX’s back office where the data would then be analyzed through Mtell. CSXT also partnered with a local integrations solution provider, ITG Technologies, Inc, to help CSXT understand the data formats, security protocols and communications of harvesting this data.

CSXT then decided to install the SORBA hardware platform (“SORBA”) as the integrating solution. This platform allowed us to perform data harvesting and edge processing with the ability to be completely open-source and scalable. The

SORBA plugs directly in to the download port of the control systems and reads in real time. This data is packaged and sent to CSXT's back office utilizing the PTC communication path. This proved to be a critical win in our journey to predictive maintenance. Having the ability to utilize this communication path without hindering PTC operations was groundbreaking.

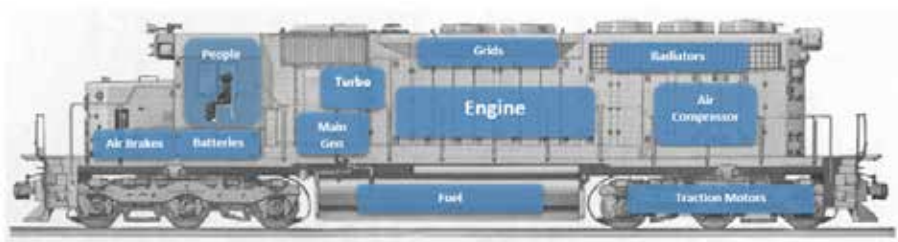


Figure 4: Locomotive Data Sources

Harvesting new data

Engine sensors

Approximately half of CSXT's locomotive fleet is not equipped with microprocessors or sensors. To have the ability to monitor these locomotives remotely, CSXT would need to install sensors that monitor critical operations and provide insight to impeding failures.

We instrumented an EMD 645 engine with a variety of sensors:

1. Oil and water pressure and temperature
2. Airbox pressure
3. Exhaust temperatures
4. Main bearing temperatures
5. Fuel pressure
6. Fuel flow
7. Crankcase pressure

These sensors were run to an IO panel that was installed in the main generator compartment where the signal was converted to digital. The signal was run through Ethernet to the SORBA where the data was collected and off-boarded.

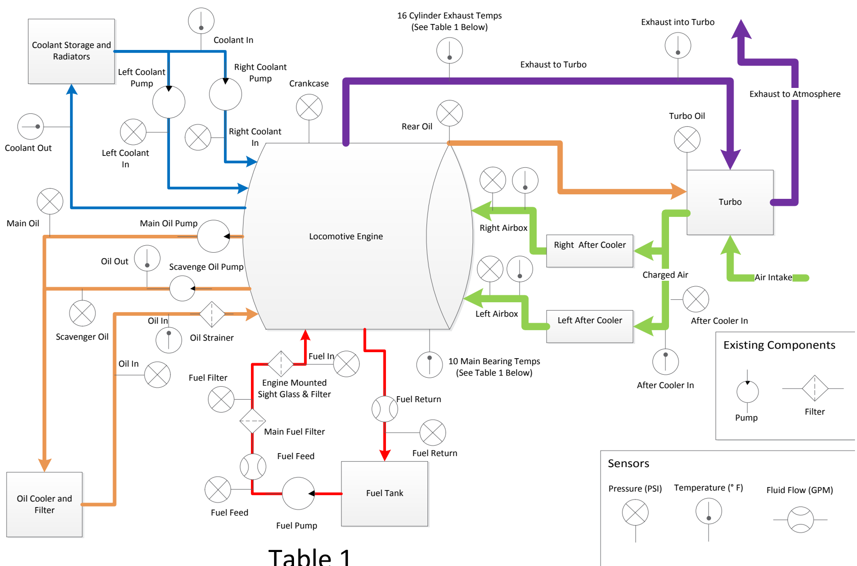


Table 1

Right Bank Cylinder Exhaust Temperature	1	2	3	4	5	6	7	8		
Main Bearing Temperatures	1	2	3	4	5	6	7	8	9	10
Left Bank Cylinder Exhaust Temperature	9	10	11	12	13	14	15	16		

Figure 5: Supplemental Engine Sensors:

Additional Sensors

If we think of the engine sensors listed above as inputs, then we can consider the harvester to be a platform to accept these additional inputs. In the case of our first EMD engine, we added inward and outward facing cameras, cell phone sensors, and battery amperage/voltage sensors.

Cameras and Analytics

A camera can be thought of as another "sensor" in which data could be collected and transmitted. When looking for a camera solution, our three main objectives were: (i) to find a product that can withstand the railroad environment, (ii) have superior quality and (iii) the ability to enhance our advancements in computer vision.

We installed three cameras in a locomotive, one outward facing and two inward facing cameras. The outward facing camera is high-definition (HD) quality and has the ability to pre-process the images before sending them to the SORBA. The two inward facing cameras are 360 degree cameras with pan/zoom ability. The cameras also have infrared capabilities for low light conditions. All cameras are Ethernet over IP and are connected to the SORBA which allows them to be viewed and downloaded remotely.

Computer vision

The science of computer vision is centered on acquiring, processing and analyzing digital images. It allows us to break an image down to individual pixels and create matrices that can be analyzed using algorithms.

Our journey into computer vision began with a study centered on train derailments, specifically the derail device. By having the ability to identify derail devices using the outward facing camera, we could notify the crew in the cab that they are approaching an applied derail. Approaching this problem from two directions yielded impressive results. In regards to rail obstructions and continuity the study reinforces the need to adhere to industry standards. The first computer vision method used to analyze this was Contour Detection. In the image below you can see a zoomed out view of a locomotive service facility and the subsequent image that has the contours identified. It is evident that the rail lacks continuity.

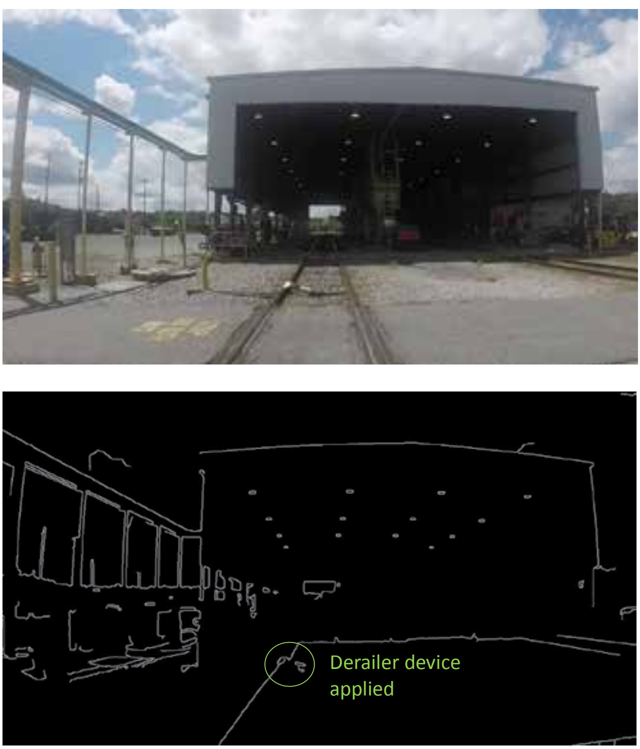


Figure 6: Computer Vision Image Contour

Our second approach was analyzing the derailer device as an individual object in the image frame. Derailer devices are unique objects that are usually colored yellow and have a distinct shape. Contours also work in this scenario, but there is significant noise in the image due to the ballast and debris.

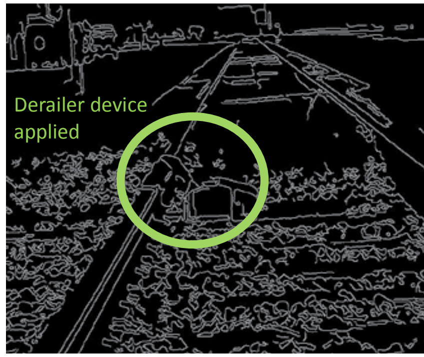


Figure 7: Asset Identification Image and Contour

To overcome this challenge we explored a different method called Feature Detection. This method identifies key points in an object such as edges and corners. To have the processing power to perform this analysis, we decreased the region that was being analyzed. We created a region in the lower-center of the frame which constrains the analysis to the contents inside the region which improved processing time by about 50%.

Figure 8: Region of Interest Training

Figure 9: Asset Feature Training

We experienced incredible success with computer vision and expanded our analysis to track inspections, misaligned switches, vehicle and pedestrian detection and gaze/fatigue analysis.

Maintenance: From Periodic to Condition-Based

Current efforts to maintain reliable cars and locomotives are based on periodic inspections, age-usage-based replacement, or in some cases, equipment conditions that suddenly exceed a specific threshold, or go/no-go inspection criteria.

Under these circumstances, maintenance is either unnecessary and costly (if a component that is running well and which has an indefinite life is replaced on a usage-based schedule) or ineffective and costly (a component fails in spite of a recent inspection event due to unforeseen/unknown conditions and creates collateral equipment damage and interruption to train service).

Age-reliability studies undertaken by United Airlines (1968), Broberg (1973), US Navy Surface (1982) and US Navy Submarine (2001) indicate that the vast majority of failures (75% for US Navy Submarine, the most conservative study performed) occur at random age intervals and that age/usage based maintenance is ineffective.

As a result of the success of the Mtell Oil Analysis project, CSXT has begun to create customized work packages for individual locomotives with work items that are tied to the performance of each locomotive based on predictive analysis. The addition of other data to the analysis will allow CSXT to create even more detailed assessments of locomotive operating condition with further insights that can be provided to maintenance personnel.

Conclusion

With a large locomotive and freight car fleet, and data that is collected or otherwise available from testing and operating these assets, there is no short supply of available data. The trick is to commoditize the data and glean meaningful information from this data that can help our personnel make better decisions and be more effective at doing their job.

In the last 3 years, CSXT has taken another run at making sense of our data. With the advent of Big Data, Predictive Analytics tools, increasingly powerful computer modeling, and a reduction in communications costs and increased bandwidth, CSXT has made significant insights that have brought savings to our bottom line. In the last year alone, this journey has resulted in a 5x return on our initial investment.

With a focus on locomotive reliability, CSX began a journey that includes putting our locomotives into our IoT, acquiring and hosting native data, testing out additional sensor packages. These sensor packages can provide greater insight into the health of our locomotives with component-specific precision, and most notably, exposure to and adoption of predictive maintenance (PdM) software that allows us to overlay operating data, maintenance and failure history, and model failures that can be cast against similar assets to “protect” them against a similar future failure.

This success has not exclusively been the result of the aforementioned technology advances. Equally vital is the convergence of IT (Technical Expertise) and OT (Domain Expertise), with a common focus on meeting or exceeding operational goals (reliability) and challenging our current ways of thinking (failures are opportunities to learn). Indeed, a combination of people, processes, and technology is what we have learned is necessary to be successful.

Design and Safety Analysis of Safety-Critical Electronic Locomotive Control Systems

An Introduction to and Summary of 49 CFR Part 229 Subpart E - Locomotive Electronics and Appendix F to Part 229 - Recommended Practices for Design and Safety Analysis

Prepared by:
Adam Bennett, R. J. Corman Railpower Locomotives

Summary

This paper provides an introduction to 49 CFR Part 229 Subpart E – Locomotive Electronics. You will learn what products are subject to this subpart, key deliverables for the subpart and the railroad's associated responsibilities, what the FRA expects in a Safety Analysis for covered products, and what are some recommended design practices for these products.

Disclaimer

The information in this presentation is based on my review and understanding of the associated Code of Federal Regulations and AREMA (American Railway Engineering and Maintenance-of-Way Association) C&S (Communications and Signals) Manual Part 17.3.1 – 17.3.5. You should consult the CFR or your company's safety expert; don't rely on the information in this paper for your business decisions – especially when determining covered product.

A large part of the language and statements in this paper are direct copies out of 49 CFR Part 229 Subpart E and Appendix F. This presentation does not primarily consist of original work.

Introduction to the CFR

The main objective of this subpart is to promote the safe design, operation, and maintenance of safety-critical electronic locomotive control systems, subsystems, and components.

This subpart was added to the CFR via 77 FR (Federal Register) 21348 on April 9, 2012. The best way to find the latest version of this subpart is to simply perform an internet search for "49 CFR Part 229 Subpart E".

Upon reading the subpart, one will notice the requirements in Subpart E are a lightened version of Subpart H, which is for vital signal and train control equipment. Railroads and suppliers that are already implementing Subpart H as part of their PTC program will have a template to follow. Subpart H was developed about seven years previous to Subpart E, in 2005. While the concepts are similar, there are scope and nomenclature differences.

The contents of this CFR should interest both vendors of electronic locomotive control systems and railroads that operate locomotives with electronic control systems, which includes all modern domestic locomotives.

Covered Products

This subpart 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 hardware and software. Note that locomotive control systems, subsystems, or components that comingle with safety-critical signal and train control systems (i.e. PTC) are not covered by this subpart; rather they are covered by Part 236 Subparts H and I. For example, an HMI (Human Machine Interface) screen that shows PTC or signaling directives to the crew falls under Part 236 Subparts H and I.

Products fully developed prior to June 8, 2012 are exempt. However, changes that result in degradation of safety or increase in safety-critical functionality are not exempt, no matter when developed. Also, the applicability is irrespective of the location of the control system, subsystem, or component. For example, if, for some reason, the railroad's back-office equipment tied into the locomotive control system and performed any function directly related to the safe movement and stopping of the train, it would likely be covered by this subpart.

Even though not cited as a reference in Part 229 Subpart E, AREMA C&S Manual 17.3.5, referenced in Part 236 Subpart H, is very useful to help determine covered products. Instead of vital or non-vital, the AREMA manual recommends three product safety classes: safety-critical, safety-related, and non-safety related. Only the safety-critical (vital) products are subject to Part 229 Subpart E.

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

Some examples of safety-related locomotive control systems, subsystems, or components include: hardware and software that deal with measurement of grounds, hardware and software that deal with current-limiting while on a load box, hardware and software that deal with voltage-limiting for battery charging, and ammeter display.

And finally, some examples of non-safety related locomotive control systems, subsystems, or components include: engine radiator fan control hardware and software, traction motor field shunt or series/parallel control and hardware, hardware and software related to data collection for post-processing.

Although not specifically addressed in the CFR, one would clearly expect the work involved with an addition or change of a safety-critical hardware component or software function to be less involved than the introduction of a whole locomotive control system. A new or next-generation locomotive control system would be covered as a whole, and have a large number of safety-critical concerns to address. On the other hand, if changing or adding a subject subsystem or component, you likely should consider the subsystem or component being modified or added and any interconnected subsystem or component in the analysis. When adding or changing a component or software function of a locomotive control system, ask "Is it directly related to safe movement and/or stopping of the train?" to help you determine if the product is covered by this subpart.

Key Deliverables

Part 229 Subpart E outlines a few key deliverables for each subject product, prior to its use on the railroad. The key deliverables include:

- Safety Analysis
- Defined process to follow for planned safety-critical design change
- Hazard log
- Product testing results and records
- Operations and Maintenance Manual
- Training and qualification program (and records of such training).

The Safety Analysis provides inputs to the other key deliverables, and as such needs to be done first. If the Safety Analysis is complete, the other key deliverables are much easier to produce.

Responsibilities

The railroads are primarily responsible for the key deliverables, especially the record keeping. However, the Safety Analysis is intended to be pushed down to the supplier of the product. The railroad can then use the information in the Safety Analysis to help create the other deliverables. The railroad must inform the FRA of intent to put the product in service and supply the required documentation.

The railroads must have configuration (revision) control measures in place for subject products. For instance, vendors must notify the railroad if a change to safety-critical locomotive control system hardware or software is required, then the railroad follows the configuration/revision control plan to implement the change across the affected locomotive fleets.

The railroad shops must maintain test results and repair records 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. If a hazard (a condition that results in an accident) frequency is above the level documented in the Safety Analysis, the railroad must take countermeasures and report these to the FRA.

Operations and Maintenance Manual

The information that enables the shops to test and repair the safety-critical product is contained in the Operations and Maintenance Manual. The OMM contains all the documents related to installation, maintenance, repair, modification, inspection, and testing of the product in one master collection. Keep in mind the product's SA (typically from the vendor) should contain the majority of the content for the OMM. Unlike a normal manual, the OMM must also document safety-critical hardware and software versions, revisions, and associated dates. Any safety-critical components, including spares, must be positively identified and handled according to the railroad's configuration control measures.

Training and Qualification Program

In order to support verification that the safety-critical functions don't diminish over time, and immediate repair of the safety-critical product if the functions are compromised, a training and personnel qualification program needs to be developed. Railroad individuals with different responsibilities will need different training. The groups to consider should include maintenance/repair/testing technicians, train operators/engine crew members, roadway/maintenance-of-way workers (to avoid interfering with proper functioning), and direct supervisors.

Development of the training and qualification program begins with a formal task analysis for each of the responsibilities. Once the goals are determined and tasks described, then written procedures can be created for each group. The training curriculum itself is then a natural progression from this formal task analysis. Note the SA should contain the majority of the material for the training program.

After the training and qualification program has been developed the railroad is responsible to perform training for the different groups, maintain records, and conduct periodic refresher training as needed. This needs to be coordinated with the product's launch and over the product's lifespan.

Safety Analysis

A Safety Analysis refers to a set of documentation that describes all safety aspects of the covered product. The SA includes procedures for the product's development, installation, implementation, operation, maintenance, repair, inspection, testing, and modification. The SA contains analyses supporting its safety claims.

49 CFR Part 229 Appendix F details the recommended contents for the Safety Analysis of the subjected safety-critical electronic locomotive control system, subsystem, or component. At a minimum, per Part 229 Subpart E, the Safety Analysis must contain the requirements for the development and implementation of the product, establish that the product's safety-critical functions will operate with a high degree of confidence in a fail-safe manner, include procedures for immediate repair of the safety-critical functions, and be made available to the FRA upon request. The FRA uses Appendix F's content guidelines when

reviewing SA documents. So if the recommended contents are followed, not only will the design be more robust, but the product will be quicker to market – that is, ready for revenue service.

The detailed contents of the safety analysis can be broken down into four stages: systems engineering, hazard analysis and mitigation, monitor through lifecycle of product, and support of railroad's responsibilities.

The systems engineering portion typically provides the "big picture" and any top-level requirements, which in this case will be safety requirements. The description of the product includes its relationship in the overall system and the railroad's operation related to the product. The operational concepts document provides a description of the products functionality and information flows. And finally the safety requirements document contains descriptions of functions the product performs to enhance or preserve safety and the manner the architecture satisfies the safety requirements.

The next portion of the safety analysis centers on hazard analysis and mitigation. The risk assessment and analysis should provide a MTTHE (Mean Time To Hazardous Event) calculation for each safety-critical subsystem or component. Assumptions are to be listed for the reliability of components. This should include MTTF (Mean Time To Failure) estimates for the components. One needs to consider both hardware and software at this stage of the analysis. To that end, assumptions are to be listed for software defects.

To correlate actual use to the analysis, a hazard log must be started. This log records all relevant safety hazards addressed during the lifecycle of the product, and should include maximum threshold limits for each hazard. Full disclosure of potential safety risks is stressed in Appendix F. For example, if a hazard is not pre-listed in the log, but occurs, it must be immediately addressed by the railroad. On the other hand, a hazard may occur and not need to be addressed if its occurrence frequency is less than the pre-estimated frequency of occurrence. The log should correlate to the hazard mitigation analysis, which describes all hazards to be addressed in the design and development, and the mitigation techniques.

The next segment of the safety analysis ensures the product is monitored throughout its life cycle. This starts with a description of the verification and validation process used for the product. Remember that validation answers "Does the design fulfill its intended objectives?" and verification answers "Was the product built correctly?". Next is a description of validation testing which includes plans and validation test procedures, typically executed with the product's first availability. List any monitoring needed to ensure the safety-critical functions are not compromised over time. Also describe any security measures of the product over its life-cycle.

The final portion of the safety analysis provides information and documentation in support of the railroad's responsibilities. These include:

- Description of training of railroad and contractors for proper and safe installation, implementation, operation, maintenance, repair, inspection, testing, or modifications of the product
- Description of procedures and any equipment to ensure proper and safe installation, implementation, operation, maintenance, repair, inspection, testing, or modifications over the life-cycle of the product (verification testing)
- Description of records to be kept for training, procedures, and hazard log
- Description of configuration/revision control measures designed so safety-critical functions are not compromised as a result of product change.

While the above Safety Analysis content may seem excessive, keep in mind these are recommended contents and actual content will vary depending on the scope of the product's addition or change.

Recommended Design Practices

Besides recommended contents of the Safety Analysis, Part 229 Appendix F also contains recommended design practices for safety-critical electronic locomotive control systems, subsystems, and components. While these recommended design practices are sprinkled throughout Appendix F, they can be broken into six main categories: focus on safety-critical functions, design considerations, human interaction, HMI design, FCC compliance, and references for product verification and validation. This paper will only summarize the first three.

The first group of recommended design practices focus on safety-critical functions. As one would expect, all safety-critical functions must perform properly under normal conditions and with expected inputs. The product must be designed to operate safely under conditions of random failure. The easiest way is to have the random failure automatically detected (self-revealing) and then automatic action taken to achieve a safe state. If the random failure is not self-revealing, then the next failure path must be considered as possible. Take, for example, Trainline 8 and 9 (Forward and Reverse). If both trainlines are high (one had short to control power and the other was selected via the reverser), the control system should automatically recognize this condition and go to a safe state. That is, select neither direction.

The product should be designed to mitigate unsafe systemic failures. Appendix F defines systemic failures as conditions which can be attributed to human error that could occur at various stages throughout the product's design and lifecycle. This includes human errors in software and hardware design, improperly designed HMI, and installation and maintenance errors. The best way to combat these are to have in place and follow proper design processes, and provide installation and maintenance instructions based on a formal task analysis.

After the hazard mitigations are complete, there must be no single point failures that result in hazards categorized as unacceptable or undesirable. Also, the system should be designed to catch errors before they propagate. These errors could be software execution errors, electrical fault conditions, or broken equipment.

A locomotive operates in a very severe environment, so there are many causes of equipment errors that could result in a hazard. Appendix F lists these design considerations. The designer should consider permanent, transient, and intermittent faults in FMEA and MTTHE calculations. Electrical influences to consider are power supply transients, abnormal range or combination of inputs, electromagnetic interference, and nominal voltage/current (not mentioned in the CFR). Mechanical influences to consider include shock, vibration, and nominal stress/strain (again, not mentioned in the CFR). Finally, environmental influences to consider are temperature, humidity, and water ingress (not included in the CFR).

Another category of recommended design practices revolve around human interaction. This includes the system in general and HMIs specifically. The system should require operator to remain in-the-loop. The system should require positive action in a prescribed manner to begin operation. For instance, to make a locomotive move forward, you must select a direction and then select a notch. The master controller does not allow direction changes while the throttle handle is out of Idle, nor does the master controller allow a throttle to be selected without a reverser handle inserted.

The HMI design shall give active functions to perform and include feedback on the results. So, when cutting out a traction motor for instance, the screen should provide visual switch feedback after the button press. The system should provide timely feedback of any automatic actions, and the reasons for such actions. However, don't distract from the operator's safety-related duties! Instead, present information if a format that minimizes the time required to understand and then act. Due to this response time, the system should warn operators in advance when action is required to be taken.

Ways to Improve This CFR

49 CFR Part 229 Subpart E and Appendix F already contain a large amount of material. However, there are places where additional material should be added. This CFR could use additional clarity as to what level of analysis is needed for changes. For example, does adding a safety-critical component trigger all key deliverables for any inter-connected subsystem and component? Also, in some places more details need to be added. Presently, review of Part 236 Subpart H and I is helpful for complete understanding of Part 229 Subpart E. For example, Subpart E should reference AREMA C&S Manual Part 17.3.5 for additional definitions and recommendations, like Subpart H already does.

Appendix F could use a better layout. For example, clearly separate items to be included in the Safety Analysis from the recommended design practices for safety-critical products.

This subpart should be updated with any lessons learned or best practices from PTC implementations, and incorporate any feedback from railroads already implementing Subpart E.

Although not directly related to improving the CFR, but still needs to be addressed by the industry, what can be done to help short line railroads with the additional burden of Part 229 Subpart E?

Summary

This paper was intended to be an introduction and summary of 49 CFR Part 229 Subpart E. While an attempt was made to highlight key portions of the CFR, there is obviously much more detail and requirements provided in the CFR. For example, products under test have some exceptions and additional processes to follow. More detail is recommended in the Safety Analysis, such as a human factor analysis. Also, the recommended practices in Appendix F provide additional information and references on HMI design, FCC compliance, and product verification and validation not covered in this paper. Please read and understand the CFR.

Prior to use on the railroad, any electronic locomotive control system, subsystem, or component directly related to safe movement and stopping of the train needs to have the following items available for review by the FRA: a Safety Analysis, a defined process to follow for planned safety-critical design change, a hazard log, product testing results and records, an Operations and Maintenance Manual, and a training and qualification program (and records of such training). The Safety Analysis is the key document and should contain most of the information for the follow-on deliverables. When followed, the safety-critical product will be more robust and have a quicker entry into revenue service.

Report on the Committee on Electrical Maintenance

Tuesday, September 19, 2017 at 8:45 A.M.

Chairman

Keith Mellin

Sales Manager, Peaker Services, Inc
Brighton, MI

Vice Chairman

Amarjit Soora

Manager of Engineering, ZTR Systems
London, Ontario

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D. Johnson	Design & App Engineer	Morgan Advanced materials	Greenville, SC
B. Locklear	Manager-Electrical Systems	CSX Transportation	Huntington, WV
G. Lozowski	Senior Applications Engineer	Morgan Advanced Materials	Greenville, SC
S. Mueting	Field Service Engineer	Siemens Mobility	Aurora, CO
C. Muir	Sales Representative	East Penn Manufacturing	Lyon Station, PA
D. Myers	Quality manager	Edwin Bohr	Chattanooga, TN
J. Paxton	Operations Manager	IAE Power Products	Aurora, IL
B. Reynolds	Sales Representative	Amglo Kemlite	Calgary, Alberta
K. Rutkowski	General Manager-Sales	IAE Power Products	Naperville, IL
P. Scholtens	Customer Relations Manager	TMV Control Systems	Cambridge, Ontario
S. Sledge	Fleet Manager	Norfolk Southern Corp	Atlanta, GA
C. Taylor	Product Specialist	Bach Simpson	London, Ontario
B. Wheless	Dir Technical sales	Edwin Bohr	Jacksonville, FL
L. White	Applications Specialist	Bach Simpson	London, Ontario
J. Whitmer	Electrical Specialist	Dakota, Missouri Valley & West	Bismarck, ND
B. Wilds	Senior Manager-Loco. Opns	BNSF Railway	Fort Worth, TX

NOTE: Bob Reynolds and Les White are Past Presidents of LMOA.

PERSONAL HISTORY

Keith Mellin

Sales Manager
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 thank Amglo Kemlite for hosting their winter meeting on February 7 and 8, 2017 in Tampa, Florida. Special thanks to Bob Reynolds of Amglo Kemlite and Butch Gaudet of PowerRail Distribution for arranging the meetings, hospitality and tours of CSX Lakeland, FL facility and Lakeland Electrics EMD Diesel Power Plant.

We would also like to thank Peter Scholtens of TMV Control Systems and Steve Alessandrini of Canadian National Railways for arranging our July 20 and 21, 2017 meeting at TMV Control Systems in Cambridge, Ontario Canada and the tour of CN's MacMillan Yard and Sherwood Electromotion in Toronto, Ontario Canada.

We Didn't Start the Fire: Best Practices for Inverter Cooling Management

Prepared by:
Peter Scholtens, TMV Control Systems

Co author:
Derya Ferendeci, ABB

Introduction – Key Message

Compared to DC, AC traction locomotives are a relatively recent technological innovation in the railroad industry. However, they have now been in use for 25 years. Inverters have evolved, moving from Gate Turn-off (GTO) thyristor inverters to insulated-gate bipolar transistor (IGBT) inverters. In fact, even IGBT inverters continue to evolve, with cooling thresholds moving to as high as 150C (http://www.mitsubishielectric.com/news/2017/0405.html).

Cooling systems have evolved as well. There are a number of key principles that we have learned that inverter designers, locomotive operators, and procurement specialists should keep in mind when considering the design and purchase of AC traction locomotives.

Inverter thermal management is a key issue in long-term inverter health. Designers and purchasers of inverters need to keep in mind three key principles.

1. Cooling systems must be designed and maintained effectively to sustain a maximum lifespan for all inverters.
2. Designers must consider that locomotives operate in a dirty, industrial environment. Cooling systems must be designed to operate effectively in these environments for the lifetime of the locomotive.
3. Inverter cooling systems should be designed to shut down inverters before catastrophic failure, and to be accessible for cleaning and servicing.

The authors of this paper hope that the lessons contained in this paper will be helpful to the designers, operators, and purchasers of locomotive AC traction systems.

Why Inverters: A History of AC Traction

In order to produce AC traction, obviously you need AC traction motors. However, you also need inverters to produce AC current for the motors. It wasn't till inverter technology advanced far enough to produce the voltage and frequency system necessary for rail traction that AC traction locomotives became available.

The first company to produce AC locomotives in commercial quantities in North America was EMD with their SD60MAC (only 4) and SD70MAC locomotives. GE followed shortly afterwards with their AC4400 locomotives.

For a variety of reasons, EMD chose one large inverter for each truck (or bogie). These reasons include wheel wear concerns, and overall cost considerations. GE chose to approach the problem by providing an individual inverter for each axle. They anticipated that the increased tractive effort allowed would be important, especially for consists with only one or two locomotives. Also, when one inverter failed, it only reduced the tractive effort by 1/6, and not by half. More recently, the industry overall seems to have concluded that one inverter per axle is the wiser choice when high adhesion is necessary, as is the case in the North American freight sector, and both US based companies have been producing locomotives with this feature.

Over the last 25 years, the industry has shifted significantly and now significant portions of the heavy haul locomotive fleet in North America use AC traction. Most AC traction locomotives used GTO inverters initially, as that was the best technology available at the time. However, GTO inverters are less efficient and difficult to control because the switching times are long and the control is through analog signals. Eventually, as insulated-gate bipolar transistor (IGBT) inverters became larger and more effective, both companies moved to that technology. Currently, even though there are other technologies available, IGBT inverters are still the most broadly accepted solution for the rail industry.

In fact, some railroads overseas are replacing GTO inverters with IGBT inverters. There are projects of this nature on electric locomotives in Europe on passenger and mixed traffic, each in the 9000HP range.

Figure 1: An example of a GTO to IGBT upgrade. Note the 3-level topology with liquid cooling system on the right. (Go to https://youtu.be/w2IOjZnCcZY for Youtube presentation. Used with permission.)

In addition, Class 1 railroads in North America are beginning to discuss their options with respect to these older GTO inverters. They are now over 20 years old and it can be difficult to find suppliers for obsolescent components. In addition, current IGBT technology is far superior to the older solutions because of its superior efficiency and ease of control.

More recently, the manufacture of new AC traction locomotives has tailed off, with very few new orders in the pipeline for either of the two large builders. There is interest in converting DC traction locomotives to AC traction, and in some cases, domestic Class 1 railroads are proceeding with conversion projects. These projects should allow the purchasers and designers of these locomotives to include the lessons learned from older inverter cooling system designs.

Figure 2: Traction inverter cubicle from Siemens' DC to AC conversion on electric locomotives in Australia. (Used with permission.)

The Thermal Problem

Why Do Inverters Produce Heat?

In all systems, as the energy is transformed from one form to another, it is never 100% efficient. This is also true within electrical systems. The main alternator in a locomotive produces AC, which is then rectified to DC. The alternator includes a rectifier bank that converts AC into a DC-Link. This is because the 3-phase voltage system coming from the main alternator cannot be fed directly into the traction motors. It would make them 'jump' or kill the diesel engine. The generator efficiency is around 96%, the rectifiers are typically quite efficient too, with only 1-2% losses.

The inverters are connected to the main DC Link and they convert the DC-Link voltage back in to a 3-phase AC system with a variable voltage-to-frequency characteristic. The inverters convert the DC back to AC.

Inverters are slightly less efficient than rectifiers. Their losses are usually in the range of 2.5%. This doesn't sound like a lot. But if you're working with 4400 HP, then the resulting heat produced is about the same as running 50 1500W baseboard heaters at full power. This is not necessarily a big deal at cold temperatures, but definitely an issue as you start getting above 30C/90F.

Cooling Methods

There are typically three different ways to cool inverters.

1. Natural Convection
2. Forced Air
3. Liquid Cooling

Each of these cooling solutions has its issues, whether they are limitations in cooling, or concerns to be kept in mind during design of the cooling system.

Natural Convection

Natural convection solutions typically use permanently sealed pipes to extract heat from power core to external fins.

Advantages

The only maintenance required is to clean the fins. There are no active parts, like pumps and fans, which may fail. Finally, there is no risk of leakage of fluid. For these reasons, many companies prefer to use natural convection when the situation is appropriate.

Figure 3: Low power inverter from CAF Power & Automation uses natural cooling with heat pipes. (Used with permission)

Figure 4: Detail from CAF P&A showing heat pipes. (Used with permission)

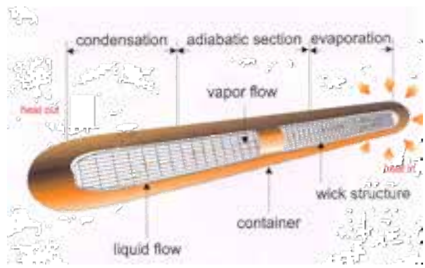

Figure 5: Diagram demonstrating the processes taking place in natural cooling with heat pipes. (Used with permission)

Areas of Concern

The downside of this technique is that it only works in low power situations. Natural convection just does not have the capacity to remove enough heat from the inverters to cool them effectively. As a result, in the rail world, it is typically only used for lighter applications such as transit EMUs.

Forced Air

Forced air cooling solutions are commonly used in medium power applications. Forced air solutions typically involves taking high volumes of air from outside the locomotive and using fans of some type to drive the air across cooling fins.

Since diesel locomotives are typically considered a medium power application, air cooled solutions are often recommended. If they are well-designed, they can be a suitable solution for this application. However, in higher horsepower diesel applications, it cannot be emphasized enough that proper cooling principles must be incorporated into the design. Railroad procurement managers should familiarize themselves with these issues, or their mechanical colleagues will be frustrated by equipment issues in the future.

Advantages of Forced Air Cooling

The benefits of forced air cooling are, first, that it delivers more effective cooling than natural convective cooling. Second, it provides better control of the cooling, as the mass of air moved can be changed as needed. Third, initial costs are usually less than liquid cooling. Fourth, it is also, at this point, the most popular solution in the North American freight market. Many locomotive maintenance specialists are familiar with it, so it will not require additional training and familiarization.

Areas of Concern

However, there are downfalls as well.

First, there are active parts, cooling fans, which may fail.

Second, inlet air systems must be designed well, as it is possible to accidentally create a heat exchange effect where inlet air is warmed up by outgoing, hot air.

Third, because a high volume of air is necessary and locomotives operate in dirty and dusty environments, anything that is suspended in the air needs to be filtered from the air before it crosses the cooling fins. This includes:

1. Diesel exhaust, a notoriously sticky and difficult material to clean.
2. Coal dust, which sticks to the diesel exhaust, reducing the cooling effectiveness still more.
3. Feathers, leaves, and other items of approximately the same density as air, which are "combed out" of the incoming air by the inverter cooling fins.

If poor filtration techniques are used, these particles are not removed. Over time, they will plug up the inverter fins, reducing cooling efficiency. When the cooling fins become dirty, cooling effectiveness will be reduced and the fins will need to be cleaned.

Finally, the filtration and the cleaning will add to the long-term cost.

These areas of concern can be addressed, but only if the cooling system is well-designed. Past lessons need to be incorporated into current designs and purchasing decisions.

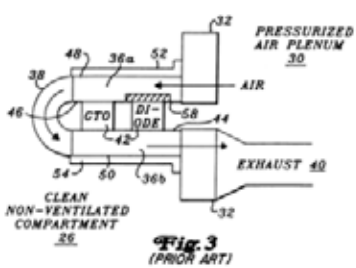

Figure 6: Typical airflow pattern in a GE GTO inverter.
(http://www.google.de/patents/US5253613)

Figure 7: Siemens GTO inverter, used in the original EMD AC traction locomotives. (Used with permission)

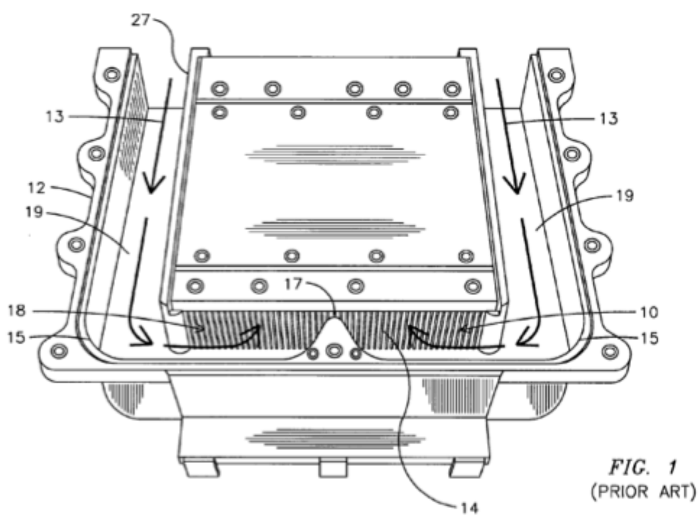

Figure 8: Typical airflow pattern in a GE IGBT inverter. (https://www.google.com/patents/US7472742)

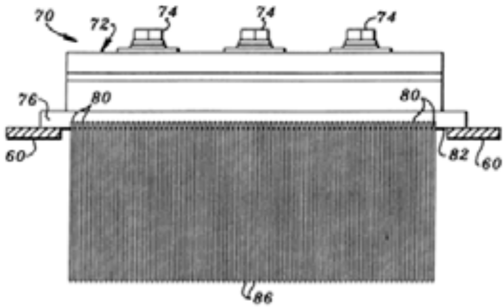

Figure 9: An illustration of the cooling fins on a GE IGBT inverter. (https://www.google.com/patents/US6233149)

There are a number of companies globally that supply air cooled inverters. In fact, some companies will build different types of cooling solutions depending on the demands of the customer and the project.

Figure 10: An example of an air-cooled power core from CAF Power&Automation, based in San Sebastian, Spain. (Shared by permission of CAF Power&Automation.)

Figure 11: An example of an air-cooled inverter supplied by MELCO to Progress Rail. (Used with permission.)

Liquid Cooling

Liquid cooling brings the most effective cooling solutions. In international applications, it is typically used for high power applications. In rail applications, this includes high speed trains powered by overhead catenary lines. Liquid cooling is a very effective method of thermal management.

Liquid cooled converters have an integrated closed-circuit cooling system consisting of a water circuit with heat sinks, expansion tank, water pump, and a re-cooler integrated in the converter housing or in a separate compartment. These converters commonly use ordinary tap-water with an anti-freeze additive. A common additive used for cooling includes diluted Glycol mixtures. These liquid cooling systems consists of numerous heat sinks connected to the heat emitting components. The heat sinks are connected to the water cooling circuit and the compartment is cooled with a small internal air-to-water heat exchanger to carry off internal losses to the water cooling system.

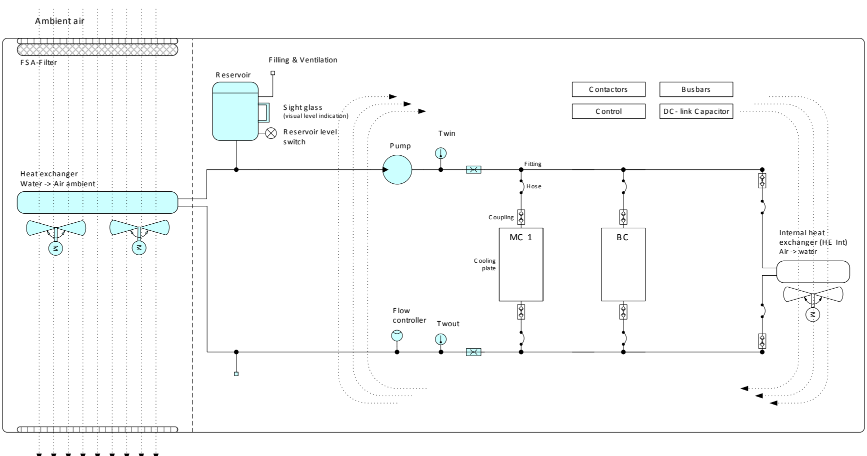

Figure 12: Diagram illustrating the movement of water and air in the ABB liquid cooled solution. (Used with permission.)

However, there are design considerations that must be taken into account. The liquid used for cooling the inverters carries the heat away from the inverters. But that heat still needs to be dissipated. So the liquid needs to be moved from the inverters to radiators where the heat is removed from the liquid before it is returned to the inverters. So the air movement that is used directly in air cooling is used on the radiators in liquid cooling.

That being said, radiators are far easier to clean than inverter fins. Radiator cooling systems are often mounted on swing out doors that can be hosed down for cleaning at suitable intervals.

Advantages of liquid cooling

There are advantages to liquid cooling.

First, one of the fundamental advantages of liquid cooled converters is the physical size or footprint of these converters. Weight and volume of liquid cooled converters, including the associated heat exchanger, is smaller than an equivalent air cooled solution.

Second, using liquid-cooled modules provides advantages in the design of the converter as well. Converter modules can be placed inside the converter box, without the requirement of having an air-heatsink at the outer wall of the converter box. Air-cooled converters require many aerodynamic considerations, whereas liquid cooled converters allow for more flexibility in the overall placement of various components which require cooling during regular operation.

Third, the individual modules of the converter design can be more compact and light weight. A liquid cooled module with the same number of IGBTs would weigh slightly less than an equivalent air-cooled module. For example, a liquid cooled IGBT-Module from one particular supplier weighs around 90lbs (41kg), whereas a similar air cooled IGBT-Module from the same supplier could weigh in at over 140lbs (65kg).

Fourth, another advantage comes from better performance of the semiconductors themselves, particularly for short-term high-power demand requirements of traction applications. Heat sink temperature can also be better controlled with liquid cooling, resulting in a longer life for the individual components due to reduced thermal cycling.

Fifth, a maintenance advantage of liquid cooled converters is that air filters are no longer needed, again providing for less maintenance for the overall system. The heat exchanger can also be designed for easy access. Although some cleaning of the radiator may still be needed, the internal components of the converters stay clean.

Figure 13: Water cooled power core from CAF Power&Automation. (Used with permission.)

Figure 14: Liquid cooled inverter from American Traction Systems. (Used with permission)

Figure 15: Illustration of the quick connect-disconnect fittings on ABB IGBT power module for locomotive propulsion system. This allows quick and easy maintenance. (Used with permission.)

Figure 16: Cooling pipe and manifold arrangement on ATS liquid cooled inverter system. (Used with permission)

First, there are moving parts to consider. In this case, in addition to the fans required to move air, pumps are also required to move the liquid.

Second, usually ordinary water is not suitable, and specialty fluids are used, such as glycol.

Third, measures must be taken to eliminate the risk of leakage of the cooling fluid. Special braided hoses are used to increase durability. Quick release connectors are often used to minimize leaking. These modules can be exchanged even with a fully filled water circuit without any leakage, thus saving time and money during any maintenance or down-time. However, they can also restrict flow, resulting in an increase in pressure demand.

Fourth, certain liquid cooling systems use de-ionizing filters which creates a need for maintenance.

Finally, a non-technical, but still very relevant issue is that liquid cooling is not very common in North American market. The North American freight market employs thousands of maintenance workers who are not familiar with maintaining water cooled systems, and this market is used to standard solutions. The railroads also often share locomotives. As a result, it may be necessary to do a lot of training in the liquid cooled solution in order to guarantee that it will get the proper maintenance.

Figure 17: AC cooling pump in ATS system. Cooling pumps are required to move coolant from inverters to radiator. (Used with permission)

Cooling Failure: Primary and Secondary Issues

Since AC traction has been available since the early 90s, inverters have been used in the industry for 25 years. Locomotive operators have learned a great deal about how inverters fail. The primary reason that inverters fail is because of control failure. Control failure happens most frequently with cooling failure.

What are the secondary causes? Why do inverters overheat?

Figure 18: Innards of an inverter after cooling failure.

The reason that inverters overheat is because of cooling system failure. A secondary reason is because, if the cooling systems fail, there is no backup system to shut down the inverters before they fail.

Main Causes of Cooling System Failure

Inverter cooling systems can fail for several reasons. These are:

1. Heat exchange effect
2. Poor filtration
3. Poor monitoring

Designers and purchasers should take these factors into consideration when designing and building inverter cooling and monitoring systems.

Heat Exchange Effect

First, in air cooled systems, incoming air must be kept cool. In some systems, incoming cooling air runs in parallel to outgoing warm air, inadvertently creating a heat exchange effect. If ambient temperatures are already high, this can create high temperatures even before the air moves across the cooling fins!

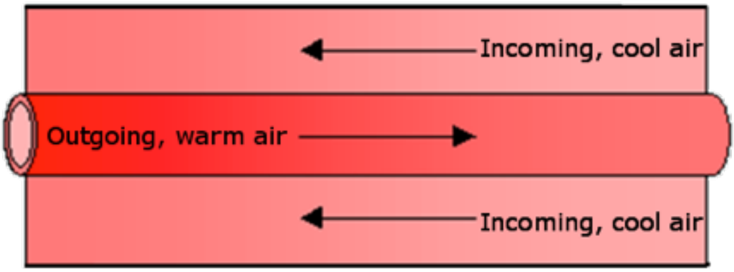

Figure 19: Some cooling systems inadvertently created a heat exchange effect by running incoming, cooling air next to outgoing, hot air. (Modified – original image available at http://www.real-world-physics-problems.com/heat-exchanger.html)

Recommendations:

System designers should ensure that incoming cooling air is not warmed through a heat exchange effect.

Poor Filtration

Second, inverter cooling only works effectively when the inverter cooling fins are kept clean. It should be assumed that, because locomotives work in dirty, industrial environments, that the inlet air will be contaminated. Inlet air, if not well-filtered, often contains diesel exhaust, coal dust, and a number of other materials kicked up by passing traffic or air currents around the locomotive. If this material comes in contact with inverter cooling fins, it collects and reduces the cooling efficiency of the inverters. When this happens, the cooling fins cannot remove heat effectively from the inverters.

Figure 20: Dirt and debris accumulated on inverter cooling fins.

Recommendations:

Designers should ensure that incoming air is filtered effectively so that particles that are approximately the same density as air (leaves, feathers, coal dust, and exhaust particles) are not carried to the inverter fins. The inverter fins will act like a sieve, trapping the larger items and restricting the air flow. Smaller particles will pass through, but if they are naturally oily, like exhaust particles, then they will stick to the fins.

In addition, it should be assumed that all cooling systems operating in a railroad environment can and will get dirty. Inverter systems, especially if air cooled, should be designed so that cooling fins can be cleaned. The cooling fins will get dirty over time. If the fins are inaccessible, then the dirt will accumulate and cannot be dealt with.

Poor Monitoring

When everything works perfectly, then there is no need to track the internal temperature of inverters. Then, cooling can be modelled based on air flow and ambient temperature. The cooling flow can be controlled entirely on a computer model.

However, since locomotives operate in dirty environments, then inverters get dirty. When this takes place, the cooling systems are not as effective and the models no longer represent the reality of the system. If thermal runaway takes place and the inverters are not shut down, then they will fail. Sometimes failure can be catastrophic. In older systems, inverters can get so hot that the solder used to connect the cooling fins to the inverters can actually melt!

Figure 21: Solder melt.

Therefore it is not wise, as a design principle, to cool inverters only based on computer models. It is important to monitor the internal temperature of the inverters. This allows the control system to monitor internal inverter temperature and shut down inverters before they fail.

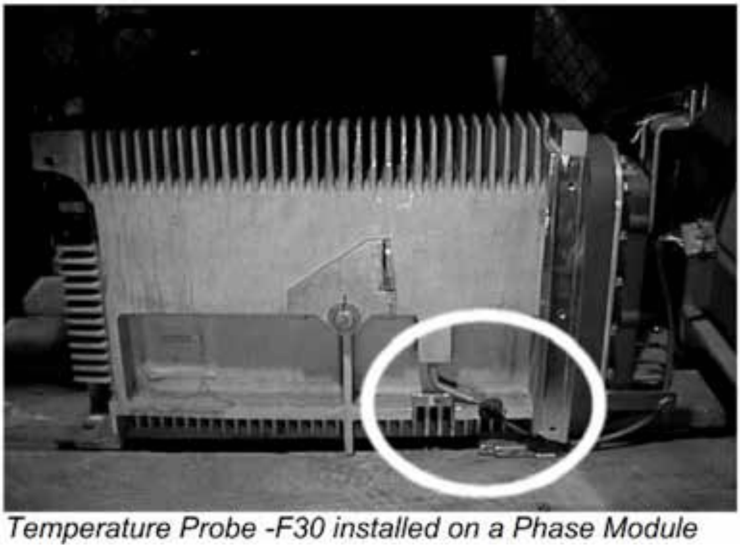

Figure 22: Siemens GTO inverter with probe to monitor internal temperature. (Used with permission.)

Recommendations:

Designers should ensure that inverter cooling is not based on thermal models alone. Temperature sensors should be included in inverter system design so that real data captured by sensors should be included in the cooling control.

In addition, control systems should be capable of shutting down inverters before catastrophic failure takes place. This will safeguard equipment and prevent the need for replacement of expensive hardware.

Conclusions

AC traction locomotives have been used for the past 25 years. Because of this experience, we have learned a number of key principles that inverter designers and locomotive operators should keep in mind when considering the design and purchase of AC traction locomotives.

One of these main principles is that inverter thermal management is a key issue in long-term inverter health. Designers and purchasers of inverters need to keep in mind three principles.

1. Inverters must be kept cool to maintain their maximum lifespan.
2. Designers must consider that locomotives operate in a dirty, industrial environment. Cooling systems must be designed to operate effectively in these environments for the lifetime of the locomotive.

3. Inverter cooling systems should be designed to shut down inverters before catastrophic failure, and to be accessible for cleaning and servicing.

The authors of this paper hope that the lessons contained in this paper will be helpful to the designers and purchasers of new AC inverter systems. These lessons will be helpful, whether they be for new locomotives, or for DC to AC and GTO to IGBT conversion projects on older locomotives.

Troubleshooting the Excitation Circuit on an EMD SD40-2

Prepared by:
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Shane Sledge – Norfolk Southern Corp. (NS)

1. Introduction

The EMD Dash 2 excitation circuit provides a good foundation for troubleshooting any locomotive excitation system. The basic troubleshooting principles can be used to diagnose faults in any locomotive excitation system and is a good starting point for the novice electrician. This paper will examine an EMD SD40-2 excitation circuit under Self Load conditions. This document should be used as a guide and should only be used in accordance with local shop safety rules and practices.

2. Self Load Test Setup

Setup is the first step in performing a Self Load Test on any locomotive. It is important to verify these settings prior to beginning the troubleshooting process. If you have to step away for any reason during this process, take a minute to look over the settings before resuming your work. It only takes a few seconds for someone to change these settings while performing other maintenance.

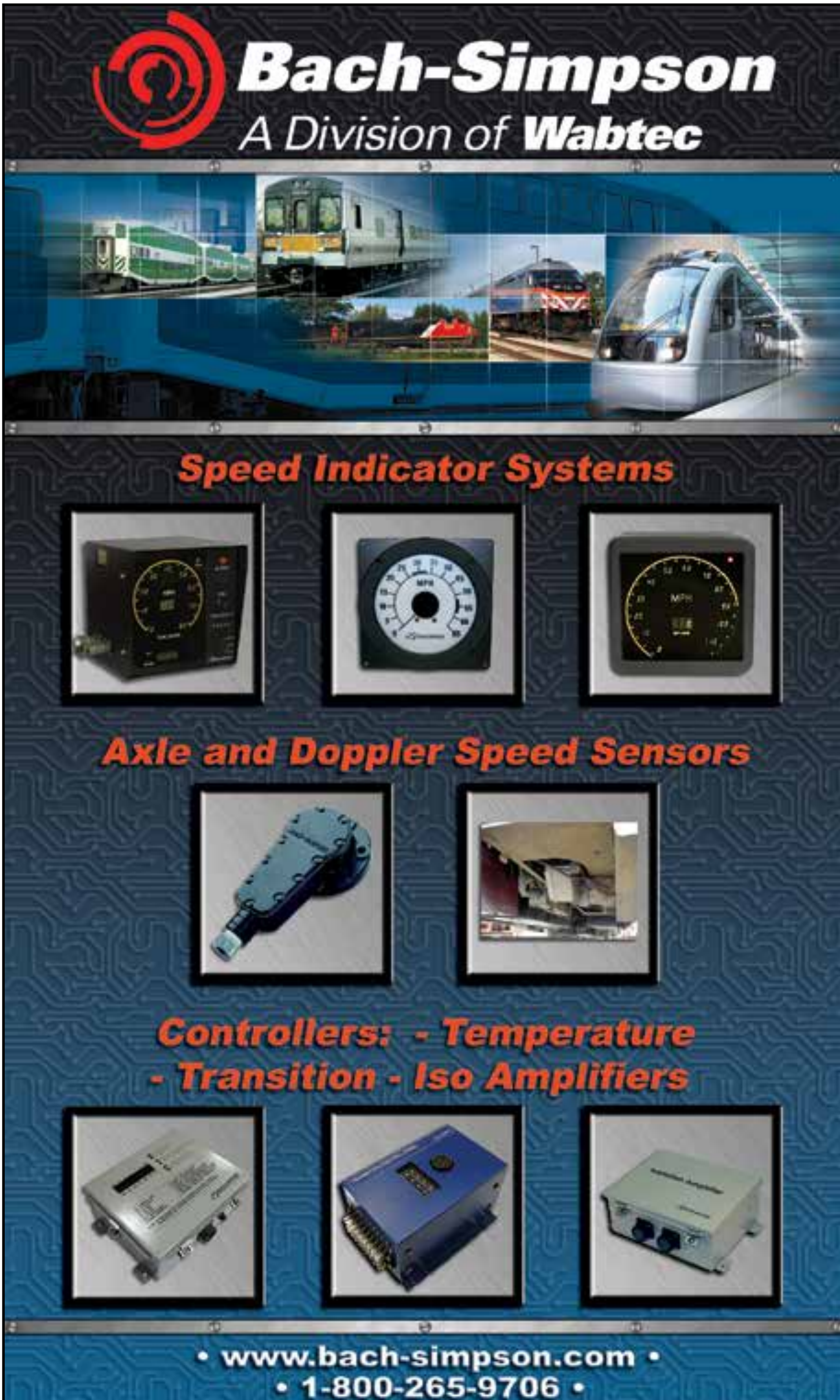
A typical Self Load Test setup on a SD40-2 locomotive already running is as follows:

a. PCS OPEN light is OFF
b. GEN FLD switch is UP
c. IS switch is in RUN
d. Reverser Handle is in NEUTRAL
e. TEST SW is in SELF LOAD
f. THS handle to N1 or higher

The locomotive should be loading at this point. If the locomotive is not loading then check that the GFX relay has picked up. If the GFX relay has not picked up then proceed to the next section.

3. Self Load Test Sequence

Verify that the Setup, Switches, and Circuit Breakers are in the correct position before checking the sequence.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a. GFA,GFD ↑ (IS = "RUN")
b. TSR ↑, FOR, RER ↑ (Reverser Handle = "Centered")
c. LTT1, LTT2 ↑ (TEST SW = "Self Load")
d. MR ↑ (THS = "N1-N8")
e. EQP ↑
f. GFC ↑
g. GFX ↑

The sequence can vary so be sure to use a print for the locomotive you are working on but the troubleshooting method will be the same. The order of inspection can be first to last or last to first. In this example, we will examine the GFX relay first and work backward.

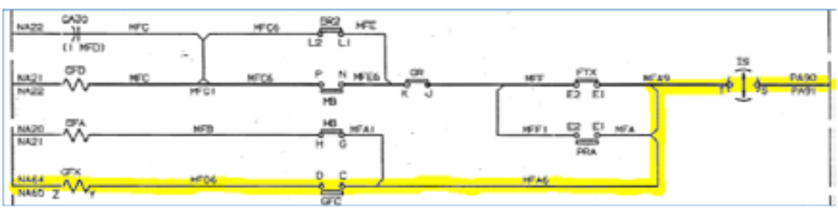


Figure 1. Example GFX circuit on a SD40-2 locomotive

Figure 1 shows an example of the GFX circuit. If the GFX relay has not picked up, then the locomotive will not load. From the circuit above, we can see that the GFX relay depends on the GFC relay picking up and the Isolation Switch is in RUN. If we verified setup previously, then the Isolation Switch is in RUN and we need to examine the GFC relay.

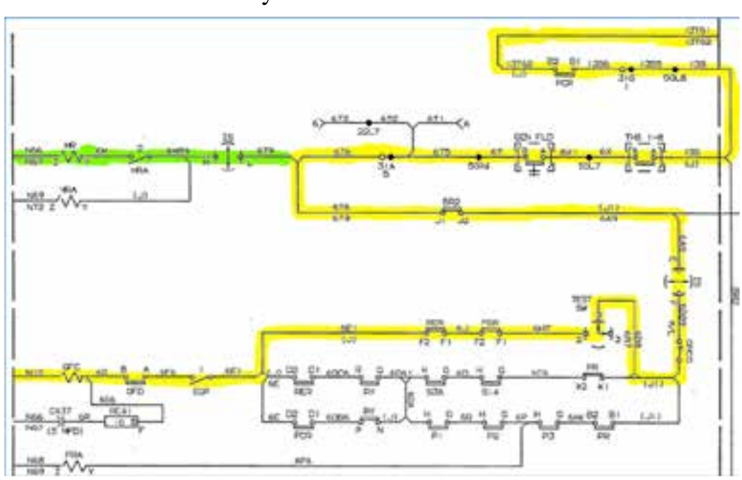


Figure 2. Example GFC circuit on a SD40-2 locomotive

Figure 2 shows an example of the GFC circuit. The PCR relay will be picked up if the PCS OPEN light is OFF. The THS 1-8 relay will be picked up if the THS handle is set to N1 or higher. The GEN FLD switch should be UP. If the Reverser Handle is set to the NEUTRAL position; the BR2, RER, and FOR relays will NOT be picked up. The Isolation Switch should be in RUN and the TEST SWITCH in SELF LOAD. The previous parameters were all determined by the Self Load Test setup.

From the circuit above, we can see that the GFC relay is only dependent on the GFD and EQP relays being picked up.

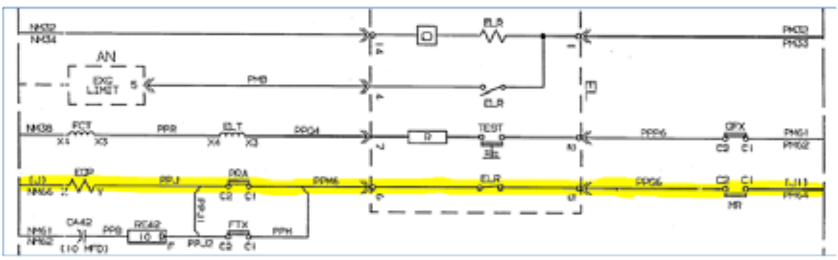


Figure 3. Example EQP circuit on a SD40-2 locomotive

Figure 3 shows the EQP relay is dependent on the MR relay and the Excitation Limit Module. The EL Module prevents the main generator excitation current from exceeding 114 amps. A quick check of the EXC Limit light on the annunciator panel will confirm or exclude this condition. The MR relay was picked up when the THS handle was set to N1 or higher in the previous Figure 2.

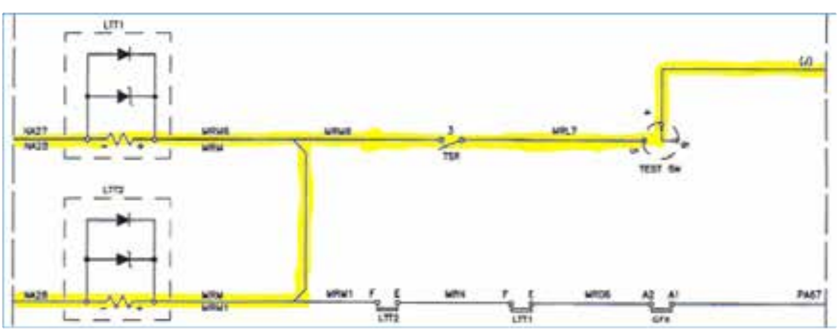


Figure 4. Example LTT circuit on a SD40-2 locomotive

Figure 4 shows an example of the LTT circuit. The LTT relays initialize on the TSR relay picking up and the TEST SWITCH in SELF LOAD. Once the GFX relay picks up, the locomotive is held in the Self Load Test Sequence until loading ceases.

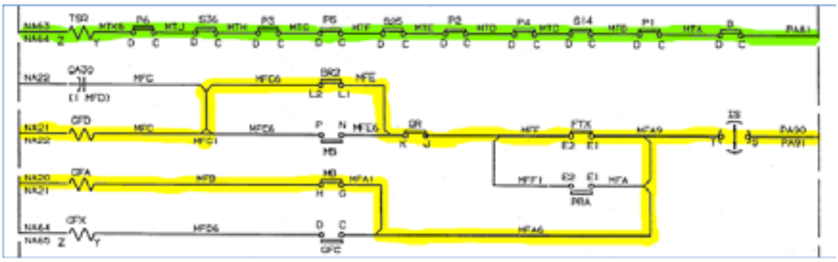


Figure 5. Example GFA, GFD, and TSR circuit on a SD40-2 locomotive

Figure 5 shows the TSR and GFD relay circuit. TSR will be picked up if the Reverser Handle is set to the NEUTRAL position. In addition, the BR2, FTX, and MB relays will NOT be picked up when the Reverser Handle is centered. The GFD relay is energized if there is NOT a ground fault and the Isolation Switch is in RUN.

From the previous analysis, the GFD relay picks up the GFC relay which picks up the GFX relay. The locomotive will be loading at this point.

4. Excitation Circuit Troubleshooting

The EMD Dash 2 excitation circuit can be separated into the following three distinct circuits which are presented in Figure 6.

a. Reference Circuit

The Reference Circuit provides an output reference signal related to throttle position. The Reference Circuit is composed of the TH, RC, WS, and SB Dash 2 Modules. In addition, the Load Regulator completes the Reference Circuit.

The TH module is the Throttle Response Module and provides a 0-68 Vdc signal proportional to throttle position. Table 1 shows TH module test point voltages as a function of notch.

Notch	TP#4	TP#5	TP#6	TP#7	TP#3
Idle	0	0	0	0	0
1	0	0	0	0	11
2	72	0	0	0	22
3	0	0	72	0	29
4	72	0	72	0	36
5	0	72	72	72	43
6	72	72	72	72	51
7	0	72	72	0	61
8	72	72	72	0	68

Table 1. TH Module Test Point Voltages as a Function of Notch

The A, B, C, and D valve voltage signals from the Throttle Handle at the Engineers Control Stand are input to the TH module test points TP#4, TP#5, TP#6, and TP#7 respectively. A proportional reference signal is output on TP#3.

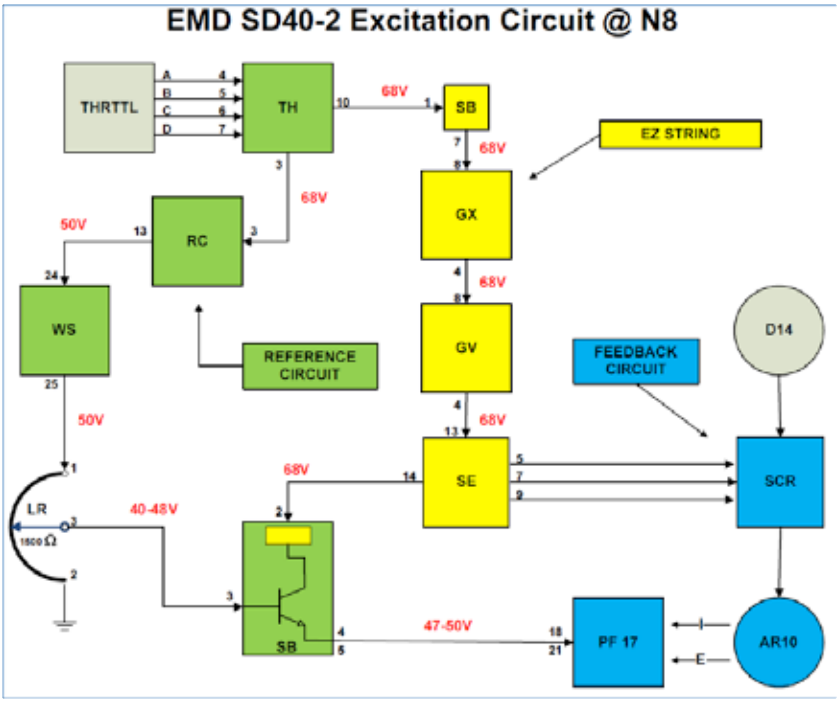


Figure 6. EMD SD40-2 Excitation Circuit at Notch 8

The RC module is the Rate Control Module. The RC module reduces the reference signal and ramps it up slowly during notch changes. This lets the engine speed up before applying load to keep the engine from bogging down. Reducing the voltage allows the TH module to aid the charging of the RC module to allow the unit to load more quickly.

The WS module is the Wheel Slip Module. The WS module reduces the reference signal during wheel slip events to allow the unit to regain traction. The WS module should not be active during self loading.

The Load Regulator provides feedback from the engine governor to the excitation circuit. The LR is hydraulically driven by a pilot valve in the engine governor which controls the direction of flow of pressurized governor oil. When the load regulator is in a balanced position, it will have reduced the value of the reference voltage to whatever value is needed to achieve that balanced condition. It is a mistaken belief that when the LR is in the 9 o'clock position, the load provided by the excitation circuit is balanced to the output of the engine. A balanced condition is any position where the engine load (governor rack position) is correct for a given notch position with a steady LR position. However when the LR is in the 7 o'clock (maximum) position, the reference voltage is not being reduced. Alternately when the LR is in the 5 o'clock (minimum) position, the reference voltage is reduced to zero. Refer to the final section of the paper for more information.

The SB module is the Sensor Bypass Module. The SB module compares the reference signal from the Load Regulator and the feedback signal from the Feedback Circuit to determine loading. If the LR output is more than the PF input, the generator will load. If the LR output is less than the PF input then the generator will not load. The SB module also provides a stable voltage to the EZ string.

b. EZ String

The EZ string controls generator excitation and is also called the Sensor String. The EZ string is composed of the GX, GV, and SE Dash 2 Modules. The SB module provides a stable 68 Vdc to the EZ string. There should not be less than a 2 volt drop across the EZ string under normal operation.

The GX module is the Generator Excitation Module. The GX module provides protection against excessively high excitation current. The GX module limits the generator field current to 108 Adc by lowering the voltage to the EZ string. A voltage drop across the GX module indicates high excitation current or a problem in the GX module or circuit.

The GV module is the Generator Voltage Module. The GV module limits the maximum output voltage of the generator to 1,250 Vdc. The GV module does this by lowering the voltage to the EZ string. A voltage drop across the GV module indicates high output voltage or a problem in the GV module or circuit.

The SE module is the Sensor Module. The SE module controls the generator field excitation current. The SE module does this by providing gating pulses to the SCR. Decreasing the EZ string voltage to the SE module results in a decrease in excitation to the generator.

c. ***Feedback Circuit***

The Feedback Circuit is composed of the SCR, AR10 generator, and a PF module. The Feedback Circuit produces an electrical feedback signal which contrary to popular belief is not directly proportional to power. Some PF modules supply two (2) feedback signals, power and performance. They are applied to the SB pins 4 and 5. The lowest of the two feedback signals will control the SB module. The SB module compares the reference signal from the LR to the feedback signal from the PF module. If the reference signal is less than the feedback signal then the generator will not load. If the reference signal is greater than the feedback signal, the generator will load.

The SCR is the Silicon Controlled Rectifier assembly and is presented in Figure 7. The SCR takes three phase AC power from the D14 companion alternator and produces a DC excitation current to the AR10 generator field coil. Gating pulses are applied to the SCR from the SE module as necessary to maintain the required level of excitation to the generator.

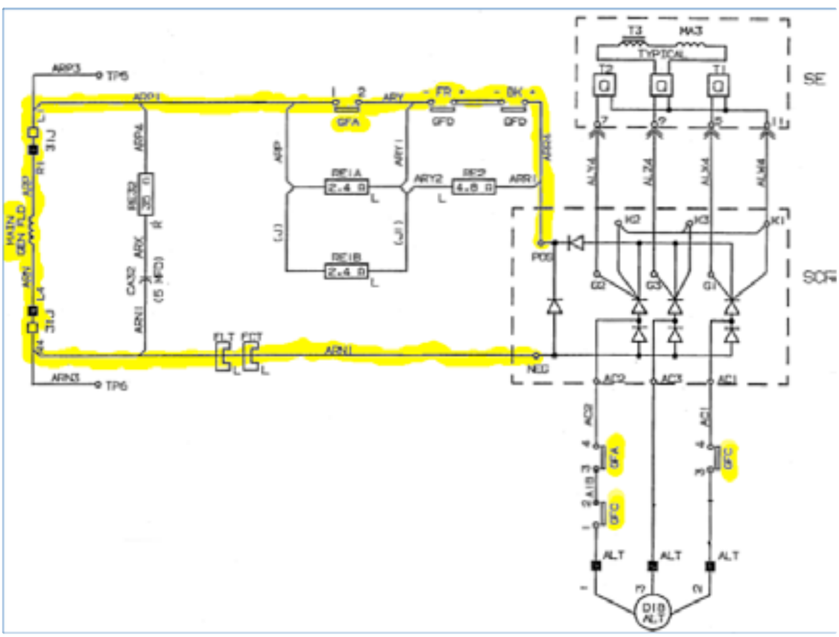


Figure 7. EMD SD40-2 SCR Circuit

The gating pulses are phase specific and will not produce the correct excitation power if the D14 phases are crossed and not in the correct order. If the wrong phase rotation is present (often due to the wrong connections at the CA output terminals), the SCR bridge will experience a "snap on" condition and not be able to control low levels of output current. Check that both the GFA and GFC contactors are picked up to power the SCR during motoring and self load testing. The GFA contactor drops out during dynamic braking to increases the range of controllability of the SCR, when the large AR10 main generator needs to control relatively low values of output current. Also, check that the AR10 brushes are not worn and make good contact on the slip ring to deliver the full excitation power to the generator. To test for a shorted SCR, remove the SE card and advance the throttle to N1. There should be no voltage across the AR10 field coil. A "snap on" condition (the wrong phase rotation is present at the SCR terminals) can be checked by operating the locomotive in standstill dynamic brake at a low brake handle position and checking for a steady output current from the main generator.

The AR10 generator converts the mechanical engine power into electrical power. The AR10 generator is deliberately oversized compared to the engine that drives it. If the excitation system is operating properly, the AR10 generator should have no problem loading the engine to full power. The AR10 generator has Current Transformers (CT) and Generator Potential Transformers (GPT). The CT's provide a signal proportional to the generator output current. The GPT's provide a signal proportional to generator output voltage.

The PF module is the Performance Control Module. The PF module takes the current and voltage signals from the AR10 generator and generates a feedback signal. The feedback signal is sent to the SB module to compare with the reference signal. If the reference signal is greater than the feedback signal, excitation is applied and the generator will load. The amount of excitation applied is proportional to the difference between the reference signal and the feedback signal. If the reference signal is less than the feedback signal then excitation is removed from the generator.

5. Governor Rack/Load Regulator (Engine or Generator)

In order to regulate main generator power at a constant power level, the system relies on the load regulator. When the load regulator is in a balanced position, it will have reduced the value of the reference voltage to whatever value is needed to achieve that balanced condition. This condition corresponds to engine operation at a particular governor rack setting, and practically, at the corresponding power level.

Troubleshooting an Engine/Generator system can be challenging since both affect each other. The Load Regulator position and the Governor Rack position can be used to determine which one is at fault. This troubleshooting is typically conducted at N8 (full power). If the governor nameplate specifies a full rack position of 0.82 then anything greater than 0.82 is considered less than specified. This is because the rack position starts at 1.96 or greater and goes down as power is increased.

a. Maximum Field

If the Load Regulator is at the 7 o'clock position then the engine governor is calling for maximum field current to be applied to the generator.

i. Governor Rack Position Less Than Specified (Generator Problem)
If the governor rack position is less than specified then the engine is running less than full power. If the engine is running less than full power and the excitation system is at maximum, then we need more excitation.

Check both the GFA and GFC contactors are picked up to power the SCR and that the AR10 brushes are not worn and make good contact on the generator slip ring assembly. Check the SE module for crossed phases to the SCR assembly. Replace the SE module with a known good SE module.

ii. Governor Rack Position More Than Specified (Generator Problem)
If the governor rack position is less than the nameplate (i.e. the rack position reads 0.78 and the nameplate reads 0.82) then the engine is running greater than full power. The generator is making too much power and we need less excitation.

The excitation system may think that it is producing less power than it actually is. Check the feedback signals from the generator to the PF module. The generator voltage power feedback signals (PF module test points TP#2, TP#4, and TP#6) should be within 2 Vac of each other. The generator voltage performance feedback signals (PF module test points TP#8, TP#10, and TP#12) should also be within 2 Vac of each other. Finally, the generator current feedback signals (PF module test points TP#15, TP#16, and TP#17) should be within 2 Vac of each other. Replace the PF module with a known good PF module.

b. Minimum Field

If the Load Regulator is at the 5 o'clock position then the engine governor is calling for no excitation to be applied to the generator.

i. Governor Rack Position Less Than Specified (Engine Problem)
If the governor rack position is less than specified then the engine is running less than full power. If the engine is running less than full power and the excitation system is at minimum, then we need more engine power.

Check the engine fuel and boost systems for proper operation.

ii. Governor Rack Position More Than Specified (Generator Problem)
The generator is making more power than the engine can supply. This condition will probably be noticed at the lower notch positions.

The SCR is supplying excitation when it is not supposed to. The SCR phases are likely crossed and the SCR bridge is experiencing a "snap on" condition. Also, check for a shorted SCR.

c. Unbalanced Condition (LR Hunting)
If the Load Regulator does not achieve a balanced condition then check the following.

i. Load Regulator
Check for a worn spot in the LR. This will cause the engine to hunt as the governor backs off and the LR makes contact again.

ii. Governor
The governor is responding too fast and overshooting the desired rack setting. The governor has a compensation needle valve that dampens the rate of change of rack position. Adjusting the compensation needle valve will slow the change in rack position.

6. Conclusion

This paper is intended to help locomotive electricians troubleshoot common excitation problems on SD40-2 locomotives. This document should be used as a guide and should only be used in accordance with local shop safety rules and practices.

APPENDIX A - List of Abbreviations

AN	Annuciator Module
B	Brake Power Contactor
BR	Brake Relay
CT	Current Transformer
EL	Excitation Limit Module
ELR	Excitation Limit Relay
ELT	Excitation Limit Transductor
EQP	Equipment Protective Relay
FCT	Field Current Transductor
FOR	Forward Directional Relay
FTX	Forward Transition Auxiliary Relay
GFA	Generator Field Auxiliary Contactor
GFC	Generator Field Contactor
GFD	Generator Field Decay Contactor
GFX	Generator Field Auxiliary Relay
GPT	Generator Potential Transformer
GR	Ground Relay
GV	Generator Voltage Module
GX	Generator Excitation Module
IS	Isolation Switch
LR	Load Regulator
LTT	Load Test Transfer Switch
MB	Motor/Brake Transfer Switch
MR	Motoring Relay
MRA	Motoring Relay Auxiliary
PCR	Pneumatic Control Relay
PCS	Pneumatic Control Switch
PF	Performance Control Module
PR	Parallel Relay
PRA	Parallel Relay Auxiliary
P	Parallel Power Contactor
RC	Rate Control Module
RER	Reverse Directional Relay
RV	Directional Transfer Switch
SB	Sensor Bypass Module
SCR	Generator Excitation Controlled Rectifier
SE	Sensor Module
S	Series Power Contactor
TH	Throttle Response Module
THS	Throttle Handle Switch
TSR	Transfer Switch Relay
WS	Wheel Slip Control Module

AESS (AUTOMATIC ENGINE START STOP)

Prepared by:
Mike Drylie, CSX Retired

KEY POINTS:

The CMOs of the Class I railroads determined that AESS Systems are difficult to use because of the many differences between systems on other railroads, between builders, and even within a given class of locomotives on a single railroad. The vast majority of the issues can be fixed if one focuses on the following five desires detailed below as "can we" questions.

1.) Can we manually shutdown the locomotive while leaving AESS Active to restart the locomotive?
2.) Can we reset a disabled AESS to allow it to maintain locomotive parameters without restarting the main engine?
3.) Can we choose to sometimes maintain air and sometimes not maintain air?
4.) Can we provide an easy way to allow crews and maintainers to KNOW the AESS system is fully functional or to tell them what needs fixed?
5.) Can we make the AESS systems more standard?

The answers to all these questions are the same: Yes. Unfortunately fixing these cannot happen overnight and there are costs to implementing these desires. Some estimates to modify a single railroad's fleet have been in the range of $10 million, $3000+ per locomotive. Much of this is due to the AESS System being linked to (embedded in) the locomotive control software and in some cases only a few locomotives have identical software. This paper does not intend to focus on costs but railroad management is concerned with the costs and the benefits they will achieve from those costs. Cost justification is not a part of this paper but has been accomplished previously.

INTRODUCTION:

This paper provides a place to begin for railroads to answer/fix those issues and standardize AESS Systems with an end goal to improve its use on an individual railroad and in interoperability. The paper attempts to identify the concerns railroads have with the AESS systems and suggests a path to follow to correct those issues and make the systems appear "standard" for the users; the locomotive engineer/crew, the maintainer, and others needing access to AESS data or systems.

This analysis of the AESS systems was requested by the Class I CMOs to determine what steps to take to improve the systems, especially in the area of interoperability. The paper was developed in part by using the author's personal experience and polling member railroads with a set of questions regarding types of AESS, issues seen, complaints, AESS options they like, and what they would like to see improved.

It was determined during the development of this paper that there is no short answer. Fixing AESS will be a multi-year project each railroad must undertake. It is also possible that follow up papers will be requested to document the successes, or failures, of many changes to the AESS systems. Some of the fixes may not be inexpensive and some may need to be incremental. The author has tested many of these fixes on various locomotives and has seen them improve AESS performance and locomotive reliability. The author has also taken into account both FRA and EPA requirements.

HISTORY:

AESS Systems have been around for decades. The original systems were very simple but effective in saving fuel and cutting down on noise around the yards caused by idling engines. The systems also began to point to some of the weak links in starting and engine systems. Engine Protection Devices, Governors, Starting Motors, Batteries and other devices/systems started having more failures. Many of these failures were blamed on the AESS systems themselves. Usually this system was not to blame. If the AESS system failed to restart a locomotive during cold weather there was a potential for freeze damage. This is still an issue today.

Early systems monitored time, idle/loading status, water temperature, and battery volts. Over time more sensors were added; battery charging current, air pressures, ambient air temperature, status of brake set-up, handbrakes on or off and other parameters have been added. As more systems had parameters monitored and maintained, the AESS system became more complex. As complexity increased so did the number of sensors. Or is it the other way around?

WHAT ARE THE MAJOR ISSUES?

Suffice it to say that to the railroads any issue is a major issue. Fortunately, the author believes there are "mostly easy" fixes to the issues with AESS. I do recommend that the railroad AAR Cab Committee discuss the solutions as well as look for others and come to agreement as to how to best implement. As one of the major issues involves interoperability, the fixes may need to be agreed to via the AAR. It is possible that AAR S-5502, the AESS Standard, should be revised.

Some of the fixes will be listed with the issue and some of the fixes will be addressed toward the end of the paper.

One of the first issues the author sees is a lack of an expert on each of the railroads. You may question why this is in a technical paper but think about it. Who is your technical expert? Who is that one person that knows the differences between the various classes and locomotives within a class with AESS? Is this a person that will go out and fix or investigate issues or have they been promoted or transferred out of that type of position? How long have they been in their position? Can you send him/her out and verify a locomotive is working properly without outside help? My guess is the AESS person has less than 1-2 years experience with AESS and has only been on a few different classes of power. They cannot tell you how often a specific locomotive was shutdown last month or why it was idling for days at a time. There is really only one fix to this and that is to have some people become experts on AESS. The rest of the issues and fixes are difficult to properly understand and fix without your expert knowing the system and the impacts of various changes.

Although the AESS systems have improved, and increased in complexity, many early designs are still in place, usually with newer or reconditioned components, but with the original design philosophy. Sometimes this original design philosophy does not match current operational needs or desires. A factor that prevents upgrading these systems is that to upgrade often requires additional sensors, new circuitry, new circuit boards with additional inputs and possibly a new computer, all of which may be cost prohibitive. A common reason for leaving things the way they are is "we will retire this fleet in the next two years." This has often been said of the same locomotive for 10 years or more. With few corrective actions applied and railroads often utilizing a manual shutdown policy to obtain the most fuel savings while disabling the restart feature of AESS there are numerous issues with locomotive health and railroad operations. There is a solution to these issues and will be discussed later.

There is a lack of commonality between the various classes of power on a railroad and even within a class. As an example some locomotives monitor Main Reservoir Pressure 1 and some monitor Main Reservoir Pressure 2. How often you restart will vary depending upon which one you monitor. Some locomotives restart if battery volts drop to 65 volts, some 64, some 63 etc. Not only will this affect how often you restart but it will also be a factor in how easily the locomotive restarts.

One major railroad has a concern because they park trains in sidings and leave them for a long period of time. When a replacement crew arrives, train brake pipe pressure has dropped below minimums and the crew has no idea how long the train has been "off air." This results in the replacement crew needing to "walk the train" performing an air brake inspection looking for leaks and other issues. This may occur in inclement weather and in areas that are not easily accessible and occasionally not safe. With trains often being over a mile long, this turns into a 2-3 mile walk on non-level ballast, and, in addition to not being necessarily safe, the train is further delayed. One major cause of this was a desire to cut down on restarts by not maintaining air pressure if the system "knew" the handbrakes were applied. With the advent of electric handbrakes this was easily done.

There are several related issues. What happens if there is a component failure and the locomotive engine does not restart? It does not matter if the component is an engine component, a sensor, the batteries, a relay or anything else. If the locomotive does not restart when the AESS System asks it to then there could be catastrophic problems. The biggest issue is freeze damage which is caused by none or not all of the water draining out of engines, water lines, radiators, air compressors, or elsewhere. Additionally, Guru valves sometimes open when they should not, or are not expected to, and also draining the engine of water sometimes while operating on the mainline. This is almost always caused either by improper installation or not following replacement time guidelines.

By design, the major locomotive manufacturers limit the number of restarts by limiting the number of auto shutdowns. Limiting the number of restarts is an attempt to reduce component failures. Due to other design criteria, usually maintaining main reservoir air pressure, the locomotive can use up all of its daily allotted restarts in a few hours and then remain running for 10-20 hours, or longer, before auto shutting down again. In an attempt to continue getting fuel savings, crews and service center craftsmen are instructed to manually shutdown the engines resulting in the system being disabled. The end result is what is often called an improper shutdown. Some systems are left on, the batteries are not being maintained, engines are shutdown while too hot, and a host of other problems can occur.

Along with the issue of not shutting down for long periods of time due to reaching a limit on shutdowns one of the complaints is that "no one knows" why this particular locomotive is still running. How do they find out if the locomotive is running because of the start counter, weak batteries, a bad sensor or something else? If all you have is a red LED or an asterisk by a parameter do you know if it is a sensor problem or something else? Do your people even know where to look for that info and can they get to it or is it buried in a level 2 or 3 screen?

The author believes all the major issues are listed above. At this point we will look at potential ways to fix the issues.

HOW CAN WE FIX THE AESS ISSUES?

Returning to the Can We questions from earlier, we have:

1.) Can we manually shutdown the locomotive while leaving AESS Active to restart the locomotive?
2.) Can we reset the disabled AESS to allow it to maintain locomotive parameters without restarting the main engine?
3.) Can we choose to sometimes maintain air and sometimes not maintain air?
4.) Can we provide an easy way to allow crews and maintainers to KNOW the AESS system is fully functional or to tell them what needs fixed?
5.) Can we make the AESS systems more standard?

As stated previously each railroad needs an overall expert. Railroads have a person responsible for EPA compliance, Positive Train Control, Remote Control, and many other systems. There needs to be an AESS Expert. All locations, such as shops and service centers, need people familiar with AESS and especially on one or two classes of power. As systems are more standardized these local experts will

become more and more familiar with all the systems and eventually move up to be the system expert allowing the original AESS Expert to not be stagnant in their career. These local experts would also assist in making and testing the necessary changes to their respective locomotive classes of power.

The vast majority of the issues can be fixed with a few simple changes. There are hundreds of locomotives in service today with each of these recommendations in place in some fashion or the other.

1. The crew performs a manual shutdown, and disables the AESS, by pressing the ESP or EFCO button. On most AESS locomotives there is a way to reduce the timer to a few minutes or extend the timer. This is via a button or switch. Revise the software so that if the locomotive is running and the button/switch is pressed/activated and the locomotive engine is running, then the locomotive will shut down in an AESS active mode. Without this feature the crews will continue to manually shutdown the locomotives, usually with the EFCO Button. Pressing the EFCO/ESP button will still shut down the loco and disable the AESS per FRA requirements. An additional enhancement is that the button should be held on for 4 seconds followed by a chirp or alarm that indicates the 4 seconds has expired and the computer is ready to shut down the engine. This prevents an inadvertent pressing of the button and also ensures the button is not released after 3.5 seconds.

2. Next, revising Software if the engine is off and the AESS is inactive then pressing the same button as above, again for 4 seconds, the AESS will become active following the chirp. Here the 4 seconds is even more important. This prevents an inadvertent pressing of the button from activating the system. Why this feature? Today on most locomotives to reset the AESS, you must restart the locomotive, allow it to run the minimum amount of time and only then you are active following shutdown via AESS. This feature provides for a crew mistakenly (usually because of habit) pressing the EFCO/ESP and only then realizing their mistake and needing to restart the engine.

3. Provide a method to tell the AESS System to maintain, or not maintain, air pressure even if the electric handbrakes are set. This can be done via a switch but there may need to be some thought into implementation to ensure that the Event Recorder records that the handbrake is set even though air pressure is still maintained. Proving the handbrake was set could be important in court cases. This feature is one that may require some discussion via the AAR cab committee and may require a revision of AAR Standard S-5502.

4. Letting people know what parameter is preventing a problem is often done with asterisks on screens but showing actual data is on few locomotives.

Locomotives with only LEDs, not screens, can provide the information regarding which parameter or sensor by flashing the LEDs with a handy list to decipher the flashes. In practice this was available 15 years ago showing 45 different codes for the maintainer. Obviously, the "handy list" will be necessary if all you have are LEDs. Whether your railroad uses LEDs on older locomotives or screens on newer systems there are numerous ways to let the crews know why the locomotive is not shutting down. Whatever the solution, it should be one that crews and maintainers can use.

5. We always forget something. The author in recognizing this had an add-on AESS system include two spare inputs. This required the replacement of a digital input board to be one that included more inputs. The software in the add-on system was set up simply as "if input 1 goes high (74 volts) then turn off the main engine." "If input 2 goes high and AESS is active then start the main engine." Via the use of diodes any number and type of sensors can be added to meet future needs.

6. What about standardization? The above features make the locomotives much more standardized. Whether one locomotive maintains batteries at 65-74 volts and another one maintains at 63-74 volts is unimportant. What is important is that when used in consist with other locomotives and especially in interchange service.

7. In each cab with AESS there is an information decal. This decal should be revised to indicate how to properly start and shutdown the locomotives. It should include which circuit breakers to turn on/off and should be tested on each class for each railroad. CSX Railroad did this in 2014 and reduced many starting and shutting down issues. The decals used on SD70MAC and SD70AE locomotives on CSX are shown in Figures 1 and 2.

8. Finally there are a few things that should be looked at in regards to reliability. With AESS came increased engine starts and failures in the starting systems. Adding components, such as sensors, switches, etc. adds new failure items. Redundancy, improved reliability of components, or testing of sensors may be necessary.

SUMMARY:

The author's opinion is that there are simple fixes to the many AESS issues seen by today's railroads. The various railroads need to work together to resolve these issues as this is an interchange issue in many cases. The author has participated in many AAR meetings and sees no anti-trust issues in this. This is not a quick process and may take a few years to complete.

SD70AC Class Engine Control Panel

Manual Startup Process

1. OPEN Computer Control circuit breaker
2. CLOSE Battery Knife switch
3. CLOSE Auxiliary Generator (AUX GEN)
4. CLOSE all circuit breakers in the black panel areas of the circuit breaker panel
    - CLOSE Computer Control circuit breaker last
5. Set Isolation switch to position: START/STOP/ISOLATE
6. OPEN Generator Field and Engine Run switch
7. CLOSE Control and Fuel Pump switch
8. Press the Start switch push-button

Manual Shutdown Process

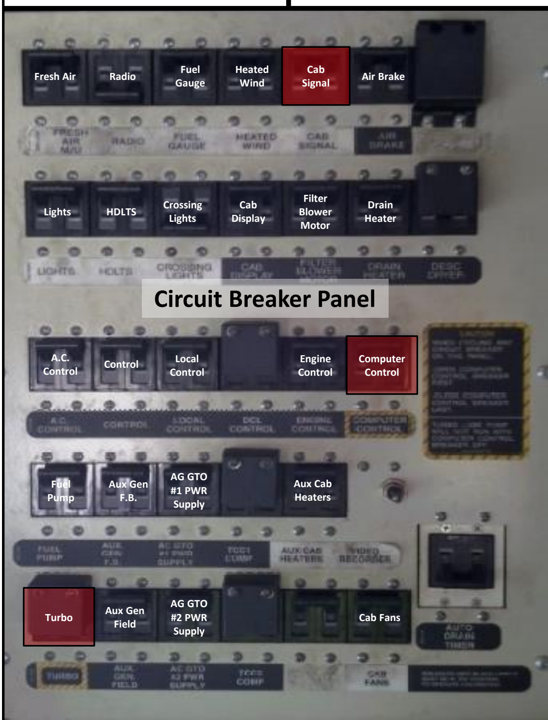
1. Secure locomotive following all Railroad Operating Procedures
2. Center and remove reverser lever
3. Set Isolation switch to position: START/STOP/ISOLATE
4. Press Engine Stop button for four seconds
5. Wait for engine to completely stop rotating and is quiet
6. OPEN all breakers (including covered breakers)

- *Leave the following breakers CLOSED at all times:*
- *PTC Radio / Positive Train Control Cab Signal / Computer Control Breaker / Turbo Lube*

7. OPEN Generator Field, Engine Run and Control switches
8. OPEN Battery Knife switch

AESS Setup Process

1. Secure locomotive following all *Railroad Operating Procedures*
2. Center and remove reverser lever
3. OPEN the following switches:
    - Generator Field (GEN FLD)
    - Radio
    - Crossing Lights
4. OPEN the following switch if Operating Rules allow:
    - Head Lights
5. CLOSE all other breakers
6. Leave Isolation switch in position: START/STOP/ISOLATE
7. Verify green "ENABLED" light is lit on Auto Start panel



SD70AC

Figure 1. SD70AC Cab Information Decal

SD70AE Class Engine Control Panel

Manual Startup Process

1. OPEN Computer Control circuit breaker
2. CLOSE Battery Knife switch
3. CLOSE all circuit breakers in the black panel areas of the circuit breaker panel
   - CLOSE Computer Control circuit breaker last
4. Set Isolation switch to position: START/STOP/ISOLATE/INSPECT
5. OPEN Generator Field and Engine Run switch
6. CLOSE Fuel Pump switch
7. Press the Start switch push-button

Manual Shutdown Process

1. Secure locomotive following all Railroad Operating Procedures
2. Center and remove reverser lever
3. Set Isolation switch to position: START/STOP/ISOLATE/INSPECT
4. Press Engine Stop button for four seconds
5. Wait for engine to completely stop rotating and is quiet
6. OPEN all breakers (including covered breakers) in cab

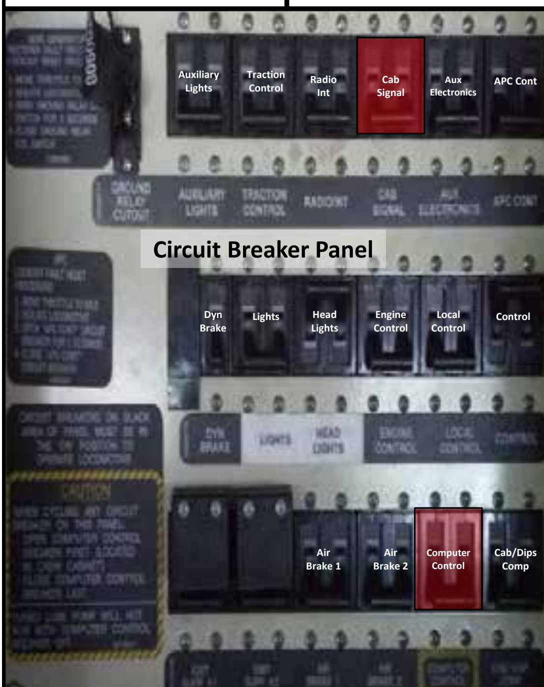
- *Leave the following breakers CLOSED at all times: Cab Signal / Computer Control Breaker / Turbo Lube (in Electric Locker)*

7. OPEN Generator Field, Engine Run and Fuel Pump switches
8. OPEN Battery Knife switch (located in the Generator Room)

DO NOT SHUTDOWN UNLESS COUPLED TO ELECTRIC START LOCOMOTIVE

AESS Setup Process

1. Secure locomotive following all *Railroad Operating Procedures*
2. Center and remove reverser lever
3. OPEN the following switches:
   - Generator Field (GEN FLD)
   - Radio
   - Crossing Lights
4. OPEN the following switch if Operating Rules allow:
   - Head Lights
5. CLOSE all other breakers
6. Leave Isolation switch in position: START/STOP/ISOLATE/INSPECT
7. Verify green "ENABLED" light is lit on Auto Start panel



SD70AE

Figure 2. SD70AE Cab Information Decal.

A Study of Locomotive Battery Charging and Performance

Prepared by:
Jason Fox – Union Pacific Railroad
Gibson Barbee – Norfolk Southern Railroad

Abstract

A review of flaws in how Automatic Engine Start/Stop systems have handled battery charging. Data shows that monitoring charging current and waiting to shutdown the engine until the batteries have a high state of charge can increase overall engine shutdown time. Testing shows that fully charged batteries have enough energy to restart a locomotive down to a 25% state of charge or lower. Recommendations include using battery charging strategies recommended by the battery manufacturer and minimizing the loads left on the battery when the knife switch is opened.

Railroads provide a service to their customers by using locomotives to pull freight. Depending upon the duty cycle of the locomotive on the railroad, locomotive idle time may be as high as 60%. Fuel is expensive. Ideally, if locomotives are not pulling freight, they will be shutdown to conserve fuel. Automatic Engine Start Stop (AESS) has helped railroads reduce emissions, satisfying 40 CFR Part 1033, and save fuel by shutting down locomotives when in idle. The railroads leverage these AESS Systems to save money on fuel expenses.

This paper will consider battery voltage as a critical parameter of the AESS system. Battery voltage is a simple measure of a battery's state of charge. With most locomotives, battery power is used as the main energy source to start the locomotive. Regardless of the state of main reservoir air pressure, engine temperature or any of the other parameters that AESS considers, the locomotive will not restart if the battery is not properly charged to produce necessary power to start the engine.

Historically, the main function of the battery is to start the locomotive. The addition of AESS has required the battery to also maintain hotel loads when shut down. These hotel loads include: lights, locomotive control systems, Positive Train Control, and other systems. As the locomotive systems have evolved, the electronics have gradually increased the hotel loads draining the battery while shut down.

AESS Problems

The AESS system considers many different parameters to determine if an engine can be shut down or requires starting. Among these parameters are main reservoir air pressure, engine oil and water temperature, and battery voltage. Battery driven AESS restarts, which vary by locomotive model and railroad, can account for 25-40% of the locomotive AESS restarts in operation; with the remaining restarts caused by air pressure, water temperature, or oil temperature.

Locomotive control system software has been designed to allow up to 16 AESS restarts in a 24 hour period resulting in multiple daily battery discharge cycles. These discharge cycles reduce the life of the battery proportional to the depth of discharge (DOD). DOD is the percentage of battery capacity discharged during each cycle.

AESS systems control DOD by monitoring battery voltage and restarting the locomotive when a specific voltage set point is reached. This set point is the End of Discharge Voltage (EODV). In an attempt to maximize shutdown time, Original Equipment Manufacturers (OEM) reduced the EODV to 62V. Consider that locomotive starting batteries consist of 32 lead acid cells in series, an EODV of 62V is equivalent to 1.93 volts per cell. This is highly discharged at nearly 100% DOD. With the AESS system designed to allow 8-16 daily restarts, the frequent high discharge cycles result in poor battery life.

AESS systems are not allowing the batteries to be charged to the manufacturer's recommended 2.4 volts per cell across 32 cells in series or 76 volts. Some AESS systems would allow an engine shutdown when battery voltage had only been charged to 69 V. This did not allow for a reasonable charge; where the necessary chemical reaction could take place allowing the lead sulfate to return to solution. Due to this poor charging, the batteries have reduced energy storage capacity and will reach EODV very quickly during discharge. Shutdown time is reduced because of this reduced energy storage capacity.

Chart 1 shows a locomotive with AESS enabled for 24 hours; data channels include: battery volts, amps, and accumulative Amp*seconds. The voltage drops and negative battery current in the charts demonstrate the locomotive cycled through 8 start/stop events within 8 hours. After reaching the maximum allowable restart events for a 24 hour period, the locomotive idled for the remaining 16 hours.

Battery discharge per shutdown can be estimated by integrating discharge current. Over these eight shut down events, only 110 Amp hours was discharged from the battery or an average of 14 Amp hours per shutdown. The flooded battery in this locomotive has an estimated capacity of 650 Amp hours. The locomotive only charged its batteries for approximately 10 minutes between shut downs. This short shutdown duration, limited discharge capacity, and short charge interval was documented multiple times on several locomotives in service. The Amp*Seconds graph shows that the batteries were not able to replace the Amp-hours used during the discharge events until AESS had reached its maximum restart limit and the locomotive ran in idle for the remaining 16 hours of the day.

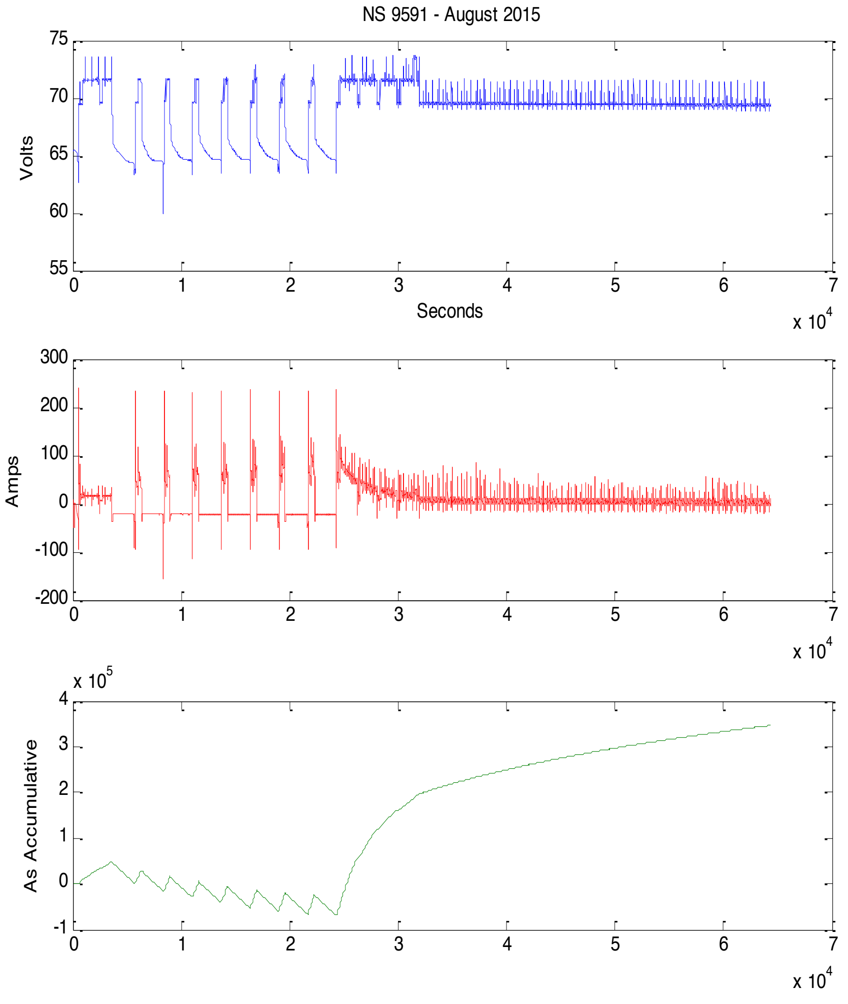


Chart 1: NS9591 – Monitoring AESS for 24 hours

AESS Changes

Based on the lessons learned in the example above, new battery software was implemented on this locomotive series. The software increased End of Discharge Voltage (EODV) from 62 V to 65.5V. By increasing the EODV, the depth of discharge during each shutdown cycle was reduced from near 100% to approximately 60%. A battery has a limited life. It is often measured in accumulated amp hours. Reducing the depth of discharge allowed for each start/stop cycle results in improved battery starting ability and increased battery life.


ULTIMATE
Air Dryer
Innovation
Thrives
OUTSIDE
THE BOX
AGAIN...
Push Button Self-Test Equals Reduced Train Delays
Intelligent Purge Control Equals Air Savings
Real-time Performance Monitoring Via Locomotive Ethernet
IoT Technology Leader
994
AIRSMART
PRECISION SERIES
GRAHAM-WHITE
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A Battery Current Module (BCM) was also added with this software package to control the battery charging. Newer locomotives were already equipped with a BCM and only required a software update to the new strategy. Older locomotives required a hardware upgrade to add the BCM along with the improved control logic. The BCM allows the software to monitor battery current and wait until the charge current is low before shutting down. A low charge current means that the battery has accepted a significant amount of charge and will be at a high State of Charge when shutting down for AESS. Examples of pre-BCM and post-BCM conditions are presented in Chart 2.

The pre-BCM NS9591 was only charging for 10 minutes prior to shut down. When AESS allowed the locomotive to shutdown, charging current was still 40A. The starting battery is not sufficiently charged at 72 V and the engine shutdown too soon with an insufficient State of Charge indicated by the high charging current of 40A. The State of Charge prior to shutdown was increased with the BCM software package by requiring the control system to see a maximum charging current of 10A prior to an AESS shutdown.

The post-BCM NS9007 saw charging time between shutdowns increased from 10 minutes to 80 minutes. While the idle time between shutdowns increased with this software change, the total shutdown time in a 24 hour period also increased from 36% to 56%. This increase can be attributed to allowing the locomotive to better charge the battery prior to a shutdown resulting in a battery with a higher State of Charge that can support a longer shutdown. This improved performance has been documented on multiple locomotives that have received the BCM modification.

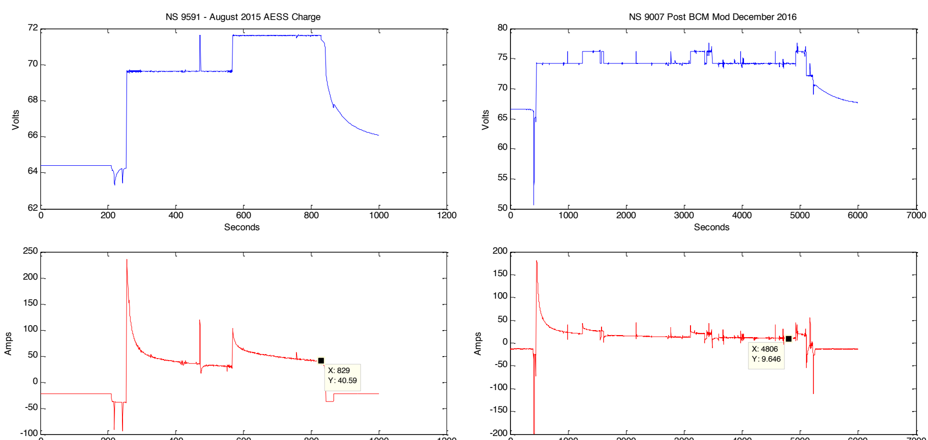

Chart 2: Pre & Post BCM AESS cycles

Study continues on the charging strategy for locomotives. In December 2016, a coincidental MU failure on the instrumented post-BCM NS9007 allowed the equipped data acquisition system to collect 3 full days of AESS shutdown/restart cycles. While the BCM did allow the unit to be shutdown 56% of the time, there may be room for further improvement. Integrating the amps channel allows an estimate of amp hours charged and discharged. Amp-hours put back into the battery through charging roughly equaled amp-hours discharged out of the battery over this three day period. The inefficiency of lead acid batteries is commonly estimated at 85% for new batteries. Ideal charging might require that 120% of discharged Amp-hours must be returned to the locomotive battery through charging. Considering 600 Amp-hours were discharged, the 604 Amp-hours charged into the battery may still be producing a deficit charge.

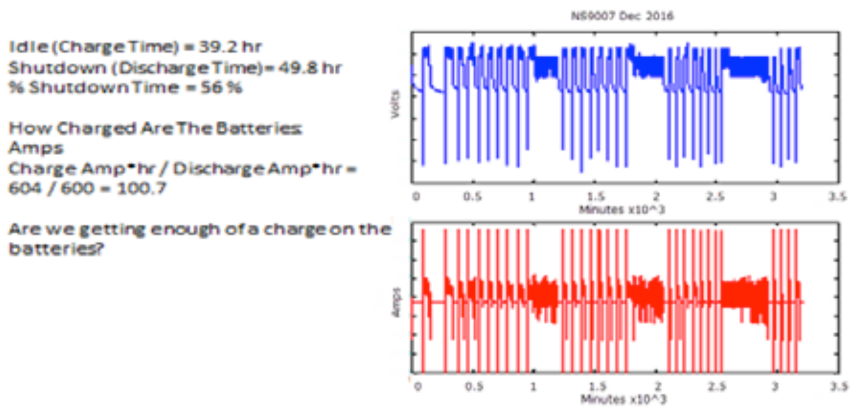

Chart 3: Still an opportunity to improve charging

Another opportunity to improve battery charging is to select the proper charge voltage. Charging voltage of flooded batteries in locomotives is often less than the charging voltage specified by the battery manufacturer of 2.4 volts per cell or 76 V for the 32 cells in series. Even with the BCM, we may not be getting a high enough state of charge to reverse the effects of discharge and improve reliability and life of the battery. By raising the charge voltage, additional amp-hours are returned to the battery faster thus improving charge and reducing idle time. The locomotive manufacturers have intentionally applied a lower charge voltage to allow the locomotive to operate 184 days between scheduled maintenance (i.e. watering flooded batteries). Discussion continues as to the ideal charging voltage and if flooded batteries can be charged to 76 V to achieve a high state of charge without drying out the batteries between a 184 day schedule maintenance.

A Test - The Problem Statement

A 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.

There are several different types of starting strategies on a locomotive. A first strategy is the Air Start Method. A magnet valve is used to control compressed air to power a motor that turns the fly wheel of the engine to start it. On Air Start locomotives, compressed air is the primary energy source used to start the locomotive. Only enough battery power is needed to keep the computers powered on and the starting magnet valves picked up. The voltage drop during starting is not as severe on the Air Start locomotives as locomotives with other starting strategies. This starting system is much more forgiving in regards to low battery voltage. Air Start locomotives will not be considered in this paper.

The most popular starting strategy for many modern locomotives is the Generator Start method. Inverters apply battery power to the generator to turn the engine and start it. Another starting strategy is the Electric Start method. Batteries are used to power a strong electric motor that turns the fly wheel of the engine to start it. Both of these starting strategies are sensitive to battery voltage to facilitate reliable engine starts. Table 1 summarizes what locomotives, starting types and battery types were tested.

AESS parameters should be selected to minimize engine idling time while maintaining locomotive and train health. This test will explore what battery SOC is required to start a locomotive. How many times can a fully charged battery start a locomotive?

	Battery Type	Starting Type	Model	Number
Locomotive 1	Flooded	Electric	SD70M	UP4891
Locomotive 2	Sealed	Generator	EVO	UP7365
Locomotive 3	Flooded	Generator	C44	UP6226

Table 1: The test locomotives

The Test Setup

To answer this question, locomotives equipped with either electric start or generator start strategies were instrumented to collect battery voltage, charging/discharging current and temperature data. The testing occurred August 23-26, 2016 in North Platte, NE at the Bailey Yard Diesel Shop. Two types of test equipment were used. Low Sample Rate (1Hz) test equipment was used to monitor discharge and recharge data. High Sample Rate (100Hz) test equipment was used to record battery voltage drops and current discharge rates during the locomotive starting sequence. The profiles of the starting sequences that were to be recorded required a sample rate much higher than 1 Hz.

For each locomotive, a standalone battery charger was used to make sure the batteries were fully charged before starting the test. Locomotive 1 & 3's batteries were determined to be fully charged when the Specific Gravity, measured by a digital Hydrometer, reached approximately 1.255. Specific Gravity allows a measure of the lead sulfate in solution and is a good indicator of State of Charge. The Specific Gravity of the sealed batteries on Locomotive 2 could not be measured with the Digital Hydrometer. These batteries were determined to be fully charged when the charging current was less than 5A.

One note made about the batteries on Locomotive 1 is that one battery would not reach a Specific Gravity higher than 1.15. This battery was several years old and was determined to have at least one damaged cell. In the attempt to get this damaged battery fully charged, the second battery was overcharged. Due to shop time constraints and spare battery availability, the test group made the decision to proceed with the test as planned despite the under and overcharged battery. This is a real situation that a locomotive would see on the railroad.

The test would begin with a fully charged battery. The Low Sample Rate test equipment would be connected and record data during the entire test. The High Sample Rate test equipment would be connected to the locomotive for the entire duration of the test but it would only be triggered to record data during the starting sequence. The test would proceed as follows for each locomotive.

1. Start the locomotive and record the starting voltage and current using the High Sample Rate test equipment.
2. Shut down the locomotive as soon as the voltage reaches a steady state charging voltage.
3. Configure the locomotive, using headlights, ditchlights and any other ancillary loads available to discharge 10% of the rated Amp-Hours. For example, Locomotive 1 had 650A-h batteries installed. We wanted to deplete 65A-h from the battery. We were able to have a steady discharge current of 37Amps. By discharging 37Amps for 1 hour 45 minute we were able to deplete 65A-h; 10% of the total AmpHours available.
4. Repeat steps 1-3 until the locomotive does not successfully restart.

Upon a failed starting attempt, the standalone charger was attached to the locomotive. The battery was charged just long enough to have a successful start attempt. Once the locomotive was successfully started, the charger was removed and the locomotive was allowed to run so that the battery was fully charged using the onboard charging system.

The Results

This section will outline the results of the test for each of the three locomotives. The results were somewhat surprising in that the batteries were able to successfully restart the locomotive at a very low SOC. One important note about our testing is that conditions were near ideal. The weather was very mild with temperatures in the mid-upper 70 degrees Fahrenheit. A participant of the test actually made the comment during one of the start events "The temperature is 77 degrees F. This is lab conditions". We all know that locomotives do not operate in lab conditions. So it must be remembered that the cold weather will demand stronger batteries to start a locomotive.

Electric Start – Flooded Batteries

The locomotive with Electric Start was able to be restarted eight times with a set of fully charged 650Ah flooded batteries (Chart 4). The batteries completed 8 successful restarts discharging to 20% State of Charge before failing to start.

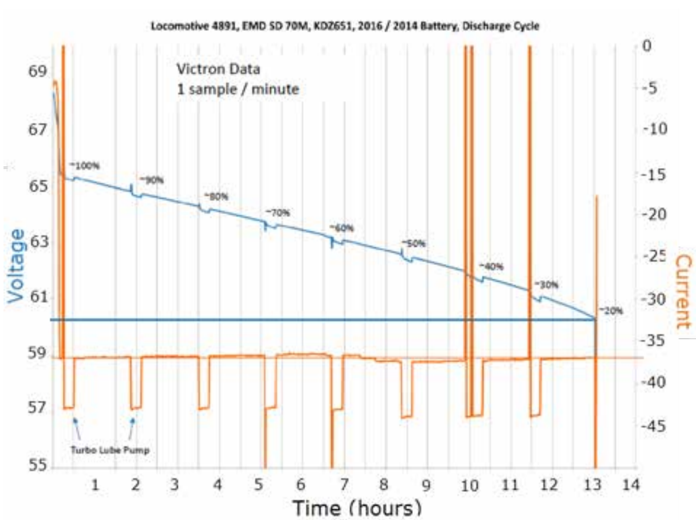

Chart 4: Locomotive 1 Battery Discharge Cycle

The electric start locomotive took 3-4 seconds to start (Chart 5). During breakaway, the Voltage would drop below 40 volts and have a discharge current of nearly 1800 Amps. Breakaway is that period of the start sequence that requires the highest torque to begin the initial rotation of the engine. The charts do show that the start cycle does get longer as the battery's State of Charge decreases. Notice that after breakaway, the current during cranking is approximately 1300A for less than 1 second.

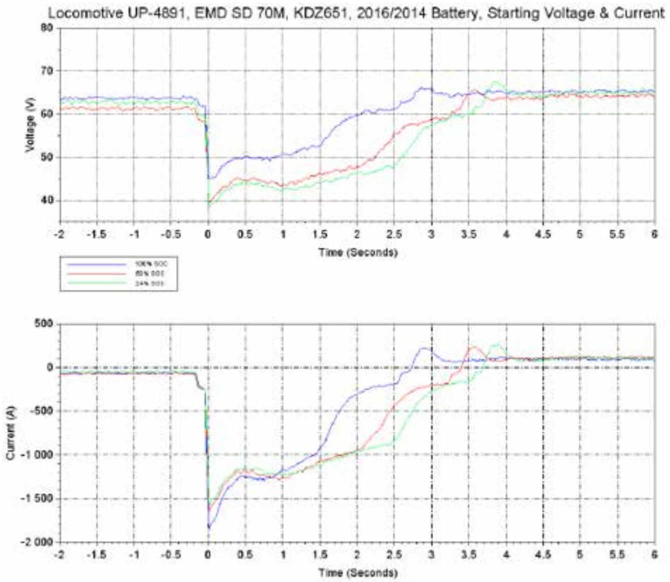

Chart 5: Locomotive 1 Starting Sequence

After 11 hours of on-board charging, the batteries were charged such that the charging current was less than 10A (Chart 6). Two anomalies of note during the test were the two AESS locomotive shutdowns. These shutdowns were an oversight of the test group. After the 2nd AESS shutdown, the AESS was disabled to allow the battery charging current to get below 10A.

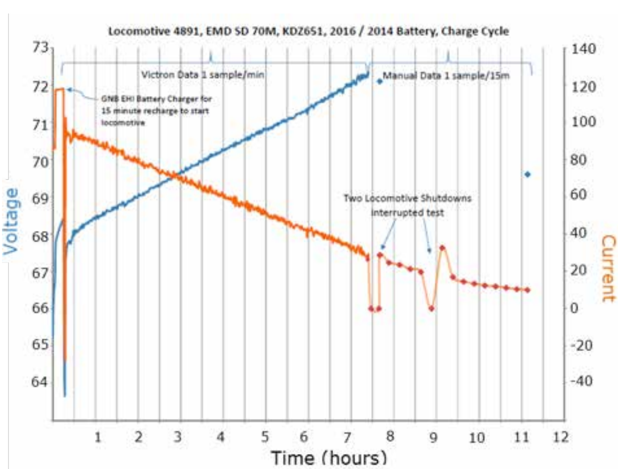

Chart 6: Locomotive 1 Battery Charging Cycle

Generator Start – Sealed Batteries

The locomotive with Generator Start was successfully started 14 times with a set of fully charged 710Ah Sealed batteries (Chart 7). The batteries were depleted down to a 5% State of Charge and still successfully restarted. At this point, the test team aborted the test. Diesel shop resources were limited and it was decided that the 5% State of Charge was below the practical point of discharging the battery.

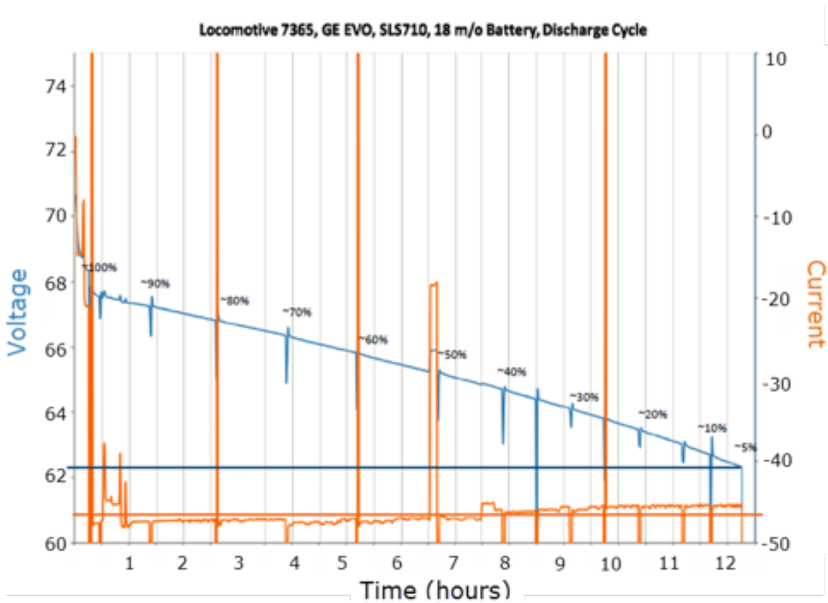

Chart 7: Locomotive 2 Battery Discharge Cycle

The generator start locomotive with sealed batteries took 11-14 seconds to start. During breakaway, the voltage would drop below 55 volts and have a brief discharge current of nearly 1300 Amps. The charts do show that the start cycle does get longer as the battery's State of Charge decreases. One point to notice in Chart 8 is the steady state discharge current during cranking is approximately 500A. This steady state discharge current is much lower than the electric start but the duration is nearly 30 times as long. Once this locomotive is started, it takes 35 seconds for the auxiliary alternator to begin charging the battery.

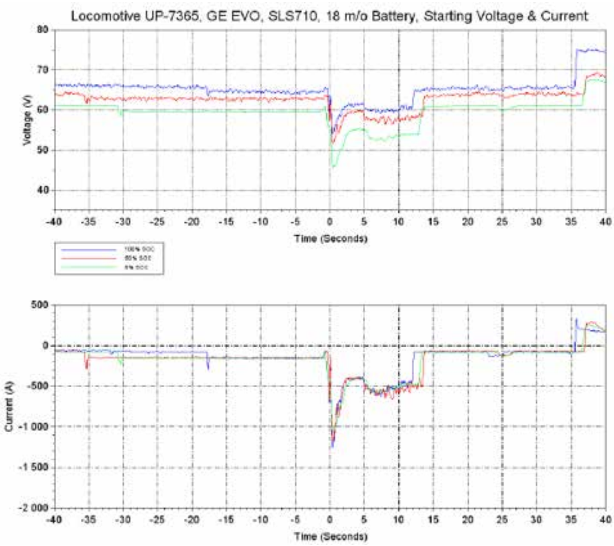

Chart 8: Locomotive 2 Starting Sequence

This locomotive uses a three stage charging strategy. This is the charging profile that is recommended by the battery manufacturer. Chart 9 shows that after 3 hours the battery charging switches from constant current mode to constant voltage mode. Finally, after nearly 5.5 hours, the battery charging switches to a float charge; a very effective recharge event.

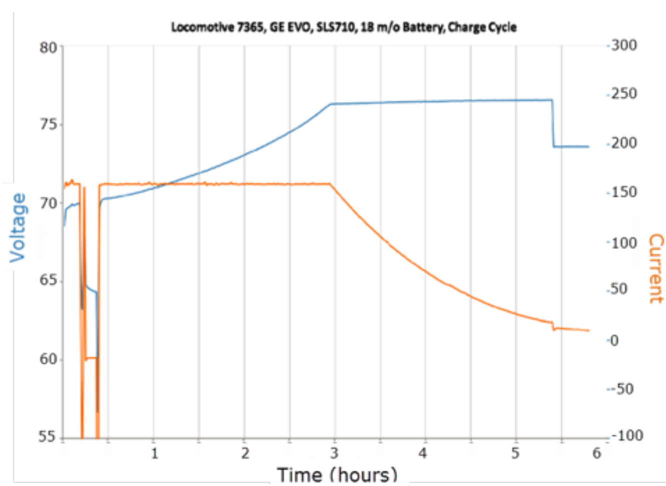

Chart 9: Locomotive 2 Battery Charging Cycle

Generator Start – Flooded Batteries

The locomotive with Generator Start was successfully started many times with a set of fully charged 650Ah Flooded batteries. The batteries were depleted down to a 5% State of Charge and still successfully restarted. Again, at this point, the test team aborted the test. Diesel shop resources were limited and it was decided that the 5% State of Charge is below the practical point of discharging of the battery.

Chart 10 shows an anomaly in this Discharge Cycle in the ~50%-20% State of Charge portion of the graph. The test team was attempting to add additional loads to the discharge cycle hoping to reduce the time that it would take to reduce the State of Charge by 10%. The fluctuation in the current plot was the team experimenting with different loads to discharge the batteries. After the 20% State of Charge point, the team was successful at increasing the current draw from about 50A to nearly 80A. This decreased the time between starts from about 75 minutes to about 45 minutes.

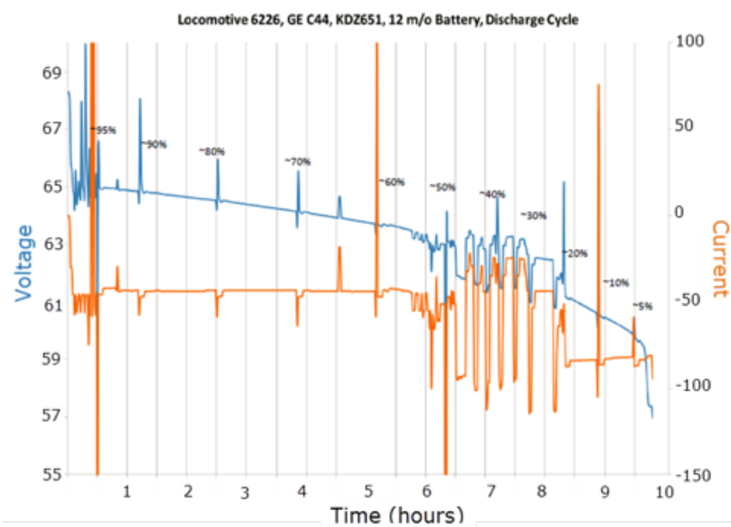

Chart 10: Locomotive 3 Battery Discharge Cycle

It should not be surprising that the starting voltage and current of the generator start locomotive with flooded batteries are very similar to the sealed batteries. Locomotive #3 took 10-12 seconds to start (Chart 11). Once started, it takes 35 seconds for the auxiliary alternator to start charging the batteries. The breakaway voltages were slightly lower dipping down to about 50V. The instantaneous discharge and steady state currents are about the same at about 1300A and 500A respectively.

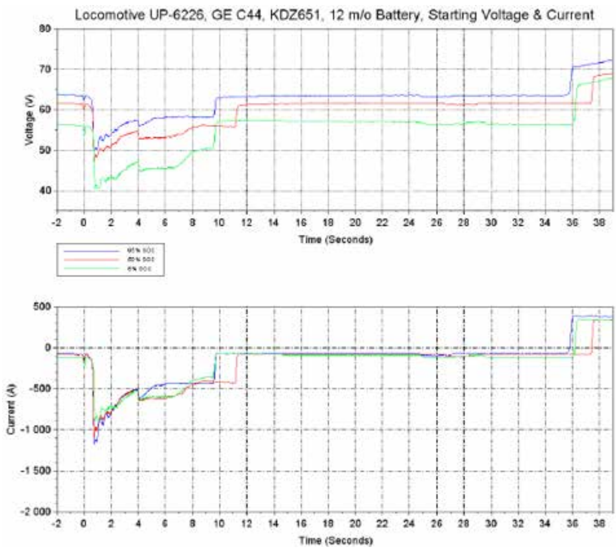

Chart 11: Locomotive 3 Starting Sequence

After 10 hours of on-board charging, the batteries were charged such that the charging current was less than 10A. The alternating high and low charging voltages shown in Chart 12 are very interesting. The fleet management team is working with the OEM to migrate toward a three stage charging method to get more in-line with what is recommended by the battery manufacturer.

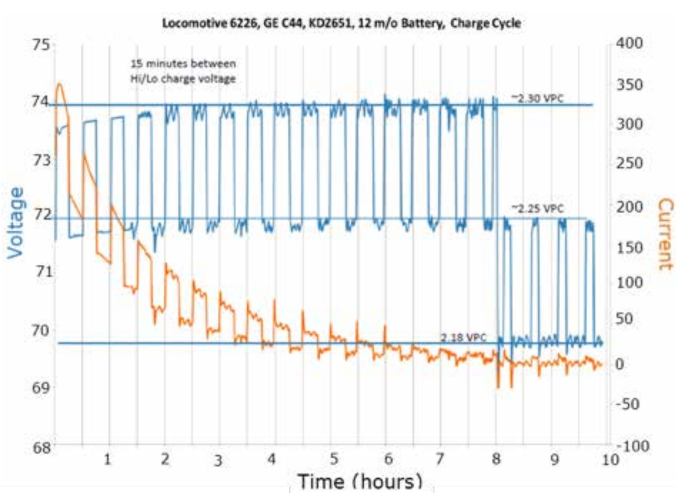

Chart 12: Locomotive 3 Battery Charging Cycle


PERFORMANCE FOR THE FUTURE.

Conclusions and Recommendations

The introduction of AESS has increased discharge cycling of the lead acid starting batteries to support hotel loads when the engine is shutdown. In the last three years, significant improvement has been made to the locomotive AESS systems to improve battery health and reliability. Adding hardware to monitor battery charging current can provide information necessary to maintain a healthy battery. Properly implemented AESS systems can improve battery health and increase total shutdown time from 36% to 56%.

Wayside chargers have been installed in many locomotive shops. A proper maintenance charge can greatly improve battery health while in shop. Locomotive maintenance facilities should use these chargers while locomotives are being serviced within shops to provide healthy batteries at near 100% SOC when locomotives are released.

Use the proper battery charging profiles as recommended by the battery manufacturer on board locomotives. In the test, the locomotive with the recommended three stage charging method was able to recharge the batteries from 5% Stage of Charge to 100% State of Charge in approximately 5.5 hours. This is nearly half the time than it took locomotives with alternate charging methods equipped with smaller batteries. More testing is needed to understand what starting and charging profiles look like in cold weather.

In the world where fuel savings is very important to the efficiency of railroad operations, it is very important to charge batteries as quickly as possible. The faster the batteries reach an acceptable state of charge the sooner the locomotive can be shut down when not pulling freight.

A key take away from the testing is to have a large enough load so that the locomotive batteries can be discharged quickly. The test team put in some very long days during this test. Anything that can be done to speed the test along is beneficial to the test team and the facility hosting the test. The team was cautious about discharging the batteries too quickly since capacity is a function of discharge rate (i.e. capacity is normally measured at the 10 hour constant current rate, increasing discharge rate will reduce battery capacity).

Much work remains considering that the Class I Railroad operating practice of manually shutting down locomotives will disable the AESS system. Even when properly shut down by pulling the knife switch, some loads are left on the hot side of the battery knife switch and discharge the battery without the control system powered on to monitor voltage. Too often, this practice results in excessive battery discharge reducing battery life and reliability. A variety of projects are underway to reduce current draw when the unit is shutdown to improve battery health. Railroads should evaluate what loads remain powered when the knife switch is pulled and work to reduce the number loads to the minimum necessary.

Whether a railroad chooses equip their locomotive with sealed or flooded batteries, proper battery charging methods and maintenance practices are critical to the health of the battery. Once these are established, the AESS parameters can be selected to further reduce fuel consumption.

Special Thanks
Sid Bakker, Josh Dummeller, Chris Adams – TPSC/ARMS
Chris Miller, Mike Cook, Scott Jedlicka - UPRR
Brent Ballew - NSRR

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.