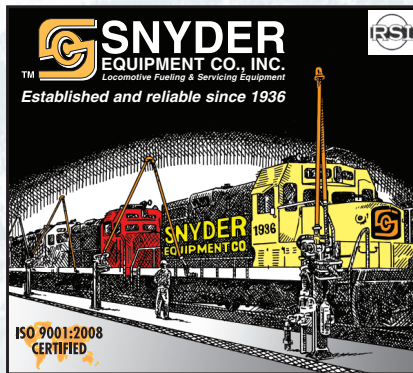


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Locomotive Maintenance Officers Association

Proceedings of the 75th Annual Meeting
SEPTEMBER 30 – OCTOBER 1, 2013
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2012 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 2012.

NAME	COMMITTEE
Jeff Clapper, Wheeling & Lake Erie RR	New Technologies Committee
Mike Drylie, CSX Transportation	Diesel Electrical Maintenance Committee
Tom Gallagher, Chevron/Oronite	Fuel, Lubricants & Environmental Committee
Mike Kader, Union Pacific RR	Diesel Material Control Committee
Ted Stewart, Peaker Services, Inc	Diesel Mechanical Maintenance Committee

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

LMOA EXECUTIVE COMMITTEE

The LMOA Executive Board would like to express their sincere appreciation to CSX Transportation for hosting the annual LMOA Joint Technical Committee Meeting in Huntington, West Virginia on May 6 and 7, 2013.

Special thanks to LMOA Regional Executive Mike Drylie for getting CSX approval to host the meeting and for arranging the tour of Huntington shops and to 1st Vice President Dave Rutkowski for coordinating the meeting details.

Thanks to Paul Foster and Bob Harvilla of PowerRail Distribution for hosting the luncheon on Monday, May 6th.

We also wish to thank Magnetech and Garry Fadale for allowing the LMOA committee members to tour their facility and for sponsoring the luncheon on Tuesday, May 7th.

The Executive Board of the Locomotive Maintenance Officers Association would like to express their deep and sincere gratitude to Dwight Beebe of Temple Engineering for sponsoring an Executive Committee meeting luncheon at the Chicago Sheraton Hotel and Towers on Tuesday, September 25, 2012.

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



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1959 E.V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry.
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1980 J.H.LONG (Deceased) Manager-Locomotive Department, Chessie Systems
1981 R.G.CLEVENGER, Retired, General Electrical Foreman, Atchison, Topeka & Santa Fe Rwy

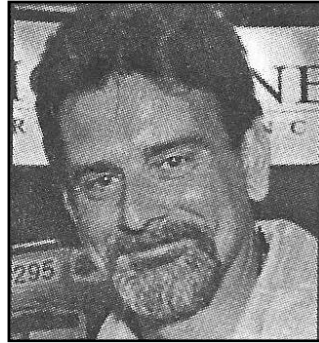
- 1982** N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
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- 1986** D.H.PROPP, Retired, Burlington Northern RR, 10501 W. 153rd St, Overland Park, KS 66221
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- 1990** P.F.HOERATH, 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
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- 1993** W.R.DOYLE, Project Manager, Sound Transit, Seattle, WA 98104
- 1994** M.A.COLES, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
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- 1997** D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
- 1998** H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
- 1999** JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak 1130 Walnut Ave, Osawatomie, KS 66067
- 2000** RON LODOWSKI, Retired Production Mgr, CSX Transportation, Selkirk, NY 12158
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- 2003** BRIAN HATHAWAY, Consultant, Port Orange, FL 32129
- 2004** BILL LECHNER, Retired, Sr Genl Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp, Altoona, PA 16601
- 2005** TAD VOLKMANN, Director-Mech. Engrg., Union Pacific RR, Omaha, NE 68179
- 2006** BRUCE KEHE, CMO, CSS&SB, Michigan City, IN 46360
- 2007** LES WHITE, Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
- 2008** MIKE SCARINGE, 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, VP. Sales, Graham White, Salem, VA 24153
- 2012** RON BARTELS, Sr. Manager - Equipment Reliability and Electrical Engineering, Via Rail-Canada, Montreal, Quebec

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Newly elected President, Brad Queen, BNSF, accepting gavel from outgoing President Ron Bartels, Via Rail which was witnessed by Past President Bob Reynolds, Anglo Kemplite.



Past Presidents Bob Runyon (left) and Tad Volkmann, Union Pacific, presenting outgoing President Ron Bartels with LMOA watch.



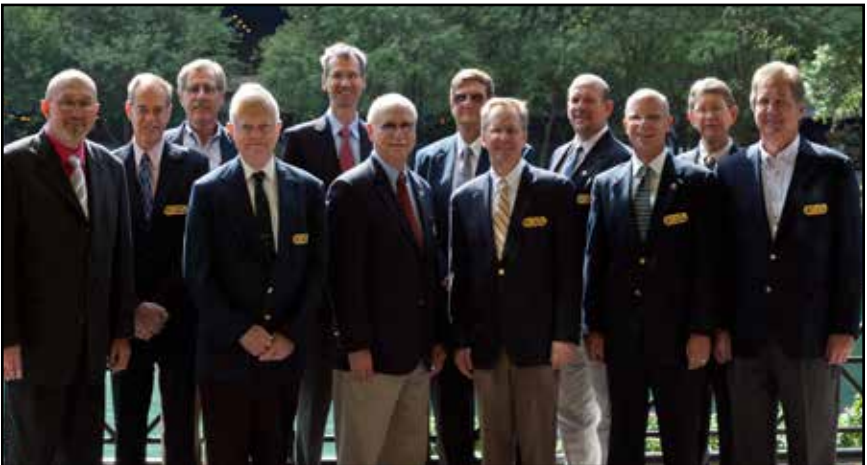
Past President Les White, Wabtec/Bach Simpson, is about to present outgoing President Ron Bartels with the Past President's Pin. Ceremony was witnessed by newly elected President Brad Queen and Past President Jack Kuhns, Graham White Mfg.



Past President Bob Reynolds assists newly elected 3rd VP Stuart Olson, Wabtec, with his LMOA Blazer. Past President Dennis Nott, Northwestern Consulting, (left), newly elected President Brad Queen and Past President Bruce Kehe, Chicago South Shore and South Bend RR, attended the ceremony.



Outgoing President Ron Bartels presents Past President Tad Volkmann with an LMOA Lifetime MVP plaque in recognition of Tad's outstanding service to LMOA. Newly elected President Brad Queen attended the presentation.



Executive officers who attended the Rail Show Conference at the Chicago Sheraton Hotel. Back Row (left to right) Past President Jack Kuhns, outgoing President Ron Bartels, Past Presidents Les White and Bruce Kehe and newly elected 3rd VP Stuart Olson. Front Row (left to right) Secretary-Treasurer Ron Pondel, Past Presidents Bob Reynolds, Bob Runyon and Dennis Nott; newly elected President Brad Queen, Past President Tad Volkmann and newly elected 2nd VP Bob Harvilla, PowerRail Distribution.

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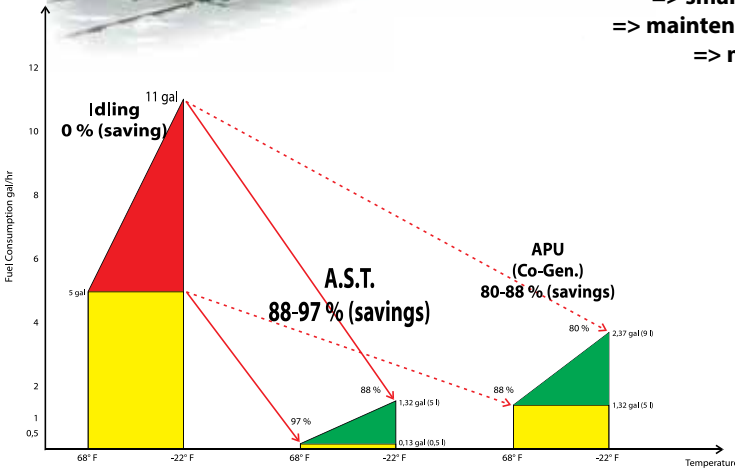


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2012 State of the Union Address

President, Ron Bartels

Monday Afternoon , Spetember 24, 2012

Good afternoon, ladies and gentlemen. Welcome to the 2012 session of the LMOA technical presentations and I want to thank you all for attending.

For the next few minutes I'll give you a snapshot of the year 2012 from an LMOA standpoint.

In the second week of May, we held our annual Joint Committees meeting in Overland Park, Kansas, at BNSF's training center. We had a good turnout of about 60 people, and we got a chance to preview and critique some of the presentations you have heard this morning or are about to hear this afternoon and tomorrow morning. Brad Queen, our first VP and also from BNSF, did a fabulous job of organizing the meeting and, Brad, I want to thank you for that and also your employer, BNSF, for hosting and sponsoring the event. After the meetings and presentations, we were given a tour of the training center. It is a very impressive facility and I can't think of a railroad trade that isn't taught there.

Sponsors are also an important part of this conference. It was made possible in part by: Loram Maintenance of Way, The Greenbrier Companies, Norfolk Southern Thoroughbred Mechanical Services, GATX Corporation, New York Air

Brake Corporation, and Sterling Rail. Specifically, our LMOA audio-visual requirements were sponsored by Graham-White. We all have these companies to thank for their generosity so I think they deserve a round of applause. Make sure you visit their exhibits, and all of the others, too, when you're not attending the presentations.

I'm going to go back to the joint committees meeting for a minute. There was a lot of technical talk but we also took the time to honor one of the LMOA's most valuable members. If you weren't at the meeting, you may be wondering "Who is this person" or "What did he or she do"? Those are good questions. You might be thinking that he gave inspirational technical presentations and wrote informative papers: No. Maybe he chaired a committee or two: No. He must have served as Regional Executive, Vice President or President of the LMOA. Guess what. No, again. So if he hasn't done any of those things, why am I even talking about him?

The person I'm talking about is Ron Pondel. Since Ron has been Secretary-Treasurer of the LMOA, (by the way, it has been almost 25 years, quite an accomplishment) in one way or another he has been

a part of every presentation and paper produced by the technical committees. He has guided every chairperson, Regional Executive, VP, and President through their LMOA careers to make everything go as smoothly as possible. He has done everything in his power to make every LMOA meeting and event a success and he never hesitates to help out when help is needed. I remember a few years ago at the annual conference at the Hilton, I was setting up with Dean Becker to demonstrate a high intensity headlight for my presentation and we needed the right background to illuminate. Ron saw what we were trying to do and in no time he had the Hilton staff hopping and bringing in different curtains on moveable racks to get just the right effect. This is just situation normal for Ron.

The inspiration for the Ron Pondel Lifetime Achievement Award came from our second VP, Dave Rutkowski. Thanks, Dave, for that brilliant idea. The award gives recognition to those individuals who have provided exemplary service to the LMOA. The Executive Committee felt that Ron Pondel truly exemplifies the values of the LMOA, and wanted to recognize his service by naming this award in his honor. The award will live on in Ron Pondel's name and only those people who show the same qualities and devotion to LMOA as Ron will have the honor of receiving the award. Congratulations, Ron.

We had another first for 2012: This year was the first full year of the newly branded Shop Safety, Processes, and Equipment committee. It used to be known as the Shop Equipment committee but last year the committee's focus was expanded to emphasize safety and include processes in its mandate. This change alone may not be worthy of an award but it is noteworthy. Committee chairman Bill Peterman actively marketed the broader mandate of the committee last year within the industry but did not get much reaction. He will be continuing his promotion of the committee at this conference so if you or someone you know wants to contribute to the committee, or just find out more about it, please talk to Bill. Also, make sure you are here tomorrow morning at 10:45 when Bill and the committee educate us about Shop Safety, Processes, and Equipment.

Some of you may recall at last year's Joint committees meeting at Union Pacific headquarters in Omaha, John Estes of UP appealed to the LMOA to address the unsatisfactory reliability of locomotives, especially when they are fresh "out of the box". The LMOA took this request very seriously and this past year, locomotive reliability has been a major focus within the LMOA. This afternoon and tomorrow morning, the New Technologies and Electrical committees will give three presentations dealing with reliability, both building it into locomotives and systems and improving it throughout

the life cycle. The Mechanical committee also has a written paper on the subject. You can find it in the 2012 LMOA Proceedings. A good number of the remaining presentations at this conference describe specific methods, tools, or components that will help improve a locomotive's reliability. Pay close attention to the presentations and ask questions if you want to know more. Our members will do what they can to help you.

If you ask me, they already have been helping. Just look at some encouraging reports from the North American railroad industry. Since the year 2002, Amtrak's ridership has increased by 44%. In the 2nd quarter of 2012, the majority of North American Class 1 freight railroads reported strong financial results and set a number of financial records. Many of them showed strong revenues. At the same time, costs, productivity, and operating ratios were mostly favorable. The LMOA can have a big impact on those indicators. Our activities help improve safety, reliability, productivity, and maintenance costs, and provide solutions to reduce the railroads' impact on the environment. Ridership and revenues are equally impacted by LMOA activities. Try attracting new customers or maintaining your customer base when trains don't reach their destination or are late due to unreliable locomotives. Judging by the number of railroad members who registered early for LMOA at this conference, the

railroads are realizing the value of participation in the LMOA and that helps ensure a strong future for the organization.

My year in this position is just about over and I would not have made it here on my own. I want to thank the three most important people in my life, my wife, Karen, and my two daughters, Kaitlin and Hannah for always being there for me. I also owe thanks to my employer, VIA Rail Canada, for supporting me and believing in the LMOA. And last but not least, I want to thank our three VP's, Brad Queen, Dave Rutkowski, and Bob Harvilla, our Secretary-Treasurer Ron Pondel, and all the members of the LMOA for being so dedicated and always helpful.

Thank you, and enjoy the rest of the conference.



LMOA Executive Board Meeting on Tuesday, September 25, 2012 at the Chicago Sheraton Hotel and Towers.

Acceptance speech

Brad Queen

Tuesday Morning, September 25, 2012

Before I begin, I would like to thank Ron Pondel for all his dedication and tremendous support to this organization.

I am extremely honored to have been selected as the next President of the LMOA for 2012-2013. Above all, I am grateful to all the members who have provided excellent mentorship and professional advice throughout the past 12 years of membership, which has brought me here today accepting the responsibilities and your trust as President for the LMOA. I began my railroad career in Lincoln NE at the Burlington Northern's Lincoln Diesel shop as an Electrician Apprentice about 18 years ago after serving in the US Navy. I got a chance to learn how to work on GP-9s, SW1500s, Dash 7s, and my favorite locomotive the SD40-2. Then, I saw the first SD70 Mac that came on property. I couldn't wait to go to that first electrical class at our TTC to learn how to work on one of those! In 2000, I was promoted to Mechanical Foreman at the BNSF Topeka System Maintenance Terminal or as it is more popularly known as our "Locomotive Back Shop". It was that year I was asked if I wanted to join the LMOA. Looking back at those five years in Topeka, I learned to work in every department there, got my degree at night school,

and wrote 3 papers for the LMOA's New Tech Committee. One other achievement in Topeka during my last year there was that we finalized production to begin rebuilding those SD70-Mac's AND we had an entire shop go injury free. Also during this time, I would volunteer during my off time and used LMOA to learn more about subjects like remote control locomotives, visiting other shops and industries to see their best practices, and helped identify improvements to equipment or processes.

In 2005 I went to Barstow California as a General Foreman and also served as Chairman of the LMOA's New Technologies Committee. I hosted quite a few LMOA committee meetings at this major locomotive facility which was exciting to brainstorm improvements or Best Practice ideas with our members on subjects such as engine change outs, the number of locomotives we service a day there, and the heat! I kept working with these remote control locomotives there in Barstow as well. I then went on to work as a Quality Manager and then our Mechanical Best Way Process Improvement Team.

At the end of 2011, I became a member of a new Remote Control Locomotive department at our Fort Worth headquarters. I truly believe

that the majority of my success has been from the network of contacts that I have made through the LMOA organization and by LMOA providing me the opportunity to share our research of the railroad industry to audiences such as everyone sitting here today at these technical proceedings.

Every time something new came along such as Gen Sets or something old such as fuel tank repairs that I needed to get a better understanding of, I used the LMOA as a tool to do the necessary in-depth research with suppliers or even other Railroads to write papers on these subjects. The results of this knowledge or experience have advanced me and my teams within the Railroad industry.

I would also like to tie LMOA together to what is taking place to our Railroad industry which is in the midst of colossal greatness. We are the movers! And it just isn't possible to keep adding more lanes on to our current highway systems. We also have a huge technological change with positive train control, live remote monitoring capabilities of our equipment, and electronic train inspections. In addition, we provide the greenest possible service that is a proven benefit to the air, ground, and noise that we need and have to take responsibility for. We are also moving forward every day towards the safest possible industry as a transportation service. Everything is safety, to how we do our work to how our suppliers deliver or make their products we use. We get it and we do it!

Yes, we are making history with our innovations and we are able to aggressively adapt like no other industry. So much so, that you can now go to school to become a "Railroader". This is why LMOA is so important as to not only provide excellent personal development; we are also the platform for our industry to uncover these technologies, services, and safety possibilities of our railroad industry.

Highlight of this year's papers are:

Diesel Material Control Committee

*Chairman Fred Miller, Relco
Locomotive*

1. Tracking Cores: Mike Kadar,
Union Pacific RR

2. Bar Coding Update-Ron
Delevan-Morgan AM&T/National

Diesel Mechanical Maintenance Committee

*Chairman Ian Bradbury, Peaker
Services*

1. Generator Alignment &
Changeout-Rich Aranda, Belt Rwy
and James Sherbrook, LocoDocs

2. Proper Torqueing Procedures
Update – Tim Standish, EMD

3. (Website) Finding an
EPA Certified Emissions Kit for
Locomotive Engine Overhaul-Ted
Stewart-Peaker Services.

4. Locomotive Idle Minimization
(Use of APU or AESS)-Bill Edwards,
MRL & Dave Rutkowski, Providence
& Worcester RR

(Failure Modes and Effects
Analysis paper by Tom Kennedy, UP
RR published in the LMOA book)

Fuel, Lubricants & Environmental Committee

Chairman Dwight Beebe, Temple Engineering

1. Gen-6 Locomotive Engine Oil Definition -- The Next Generation Loco Engines for Heavy Haul-George Lau, CN, Tom Gallagher, Chevron Oronite

2. Biodiesel Background for the RR Sector-Kyle Anderson & Richard Nelson, National Biodiesel Board

3. Incipient Engine Failure Detection Tool-Najeeb Kuzhiyil & Manoj Kumar, GE

4. Locomotive Durability Test Protocol for Alternate Fuels & Biodiesel (Suggested field test protocol to evaluate the impact of blended biodiesel) -Dennis McAndrew, Dennis W. McAndrew Inc.

New Technologies Committee

Chairman Jim Christoff, Morgan AM&T/National

1. Using the A3 Problem Solving Solution-Tad Volkmann, Union Pacific RR

2. Locomotive Repower with a High-Speed Engine & Reduction Gearbox-Bruce Wolff, MTU

3. A New EFI Tier 0+ Solution for EMD 645 Engines-Jeff Clapper, Wheeling & Lake Erie RR

4. Tractive Effort and Adhesion-A Study-Tom Mack, Motive Power & Equip Solutions

Congratulations to newly elected Chairman Tom Mack & also newly elected V-Chair & MVP Jeff Clapper, Wheeling & Lake Erie RR. Lastly, Tad Volkmann, Union Pacific RR as our Life Time MVP Achievement award.

Diesel Electrical Maintenance Committee

Chairman Mike Drylie, CSX Transportation

1. Extending Locomotive Maintenance to 184 days-Part II-Mike Drylie, CSX

2. Lifecycle Reliability Analysis of Locomotive Systems Design-Guest Speaker Scott Werner, Wabtec Motive Power

3. Design for Reliability- Locomotive Control Systems- Guest Speaker Jason Fox, Union Pacific RR

4. Three Stage Battery Charging for EMD Locomotives- Bud Wilds, BN

Shop Safety, Practices and Equipment Committee

Chairman Bill Peterman, Peterman Railway Technologies

1. Application of Machine Vision in the Railroad Industry-Trackside Systems for Measuring Condition of Many Freight Car Undercarriage Parts – Potential Use in Locomotive Applications-Sam Williams, Beena Vision Systems

2. Parts Washing by Proceco

3. Train Washing with Emphasis on Recycling Water

If you haven't notice, three of these authors or presenters are from the Union Pacific Railway. I wish to congratulate them for their dedication and professional railroad knowledge. There is an overwhelming amount of personal commitment for these papers as well as time practicing presentation skills which is just not easy for a lot of people. It is one thing to write some type of presentation to send out for everyone to simply read but to write a presentation and stand up in front of a large group to present it is not easy and takes courage. Also congratulations to the MVP recipients from the committees. Their managers will get a letter recognizing their special contributions to their respective committees along with a plaque presented to the recipient on behalf of the executive officers of LMOA.

There is also a large number of our Past Presidents who have returned back to committee work which shows the dedication within the ranks of LMOA. Please thank: Les White & Bob Reynolds – Electrical. Dennis Nott & Jack Kuhns – Mechanical. Bruce Kehe & Tad Volkmann – New Technologies. Mike Scaringe – Shop Safety Processes & Equipment. And of course Bob Runyon who stays active on the executive board.

I would like to now thank President Ron Bartels, Via Rail. Ron's dedication to this organization has carried it on for another year of success. I would also like to thank the guest speaker for the opening general session and for his support, Carl Ice the President & COO of BNSF

Railway. Also for the BNSF Technical Training Center in Overland Park KS for hosting the 2012 LMOA Joint Committee meeting in May.

I wish to thank the advertisers who make the printing of the LMOA book financially feasible and those who have committed to doing this for a long time. Thank you to the companies who supported/sponsored committee meetings during the year. Also a very special thanks to Graham White who generously contributed to RSI to help out with AV expenses for LMOA presentation. Lastly, thanks to the more than 100 vendors who are displaying this year. Well done to all!

I would encourage all railway executives, managers, shop personnel, and railroad suppliers to be supportive and inspire their companies to actively participate in the LMOA. In closing I would like to challenge everyone to communicate a few of LMOA's benefits to our professional associates.

- The ability to work with others to achieve a common goal
- Increase in the railroad industries' technical or educational knowledge
- Experience of speaking or presenting in front of a knowledgeable audience
- Ability to follow through on a deadline
- Expanded people skills

I look forward in seeing everyone here today and more again at our 2013 Convention in Indianapolis, Indiana September 29 - October 1.

Report on the Committee on Shop Safety, Processes and Equipment

Monday, September 30, 2013 at 9:30 A.M.



Chairman

Bill Peterman

Director–Rail Operations
B.P. Railway Services
Baie D’Urfe, Quebec

Vice Chairman

Tom Stefanski

President
Tom’s Locomotive and Cars
Plainfield, IL

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R. Covert	Product Manager Frt. Rail	Macton Corp.	Oxford, CT
C. Fette	President	TESCO	Erie, PA
M. Scaringe	Dir. Locomotives	Amtrak	Beech Grove, IN (Past President)

PERSONAL HISTORY

Bill Peterman

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

completing his time with the railway as Manager Facilities Engineer.

Currently, Bill is Director-Rail Operations of B.P. Railway Services, a company specializing in assisting with Rail Maintenance designs, equipment and processes, providing specialized rail maintenance services and acting as a liaison between railway and non-railway entities.

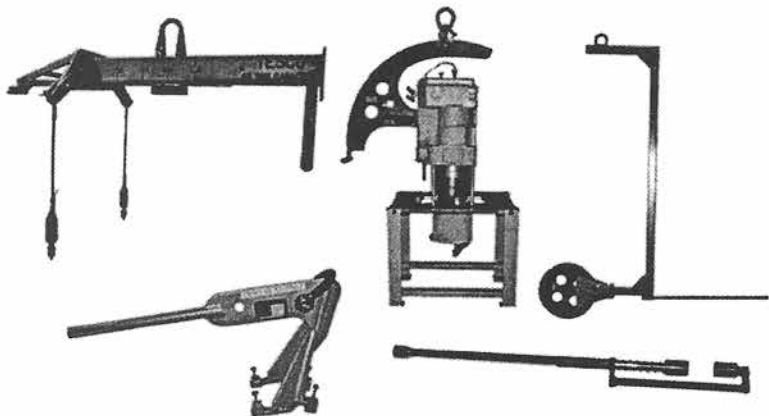
He has been Chairman of the Shop Safety, Processes and Equipment Committee for several years. Bill lives in Montreal and is married with 5 children and finally has 3 grandchildren.

The Shop Safety, Processes and Equipment Committee would like to extend their sincere gratitude to the Canadian Pacific Railway for hosting the committee meeting in Montreal, Quebec, Canada in November 2012.

The committee would also like to thank the BNSF for hosting their March 2013 meeting in San Bernardino, California and for sponsoring a luncheon.



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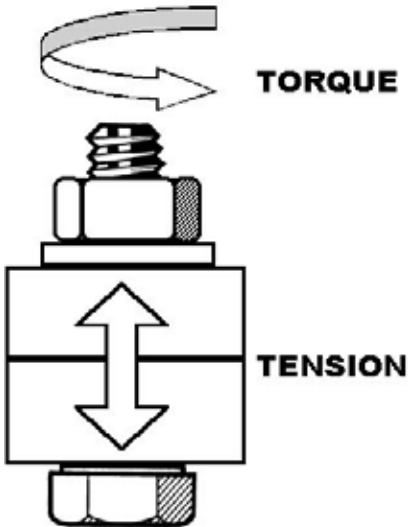
Bolt Torquing / Tensioning Manual Torque Wrenches and Adapters

Prepared by: John Fette, TESCO

Presented by: Chuck Bentler, Norfolk Southern

Overview

The function of a fastener such as a bolt is to hold or clamp two surfaces together. In order for the bolt to properly perform this function, the correct amount of torque needs to be applied to the bolt with properly lubricated and undamaged threads. This applied torque will cause the bolt to stretch and act as a spring to clamp and hold the joint together.



The amount of bolt tension or stretch is what determines a properly fastened joint. If the bolt is not stretched enough, the joint will be loose and could possibly lead to failure. Too

much stretch can weaken the bolt and also possibly lead to failure.

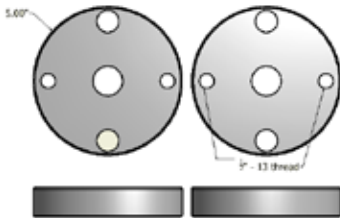
The relationship between torque and bolt tension can be influenced by several factors, these being: the type of lubricant used on the threads, the material from which the bolt and nut are made, the type of washers used, the class, finish, and condition of the threads.

To demonstrate these relationships, a study was performed to show how dramatically these factors influence the amount of clamping force on a joint.

Study Summary

This study was performed to calculate the amount of bolt stretch and clamping force that is generated by a fastener that is properly lubricated, has clean and undamaged threads, and where the installation is performed with a properly calibrated torque wrench. This clamping force will then be compared to the clamping force generated by the following installation conditions:

1. Installation with an improperly calibrated torque wrench
2. Installation with a non-lubricated fastener
3. Installation with damaged threads on fastener

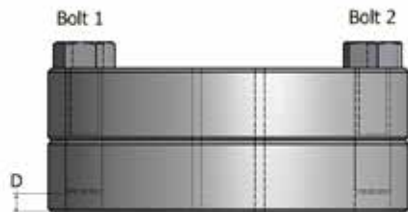
Fasteners Used for Study:**Test Plates**

Torque Wrench Used: 30-250 Ft-lb Micro-Adjustable Wrench with 1/2" square drive

Lubricant Used:
Molycote GN Metal Assembly Paste

Test #1 – Calibrated Torque Wrench/Clean and Lubricated Threads

Our Test #1 was set up to show how a properly assembled and torqued joint would behave. Thread gauges were used to check both the male threads on the bolt as well as the female threaded holes in the test plate. We verified the set points of the torque wrench using an electronic torque tester with an accuracy of +/- .5%. The bolts had their bottom surfaces ground flat, perpendicular to the bolt's axis. The bolt threads were properly lubricated and then used to attach the test plates together as shown.



The bolts were torqued to an initial torque of 10 Ft-lbs. At this point, the depth D was measured to provide a base point for the bolt length. The bolts were each then torqued to a final torque value of 65 Ft-lbs. The depth D was again measured for each bolt. The difference between the initial D and final D gave us the amount of bolt stretch. The results were as follows:

	Initial D	Final D	Stretch
Bolt 1	.238"	.233"	.005"
Bolt 2	.241"	.236"	.005"

Using the following equation for the bolt stretch, we can calculate the clamping force for each bolt:

$$\text{Stretch (S)} = \frac{FL}{AE}$$

- F = clamping force
- L = initial bolt length (1.725")
- A = cross sectional area of bolt (.1142 square inches)
- E = Modulus of Elasticity (30000000 psi)

Using the stretch value of .005", we can calculate for the clamping force F.

$$F = \frac{SAE}{L}$$

$$F = \frac{(.005")(0.1142 \text{ square inches})(30000000 \text{ psi})}{1.725"}$$

$$F = 9930 \text{ pounds per bolt}$$

With the clamping force now calculated based on the bolt stretch, we installed the test plate assembly into a hydraulic testing rack as shown below.



The test rack was designed so that it would attach to and hydraulically pull the plates apart. The purpose behind the test was to incrementally increase the amount of force used to pull on the plates up to the point where separation occurs between the plates. This would indicate the point at which the clamping force has been overcome and provides us with a way to verify what that clamping force actually is.

The test rack is equipped with a single acting hydraulic ram with an effective area of 11.05 square inches. The hydraulic pressure is indicated on a 10,000 psi gage which has been calibrated using a Fluke P-3116-3 Dead Weight Tester which has an accuracy of .015% of the reading.

The results for the pull test on our Test #1 assembly are as follows:

Force Applied (lbs)	Separation at Bolt #1	Separation at Bolt #2
13260	None	None
14365	None	None
15470	None	None
16575	None	None
17680	None	None
18785	None	None
19890	.001"	.001"

With separation occurring evenly at 19890 pounds, it translates into 9945 pounds of clamping force per bolt. This is within .2% of our calculated value based on the bolt stretch.

Test #1 Summary

The purpose of this first test was to provide us with a baseline to compare to in subsequent tests. We have shown that by using a properly calibrated torque wrench along with clean and lubricated threads, this fastener when torqued down to a value of 65 Ft-lbs will provide 9945 pounds of clamping force.

In this test, the theory has been validated in practice.

The following tests will show the impact that such things as torque wrench calibration, lubrication and thread condition can have on the clamping force.

Test #2 – Out of Calibration Wrench/Clean and Lubricated Threads

In this test, the condition of the threads and lubrication were the same as in Test #1. The only difference was that the set point of the wrench was dropped to 50 Ft-lbs. This was intended to simulate what could happen if a wrench is out of calibration. The bolts were torqued down and the test plate assembly was placed into the hydraulic testing rack. The results were as follows:

Force Applied (lbs)	Separation at Bolt #1	Separation at Bolt #2
8840	None	None
9945	None	None
11050	None	None
12155	None	None
13260	None	None
14365	None	None
14917	.001"	.001"

This shows us that a clamping force of only 7459 per bolt is generated versus the expected value of 9945.

In this test, theory is not supported by the practice.

Test #3 – Calibrated Wrench / Clean and Non-Lubricated Threads

In this test, a calibrated torque wrench was used, set and verified at 65 Ft-lbs. The threads on both the fastener and hole were clean, but no lubrication was used. The results of this test were as follows:

Force Applied (lbs)	Separation at Bolt #1	Separation at Bolt #2
5525	None	None
6630	None	None
7735	None	None
8840	None	None
9945	None	None
11050	.001"	.002"

The uneven amount of separation shows that the clamp forces generated by the bolts were not equal. The average force per bolt was 5525 pounds, well below our value of 9945 in Test #1. What this shows us is that with the bolts not being lubricated, a greater amount of the input torque is absorbed by the system friction, causing less to be applied to bolt stretch and clamping force.

In this test, theory is not supported by the practice.

**Test #4 – Calibrated Wrench/
Damaged and Non-Lubricated
Threads**

In this test, a calibrated torque wrench was used, set and verified at 65 Ft-lbs. The threads on both the fastener were damaged, and no lubrication was used. The results of this test were as follows:

Force Applied (lbs)	Separation at Bolt #1	Separation at Bolt #2
3315	None	None
4420	None	None
5525	None	None
6630	None	None
7735	None	None
8840	.001"	.002"

Again we see that there is an uneven amount of separation on the bolts. The average force per bolt is only 4420 lbs which is 56% lower than our clamp force in the initial test.

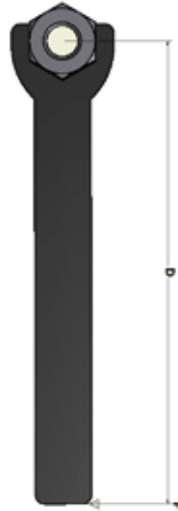
In this test, theory is not supported by the practice.

Test Conclusions

These tests show that there is more to torquing down a fastener than simply setting a torque wrench and installing the fastener. Factors such as wrench calibration, thread condition and thread lubrication have a significant impact on the final clamping force of that fastener. This clamping force being what holds the joint together and prevents potential failures at that joint.

Torque Definition, Formula, and Units

Torque is defined as a force which when applied tends to produce rotation. Its magnitude is a product of the force applied and distance.



In the case of this wrench above, a Force **F** applied at a Distance **D** from the center of the fastener as shown:

$$T \text{ (Torque)} = F \times D$$

Torque is expressed in the following common units of measurement

- in.lbs (Inch pounds)
- ft.lbs (Foot pounds)
- Nm (Newton meters)

Unit conversions are:

$$1 \text{ Foot Pound} = 12 \text{ Inch Pounds}$$

$$1 \text{ Inch Pound} = .11298 \text{ Newton Meters}$$

$$1 \text{ Foot Pound} = 1.356 \text{ Newton Meters}$$

Manual Torque Wrenches and Adapters

There are several different methods that can be used to tension a fastener. There are the methods that apply torque to the fastener itself either hydraulically, pneumatically, or mechanically. There are also methods that attach to and stretch the fastener to achieve the proper amount of clamping force.

Below will be detailed the most common fastener torquing method, the use of manual torque wrenches and adapters.

Micro- Adjustable Torque Wrenches

The Micro-Adjustable style torque wrenches have the ability to be adjusted to different torque values within the operating range of the wrench. They feature a micrometer style adjustment ring which can be turned and locked into place at the desired torque setting. These type of wrenches are often referred to as “click” style wrenches due to the fact that when the torque set point is reached, an audible “click” can be heard and also felt through the handle.

This style wrench is available in a fixed ratcheting head style:



Micro-Adjustable Torque Wrench
Fixed Ratcheting Head

It is also available as an interchangeable shank head style:



Micro-Adjustable Torque Wrench
Interchangeable Head

These wrenches have an accuracy of within $\pm 4\%$ clockwise and $\pm 6\%$ counterclockwise of any setting from 20% of full scale to full scale.



Shank Size	Diameter
J	.425"
Y	.560"
X	.735"

Pre-Set Torque Wrenches

Pre set torque wrenches are used in applications where one specific torque is required in a repetitive operation. These wrenches feature the same “click” style operation as the micro-adjustable wrenches. They also feature the interchangeable shank head style. These wrenches also have an accuracy of within $\pm 4\%$ clockwise and $\pm 6\%$ counterclockwise of any setting from 20% of full scale to full scale.

Adapter Use and Torque Calculations

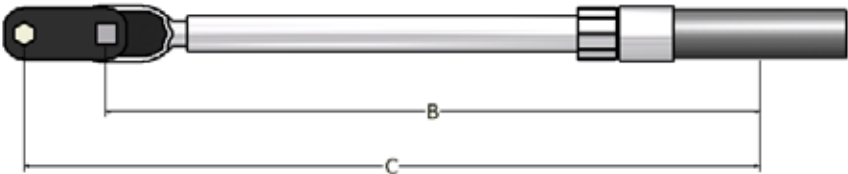
One aspect that is essential when using manual torque wrenches is to properly understand when torque calculations are needed in setting the wrench and how to make these calculations. Below are formulas that can be used for both the fixed ratcheting head style as well as interchangeable head style wrenches.

1. Fixed Ratcheting Head Style – Used with Socket



t (Torque Setting on Torque Wrench) = T (Torque on Fastener)
 No Calculations Required

2. Fixed Ratcheting Head Style – Used with Adapter



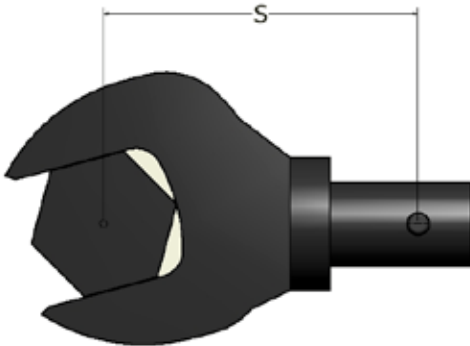
t = Torque Setting On Wrench
 T = Torque on Fastener

$$t = T \times \frac{B}{C}$$

3. Interchangeable Head Style – When Used With a Standard Length Adapter



t (Torque Setting on Torque Wrench) = T (Torque on Fastener)
No Calculations Required



Standard Adapter Length (S)
From Center of Fastener to
Center of Retaining Pin

J shank - 2.50"

Y shank - 3.00"

X shank - 4.50"

The above represents the current standard adapter lengths for the different shank sizes. Older wrenches may have different “click” arm calibration. It is always recommended to check torque wrench setting using a torque analyzer.

Torque Wrench Verification

When using torque wrenches, it is essential that their accuracy is checked on a regular basis. These testers can be used for periodic wrench calibration and also are helpful in checking accuracy of torque calculations when using adapters as described above.

This electronic tester can be used in conjunction with adapter sets that are available in ranges of both standard and metric sizes.



Tesco Torque Wrench Tester – T18961

This tester operates between 30.0 and 1500.0 Nm (22.0 to 1106.0 Ft-lbs) Guaranteed classification to BS7882:2008, Class 1 or better over the primary calibration range (20% to 100% of full scale), Class 1 equates to +/-0.5% of reading



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T57580*



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Mechanical Seven Safety Absolutes-BNSF Railway

*Prepared by:
Ron Hennessey-BNSF*

INTRODUCTION

On August 22, 2005, our Mechanical Team began a communication campaign called “Mechanical Seven Safety Absolutes”. These seven areas have the greatest potential for loss of life or severe, possibly career ending injuries. Through this campaign, we review the critical rules and policies associated with these topics.

Objectives of Safety Absolutes

1. Understand the significance of these critical tasks
2. Emphasize individual responsibility in eliminating at-risk behavior
3. Provide supervisors with the knowledge and tools to address specific at-risk behavior
4. Provide all Mechanical employees with the knowledge to identify and correct at-risk work behaviors

The Seven Safety Absolutes include:

- Blue Signal Protection
- Lockout/Tagout
- Jacking Equipment
- Vehicle Operations
- Fall Protection
- Crane Operations and Rigging
- Locomotive and Car Movement

Blue Signal Protection

Proper Blue Signal Protection must be in place prior to inspecting, testing, repairing, or servicing rolling equipment. Without proper protection, workers would be exposed to potential serious injury or death from moving equipment.



Lockout/Tagout (LOTO)

LOTO must be used whenever maintaining, repairing or servicing equipment or machinery that could unexpectedly start-up, energize, or release stored energy and the work being performed involves:

- Removing or bypassing guards or other safety devices
- Placing any part of your body in the point of operation
- Placing any part of your body in the danger zone during equipment cycle



Jacking Equipment

Proper procedures must be used whether jacking equipment on the road with portable jacks or in the shop with floor jacks. Never jack equipment if you're unsure it can be done safely. Take the time to evaluate the risk and involve your supervisor in determining the safe course of action



Vehicle Operations

Proper operation of all motor vehicles to include trucks, automobiles, utility vehicles, and ATVs is essential. All operators must have proper training and authorization prior to operating any type of vehicle.



Fall Protection

Injury from falls has the potential to be a life changing event and each year injuries from falls rank at or near the top in causes of fatalities at home and at work. They can be prevented by proper use of fall protection methods and by following BNSF Safety Rules and Policies



Crane Operations and Rigging

Cranes, boom-equipped vehicles, hoists, and rigging are used in compliance with manufacturer's instructions and BNSF Railway requirements.



Locomotive and Car Movement

Moving locomotives and cars in mechanical limits could easily be considered the most hazardous job we do. The size and weight of these huge pieces of equipment coupled with movement creates the potential for devastating consequences if not handled safely. Proper procedures must be used when moving or spotting cars and locomotives.



Communication

In addition to the briefing information, observation checklists were distributed to identify the key elements required to perform these activities safely. These checklists are utilized by all employees during Work Practice Observations to identify and correct any at-risk behavior that may lead to injury. Supervisors also focus their operations testing and employee safety contacts in these areas.

Conclusion

We are working to reduce at-risk behaviors by raising employees' awareness and understanding of the rules and policies that will assure their safety and that of their co-workers. We believe all accidents and injuries are preventable and that one day we will achieve an injury-free workplace. Knowledge and compliance with our Mechanical Safety Absolutes will help us in this effort.



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PROPER TRAIN WASHING- More Than Just Brushes and Nozzles

*Prepared by:
Al Gould and Tracy Briggs, Interclean Equipment, Inc.*

When selecting the proper train wash there are a number of considerations to take into account:

- Site Conditions (Figure 1)
- Train Car Style (Figures 2 and 3) – Overhead Catenary and Third Rail
- Number of Vehicles
- Frequency of Wash (Figure 4)
- Water Quality
- Regulations



Figure 1



Figure 2



Figure 3



Figure 4

There are many solutions:

- Chemical – Soap (Figure 5) – You need to understand the details of each problem or application and then design the best wash solution. Figure 6 shows a brushed aluminum train car with iron oxide staining and figure 7 shows the train car after it was cleaned with the correct chemistry. Typically a train wash will use two chemicals (acid and alkaline)-see figure 8.



Figure 5



Figure 6



Figure 7



Figure 8

- Friction and/or High Pressure (Touchless and Hybrid) –It is sometimes almost impossible to clean with brushes (friction). In these situations, touchless cleaning is the only alternative (Figure 9). Figures 10 and 11 show a train wash system (hybrid cleaning) using touchless cleaning for the front and rear of the train car and sprays from the top instead of the sides. The sides are still cleaned with brushes. This system

works well with OCS and third rail passenger train cars. Some of the advantages of Hybrid Cleaning (Figure 12) are that the brushes rotate, but do not move into the path of the train therefore preventing damage to the train. Also, the wash equipment requires much less maintenance and allows for different types of trains to be washed on the same line without modifying the design.



Figure 9

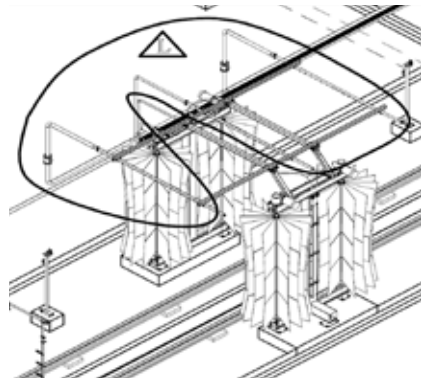


Figure 10



Figure 11



Figure 12

- Reclamation System-

The water reclaim system is made up of:

1. Settling Pit
2. Filtration
3. Separation
4. Circulation
5. Aeration
6. PH Neutralization

Many new train wash systems that are designed are incorporating settling systems for the wastewater collection regardless if the systems use fresh or recycled water. In some cases where the regulatory rules are already very strict, wash manufacturers are partnering with companies to provide treatment systems specifically designed to address the oils,

suspended solids and heavy metals in the waste water stream. With settling pits present, treatment systems can very easily be added to the system at a later time (Figure 13 and 14).

The cyclone separator and 550-gallon tank cyclone (Figure 15) are designed to separate dirt on continuous basis and flush separated dirt from their bottom drainage ports. All separated dirt with aerated water is constantly being sent to the dirty end of the settling pit to concentrate the solids at a single point in the treatment system. This style of recycling tanks rarely will need to have the accumulated dirt build up flushed out. The settling pit is the only component that needs to be cleaned out on a regular basis.



Figure 13



Figure 14



Figure 15

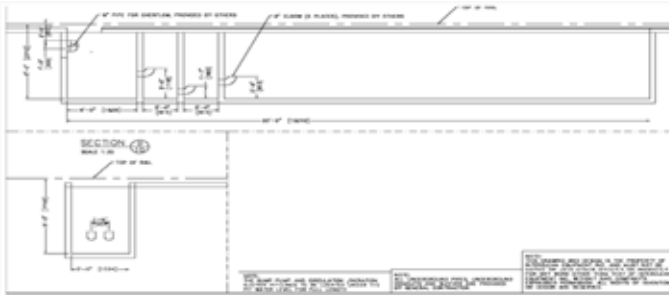


Figure 16

Odors:

The constant exchange of water between the clean end and the dirty end of the pit keeps aerated water always moving throughout the system. This guarantees that the captured water in the reclamation system does not develop objectionable odors usually associated with recycling systems.

The odors within recycled water are caused by a lack of oxygen and the bacteria going anaerobic. The circulation pump keeps the discharge from the wash system constantly flowing, oxygenating the re-cycled wash water.

Recycling systems also have the ability to add enzymes, bacteria and nutrients to the recycled water. This Enhanced Biological Water Treatment System has proven to greatly reduce

oils, greases, and other organic waste loading in the recycled water. This procedure is the same as many municipal wastewater treatment plants utilize. It also addresses a major issue in meeting regulations for discharge to sanitary sewer.

The settling pit (figure 16) is designed for passive settling and minimum maintenance. It has an automatic filter backwash, an oil-water separator and an automatic level sensor and adjustment feature.

After the reclaimed water passes through the setting pit, it is filtered through an InterScreen and then processed through two cyclonic separators for additional solids removal. A section of an InterScreen filter is displayed in figure 17.



Figure 17

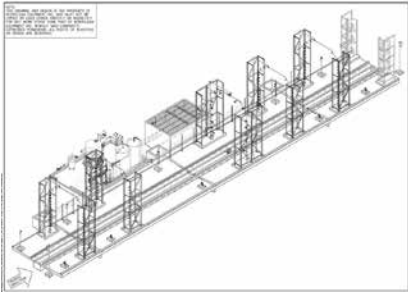


Figure 21

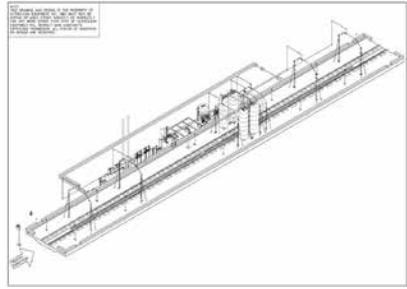


Figure 22

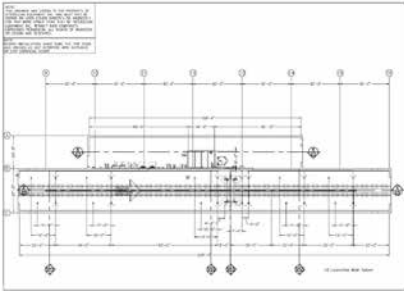


Figure 23

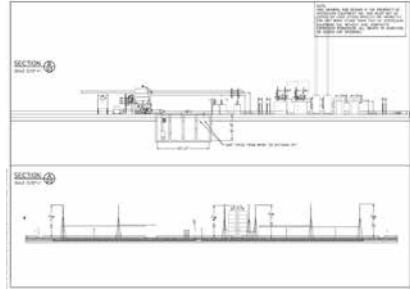


Figure 24

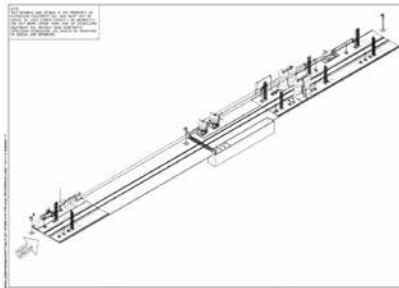
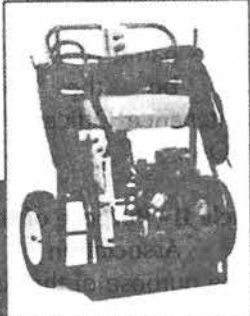
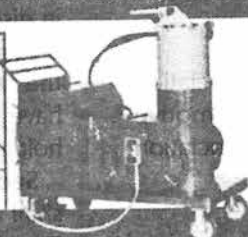


Figure 25

T

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Report on the Committee on Diesel Material Control

Monday, September 30, 2013 at 10:45 A.M.



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VP Sales
Chromium Corp
Medina, OH

Vice Chairman

Michael Hartung

Senior General Foreman-Distribution Center
Norfolk Southern Corp
Roanoke, VA

Committee Members

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R. Delevan	Mgr-Transportation Products	Morgan Advanced Materials	Dallas, PA
P. Foster	President	PowerRail Distribution	Duryea, PA
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B. Marty	Marketing Director	Metro East Industries	E. St. Louis, IL
M. Zerafa	Corporate Director-Purchasing	National Railway Equipment	Dixmoor, IL

Note: Michael Hartung has replaced Fred Miller as Chairman of the Material Control Committee.

2nd VP Bob Harvilla and Regional Executive Ron Sulewski actively participate on this committee.

PERSONAL HISTORY

Fred Miller

Fred Miller began his railroad career at Teledyne Metal Finishers in 1969. He continued his career at Chromium Corporation, Durox and RELCO. After a very brief retirement Fred rejoined Chromium Corporation as VP Sales. His responsibilities include sales to all the North American Railroads. He has an office at Chromium's facility in Cleveland, Ohio along with his home office in Medina, Ohio. Fred and his wife Marsha combined families about 13 years ago and have 7 children. Their 9 grandchildren keep them busy and young at heart.

The Diesel Material Control Committee would like to thank David Bird and the Kansas City Southern Rwy for hosting a meeting in Shreveport, LA on February 11-12, 2013.

The Committee would also like to extend their gratitude to the Norfolk Southern for hosting a presentation at the Southern Southwestern Rwy Club in Altoona, PA on June 20-22,2013.

The Committee also conducted a conference call on March 8, 2013.

Recycling of Materials

Prepared by:

Mike Hartung, Norfolk Southern

FACTS

The recycling industry employs more than 130,000 people in the U.S. and generates more than \$77 Billion in sales each year. Recycled materials account for more than \$30 Billion in export sales annually, with most of the transportation to ports provided by Rail in containerized units. Recycling saves about 500 M tons of CO₂ gas annually. One auto saves 502 gallons of gas and 8,811 lbs of CO₂. Four tires save 18 gallons of gas and 323 lbs of CO₂.

More than 60% of iron and steel made in the U.S. is produced with recycled metals-much of it hauled by Railroads to the refiners. Recycling one ton of aluminum cans conserves 36 barrels of oils. In 2010, the U.S. recovered 51.5 million tons of paper, which was 64% of paper consumed-334 lbs of paper per person in the U.S. Recycled scrap copper is utilized to produce 50% of all copper produced in the US each year.

BENEFITS

- Prevents emissions of air and water pollutants
- Reduces greenhouse gas emissions
- Saves energy
- Supplies valuable materials to the industry
- Stimulates the development of greener technologies
- Conserves resources for our children's future
- Cost control

The benefits add up

- 132 million metric tons of scrap material processed every year
- 74 million tons of iron and steel
- 47 million tons of paper
- 4.6 million tons of aluminum
- 3.5 million tons of electronics
- 1.8 million tons of copper
- 1.2 million tons of lead

Railroad Waste Streams

- Batteries
- Cross Ties
- Electronic equipment
- Fluorescent bulbs/lamps
- Plastics
- Steel
- Oils
- Copper
- Wood pallets
- Paper
- Cardboard
- Aluminum
- Locomotives/Cars
- Locomotive/Car Parts

Wood Pallet Recycling

Contributors; Linda Szilagyi (CSX) and Fred Miller (Chromium Corp)

Wood Pallet Recycling

Pallets accumulate around yards from material shipments. They occupy valuable real estate space and are a safety hazard.

Auger Technology – A Solution to Bulk Waste Handling (Figures 1&2)

Advantages of Auger Technology for recycling applications are:

- Reduces volume for transportation efficiency
- Reduces environmental impact
- Reduces labor times
- Increases safety at the site

Pallet Shredder Benefits

- Auger screw not effected by metal (nails and tie plates)
- Reduces the number of hauls up to 75% by compacting eight times more material into standard 40 yard containers
- Shredded wood recycled as boiler fuel or mulch

Paper and Cardboard Recycling (Figure 3)

- Office paper products including copy paper, newspaper, envelopes, cardboard, and magazines are recycled
- CSX utilizes blue bins called “slim jims” with blue tops and are placed in various locations for collection
- CSX also utilizes small desk side bins for recycling in office areas
- Auger shredders can also be used for cardboard

Recycling Copper in the Rebuild Process

Contributor: Ron Sulewski (Rail Products International)

Copper Recycling

Recycling is the basis of electrical rotating rebuild business. Almost 100% reuse of UTEX core exchange. Regularly see electrical components originally built new 20-40 years ago – recycling at its best.

Process Initiation

Most recycling programs start with partnering with processors, converters and mill operators.

RPI’s process is as follows: *(Figures 4&5)*

Collect and separate “spent” copper from motors, generators, armatures and coils. The “spent copper: is then sent to a converter-processor to chop and separate number one scrap from number two scrap copper. After all the insulation is removed, the material is chopped, shredded or mechanically processed for the next stage.

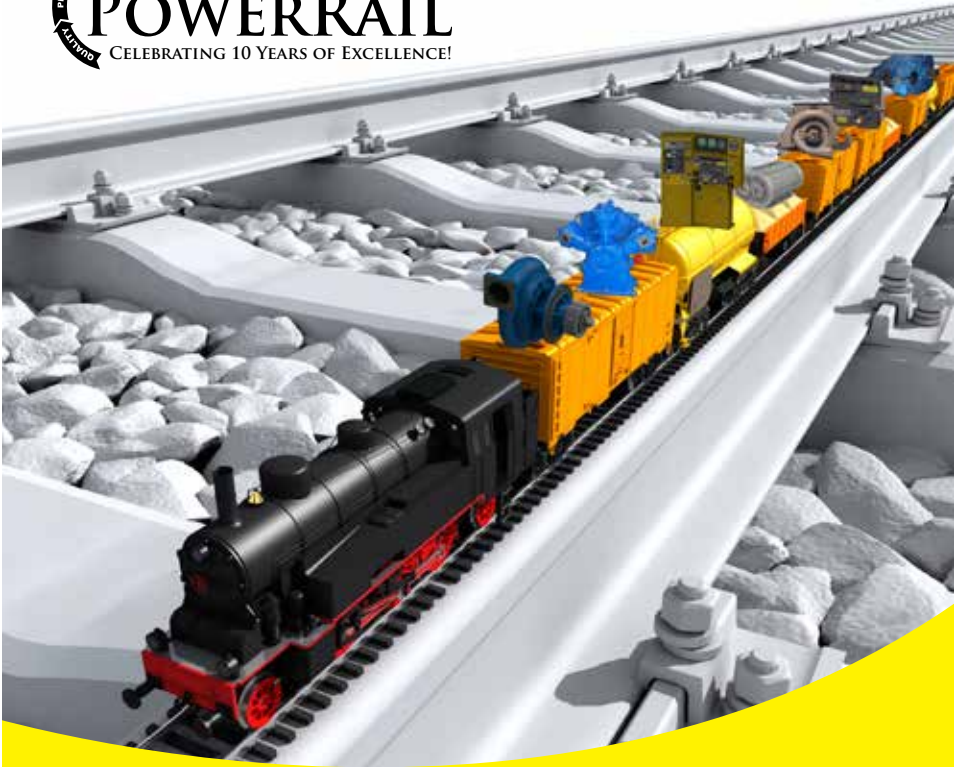
Material is then melted which further refines base material. The “melt” is then classified and blended with new base metal (if required) in order to meet acceptable metallurgy. This material then becomes cathode billets. *(Figure 6)* The billets are then converted at the mill using a continual cast process into copper rod. The rod is then processed in one of two wire mills into usable wire of various sizes for multiple Railroad products. *(Figure 7)*

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Other Cost Benefits

This recycle process enables companies to stock a large inventory pool of usable copper for numerous products. RPI does not buy finished wire products because of the volatile price based on market conditions. Cost is controlled by managing the pool volumes based on market prices (BUY low-SELL high).

Cost Control

The only actual cost experienced is the processing fees which are fairly stable. Number two copper is not recycled as this contaminates the melt, which requires new material to be added. Number two copper (very small amounts) is sold to offset the processing and transportation costs.

Filter Crushing/Recycling

(Figures 8 & 9)

*Contributor: Bob Harvilla
(PowerRail Distribution)*

Recycling Locomotive Filters/Lube Oil

Filters can be crushed to:

- Reduce waste that has to be handled
- Recycle lube oil
 - Sell lube oil to reclaimers
 - Utilize lube oil for heating

Drained 36" oil filter can be crushed to 6" and will yield ¾ gallon of recyclable lube oil. This reduces waste management and maximizes lube oil recycling benefits.

Use Oil Recycling

*Contributors: Eric Fonville (NS) and
Mike Hartung (NS)*

Sources:

- Locomotives and waste water
- Separator
- Operations

Two Methods:

- Sold to vendor or
- Used for heating

WWTP Captured Oil

- High water content
- Sold to vendor for recycling
- Belt skimmer project to reduce water content and improve oil quality

On-Site Disposal (Figure 10)

- The most efficient means of recycling
- No off-site transportation costs
- Low maintenance costs
- Can easily be located in worker areas

Enola Locomotive Shop

Estimated annual heating fuel consumption is 75K gallons. The estimated annual used oil generation is 100K gallons. Equipment has been installed in three buildings as a pilot program. Payback period analysis shows ROI <two heating seasons



(Figure 1)



(Figure 2)



(Figure 3)



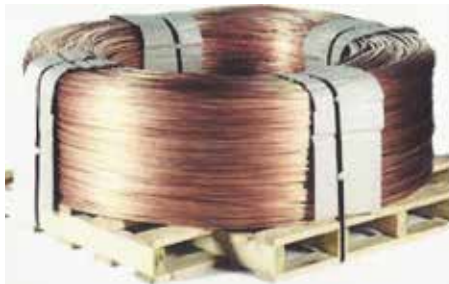
(Figure 4)



(Figure 5)



(Figure 6)



(Figure 7)



(Figure 8)



(Figure 9)



(Figure 10)



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Material Solutions for Implementing PTC

Prepared by:

Eric Armstrong, Miller Ingenuity and Brian Marty, Metro East Inc

Positive train control (PTC) is a system of functional requirements for monitoring and controlling train movements to provide increased safety. Additional benefits can include increased equipment utilization, better personnel utilization, and fuel management platforms. The rail safety improvement act was signed into law on October 16, 2008 setting a deadline of December 15, 2015, for implementation of positive train control (PTC) technology across most of the U.S. rail network. This paper addresses the opportunities to improve the ordering and handling of the material prior to installation on locomotives.

Constant Changes to Material Needs

The biggest overall challenge described by the various railroads that participated in this paper were the huge variety of locomotive applications and the ongoing changes in the regulations and materials available. One railroad described their locomotive fleet as a, “bunch of snowflakes,” giving a feel for the magnitude of the challenge relative to the number of kits needed to address each fleet. Each railroad also has specific requirements that vary based on install process, installers and

component suppliers. Add to that as late as December 2012 the regulations are still changing aggravates the problem even more.

Railroads are addressing these issues coupled with the impending deadlines with a couple of different approaches. First is to provision locomotives with the basic wiring, antenna farms and bracketing in anticipation of a final push before the implementation deadline. The plan would be to install the final components and test the units with final versions of software in the months prior to the deadline. Another railroad is taking the approach of outfitting the locomotives in their entirety to validate functionality as soon as possible. This approach assumes the basic hardware will remain the same and the only major changes to the system will be software related. This approach has already proven less than perfect, as the new requirements are changing cabinet requirements for all installations, e.g. locking cabinets for verification of equipment integrity.

All of these factors (and MANY more) have made material ordering, handling and installation frustrating for the railroads as well as the supply community. While many of the parts themselves are completely new to the

industry, all of the part numbers being created are new. Standardization of process at least within the large railroads is the clear recommendation however with changes still coming in it will not resolve the problem, only manage it better.

To Kit or not to Kit?

The question of kitting the various parts leads to the same challenges normally found in the use of kits. A major issue with this particular project is that with the kits in the field so far the persistent changes have caused a lot of material to not be used on installation and replaced with other materials. This means going back in to the kits in the warehouse and removing/replacing components before they are delivered to the shop for installation. Alternatively having the shop replace the material in the kit and return the excess to the supply department is an option. Disposition of the excess and unused materials has been a problem as they tend toward wiring harnesses and various parts that have no application in other areas for the railroads or the suppliers.

Pros and Cons of kitting for the PTC project:

Pro

- Easier to control, less part numbers, standardization
- Better part management of offsite installations
- Parts coming from multiple suppliers,... coordination is simpler if centralized

- Installers become more proficient with consistent material packaging, thus eliminating waste and redundant work

Con

- Various applications creating specific part numbers that may not be used very often
- Not everything in the kits is being used sending the parts back to stock or paying a restocking fee to suppliers
- Not all parts can be kitted because they are not used in all applications

Storage

Most of the railroads have been busy over the past few years utilizing lean management processes, and operations for efficiency improvements. A major improvement has been a reduction in space needed in warehouse operations. Unfortunately the rapid onset of the PTC program and oncoming deadlines have required the railroads to tactically respond to an increased need for space to store these products. The sheer scope of this implementation project is daunting and most of the planning has been, “on the fly.”

In the changing landscape lead times and ramp up time are inconsistent at best and require more material on hand than would be normal for projects this large. Aggravating the limited storage space issues even more is that many of the programs are lagging behind schedule leaving more material in supply operations awaiting application.

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The key for resolving many of these issues has been to determine which materials can be stored inside versus which can be left in the weather. The antenna farms have had good success stored outside and in their original crating can be stacked. A lot of the material in kits need to stay dry but can be stored outside if left in original packaging and covered. Small parts will need to go into normal inventory in the warehouse. Excess materials will need to remain indoors until final disposition is determined.

Budget Challenges

Excess materials become problematic when the budget is factored into the equations. Many of the items are on the capital budget and do not effect the inventory cost the same as expense items. Taking them out of inventory, removing them from kits, holding on to them or scrapping them all present problems when balancing the inventory. All railroads have this challenge and need to work out a process with their finance department for each of the scenarios.

When working with some of the class one railroads, smaller railroads and installation contractors need to ask about discounts available based on contract pricing for materials at their class one partners.

Other Issues

There are a number of miscellaneous concerns expressed in discussions regarding PTC implementation. Notably the magnitude of the project initially put huge demands on manpower for entering part numbers, setting up processes and general planning. Most of the start up issues have been tackled but supply operations is still tasked on a daily basis with increased numbers of transactions, part number management, inventory challenges, etc. all in the face of limited human resources dedicated to PTC implementation. Some railroads are beginning to see that installation and maintenance of PTC is going to require long-term human assets to support the project in an on-going basis.

As 2015 nears many of the units being provisioned now will create a big demand for equipment and outfitting. Planning now and communicating your plan to your supplier or for supplier to communicate to the customer base will help to ease the stress for everyone as we move for the final date for going live with PTC.

Report on the Committee on Diesel Mechanical Maintenance

September 30, 2013 at 1:30 P.M.



Chairman

Ian Bradbury

President & CEO
Peaker Services, Inc.
Brighton, MI

Vice Chairman

Tom Kennedy

Mgr - Mechanical Engineering
Union Pacific RR
Omaha, NE

Committee Members

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S. Bumra	Asst. Supt.	Amtrak	Chicago, IL
D. Cannon	Mgr-Mech. Locomotive Maint	BNSF Rwy	Fort Worth, TX
T. Casper	VP-Sales & Marketing	Hadady Corp	South Holland, IL
S. Cronin	Fleet Engineer-Diesel	Amtrak	Chicago, IL
M. Duve	Mech. Engineer-Loco. Design	Norfolk Southern Corp	Atlanta, GA
B. Edwards	Mech. Foreman	Montana Rail Link	Livingston, MT
T. Frederick	Dir-Engine & Emissions Syst	CSX Transportation	Huntington, WV
D. Freestone	Mgr-Loco. Opns	Alaska RR	Anchorage, Alaska
J. Hedrick	Principal Engineer	Southwest Research Institute	San Antonio, TX
D. Nott	Sole Member	Northwestern Consulting	Boise, ID
<i>(Past President)</i>			
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C. Shepherd	CMO	Arkansas & Missouri RR	Springdale, AR
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B. Singleton	VP-Sales	Transpar Corp	Niskayuna, NY
T. Standish	Quality Manager	Electro Motive Diesel	LaGrange, IL
T. Stewart	Engine Engineering Mgr	Peaker Services, Inc	Brighton, MI
G. Sumpter	Sales Rep	Casey & Associates	Ponte Vedra, FL
G. Wilson	Senior Acct Manager	Graham White Mfg	Salem VA
R. Wullschleger	CMO	New York & Atlantic Rwy	Glendale, NY

PERSONAL HISTORY

Ian Bradbury

Ian was born in Sheffield, England and obtained a B.Sc. in Mathematics from UEA and a Ph.D. in Statistics from the University of Birmingham, England before coming to the U.S. He spent 4 years teaching statistics at UT Dallas and Oakland University, Michigan, and 7 years leading GM Powertrain's engine design quality effort before joining Peaker Services (PSI) as President in 1997. Ian acted as trustee for the first leveraged ESOP transaction in 2000 and PSI is now a 100% employee owned company. PSI's historical core for over 40 years has been service and upgrade of EMD engines and controls in locomotive, marine and power generation. Since joining PSI, Ian

had led the effort to diversify the company into controls for other diesel, natural and bio-gas engines, steam and gas turbines. He obtained an MBA from the University of Michigan in 2003. Ian is a member of ASME and serves on the W. Edwards Deming Institute advisory board.

Ian and his wife of 22 years, Kathy, are both keen mountain bikers and craft beer consumers. Kathy teaches yoga and 'enhance fitness' as well as smoking a mean brisket. They have two sons - James (21) and George (19). James plans to pursue a career in automotive journalism, and George, in illustration and graphic design.

The Diesel Mechanical Maintenance Committee would like to thank MTU for hosting our committee meeting in Aiken, South Carolina on March 14, 2013 and for the tour of their engine plant in Aiken. Special thanks to Joerge Klisch, Operations Mgr and Jens Baumeister, Plant Manager. Thank you to Knoxville Locomotive Works for hosting dinner for the committee on the evening of March 13th and for having their MTU powered locomotive on display at the siding in Aiken.

The committee would also like to thank S. Bumra and Amtrak for setting up a conference call for the committee on December 6, 2012 and previous conference calls.

Pacific Harbor Line Tier 3+ and Tier 4 Re-Powered Locomotive Emissions After-treatment Experience

Prepared by:

Dennis Nott, Northwest Consulting

James O'Kelley, Pacific Harbor Line RR

Robert Wullschleger, New York & Atlantic RR

Introduction:

Pacific Harbor Line (PHL), an Anacostia Company, is a short line railroad that operates the switching services for the Ports of Los Angeles and Long Beach handling approximately 10% of all the intermodal containers that arrive or leave the United States.

The current locomotive fleet replaces EMD two-cycled locomotives that were up to 40 years old. Today PHL operates and maintains 23 of the most modern and emissions friendly locomotives of any short line railroad in North America:

- 4 each 3GS21B - 2,100 HP 4-axle EPA Tier 3 Gen Set Locomotives – National Railway Equipment
- 2 each 3GS21C – 2,100 HP 6-axle EPA Tier 3 Gen Set Locomotives – National Railway Equipment
- 2 each MP20B-3PR – 1,950 HP 4-axle EPA Tier 3+ Locomotives – Progress Rail Services
- 14 each MP20C-3PR – 1,950 HP 6-axle EPA Tier 3+ Locomotives – Progress Rail Services
- 1 each PR30C – 2,800 HP 6-axle EPA Tier 4 Locomotive – Progress Rail Services

The purpose of this paper is to discuss the seventeen (17) locomotives delivered by Progress Rail Services that are equipped with after-treatment systems.

All seventeen (17) locomotives were delivered as certified EPA Tier 2 locomotives. The two PR20B, fourteen PR20C and one PR30C are all re-powered locomotives equipped with single engine prime movers and after-treatment equipment to meet their respective funded emissions levels which are more stringent than the as delivered EPA Tier 2 requirements.

- The MP20B-3PR and MP20C-3PR locomotives, with their emissions equipment, are required by funding to meet EPA Tier 3 emissions standards with the exception of PM, which must not exceed 0.36 grams per brake horsepower-hour (g/bhp-hr), for their useful life.
- The PR30C locomotive with its emissions equipment is required by funding to meet EPA Tier 3 emissions standards for its useful life but

was delivered, and operates, as an EPA Tier 4 locomotive.

Each locomotive is equipped with Automatic Engine Start Stop (AESS) and operates an average of 8.8 hours per day (3,225 hours per year) with the following average duty cycle:

Idle: 63.51%
 N1: 9.78%
 N2: 7.28%
 N3: 5.36%
 N4: 4.91%
 N5: 3.53%
 N6: 2.42%
 N7: 1.23%
 N8: 1.99%

In 2006 the old EMD fleet produced an estimated average of 8.03 tons of NO_x and 0.39 tons of PM per unit per year. By contrast, the MP20B-3PR and MP20C-3PR produce an estimated average of 4.96 tons of NO_x and 0.036 tons of PM per unit per year. This is an estimated reduction of 38% in NO_x and a 90% reduction in PM per locomotive.

The PR30C produces an estimated

1.66 tons of NO_x and 0.038 tons of PM per year. Compared with the 2006 EMD fleet this is a reduction of 79% NO_x and a reduction 90% in PM.

Because of increased business since 2006, PHL is now running a combined fleet of 23 locomotives versus the 18 older EMD locomotives that were in service in 2006. Even with the increase of five locomotives, the overall estimated annual emissions reductions have been significant; a 27% reduction in NO_x and a 79% reduction in PM.

Description of MP20B-3PR and MP20C-3PR Locomotives:

The MP20B-3PR locomotives were repowered utilizing one EMD GP38 and one GP40 locomotive core. The MP20C-3PR locomotives are a mixture of EMD SD40 and SD45 core locomotives. With the exception of the number of axles, the 14 MP20C-3PR and the 2 MP20B-3PR locomotives are practically identical with respect to the prime movers and the emissions after-treatment equipment.



Figure 1: MP20B-3PR - PHL 20



Figure 2: MP20C-3PR – PHL 65

All 16 of the locomotives are equipped with a single Caterpillar 3512C HD engine at 2,100 brake horsepower coupled to the existing Kato AA27918000 main alternator running at a maximum of 1,800 RPM. The Caterpillar 3512C HD engine, at the time of installation, was EPA Tier 2 compliant without the after-treatment equipment. The engine and the Kato alternator, as well as a standard EMD 18 Kw auxiliary generator driven off the engine Power take-off, are mounted on a skid that was designed by Caterpillar. The skid is isolated from the locomotive frame.

The after-treatment on the locomotives is a single passive Diesel Particulate Filter (DPF) as manufactured by Hug Engineering of Switzerland. Caterpillar and Hug jointly developed the DPF based on operating experience in Europe of

similar engines in a railroad operating environment.

Both the engine and the after-treatment system can accommodate ULSF fuel with up to 5% biodiesel. PHL currently burns ULSF 2% biodiesel. The 2% biodiesel is used to provide increased lubrication for the fuel injectors.

The DPF is an 80.7" long by 55.8" wide by 28.7" high stainless steel box containing multiple proprietary ceramic substrates that remove the particulates from the exhaust. The box has one clean-out port in the front side and two exhaust stacks on the top near the rear. The containment box and ceramic substrates weigh approximately 2,500 lbs.

The locomotives are not equipped with dynamic brakes so the logical positioning of the DPF was above the engine. Since the DPF framework was to be attached to the locomotive frame



Figure 3: Front of DPF – Note Exhaust intake in Middle, Clean Out on Right Side and Exhaust Out at the Rear

and the engine is mounted on a skid that allows movement, the positioning and strength (resistance to movement) of the DPF framework was critical to assure that there would be minimal movement between the engine exhaust and the DPF. The DPF is supported by a framework of 4" X4" X 0.25" steel tubing with four vertical members fastened to the locomotive frame and four angled braces (two at each end) that are also fastened to the frame. The DPF support framework was designed to AAR S-580 standards and can withstand forces of 5.0 G's longitudinally, 1.5 G's laterally and 2.0 G's vertically. The DPF is bolted to the support framework. The DPF framework was also designed to maximize access to the engine for maintenance purposes.



Figure 4: Engine and DPF Support in Car Body



Figure 5: DPF Support Frame – Note; End Bracing for Structure Not in Place

As mentioned, the DPF has a clean-out access in the front to periodically remove any ash build-up because of operation. To access this clean-out access a side access door was placed on the left side of the locomotive directly behind the inertial filter hatch.



Figure 6: DPF Clean-out Access – Exhaust Connection to DPF Not Installed

In addition to the clean out door the area for maintenance of the DPF the car body hood above the DPF was made into a hatch so that the entire DPF can be removed at the time the ceramic substrates require to be removed for cleaning.



Figure 7: Installing DPF with Top Car Body Hatch Removed

Prior to awarding the contract to Progress Rail Services to install the Caterpillar engines and the Hug DPF, PHL voiced concerns with 1) engine torsional vibration damage to the engine/main alternator coupling because of cylinder miss-fire and 2)

the use of a passive DPF that could “plug” with soot causing excessive backpressure on the engine if the PHL duty cycle was not high enough to allow enough exhaust heat to clean and regenerate the ceramic substrates.

The Caterpillar answer to the engine/main alternator issue was to: 1) perform torsional vibration testing of the Caterpillar designed engine/main alternator coupling to assure the coupling was robust and 2) add temperature sensors to the cylinder heads to determine “cold” cylinders that could cause engine miss-fire and torsional vibration issues with the engine/main alternator coupling. Torsional vibration testing by Caterpillar proved that the engine/main alternator coupling was adequately designed. Caterpillar worked with Q-tron to feed information to the locomotive cab QES screen should the cylinder temperature in a cylinder drop below a predetermined temperature warning the crew of a potential vibration problem due to a cylinder miss-fire.

Regarding the backpressure issue with the DPF, Caterpillar agreed to: 1) test the system and determine at what exhaust temperature the DPF would regenerate, 2) make the turbocharger exhaust temperatures that were being measured by the Caterpillar engine system available on the Q-tron control system and 3) install backpressure monitoring on the DPF that would report back through the Q-tron control system. Testing by Caterpillar determined that the exhaust temperature at notch 3 unloaded

was sufficient to regenerate the DPF ceramic substrates. Turbocharger exhaust temperature monitoring and DPF backpressure monitoring were also successfully integrated into the Q-tron control system. When the backpressure sensor reaches 6.7 kPa the QES system will place the message “Service DPF Soon” at the bottom of every screen choice of the QES screen. If the backpressure reaches 8.0 kPa the QES system will shut down the engine. The backpressure monitoring system fault display is a “Latching Fault” that requires resetting a relay to eliminate the fault message.

A benefit to the DPF with the turbocharger exhaust monitoring and the cylinder temperature was also

realized; should a cylinder over-fire with excess fuel both the cylinder temperature and exhaust temperature would raise accordingly. This will give a warning of any excessive high temperature or burning of excess fuel in the DPF, which could cause a fire in the DPF.

In addition to the DPF, the Caterpillar engine also has emissions critical components that will require periodic maintenance to maintain the emissions certification. Caterpillar requires the following maintenance for the engine and the DPF to maintain emissions levels (emissions equipment highlighted in “yellow”):

Operating Hours	Fuel Burned (Gallons)	Maintenance Requirement
6,000	NA	Clean DPF
12,000	NA	Refurbishment of DPF (clean and bake, replace defective elements/substrates as required)
18,000	259,000	Replace electronic injectors with remanufactured electronic injectors
18,000	259,000	Replace valves and cylinder heads with remanufactured cylinder heads with valves
18,000	259,000	Replace turbochargers with remanufactured turbochargers
18,000	259,000	Clean, test and reseal after-cooler cores
24,000	NA	Replace DPF/DOC substrates
72,000	1,036,000	Replace pistons
72,000	1,036,000	Replace piston rings

MP20B-3PR and MP20C-3PR Operating Experience and Maintenance Experience:

The first locomotive was successfully track and emissions tested in July of 2011 and went into service at the end of July of 2011; the last locomotive was delivered at the end of 2011 and went into service mid- January of 2012. The following picture shows the interior of one of the exhaust stacks and the interior of the DPF after a week and a half of track and emissions testing.

To date there have been no train operating issues with any of the PR20B or PR20C locomotives; they have performed trouble free in all of PHL's various switching operations.



Figure 8: Inside of Exhaust Stack and DPF after Initial Testing July, 2011

Maintenance of the locomotive engines and after-treatment has been virtually trouble free. PHL started inspecting the DPF filters on a 92 day basis to assure that the ceramic substrates were regenerating; but while there was some soot there was very little ash buildup in the interior of the DPF's and the inspection of the DPF's. Since no issues were found, the DPF inspections have been moved to an annual basis for convenience, even though the recommended clean-out is every 6,000 hours. While there is some soot, it is apparent that even with the low duty cycle of the PHL locomotives the exhaust temperatures are high enough to burn off the trapped particulates with very little ash accumulating.

It currently takes approximately two man-hours to clean and inspect the DPF. Inspection consists of opening the car body hatch to access the DPF inspection hatch. After opening the inspection hatch, the interior of the DPF is cleaned of any existing ash and loose soot by vacuuming. After cleaning, because the inspection access is so small, the inspection of the interior is made by taking pictures of the interior. The pictures are reviewed to make sure all loose ash and soot has been removed and to verify the integrity of the ceramic substrates. The following pictures (Figures 9 through 15) were from the last inspection of PHL 66 on at 5,083 hours of operation on February 2, 2013:



Figure 9: Access for DPF Cleaning and Inspection



Figure 10: Inspection and Cleaning Access to DPF



Figure 11: Interior of DPF before Cleaning



Figure 12: Finger Mark in Soot before Cleaning



Figure 13: Exhaust Diffuser in DPF before Cleaning



Figure 14: Interior of Exhaust after 5,083 Hours



Figure 15: Exhaust Stack after 5,083 Hours



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When Figure 15 is compared to Figure 8, it is apparent on how clean the exhaust of the locomotives has been over the 5,000 hours.

A minor issue has been backpressure sensor calibration. As with any new design, the sensors and their calibration are designed to protect the systems they monitor; but as always, there are products in the population that do not act the same way as others. Two of the 16 locomotives consistently operate at 6.7 to 6.9 kPa backpressure with a constant fault message on the QES screen to service the DPF. Consideration is being given to adjust the acceptable fault display backpressure up to 6.9 kPa.

PHL also performs a load test on an annual basis to check the backpressure. The backpressure sensor is removed and a digital read out test gauge and sensor are put in its place. This is to verify that the backpressure is <6.7 kPa at full horsepower.

In addition, there have been no miss-fire faults (cold cylinders) to date. Inspection of the engine/main alternator coupling indicates that there have been none.

Description of PR30C Locomotive:

The PR30C was rebuilt using an EMD SD40-2 locomotive core. The locomotive is equipped with a Caterpillar 3516C-HD engine coupled to a Marathon model 1020 main alternator. The emissions control equipment consists of a Selective Catalytic Reduction (SCR) system and a Diesel Oxidation Catalyst (DOC). Locomotive control is provided by a ZTR Nexsys microprocessor system. Both the engine and the after-treatment system are designed to burn ULSF fuel with up to 5% biodiesel.

The engine and the main alternator are skid mounted and the skid is fastened to the locomotive frame. The SCR system consists of a SCR/DOC unit mounted in the Clean Emissions Module (CEM) which is on the top of the locomotive long hood just behind the dynamic brake, a Diesel Exhaust Fluid (DEF or Urea) tank behind the fuel tank and a DEF dosing control cabinet mounted in the rear interior of the long hood between the engine and the air compressor.



Figure 16: PR30C PHL 40



Figure 17: SDCR/DOC behind Dynamic Brake and Urea Tank behind Fuel Tank



Figure 18: Engine with DOC/SCR above Engine



Figure 19: Exhaust Connection to DOC/SCR

Clean Emissions Module (CEM):

The CEM (Figure 20) consists of the following devices: the DOC, the SCR, NO_x sensors, exhaust temperature and pressure differential sensors, the DEF nozzle and the engine exhaust inlet. The CEM is 80.8" long by 94.3" wide by 32.8" high and weighs 5,950 lbs. Lifting connections are located at the bottom four corners of the CEM so that it may be removed if needed.

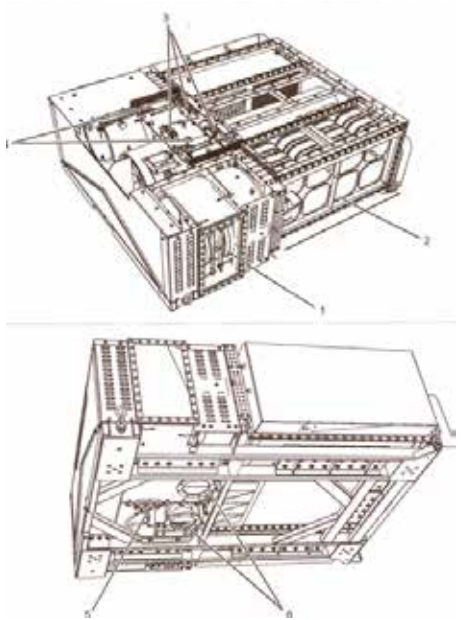


Figure 20: CEM

Top View:

1. Diesel Oxidation Catalyst (DOC)
2. Selective Catalyst Reduction (SCR)
3. Nitrogen Oxide Sensor Assemblies
4. Temperature and Differential Pressure Sensor Assemblies

Bottom View:

5. Diesel Exhaust Fluid (DEF) Nozzle
6. Exhaust Inlet



Figure 21: CEM before Installation in Locomotive

The diesel engine exhaust, one on each side of the CEM, first flows through the DOC's and then through the SCR system. The DOC's convert NO in the exhaust to NO₂ and remove as much of the Soluble Organic Fraction (SOF) as possible from the PM. Converting the NO to NO₂ is very important as the NO₂ is more reactive than NO in the SCR and higher conversion efficiency is possible with minimal amounts of DEF. The reduction of the SOF keeps the PM emissions to a minimum and keeps any "wet" PM from sticking to the face of the SCR.

There is no ammonia "clean-up" catalyst after the SCR. The CEM control system is used to minimize the ammonia slip using the fact that ammonia reacts on a NOx sensor and will give a false high NOx level. What happens is the control system will add DEF and watch the SCR outlet NOx emissions drop compared to the inlet NOx. When the DEF injection rate continues to increase, but the NOx sensor shows NOx going up, ammonia

slip is assumed to be taking place. The control system will then cut the amount of DEF being used to reduce the ammonia slip. The control system basically balances the DEF injected to hit the NOx target without ammonia slip.

Dosing Cabinet:

The DEF dosing cabinet controls the DEF (Urea) output to the SCR through inputs from the engine and the CEM. The dosing cabinet is connected by harnesses to the engine control, the DEF tank and to the CEM. The dosing cabinet also contains the DEF pump and the circuit breakers for the pump.

Dosing of the DEF takes place when the locomotive is placed in throttle Notch 2 or higher, or after the locomotive engine has run in less than Notch 2 for a total of six minutes.



Figure 22: Dosing Cabinet

DEF Tank and DEF (Urea):

Ammonia is required to reduce NO_x to nitrogen and water. Urea (DEF) is a nontoxic source of ammonia. The DEF is slightly alkaline with a pH of 9.0 to 9.5. To assure that the SCR receives a DEF that will provide the proper chemical reaction in the SCR, a 32.5% solution dissolved in demineralized water is used. Agricultural grade solutions cannot be used. If needed, the DEF concentration can be measured with a refractometer.

The DEF will also degrade if not handled or stored properly. The freeze point of the DEF is 11.3 degrees F. The higher the temperature, the shorter the shelf life of the DEF:

• Below 77 degrees F:

18 months

• 77 degrees F to 86 degrees F:

12 months

• 86 degrees F to 95 degrees F:

6 months

➤ 95 degrees F:

Test quality before use

The DEF is also corrosive and DEF tanks on the locomotive and storage tanks must be constructed of approved materials. Approved materials are:

Stainless Steels:

304 (S30400)

304L (S30403)

316 (S31600)

316L (S31603)

409 (S40900)

439 (S43035)

Alloys & Metals:

Chromium Nickel (CrNi)

Chromium Nickel Molybdenum (CrNiMo)

Titanium

Non-Metallic Materials:

Polyethylene

Polypropylene

Polyisobutylene

Teflon (PFA)

Polyfluoroethylene (PFE)

Polyvinylidene Fluoride (PVDF)

Polytetrafluorethylene (PTFE)

Materials not compatible with DEF include aluminum, magnesium, zinc, nickel coatings, silver, carbon steel and solders containing any of these materials.

Recommended materials for hoses and other non-metallic transfer equipment include:

Nitrile Rubber (NBR)

Flouroelastomer (FKM)

Ethylene Propylene Diene Monomer (EPDM)

PHL uses polyethylene totes to store the DEF.

The DEF tank is located to the rear of the fuel tank on the left side of the locomotive and has a capacity of 250 gallons. Since the locomotive has been in service, PHL typically dispenses one tote (220 gallons) of the DEF into the locomotive once per month. It takes PHL approximately 20 minutes to dispense the 220 gallons of DEF.

The following is the emissions critical parts list and scheduled change-out for the PR30C (emissions equipment highlighted in “yellow”):



Figure 23: Pump System on Urea Tote



Figure 24: Filling DEF Tank on Locomotive

Operating Hours	Fuel Burned Gallons	Maintenance Requirement
5,000	NA	Clean DOC & DEF Nozzle; replace in/out NOx sensors
12,000	NA	Refurbishment of DOC/SCR (clean and bake, replace defective elements/ substrates as required)
18,000	259,000	Replace electronic injectors with remanufactured injectors
18,000	259,000	Replace valves and cylinder heads with remanufactured cylinder heads and valves
18,000	259,000	Replace turbochargers with remanufactured turbochargers
18,000	259,000	Clean, test and reseal after-coolers
24,000	NA	Replace DOC; replace Housing SCR
72,000	1,036,000	Replace pistons
72,000	1,036,000	Replace piston rings

PR30C Operating Experience and Maintenance Experience:

To date there have been no major issues with the engine or emissions systems other than routine inspections.

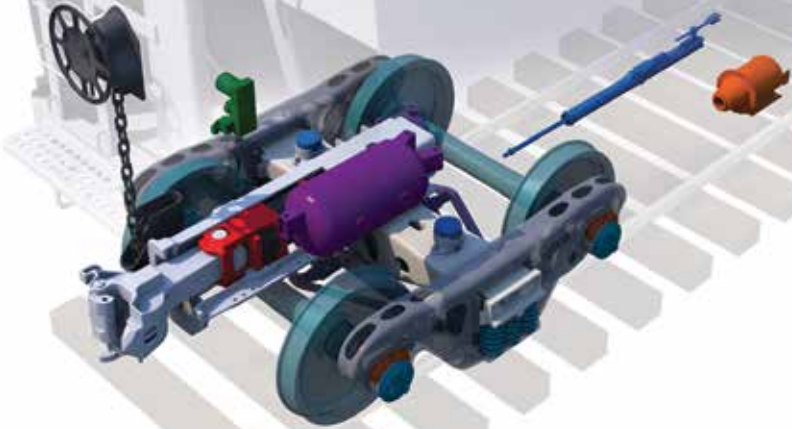
During 2012 the PR30C ran a total of 3,306 hours using 48,347 gallons of fuel. The locomotive used 2,640 gallons of Urea during the same time period, or a ratio of 5.5% Urea to fuel. Current Urea cost is from \$2.50 to \$3.00 per gallon.

At the time that this paper was completed for publication PHL was preparing to perform the 5,000 hour service on the DOC/SCR. This involves removing the side panel off the DOC/SCR and removing the DOC's for cleaning; the DOC's are first vacuumed and then blown out with compressed air. The NOx sensors

will also be changed out at this time with new sensors. The dosing injector will also be removed and cleaned. The whole process is estimated to take two days. An update on the results of this inspection and maintenance process will be provided at a later date.

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- AAR Yokes
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- Braking Components
 - Hand Brakes
 - Slack Adjusters
 - Empty/Load Devices
 - Truck Mounted Brakes
 - Brake Cylinders
 - Truck Mounted Brake Rigging
- Wear Prevention Components
 - Coupler Carriers and Wear Plates
 - Brake Beam Guides
 - Brake Rod and Bracket Protectors
 - Center Bowl Wear Liner
 - Center Bowl Horizontal Liners
 - Rear Yoke Support

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Locomotive Repower: Why Repower and What to Consider

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As locomotive fleets age, there comes a point when an economic decision needs to be made on what to do with a unit that has reached a point in its life where in kind overhaul costs outweigh the benefits. To further complicate these decisions are emission rules, new technology, and lack of new 4-axle replacement power. An option of breathing new life into these units is to “repower” them with the latest engine technology to achieve various goals of the investment such as fuel savings, emissions reduction, lower maintenance cost, etc.

Repower can be defined as replacement of an existing engine with an engine or engines of a different configuration that may include new technology, increase or decrease in horsepower, change in the number of cylinders, change in fuel delivery system, or major modifications to meet more stringent emission levels. The term repower may also be used generically to include other locomotive improvements besides the engine such as the control system, alternator, cab, cooling, etc. The goal of this paper is to educate the locomotive

community of repower options and what factors to consider to make the most economical decisions.

What Drives Repowering

There are numerous reasons to repower and all of them revolve around economics; SAVING MONEY.

- Availability of certain types of locomotives.
- Emissions requirements.
- Fuel economy.
- Maintenance.
- Locomotive fleet consolidation.
- Productivity.

In today’s locomotive market there can be, in some instances, very little choice for new replacement locomotives unless one is looking for high horsepower main line locomotives. There are very few choices when it comes to buying new, lower horsepower four axle locomotives and they are expensive. An attractive alternative is to take older four axle locomotives of low to medium horsepower and have them remanufactured. It would only be logical to assess repowering the remanufactured locomotive with a new engine at the

time of remanufacture instead of rebuilding the older engine in-kind. The incremental increase cost of the new engine, with its likely life cycle cost benefits, may prove to be more economically feasible than rebuilding the older engine during the remanufacture process.

Emissions are another reason to repower older locomotives. As a locomotive owner and operator of a railroad there reasons to be a responsible “green” citizen within the community. In addition, if the operation is located within an emissions non-attainment area there is likely to be funding from some local, state or federal sources to help defer the cost of the repower. A section later in this paper will cover emissions in more detail.

Fuel economy is an important factor when making repower decisions. New engine designs have evolved, primarily due to emissions requirements, where they are much more efficient than the older engines they replace. For example, in the case of the replacement of an older EMD engine with a new EMD engine you will find that the new engine will produce the same horsepower with fewer, more efficient, cylinders with significantly lower fuel consumption. If you replace the older engine with one of the new 4-cycle engine designs you will find that the inherent fuel savings of the 4-cycle engine coupled with the design efficiencies that have occurred during the emissions era will produce significant fuel savings. The amount of fuel reduction will

depend on the fuel efficiency of the engine being replaced versus the fuel efficiency of the new engine and can range from 15% to 25%. In life cycle cost analysis of the older locomotive versus the repowered locomotive, the fuel savings will be the largest cost factor and will often justify the cost to do the repower.

Maintenance of the old locomotive engine is another factor that often can justify repowering the locomotive. The old locomotive engine is probably not as reliable as desired with a high out of service ratio, frequent road failures, leaks or consumes copious amount of oil, and may even require parts that are harder and harder to find. Repowering with a new engine will eliminate all the undesirable reliability issues and maintenance aspects of the older engine for a significant period of time. If repowering is done on a fleet basis, the increased reliability and reduced maintenance requirements may lead to fewer locomotives being needed. Life cycle maintenance cost analysis should be performed to determine the actual maintenance cost savings.

If the railroad operates several different models or type of locomotives it is often possible to repower all the different models or types of locomotives with the same new engine repower package. Consolidation to one type of engine will reduce parts inventories and increase maintenance efficiency.

Productivity gains can be achieved by multiple avenues with a repower on a fleet basis. Often

the locomotives being repowered can receive a new engine of higher horsepower that fits in the same footprint of the old engine. If the railroad operation uses multiple units on a train, the increased horsepower may result in unit reduction and the savings associated with using fewer locomotives on a train or fewer locomotives in the fleet needed to perform the service. Even if unit reduction is not achieved, the higher horsepower will lead to increased train speed that could lower crew costs and improve customer service. If the repower is coupled with a complete locomotive remanufacture that includes improved tractive effort adhesion control unit, a reduction may be achieved as a result of the higher tractive effort. It is important to include any productivity gains that can be achieved with a repower into any life cycle cost evaluation.

Engines

When repowering an older locomotive the main part of the repower is the replacement of the original diesel engine with a newer more modern engine that is more efficient in terms of emissions, fuel economy and performance. Typically the older locomotives are powered with medium speed diesels from EMD, G.E. or Alco.

Railroads today have options as to what engines are available to them when doing a repower. The manufacturers that provide prime movers today are the following:

- Caterpillar
- Cummins
- EMD
- MTU

Each of the manufacturers listed provide a varied list of available models that range in power from 700bhp to 3600bhp for the typical switcher or road switcher applications. There are higher horsepower models available, but typical repowers are in the range mentioned above. Each of these manufacturers can provide details on the specific model required, which would include the following:

- Emissions
- Fuel Consumption
- Maintenance
- Performance Curves
- Specific Engine Installation Parameters
- Support Network

Depending on what the railroad is looking for in terms of emissions from the engine an aftertreatment system may need to be installed in the locomotive during repower. This may entail a Diesel Particulate Filter (DPF), Diesel Oxidation Catalyst (DOC), a combination of both, a Selective Catalytic Reduction (SCR) system or all of the above. Each engine manufacturer is responsible to provide the aftertreatment system needed when supplying a particular level of emissions with an emission certificate.

Depending on the engine manufacturer chosen, there will be

specific criteria that have to be met with the installation to ensure that the engine operates properly in the repowered locomotive. Cooling systems will have to be upgraded in most cases as newer engines require a split circuit cooling system where the aftercooling system is separate from the jacket water system as part of the emission reduction strategy. This will entail new radiator cores as the newer lower emission engines generate higher heat rejection to the cooling systems. Depending on the size of the engine, a new or revamped cooling hood may be required.

Most of the new engines today use High Pressure Common Rail fuel injection. These systems require a much higher level of fuel filtration due to the close tolerance of the high-pressure pumps and injectors used. Filtration down to 5-10 Microns will be needed. In addition the fuel tank needs to be thoroughly cleaned out of any debris or sludge. Depending on the particular repower, the fuel tank may require an upgrade to a new crash worthy tank.

Each engine manufacturer will have a suggested maintenance program that will give the maximum performance of the engine components throughout the life of the engine to overhaul. Depending on the locomotive duty cycle and the particular railroads maintenance program, either a 92-day or 184-day cycle can usually be attained. The longer 184-day cycle may require larger oil or fuel filtration to meet this requirement.

Support networks for the engines should also be looked at.

- Will the engine manufacturer train the railroad employees to do maintenance and normal repairs on the engine?
- What is the availability of replacement engines at time of rebuild?
- Is there a good network for replacement parts and at times trained factory technicians?

All of the above needs to be looked in the decision making process to ensure that the repower is a success and the performance being sought is attained.

Alternators

The repower will also require the replacement of the traction alternator if the new engine is a high-speed (1800rpm) engine. There is a good list of alternator manufacturers both in the US as well as Europe that make high-speed alternators. If the repower is replacing an older EMD with a newer EMD engine then the existing medium speed alternator or DC generator can either be re-used, rebuilt or replaced with a new or upgraded unit. Manufacturers of alternators for the rail industry are:

- Baylor (national Oil Well)
- EMD
- GE
- Hitzinger
- Kato
- Lechmotoren
- Marathon
- Newage

All of these manufacturers produce quality products. Make sure that the performance of the alternator meets the requirements of the particular locomotive in regards to voltage and amperage. Depending on the amount of amperage it will have to produce will determine the size of the rotor in the alternator. Engine manufacturers will have a maximum rear bearing load that has to be adhered to. If this is exceeded then a two bearing alternator will have to be specified. When this happens the coupling between the engine and alternator will change from a simple flex plate to a more sophisticated torsional coupling.

Torsional Couplings

As mentioned above, when a torsional coupling has to be used, then a torsional vibration analysis should be calculated by the engine manufacturer. There are various coupling manufacturers who offer variations of rubber couplings to steel spring type couplings. Rubber couplings will either be a bonded rubber coupling that operates in shear mode or a non-bonded rubber coupling that operates in compression. When rubber couplings are used whether in shear or compression, it is important to take into consideration the operating temperature they will be subjected to in order to select the proper type of rubber or in some cases silicone in order to get maximum life out of the coupling. Steel spring couplings use either encapsulated oil or oil from

the engine lubrication system for their damping effect. These types of couplings are not as heat sensitive as rubber, but require proper analysis in order to determine the proper sizing of the springs. Steel spring couplings can go to engine overhaul and are rebuildable at that time.

Auxiliary Drives

When doing a repower, there will be specific auxiliary drives that will have to be either renewed, replaced or added. This could range from an air compressor, auxiliary generator, traction motor blower, or other drives specific to a certain locomotive installation.

Depending on the engine installed and the various drives that are required, a torsional analysis may be needed and needs to include the driven components whether they are driven from the front of the engine crankshaft or from an auxiliary PTO. In some cases, replacing an electric driven air compressor with a mechanically driven compressor off the engine is a better or more economical solution. All of these possible options need to be taken into consideration and discussed with the contractor doing the repower.

Control Systems and Other Options

When repowering a locomotive there are several choices or options that can be made to improve the locomotive. All of these choices or options will increase the initial cost of the repower but through operating or maintenance cost savings can be



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justified with an accurate life cycle cost analysis. Choices or options that are often considered during a repower are:

- Traction Control Systems
- Automatic Engine Start/Stop (AESS)
- Auxiliary Power Units (APU's) or Shore Power
- Remanufacture of other components or systems

Traction Control Systems

Traction control systems are often added at the time the locomotive is repowered to improve adhesion that reduces wheel slip issues and increases the tractive effort making the locomotive more productive. These systems vary from add on electronics that only improve adhesion to a full blown microprocessors that control other systems. Traction control systems can be purchased from the OEM locomotive builders as well as several aftermarket manufacturers.

Obviously the systems that only control adhesion will be the less costly and are the easiest to install as they require the least rewiring. These systems can be added to the locomotive repower in the range of \$25,000 to \$30,000 per locomotive installed.

The more complex microprocessor systems control more functions than the adhesion system such as fan control, alternator control, auxiliary generator control, air compressor control and dynamic braking, and in some cases engine

control. They will also provide a way to interface with these controls and systems to provide alarms and capture faults and other troubleshooting information. One major advantage is that most of the relays and/or circuit board technology in the electrical cabinet will be replaced by the microprocessor system leading to better reliability.

If repowering with an engine from one of the OEM locomotive builders, the microprocessor will usually control the engine functions as well as traction control and other systems control.

If repowering with an engine from one of the OEM engine builders, they will provide their own engine control microprocessor with the engine but this may not or may not necessarily provide traction control. With an engine from an OEM engine builder an aftermarket microprocessor will interface to provide engine throttle control; however, some of the aftermarket microprocessors can be adapted to receive information from the OEM engine control system and display it on the aftermarket microprocessor interface screen. It is recommended that each manufacturer of aftermarket and locomotive OEM microprocessor systems be consulted to determine what each of their products will provide over and above the traction control and decide what fits the locomotive being repowered best.

The full microprocessor control system also requires a more costly installation process as it requires removal and replacement of most of the old relay logic and/or circuit

board technology and wiring. Depending on the degree of control chosen, there may be a requirement to install current measuring devices and sensors on the operating systems on the locomotive. Keep in mind that any traction control system will also require some method of speed control measurement system such as axle alternators, traction motor speed probes or radar. Cost for the full microprocessor control system can vary from \$50,000 to \$100,000 depending on what system control functions and engine interface are required or chosen.

Automatic Engine Start/Stop

Automatic Engine Start/Stop will be an option unless the locomotive being repowered falls into an Environmental Protection Agency (EPA) category where the age of the locomotive and the EPA emissions tier level mandates the installation of AESS (See Section on Emissions).

AESS is basically an add on system that allows the locomotive engine to shut down from idle under certain parameters when not needed to conserve fuel, reduce emissions, reduce lube oil consumption and reduce wear and tear on the engine. If the parameters such as main reservoir air pressure, battery voltage, ambient temperature, or engine water temperature are within acceptable levels the engine can shut down. When any of the parameters drop below the acceptable level the engine will restart and run until the parameter(s) are restored, then shut

down again. AESS also keeps the locomotive in a state of readiness; it is always warmed up and ready to go.

Some AESS systems can also provide other functions such as load shedding to better protect the battery charging and reduce the number of starts/stops or control over APU's. Adding AESS to the repower can bring more fuel savings to the bottom line; particularly for operations in colder climates.

Auxiliary Power Units (APU's) or Shore Power

Auxiliary Power Units (APU's) or Shore Power are two add on systems that that can work with an AESS system or by themselves. APU's and Shore Power are basically ways to protect the engine and batteries, save fuel, and reduce emissions when the locomotive is not being used and the engine is not running during cold weather. Both systems usually include on-board pumps that heat and circulate engine cooling water and a system to provide battery charging; the difference is the power source for each method.

APU's have their own small diesel engine that operate at a fuel consumption rate that is significantly less than that of an idling locomotive engine. The small diesel engine runs the equipment that heats and recirculates the engine cooling water throughout the locomotive wherever the cooling water circulates. In addition, the APU provides the battery charging to keep the batteries fully charged while the engine is not running.

Shore Power has the same onboard features and functions as the APU but instead of being powered by a small diesel engine the equipment is powered by electricity provided from a wayside power source like those used by boats and ships (hence the term “Shore Power”). The main drawback to shore power is that wayside infrastructure for the power source is required wherever the locomotive is parked.

Remanufacture of Other Components or Systems

When a locomotive is repowered it also an excellent time to totally remanufacture and/or upgrade the rest of the locomotive. One way to look at it is that the new engine now has a typical life of 15 to 20 years and the rest of the locomotive may be worn out; while reliability of the engine has increased the rest of the locomotive may be a basket case.

Cost to rebuild or remanufacture can double or triple the cost of the repower but essentially the whole locomotive will be “New” at the end of the process. Due diligence during the life cycle cost analysis will dictate whether or not a total remanufacture is cost effective.

Emissions Regulations for Repowers

Repowering a locomotive does not necessarily mean the locomotive now meets emissions requirements for new locomotives. The emissions regulations that apply to the repowered locomotive

depends upon the amount of used versus new components and the year of the repower. EPA regulations pertaining to repowers are found in 40CFR1033.640. Table XX is a summary of 40CFR1033.640, but the table does not include every detail. It is strongly suggested that each railroad or locomotive rebuilder review the regulations with its legal counsel once the work scope for a repower is done and the amount of new components are determined.

Potentials for Government Funding

Since low horsepower locomotives are used in low mileage, low duty cycle yard and local service, the fuel savings and maintenance savings may not be enough to justify the cost of repowering a locomotive. In certain cities or highly populated counties, there might be a source of funding through government grants. The EPA has established National Ambient Air Quality Standards (NAAQS) that sets the limits on pollutants such as carbon dioxide, lead, nitrogen dioxide, ozone, particulate matter (PM-10 and PM-2.5) and sulfur dioxide. Generally areas of large populations or areas where there is a large concentration of industries such as paper mills or power plants do not meet the NAAQS standards. Those areas that don't meet the NAAQS standards are known as non-attainment zones. (See the following table for Non-Attainment counties.) In most states, there are public funding opportunities through either the Diesel Emissions

TABLE XX
40CFR1033.640 PROVISIONS FOR REPOWERED AND REFURBISHED
LOCOMOTIVES

% Used Parts*	<25%	≥25% AND <50%	>50%
EPA Terminology	Freshly Manufactured	Remanufactured "AND" Refurbished	Remanufactured
Regulations	The manufacture date is changed to the day when the re-manufacture is completed, which is the NEW manufacture date. All emissions regulations corresponding to NEW locomotives on the NEW manufacture date are applicable.	Switch Locomotives: <ul style="list-style-type: none"> • Before 1/1/15 Tier 0 locos must meet Tier 0 Switch and Line Haul Standards. • After 1/1/15 Tier 3 and all other switch locos must meet Tier 3 Switch Standards Line Haul: <ul style="list-style-type: none"> • 3000 HP must meet Freshly Manufactured (NEW) standards for date of completed refurbishment. • Before 1/1/15 <3000 HP, Tier 0 locos must meet Tier 0 Switch and Line Haul Standards. After 1/1/15 NEW loco emissions standards. Generation of emissions credits is prohibited. 	The original date of locomotive is retained. All regulations that are applicable to the original date of locomotive manufacture are in effect.
Additional Labeling	Secondary locomotive label required stating the locomotive is refurbished and certified EPA tier	Secondary locomotive label required stating the locomotive is refurbished and certified EPA tier.	None

Reduction Act (DERA) Grant program or the Congestion Mitigation and Air Quality Program (CMAQ) that provide grants to repower locomotives. Generally, these grants are awarded through either local Metropolitan Planning Authorities or through the state environmental protection agency. Each planning authority or state EPA sets their own individual guidelines and policies for grant awards depending upon the type and amount of emissions reductions. Most emissions reductions grants for locomotives target nitrogen oxides and particulate matter.

A majority of the locomotive grants are through the CMAQ program. The goal of the grant is to provide subsidies such that the locomotive owner will reduce the amount of emissions to a level that is below the emissions regulations. For instance, a CMAQ grant can be used to repower a locomotive to Tier 3, which by law would only be required to meet Tier 0+. Most grants cover 70 to 80 percent of the repower costs, with the locomotive owner matching the rest. However, there are many conditions attached to the grants which may not be palatable to most railroads.

The CMAQ grant funding usually has several stipulations such as the locomotives funded must stay in Non-Attainment zone for a minimal amount of time, usually around 80% for five to ten years, which reduces operations flexibility. In addition, there are certain certifications that a grant

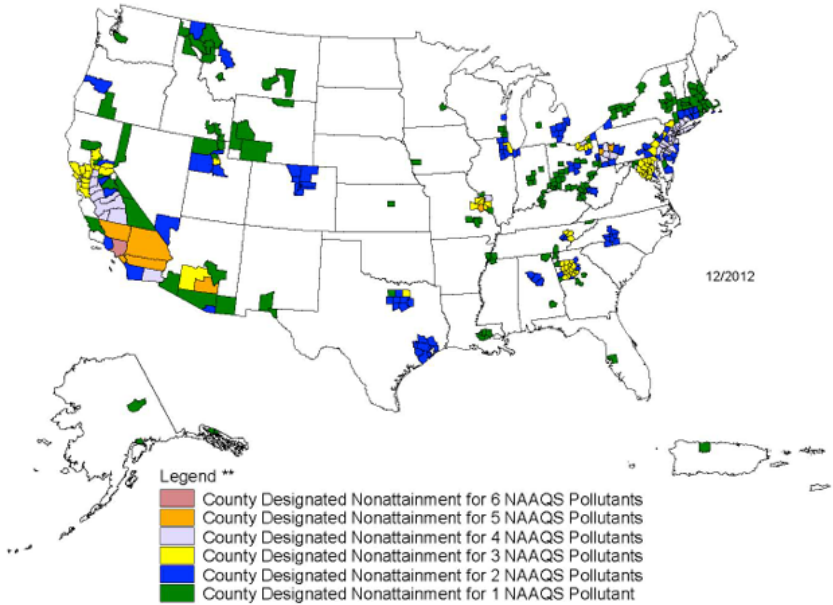
award must comply. There are also reporting requirements in which the grant recipient must report on the locomotive hours of operation, fuel used, and estimated emissions. In additions, since the CMAQ funding comes from the US Department of Transportation to the Federal Highway Administration, it is subject to all the rules and regulations governing the FHWA. One of the strictest rules is the Buy America regulations.

The Buy America Regulations for FHWA are governed under 23 CFR 635.410 which states that no more than 0.1% of non US steel or iron can be used in a project. Further, clarification from FHWA memos has revealed that a major iron or steel component is a component that is 90% or more iron or steel. Since we now live a global economy it is difficult to find an engine that meets the FHWA's stringent Buy America Requirements. In fact, there is no known engine that meets these requirements. Therefore, to apply for a one of these grants, a railroad must expect to work with the local agency providing the grant in obtaining a Buy America Waiver.

In pursuing government funding, one must be very patient as it may take a year or more to get awarded a grant and sometimes a year or more to work through the contract stage. As in the emissions regulations, it is suggested that legal counsel be consulted in regards to public funding.

Counties Designated "Nonattainment"

for Clean Air Act's National Ambient Air Quality Standards (NAAQS) *



Guam - Piti and Tanguisson Counties are designated nonattainment for the SO₂ NAAQS

* The National Ambient Air Quality Standards (NAAQS) are health standards for Carbon Monoxide, Lead (1978 and 2008), Nitrogen Dioxide, 8-hour Ozone (1997 and 2008), Particulate Matter (PM-10 and PM-2.5 (1997 and 2006)), and Sulfur Dioxide.

** Included in the counts are counties designated for NAAQS and revised NAAQS pollutants. 1-hour Ozone is excluded. Partial counties, those with part of the county designated nonattainment and part attainment, are shown as full counties on the map.

The Illinois portion of the St. Louis, MO-IL 8-hr Ozone multi-state nonattainment area has been redesignated, but the area is not considered a maintenance area until both states in the area are redesignated. All of the counties for this area are displayed as being in nonattainment

What to Repower

In theory, any older locomotive can be repowered; some are just better than others.

Here are some questions that need to be asked regarding the existing candidate for repowering:

- Is the existing locomotive doing the job?
 - Too light; not enough tractive effort?
 - Too long; won't couple on sharp curves or rolls rail over?
 - Not enough HP; won't make track speed with tonnage?
- What is the condition of the existing locomotive?
 - Frame in good shape?
 - Cab and car body in good shape?
 - Are the other systems on the locomotive not being replaced as a result of the repower in good condition?
- Are parts available for the next 15 or 20 years for the portion of the locomotive not repowered?

If there are no issues with the above questions then the locomotive could be a candidate for repowering; however, more due diligence is required to determine what repower engine package the locomotive could be repowered with.

When investigating what engines are available probably one of the most important aspects one must keep in mind is that the main generator or alternator must be matched to the engine of choice. If the locomotive is one that has been manufactured by one of the locomotive OEM's and

the repower engine is coming from the same builder the existing main generator or alternator will in all likelihood match the RPM of the new engine. This makes the repower much simpler as the new repower engine will probably be the same physical size or smaller than the engine removed. It should be mentioned that one OEM engine builder does offer a gear reduction package to drive an EMD alternator but it will add length to the engine/alternator package in the locomotive.

If the repower engine of choice is from one of the OEM engine builders it will in all likelihood run at a maximum RPM of 1,800 RPM and a new main alternator will be required (except as noted above). The 1,800 RPM alternators are typically longer than existing locomotive OEM main generators and main alternators but the engines are typically smaller than the engines removed.

Also, most engines and alternator packages using the OEM engine builder's products have the engine and main alternator mounted on an isolated skid and the skid is mounted to the locomotive frame. The traction motor blower is also generally mounted to the front of the skid and driven through the engine crankshaft through the main alternator. The overall length of the new engine/main alternator/blower skid package can be longer than the engine/main generator or main alternator package removed. The main consideration is that after the old engine and alternator is removed there is adequate room to install the new

engine/alternator/blower skid package in the area where the old engine was removed.

Another consideration will be the engine cooling package. Is the existing cooling system adequate for the new repower engine? As new engines have been developed to meet emissions requirements the need for more cooling capacity has arisen. This can be in the form of more engine jacket water cooling or the requirement to provide additional cooling for after-coolers with split cooling systems. In some cases the increase in the size of the radiators has also driven the need for additional cooling fans. The issue to be aware of here is that the repower engine choice will require adequate cooling and there may be a need for additional room on the locomotive to provide additional radiator or fan capacity.

The choice of the repower engine will also drive how the locomotive receives its companion alternator power, the auxiliary generator and air compressor power. Again these issues are more easily addressed if the new repower engine is provided by the OEM locomotive builder that built the locomotive originally.

If an engine from one of the OEM engine builders is chosen then consideration must be made for how the companion, auxiliary generator and air compressor are driven. In most cases the companion alternator can be combined with the main alternator at the expense of making a longer skid package. The auxiliary generator can be driven off an engine PTO if the

engine accessory drive can be geared to operate at the proper RPM or it can be shaft driven off the crankshaft. If driven off the engine crankshaft it would be recommended that the auxiliary generator be of the 18kW AC type known as a "Super Aux" so that it will operate properly at the 600 RPM idle rating of most OEM engine manufacture's engines. Air compressors will probably be required to be electric motor driven.

In conclusion, there are several issues that need to be considered when deciding to repower an existing locomotive and all are space/packaging driven. It will probably be easier to repower EMD GP and SD type locomotives or GE U or dash 7 locomotives as there is usually adequate room to make choices. Switchers will probably be more difficult to repower especially the older EMD SW series; the EMD MP series will be less difficult to repower.

Current Experience

There have been approximately 475 "repowers" to date of which around 350 would fall into the multiple engine genset category and the rest (125) into the single engine repower category. Experience and reasoning for repowers vary by railroad. Emission reductions and grant funding drove early adoption of genset locomotives. Recent engine and emissions technology gains for larger diesel engines have closed that gap. The type of service that the repowered locomotive is used in also contributes to its success and certain

models may find a better niche than others for example is it for yard work or for road switching?

As stated in the beginning, there are many reasons for repowering and often have one main driving factor with other minor factors. For example, one railroad's main factor was fuel efficiency along with simplicity of maintenance. Fuel efficiency was the same with another railroad along with fleet standardization. Yet another railroad's decision was to just rebuild in kind based on some repower experience and cost models, especially if no funding is available. Another railroad found that improvements have been

made in the latest gensets since original introduction but do take more skill in to troubleshoot or repair.

Conclusion

There are many factors to consider when deciding on whether or not to repower locomotives and unfortunately no simple answers. This hopefully gives a good basis to start the analysis. Each railroad will have to assign weighting factors to the importance of each of the items along with associated costs and decide what repower decision is the most economical.

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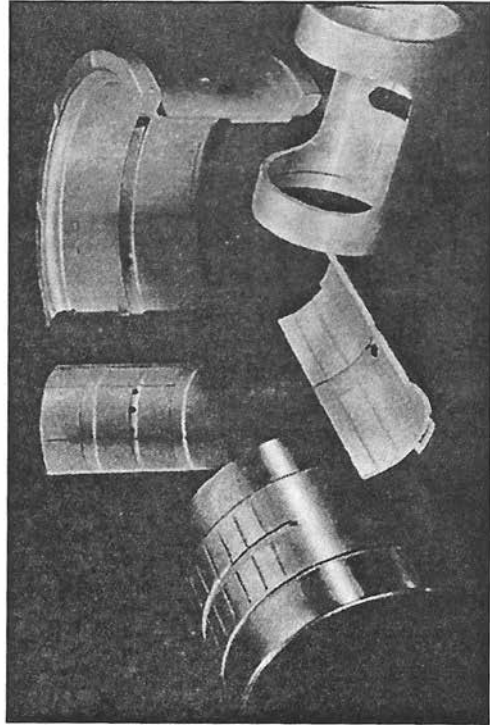
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Chief Mechanical Officer, Arkansas & Missouri Railroad

Introduction

The use of polymer material as a replacement for hardened steel, brass, and other bearing materials, has increased over the past several years and its use has yielded very positive and successful results. Our goal in this paper is to summarize the benefits and provide clarification on the use of nylon-plastic bushings as a beneficial replacement to steel when applied to locomotive brake rigging and related wear components.

The material used is basically nylon and the accepted supplier is a company specializing in the manufacture of polymer components. Other polymers could be used but there are a vast number available with varying properties. Careful selection and testing of alternatives is required if problems are to be avoided.

Polymer Bushings in Rail Applications

- 1) Design and Benefits
- 2) Fitting Practice
- 3) Test Data
- 4) Transit and Light Rail Applications
- 5) Passenger Service Applications
- 6) Locomotive Applications
- 7) FAQ's

Design

When designing a polymer component for replacing traditional materials, an established procedure is observed that takes into account the following considerations:

- 1) The housing and pin size – The running clearances are calculated using this data.
- 2) Load capability of the material – The working loads are calculated for each application.
- 3) Proximity to a heat source – The maximum operating temperature of the polymer is not exceeded even in extreme conditions.
- 4) Moisture absorption – The maximum growth dimensions of the polymer do not impede the running clearances for the design under all possible in-service moisture conditions.
- 5) Fire performance – The ability of the material to self extinguish and not emit toxic fumes.
- 6) Environment – The in-service con-

ditions to be assessed, including the possible interference of adjacent mechanisms.

Benefits

- 1) Reduction in wear resulting in increased performance by up to 5 times when compared to steel bushings.
- 2) Longer life for bushings and pins coupled with consistent friction, stiffness, and wear characteristics.
- 3) No alignment difficulties when assembling.
- 4) Improved likelihood of housing reclamation.
- 5) Quick and easy application and removal.
- 6) Lower material costs.
- 7) System wide reduction and potential elimination of brake head and slack adjuster seizures.

Fitting Practice

The following is a list of important requirements during the fitting of polymer material:

- 1) The tolerance limits on the housing and pins are in most cases no different to the previous limits. However, it is important that they are adhered to. Gauges are recommended in all cases to insure all housing and pin dimensions are within the tolerance band stated on the relevant drawing.
- 2) Before fitting polymer bushings, the housing and pins should be clean and free of grease, corrosion deposits, paint, burrs, and debris.
- 3) The use of excessive force to install the polymer bushing is not required.

Excessive force usually indicates a problem. Bushings should be installed using a soft-faced mallet and a block of wood. Note: Use of a steel hammer is not permitted.

- 4) Once the bushing is fitted into the housing, inspect to insure the bushing cannot be moved by hand. If the bushing can be moved by hand, remove and re-check the housing diameter.
- 5) After fitting the pin, inspect for sufficient clearance to enable free rotation. No binding or tight spots are permitted.
- 6) The polymer is not as tolerant to heat as steel and care should be used particularly if welding in close proximity to the material.
- 7) The polymer has the advantage of different color options. In general, yellow has been used for standard size components and blue for over-size. There is no difference in the performance between the two materials since they are exactly the same grade.
- 8) The material used is compatible with most grades of lubrication. In some applications, lubrication is recommended at the overhaul stage while in others it is not required. Reference should be made to the overhaul procedures.

BNSF Test Results on SD70MAC Locomotive Trucks, (1,000,000 Miles in Service at Inspection)



Brake Head Assembly Pin with 1,000,000 miles of service (SD70)MAC

Bushing	Qty Loc Item #	Bushing I.D. NEW	Bush ID At Inspection 3 year test	Pin Dia. NEW	Pin Dia. min	Pin Dia. max
8032159	(24) 1	1.127/1.125	1.150	1.111/1.107		
Slack Adj	2		1.169		1.045	1.045
	3		1.147		1.03	1.03
	4		1.142			
8052334	8	1.127/1.125		1.111/1.107	Not Measured	
HB	2		1.125			
LL						
8052336	16	1.252/1.250		1.236/1.232	Not Measured	
HB	2		1.265			
8059991	4	1.377/1.375		1.361/1.357		
LD	3		1.374		1.36	1.359
8065520	13	1.127/1.125		1.111/1.107	Not Measured	
HB	5		1.128			
LL	4		1.152			
LD	4		1.144			
8147661	1	1.502/1.50		1.486/1.482	Not Measured	
HB	3		1.513			
8197960	4	1.252/1.250		1.235/1.231		
LD 1/2	2		1.258		1.2335	1.232
LD 2/2	2		1.259			
8336929	16	1.377/1.375		1.361/1.357	Not Measured	
Hanger 1/2	3		1.390			
Hanger 2/2	3		1.392			
40023405	16	1.817/1.814		1.800/1.796		
Hanger 1/2	2		1.824		1.796	1.797
Hanger 2/2	2		1.825			
40026004	8	1.817/1.814		1.800/1.796		
LL	3		1.880		1.7955	1.1745

The test data above reflects inspection measurements taken during disassembly and re-assembly of SD 70 radial trucks in Alliance, NE. At teardown, the trucks had nearly 1 million miles of service since the initial plastic bushing application. The data and measurements taken are consistent with other

tests...virtually no wear on the pins and bushings. The minimal wear conditions will result in longer life and less maintenance between brake rigging overhauls.

Canadian Pacific Railway Test Data on GP Locomotives with Clasp Brakes



Unit # CP3071 Mileage from Dec 1997 to Dec. 2000 for Polymer Bushing Test 72,746 Miles										
CBT REF#	GM PART #	CAR	CARS	TYPE	NOMINAL BUSHING SIZES			HOUSING DIMENS	PIN DIAM	DESCRIPTION
					BUSH ID	BUSH OD	BUSH LENGTH			
695	8160207	4	16	A	1.750	2.115	1.000	2.110	1.750	Outside Brake Lever
	Measured				1.750	N/A	N/A	2.097	1.750	Top Left Bush
	Measured				1.748			2.110	1.746	
	Measured				1.746			2.098	1.749	
	Measured				1.747					
	Average				1.747			2.101	1.748	
695	8160207	4	16	A	1.750	2.115	1.000	2.110	1.750	Outside Brake Lever
	Measured				1.746	N/A	N/A	2.100	1.746	Top Left Bush
	Measured				1.748			2.095	1.749	
	Measured				1.744					
	Average				1.746			2.0975	1.748	
695	8160207	4	16	A	1.750	2.115	1.000	2.110	1.750	Outside Brake Lever
	Measured				1.749	N/A	N/A	to spec.	1.746	Top Right Bush
	Measured				1.751				1.753	
	Measured				1.752				1.749	
	Measured				1.752					
	Average				1.751			2.110	1.749	
695	8160207	4	16	A	1.750	2.115	1.000	2.110	1.750	Outside Brake Lever
	Measured				1.753	N/A	N/A	to spec.	1.746	Top Right Bush
	Measured				1.753				1.753	
	Measured				1.755				1.749	
	Measured				1.755					
	Average				1.754			2.110	1.749	
696	8065516	4	16	A	1.750	2.115	2.000	2.110	1.750	Outside Brake Lever
	Measured				1.738	N/A	N/A	2.100	N/A	Centre Left Bush
	Measured				1.742			2.095		
	Measured				1.742					
	Measured				1.740					
	Average				1.741			2.098	1.750	
696	8065516	4	16	A	1.750	2.115	2.000	2.110	1.750	Outside Brake Lever
	Measured				1.739	N/A	N/A	2.100	N/A	Centre Left Bush
	Measured				1.739			2.095		
	Measured									
	Measured									
	Average				1.739			2.098	1.750	
696	8065516	4	16	A	1.750	2.115	2.000	2.110	1.750	Outside Brake Lever
	Measured				1.746	N/A	N/A	2.100	N/A	Centre Right Bush
	Measured				1.747			2.095		
	Measured				1.746					
	Measured				1.746					
	Average				1.746			2.098	1.750	

696	8065516	4	16	A	1.750	2.115	2.000	2.110	1.750	Outside Brake Lever
	Measured				1.754	N/A	N/A	to spec.	N/A	Centre Right Bush
	Measured				1.759					
	Measured				1.752					
	Measured				1.754					
	Average				1.754				1.750	
691	8160740	8	32	A	1.750	2.254	1.250	2.250	1.750	Outside Brake Lever
	Measured				1.754	N/A	N/A	N/A	N/A	Bottom Right Bush
	Measured				1.756					
	Measured				1.759					
	Measured				1.755					
	Average				1.756					
691	8160740	8	32	A	1.750	2.254	1.250	2.250	1.750	Outside Brake Lever
	Measured				1.750	N/A	N/A	N/A	N/A	Bottom Right Bush
	Measured				1.755					
	Measured				1.754					
	Measured				1.755					
	Average				1.754					
707	8157944	8	32	A	1.747	3.110	1.937	3.105		Bush, type "A"
	Measured				1.799	3.114	1.937			Bushing, Brake head
	Measured				1.804	3.113	1.937			
	Measured				1.802	3.111				
	Measured				1.801					
	Average				1.815	3.113	1.937			
699	8107553	10	40	A	3.125	3.625	1.093	3.620		Bushing, Brake head
	Measured				3.121					
	Measured				3.119					
	Measured				3.123					
	Measured									
	Average				3.121					
699	8107553	10	40	A	3.125	3.625	1.093	3.620		Bushing, Brake head
	Measured				3.102					
	Measured				3.099					
	Measured				3.101					
	Measured									
	Average				3.100					

The test data above reflects measurements taken after 3 years of switching service for GP clasp locomotives owned by the Canadian Pacific Railway. The data again reflects minimal wear and tear on pins and bushings in a less than advantageous type of service in extreme weather conditions. The comments by mechanical personnel at teardown should not be ignored. They were simply “amazed” at how easily the rigging came apart...without heating with a torch and beating with a mallet.

Other Ongoing In-Service Tests

- 1) CN Railway – Two SD 70 Locomotives in service since 2004; no reported problems. Plastic bushings were applied at time of truck overhaul by Progress Rail.
- 2) Republic Locomotive – Slack Adjusters and Rigging used for 2 axle switching locomotive.
- 3) Miscellaneous levers and truck frame bushings for various shortline and other class I railroads currently still in service.
- 4) Canadian Pacific specifies 100% of truck overhauls require plastic bushings...ongoing in service.

Complete Brake Head Assembly (GP38-2)



Locating the bushes was tough due to the dirt and brake dust on the riggings. This was a CP tear down where the rigging came apart easily.

- 5) Arkansas & Missouri Alco Locomotive Brake Rigging and Truck Frame...ongoing in service.
- 6) Light Rail and Transit Applications with Siemens, Bombardier, and multiple transit authorities...Calgary, Montreal, Edmonton, Toronto (TTC), Skytrain, Sacramento, and Denver Transit.

The latch bushing on the left used to be steel and has been replaced with plastic due to seizers. Problem resolved with a polymer bushing. Coupler Bushing on the right was bronze and was replaced due to premature wear. Both parts have shown great improvement to the long-term performance of the applications.

7) Light Rail and Transit Applications include coupler/latch bushings, RACO hydraulic brake cylinder rods, knuckle bushings, brake rigging and brake scrubbers, suspension bushings, vertical and horizontal wear liners, center plate liners, and wear rings, center pivot liners, and brake actuators.



Bottom Right picture shows the location of the suspension bushings used by Montreal Transit for the last 15 years.

The other photos show different hydraulic brake applications with Polymer bushings installed.



Replaced bushing at the end of the hydraulic cylinder with a Polymer (Devlon A153/S) bushing. The existing steel bushing was failing due to excessive vibration when the wheel scrubber was activated. The new plastic bushing eliminated the failure from vibration due to the elastic nature of the bushing.



8) All Light Rail Plastic Applications have been approved by the each transit authority to replace the steel on steel application.



These are the old style horizontal wear pads with significant wear and corrosion.



The above (Devlon S grade) Polymer parts are the replacements for the old style vertical and horizontal parts. Bushing used to be split in 2, which made for a very difficult installation. New Bushing is press fit into the housing. Disk is about 2 feet in Diameter. Bushing is 9"-10".

Cal Train specified their entire fleet with these parts while Alstom performed the installation of the parts.



Theses photos show existing Bronze and steel parts for a light rail application. The bowl at the top of the left picture is filled with oil and the lower part is flipped over and sits in the top bowl. On the underside of the part is a wear pad that slides against the car.

The blue (Devlon S grade) parts replace the part at top left. The Red (Devlon Devlube) parts replace the wear pad that is not shown. We are researching a one-piece part to reduce installation labor.

FAQ's

1. What are the operating temperature limitations? Minus 60 degrees F to plus 300 degrees F.
2. What type of grease should be used? There are no known greases used in rail application that will have a detrimental effect on the polymer. Mineral based high melt point greases are recommended. Most manufacturers and re-furbishers specify Lithium based, calcium based with graphite, or MOS2 anti-seize compounds.
3. Does the polymer absorb moisture and if so, what effect will this have on brake performance? Yes. The hygroscopic effect is known and any small dimensional change as a result of this is catered to in the running clearances determined when engineering the bushings prior to manufacturing.
4. Will there be any detrimental effect on the polymer bushings as a direct result of corrosion or contamination by brake dust? No.
5. How are the polymer bushings retained in their housings? The interference fit determined by engineering is sufficient. No additional retention methods, such as keeper plates or adhesives, are required.
6. Are the polymer bushings directly interchangeable with the original hardened steel bushings? Yes, providing the housing condition is still within the originally supplied tolerance range. If the housing is worn, an oversized polymer bushing can be supplied and colored differently for easy identification.
7. Are the polymer bushings compatible with known aggressive fluids typical for the rail industry, such as effluent, washing solutions, etc.? Yes.
8. Under prolonged braking or dragging brakes, is there any breakdown of the polymer bushing? Test results have proven that typical loads of over 3,400 pounds simulated during the dragging brake conditions over a 60-minute period and elevated temperature of 350 degrees F, resulted in no deterioration of the polymer bushings when used in a brake shoe block holder.
9. Is there any requirement for changes to standard pins to operate with polymer bushings? No, maintain the same pin criteria and specification as originally and currently used with steel bushings.
10. Is the polymer bushing also used on freight cars? Yes, we have concentrated on passenger vehicle and freight locomotives due to the more severe acceptance criteria. Polymer is widely used on freight cars.

Conclusions

The advantages of polymer (plastic) bushings are significant enough to bring the message to the forefront of our industry. Millions of dollars are spent maintaining and overhauling locomotive trucks every year. With the data presented, we believe implementing a plastic for steel bushing alternative should be considered in many applications, including locomotive brake rigging. The results we've summarized merit further testing, research, and approval by mechanical experts in our industry.



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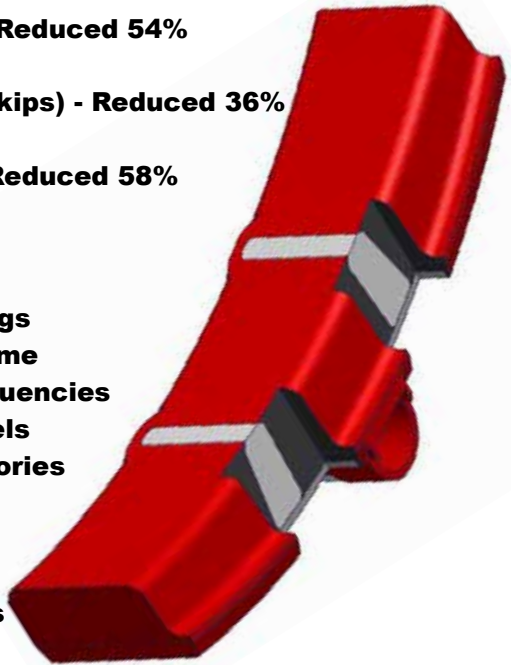
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Report on the Committee on Fuel, Lubricants and Environmental

September 30, 2013 at 3:30 PM



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PERSONAL HISTORY

Dwight Beebe

Dwight Beebe is Vice President of Temple Engineering, Inc. He has worked in the railroad industry for over 15 years. First he was manager for TSL Inc. (originally the Frisco Railroad Laboratory) which provided a variety of testing for the rail industry. Later he worked for Nalco Chemical Company as the Account Representative for railroads in the Midwest. In 2003, he started Temple Engineering, Inc. with his wife Michelle. Temple provides fine chemicals and service to the transportation and manufacturing industries.

Dwight is a retired Lieutenant Colonel of the U.S. Army Reserves.

He received a Bronze Star for his work planning transportation for the surge while serving in Iraq. He is a member of ASTM International and the American Society of Civil Engineers. He holds a BS in Chemistry from Missouri State University.

Dwight resides in Liberty, MO with his wife. They have seven children and 3 grandchildren. He is a member of the Liberty Chamber of Commerce. He is also active in the Boy Scouts of America and is the chairman of the Liberty Emergency Preparedness Fair.

The Fuel, Lubricants and Environmental Committee would like to thank American Refining Group for hosting the committee meeting in Atlanta, Georgia on February 6, 7, and 8, 2013.

The committee also conducted a number of online meetings throughout the season which were graciously sponsored by Oronite Corporation.



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Railroad's Changing Fuel Supply: Diesel No. 2 (high-sulfur, low-sulfur, and ultra-low sulfur), Biodiesel, Fischer-Tropsch, and Blends

Prepared by:

*Dennis W. McAndrew, Dennis W. McAndrew, Inc.
Corey Ruch, BNSF Railway*

For over three decades, diesel fuel supplies to the railroads were with fuels that met the ASTM D975 Diesel No. 2 Fuel Specification. However, within the last decade there has been a desire by some to use renewable fuels such as biodiesel blends as locomotive fuels. Because of the potential future use of more biodiesel blends, and the potential use of higher concentrations of biodiesel blends, and some uncertainty with engine performance and reliability, and fuel quality consistency, a survey questionnaire was distributed to members of the Locomotive Maintenance Officers Association (LMOA) Fuel Lubricants and Environmental (FL&E) committee railroad members. This survey was an attempt to understand the current biodiesel blend supply variations, extrapolate a likely future use of biodiesel blends, and how the increasing varying fuel supplies are or are not contributing to fuel related issues. The returned questionnaires showed there are biodiesel blends being used inconsistently at several locations, with varying concentrations, and with some issues being reported. There are unique chemical and physical properties present that are different between diesel fuels (petroleum) and biodiesel (fatty acid methyl ester, FAME), those differences must be understood in terms of operational and performance differences of both wayside systems and the locomotive systems.

INTRODUCTION:

For over three decades, diesel fuels supplied to the railroads were with fuels that met the ASTM International D975 Diesel No. 2 Fuel Specification for Diesel Fuel Oils. The fuels were required not only to meet the sulfur 5000 ppm maximum requirement, but to meet all the additional requirements found in the ASTM D 975 diesel fuel specification, and any additional requirements the railroads imposed above the ASTM specification. That is to say, in addition to meeting the sulfur requirement, the other specified fuel's chemical and physical properties were to be within the specification. One of the locomotive Original Equipment Manufacturers' (OEM) historical analytical fuel test data base, spanning over thirty years, supports the above statement in that the fuel supply to their facility consistently met the specification with little variation in the fuel supply.

On the occasion fuel related problems arose, the general high-quality and consistency of the fuel supply reduced some of the complications in the analytical evaluation of the fuel to find the root cause of the problems.

However, in the mid-2000s, the predictable consistencies in the fuels' chemical and physical properties started to show some regional variation in several fuel properties. In part, it was driven by the US Environmental Protection Agency (US EPA)¹ requiring the reduction of the fuels' sulfur concentration, and the California Air Resource Board (CARB) requirements for not only sulfur reduction but an aro-

matic content reduction as well. The reduction in fuel sulfur content, which can be achieved with different refining processes, resulted in not only a sulfur reduction but changes to some of the fuels' basic chemical and physical properties.

In addition to the basic fuel properties changes, from the refining process changes, there has been an introduction of renewable or alternative fuels such as: biodiesel blends of varying concentrations, Fischer Tropsch fuels, and possible other alternative blended fuels into the railroads' fuel systems. The changing basic fuel composition, along with the increasing use of alternative fuels, resulted in an increase in the variability of the fuel supply. As a consequence, when fuel issues arise, the primary cause can become more difficult to determine and to implement corrective response.

Furthermore, with the government, commercial, and private desire to use renewable fuels, and reduce the volume of imported crude oil, there could be an increasing use of biodiesel blends in the railroad industry. Because of the potential future use of more blended fuels, and the potential use of higher concentrations of biodiesel blends, and some uncertainty with engine performance and reliability, and fuel quality consistency, a survey questionnaire was distributed to members of the Locomotive Maintenance Officers Association (LMOA) Fuel Lubricants and Environmental (FL&E) committee railroad members. This was to gain insight on the current state of biodiesel blends in

the railroad industry, with the goal to understand the current biodiesel blends use, concentration variations, and how the increasing varying fuel supplies are or are not contributing to fuel related issues, and extrapolate a likely future use of biodiesel blends.

FUEL SURVEY QUESTIONNAIRE:

The fuel survey questionnaire was distributed January 2013 to US and Canadian railroads. There were a total of 3 railroads answering all or part of the survey in January 2013. The written responses were from two US railroads, and one Canadian railroad. In addition, two US railroads provided verbal comments/information. In late March additional input was received from one of the railroads LMOA Diesel Mechanical committee member via. e-mail to the FL&E committee chairperson with information on their experience with biodiesel fuels. That additional information is included after the fuel questionnaire comment section. The survey questions were as follows:

- A. Is the use of biodiesel fuel considered confidential and you cannot share any specific information?
 - a. If confidential, could you share general information?
- B. If the use of biodiesel fuel is not considered confidential, please help and provide the committee the requested information.
 1. Number of locations using biodiesel
 2. For how long has biodiesel been used
 3. Concentration of biodiesel, for example B0 to B5 at those locations
 4. Is supply consistent, i.e., always target a BX with an deviation from BX of some \pm
 5. Quality checking of the fuel, i.e., testing to verify that both the biodiesel and diesel fuel meets specification
 6. Supply:
 - a. Delivered fuel is pre blended as a component in the general diesel fuel supply as B0 to B5
 - b. B100 is delivered to the railroads' storage tanks, and the railroad blends the biodiesel into the main fuel to make a B0 to B5
 - c. B20 or some other concentrations is delivered to the railroads' storage tanks, and the railroad blends the biodiesel into the main fuel tanks to make a B0 to B5
 7. Methods of blending
 - a. Splash blended
 - b. Metered pipe flow mixing
 8. Any known pre or post storage tank filter plugging, or shorter useful filter life
 9. Storage tanks, pumps, valves, meters corrosion issues
 10. Storage tank increase in sludge
 11. Storage tank clean up
 12. Any known increase in systems leaks, i.e., failure of seals found in the pumps, meters, valves, others

13. Locomotives issues
14. The railroad is using some biodiesel, but the location and concentration is not accurately tracked or recorded
15. No known problems with biodiesel use
 - a. No known problems, but it is not tracked
 - b. No known problems and the use is tracked
16. Known problems with biodiesel
 - a. What is the problem/issue
17. Comments

All of the survey responses that were received are reported as received in the following section. In addition to the written responses, railroad 3 provided graphs and photos.

FUEL SURVEY

QUESTIONNAIRE RESULTS:

Note: --denotes no response

(R1=Railroad 1, R2=Railroad 2, R3=Railroad 3)

1. Number of locations using biodiesel
 - a. R1, 3 locations 2012 into winter 2013, by June 2013 7 locations
 - b. R2, difficult to know with some level of certainty
 - c. R3, increasing from 2009 to present, see figure 1 and 2
2. For how long have biodiesel been used
 - a. R1, since the summer of 2012
 - b. R2, since 2011
 - c. R3, The earliest sample, we have from records dating back to 2006, was a biodiesel sample in November 2009
3. Concentration of biodiesel, B0 to B5 at those locations
 - a. R1, meticulous records are maintained on the volume of biodiesel consumed at the locations receiving purchased biodiesel
 - b. R2, B5
 - c. R3, concentration of biodiesel received over time, 13 locations across the system. The biodiesel level is clearly not consistent over time, see figure 3
4. Is supply consistent, i.e., always target a BX with an deviation from BX of some +_
 - a. R1, yes
 - b. R2, B11 is mixed with ULSD in the fixed tank or locomotive
 - c. R3, biodiesel is not consistent in either content % or time delivery

5. Quality checking of the fuel, i.e., testing to verify that both the biodiesel and diesel fuel meets specification
 - a. R1, yes
 - b. R2, fuel from storage tanks is routinely tested
 - c. R3, complete testing in house. Common tests are as follows: Visual Analysis/Rating, API Gravity, Thermal Stability, Biodiesel (from known biodiesel locations as well as random samples), Sulfur analysis (3 month intervals). Lubricity / wear scar testing and cetane analysis are performed on select samples. Water and sediment are tested if sample is noted to have visual particulates or cloudiness. Winter testing includes Cloud Point, Pour Point analysis, a proprietary Cold Soak Filter Plugging Test (CSFPT) if biodiesel is present (and on random samples from across the system). Additional testing may be performed at any time.
6. Supply:
 - a. Delivered fuel is pre blended as a component in the general diesel fuel supply as B0 to B5
 - i. R1, as B5
 - ii. R2, --
 - iii. R3, This is our main method of delivery at most locations
 - b. B100 is delivered to the railroad's storage tank, and the railroad blends the biodiesel into the main fuel to make a B0 to B5
 - i. R1, ---
 - ii. R2, --
 - iii. R3, do not take delivery of any B100 that I am aware of
 - c. B20 or some other concentrations is delivered to the railroad's storage tank, and the railroad blends the biodiesel into the main fuel to make a B0 to B5
 - i. R1, ---
 - ii. R2, B11
 - iii. R3, Chicago area, we take delivery of B2 and B11 tank trucks. This fuel is then 'splash blended' in our main tanks to a B5 concentration
7. Method of blending; splash blending, metered blending in pipes
 - a. R1, metered pipe flow
 - b. R2, splashed blended
 - c. R3, B2 and B11 are splashed blended at 2 locations
8. Any known pre or post storage tank filter plugging, or shorter useful filter life
 - a. R1, First response: No issue encountered as we are using it in summer months only. Update, June 2013 added 4 more locations for a total of 7. Three locations had major contamination with water and microorganisms resulting in problems
 - b. R2, --

- c. R3, winter 11/12 incident in Chicago. 2013, a 2nd incident with a different biodiesel contaminant appears to have been caught by in-house testing at an early enough stage to be dealt with, see figures 4, 5, 6, and 7
9. Storage tanks, pumps, valves, meters, corrosion issues
- a. R1, haven't seen anything yet
- b. R2, --
- c. R3, this would be very hard to pin down as we do not perform any quantitative assessment of corrosion, and generally have no equivalent 'control' group which to make comparisons. Additionally, sulfur content has been phased out as biodiesel has been phased in which 'clouds' the picture. If a component were to fail due to corrosion, we may be able to assess how long it had been in service. Less likely, but possible, we may also know how long the previous component was in service. However, it would be virtually impossible to infer if the failure were due to increased biodiesel, decreased sulfur, other changes in fuel chemistry, or something else entirely
10. Storage tank increase in sludge
- a. R1, Initial response; haven't seen anything yet as we drain them weekly in first three locations. Update, June 2013 7 locations, 3 were contaminated with water and microorganisms where the tanks cannot be drained in winter resulting in water, organisms, and debris
- b. R2, --
- c. R3, again, we make no quantitative measure of this. For the monthly sample, each tank location is instructed to drain the sediment / water / rag layer / until clear and bright fuel is flowing, then obtain a quart sample of this clear fuel for lab analysis
11. Storage tank clean up
- a. R1, haven't done anything yet
- b. R2, --
- c. R3, this was considered for our Chicago area fuel tanks after the plugging incident of 2011/2012. However, sampling revealed the tank bottoms to be clean enough for continued use. Once the bulk of the crystalized material was trapped with at least 3 extra fuel filter changes, the remainder was caught in the final filter change, then normal filtration intervals resumed
12. Any known (increase) in systems leaks, i.e., failure of seals found in the pumps, meters, valves, others
- a. R1, haven't seen anything
- b. R2, --
- c. R3, --
13. Locomotives issues
- a. R1, nothing yet
- b. R2, --
- c. R3, An SD40 locomotive was found to have stuck/damaged injectors due to a B20 test in 2010-2011 timeframe. Several switch locomotives with HPCR injectors were found to have stuck injector pilot valves. Analysis revealed a coating of carboxylate 'soap'. This is commonly known in the industry as a reaction between corrosion inhibitor

and excess sodium in the fuel. Our issues are occurring in a location which also has biodiesel. We are examining the possibility of biodiesel bringing extra sodium to the fuel mix. Other issues are not specifically tracked and/or recorded. Again, as noted on the charts above, we do not have many locations which can be said to have a 'steady supply' of 'known percentage' of biodiesel. Even if a location has a steady supply (Chicago), many locomotives are simply 'passing through'...they may run on B5 when fueled at Chicago, but then receive B0 for the next fueling(s), see figures 8 and 9.

14. The railroad is using some biodiesel, but the locations and concentrations are not accurately tracked or recorded

- a. R1, --
- b. R2, --
- c. R3, --

15. No known problems with biodiesel use

- a. No known problems, but its use is not tracked -- No response
- b. No known problems and the use is tracked -- No response

16. Known problems with biodiesel, what is the problem/issue

- a. R1, --
- b. R2, Reports of truck fuel filters clogging – this was in the Chicago area
- c. R3, see 8c, 11c, and 13c

17. Comments

- a. R1, --
- b. R2, Fuel suppliers can provide up to B5 diesel fuel without disclosing same. Therefore, there are

probably other locations where we buy B5 that are not disclosed. Chicago and Decatur are the locations we actually purchase biodiesel. In December we tested biodiesel in samples from four other locations with concentrations ranging from 1.5 – 5%.

c. R3, --

Additional comments via. e-mail to the FL&E committee chairperson with information on their experience with biodiesel fuels that were outside the original questionnaire.

1. 30" 10 micron wayside filter plugging from poly olefins (like sludge) in B5 biodiesel
2. Primarily in Chicago area
3. Hoping to get back to monthly change out - currently weekly
4. If left too long, the pressure rise across the filters has blown them out, resulting in no wayside filtration
5. Have had as high as B20 delivered
6. Biological growth appears to be more of an issue with biological fuel content
7. Believe that bio-diesel increases both NOx and PM* (* based on previous test data generated in the industry the PM is typically lower)
8. Only operational positive seems to be reduced SCAR for ULSD
9. Concerned about fuel leak impact of biodiesel as it has a more significant impact on TBN (this is reference blow by gases)
10. Seeing higher water % in their fuel samples; believed to be due to more hydrophilic properties of biodiesel constituent



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11. Asked the OEM's about potential problems with water in the fuel at common rail fuel pressures of ~28k psi that we will likely see in T4 engines
12. Biodiesel will also eat some sealing materials (concerns for both wayside fueling systems and engines).
13. Investigation is ongoing, but changing to Viton ** seals is likely necessary (** Viton, trade name from Dupont, a fluoroelastomer)
14. One railroad have had some units in IL run for 9 months on B20 (caveat for extrapolation of results)
 - a. service was comparatively light
 - b. soy based
 - c. results may differ for different feedstock
 - d. at idle, the engine does not burn all of the fuel
 - e. resulting in lube oil fuel dilution

DISCUSSION:

Currently there exists a perception of increasing fuel problems, with the belief by some that all the problems are in part a result of the increasing use of biodiesel blended fuels. Prior to making such a blanket statement, the facts need to be gathered, e.g., was the location using biodiesel blends, the concentration of the biodiesel blends, and was the fuel tested to determine if it meets specifications, and the supplier information. Therefore, to elicit additional information that would support or not support if a given fuel issue was or was not attributed to the use of biodiesel the questionnaire/survey was distributed to railroads. Once all the inputs were

received, the questionnaire answers provided insight/information on: the number of locations using biodiesel, diesel supply variations, biodiesel concentrations, variation in biodiesel concentrations, and existing fuel issues believed to be a result of using biodiesel fuels. With this information one can extrapolate a possible future use such as increasing volume and/or increased concentrations of biodiesel blended fuels. Furthermore, with this information, quality control programs such as the one recommended in a LMOA 2008 paper on best practices⁷, could be in place to address fuel related issues and mitigate the impact.

There were reports of both wayside and locomotive fuel system problems corresponding with the introduction of low concentrations of biodiesel blends, starting in approximately 2007 to 2009, into some of the railroads' fuel supply. The wayside problems reported were fuel leaks in the fuel systems supply pumps and control valves, to premature plugging of wayside filters. On the locomotives there were reports of short filter life, to injector problems. However, before assigning fault to the use of biodiesel blended fuels, the primary cause must be determined. Not only has there been an increase in the use of biodiesel blends, but there was also a shift from high sulfur diesel (HSD) to ultra-low sulfur diesel (ULSD) along with variation in aromatic content. The change from HSD to ULSD diesel fuel supply was mandated by the EPA¹.

With two major changes to the diesel fuel supply, the primary contributing factor should be determined before

assumptions are made. The issue could be the ULSD, biodiesel blends, or a result of reaction/interaction of the blended fuels. Therefore, it is important to know the primary contributing factor or factors before corrective actions can be appropriately applied.

It has been remarked by committee members that some perceive diesel fuel as a homogenous fluid composed of one compound. They are not. Distillate fuels (petroleum) are composed of hundreds if not thousands of different molecular compounds. The same perception can be found for biodiesel, i.e., it is comprised of one compound. They are not. However, biodiesel fuels contain relatively few different sulfur free fatty acid methyl ester (FAME) hydrocarbon compounds compared to diesel fuels. A LMOA 2005² paper on biodiesel fuels in railroad applications illustrated the chemical structure of some of the biodiesel compounds; whereas a 2007⁶ LMOA paper on HSD and ULSD illustrated several of the diesel fuel chemical structures. The differences in the structures of the two fuels were clearly represented in those papers. Recognizing that there are unique chemical and physical properties present that are different between diesel fuels (petroleum) and biodiesel (FAME), those differences must be understood in terms of operational and performance differences of both wayside systems and the locomotive systems.

The blow-by gases from the fuels with different concentrations of sulfur, aromatics, and biodiesel will contain different organic species than the previous used HSD fuels. This could require

railroads using infrared spectrometer or other analytical instrumentation for used oil analysis to account for the difference in the fuel's sulfur, aromatic, and biodiesel content in their algorithms, i.e., recalibration of some of the analytical instruments used to evaluate used oil. The increasing use of ULSD has resulted in improvements to some of the used oil parameters, e.g., base retention and a reduction in oil's sulfated ash by lowering the base number (BN) down from 17 to 9. However, the increasing use of biodiesel's impact on crankcase oil and locomotive systems needs to be determined from long-term field studies

The shift from HSD high aromatic diesel fuels to ULSD lower aromatic fuels with the corresponding use of low concentrations of biodiesel fuels adds complexity to the analytical evaluation of fuel related problems.

Initial response from railroad 1 (R1) had not reported any problems in their wayside fuel systems or locomotives. However, it should be noted that this railroad's report of no problem was from three of their fueling locations where the purchased biodiesel blends started the summer of 2012. It was also noted the use of biodiesel blends were suspended in the winter. After the initial response this railroad increased the use of biodiesel from three to seven locations. Of those seven locations three of the locations could not drain the water from the tank bottoms. This resulted in a major water and microorganism contamination. On the other hand, railroads 2, 3, and additional comments from one of the Diesel Mechanical

committee members reported issues at locations being supplied B11 products, and both R2 and R3 with some locomotives with less than B5.

R3 has shared information on injector problems on a locomotive that was in storage for three months. Prior to storage the locomotive was burning B20, see figures 8 and 9. This railroad's laboratory also reported genset locomotives running on approximately 5% biodiesel have experienced numerous failures of HPCR injectors due to pilot valves becoming 'stuck' due to carboxylate film build-up. Additional testing by R3 on fuel filter's deposited material found it was compromised of compounds/chemicals that are commonly found in the makeup of biodiesel blended fuels, i.e., analysis on pasty residue deposited on fuel filters revealed the deposits were mainly palmitate (C16:0) and stearate (C18:0) monoglycerides.

Examples of some of the difficulties in identifying the actual source/location of a fuel supply that is creating a fuel related problem are as follows:

- B11 is being supplied into Chicago area
 - o B11 is blended into the main storage tanks to make something less than B5.
 - o However, not all locomotives passing though Chicago area are topped up with fuel in Chicago.
 - o The problem fuel is from another terminal.
 - o If fueled in Chicago, the biodiesel blend concentrations vary

- o Problem fuel is often consumed before fuel specimens are collected for analysis.

- Must rely on analyzing the fuel filters to determine contributing factors
- The carboxyl salts (soaps) detected on filters fouled/plugged can have been created via different source materials:
 - o Pipe line corrosion inhibitors (carboxylic acids) reacting with an alkali metal such as sodium or alkaline earth metal such as calcium to form the carboxyl salt (soap)
 - o Biodiesel decomposition products (organic acids) react with an alkali metal such as sodium or alkaline earth metal such as calcium to form the carboxyl salt (soap)
 - o With a quality analytical laboratory the difference between a carboxyl salt formed from a corrosion inhibitor and that formed from a biodiesel compound can sometimes be determined.
- Some fuel terminals are receiving low concentrations (nil to B5) without being reported to the railroad

The regional differences in the basic diesel fuels' chemical and physical properties and that of the biodiesel fuels should be evaluated for compatibility, solubility, miscibility, and fungibility before blending the two fuels. This evaluation could highlight or identify potential problems so corrective action can be applied before blending the fuels; thereby potentially avoiding some fuel related problems, i.e., address the problem in the infancy stage.

Because of the variation in fuel properties and measurements one cannot rely completely on the laboratory test results that affect performance. "When using fuel oils, it is not wise to put complete faith in all analyses, since they sometimes appear satisfactory, but actually are not. Two different oils can have approximately the same analysis, but will burn differently."³ Additional tests are often required to more completely understand the interactions of the fuels supplied and engine performance.

CONCLUSIONS:

The following points were extracted from the fuel survey information provided from the railroads.

- Biodiesel is used in the US and Canada
- Biodiesel is not used at all fueling locations
- Biodiesel supply concentration varies from nil to B20 at a given location
- Biodiesel concentration supply in the storage tanks and locomotives vary over time, i.e., not consistent
- Chicago region appears to be supplied with a B11
- The B11 fuels are splashed blended into the main fuel tanks at those locations
- Biodiesel is metered into main storage on one railroad to make a B5 fuel
- Railroads are likely receiving some diesel fuel pre-blended with biodiesel at some terminals
- On occasion, blends greater than B5 make it into locomotives
- The trend is for an increasing use of biodiesel, and possible higher concentration blends, greater than 5 percent

- Railroads are testing some of the fuel supply to determine if it is a blended fuel
- The recorded use of biodiesel fuel at one major US railroad is increasing each year from the late 2000s to present
- Issues with B0 to B20 have been reported, both in wayside systems and on locomotives
- Issues locomotive testing with B20 have been reported (railroad 2, 3, and 4)

The current fuel supply varies not only from railroad to railroad, but there are variations of fuel supply at different locations within a given railroad system and at the same location. The variations observed include not only biodiesel content but also other diesel fuel properties, e.g., fuel sulfur, aromatic content, volumetric energy content, density, cetane, lubricity, and other properties.⁶

RECOMMENDATION:

- Wayside fuel system suppliers evaluate all seals material and metal alloys use in pumps, valves, and hoses for compatibility with biodiesel fuels.
- OEM locomotive suppliers evaluate all seals material and metal alloys use in pumps, valves, and hoses for compatibility with biodiesel fuels
- Fuels are to be tested to determine if they meet the specifications, i.e., diesel, biodiesel, and blended fuels at an acceptable frequency.
- Evaluation of the possible use of

fuel additive packages to help solve some of the fuel related problems highlighted in this paper due to biodiesel blends.

- Controlled biodiesel fuel field tests, as such as the one recommended in a 2012 paper, *LMOA FL&E: Locomotive Durability Test Protocol for Alternate Fuels and Biodiesel*⁵ be conducted, and/or AAR's 1983 fuel fields test⁸, for a completely evaluated long term durability, reliability, and availability of not only the locomotives, but also the wayside fueling systems.
- If it is found the specifications miss important chemical or physical properties or the limits need to be adjusted, recommend to the ASTM improvements to specifications.
- When storing locomotives that had been burning biodiesel fuels it would be recommended that the proper storage procedure be followed as documented in the LMOA 2011 best practices paper¹⁰.
- Request that information be shared from entities that have conducted their own confidential controlled field tests that followed the AAR's 1983 field test protocol⁸, the LMOA 2012 suggested field test protocol⁵, or other quality field test protocols.

SUMMARY:

Responses from the questionnaire provided information on the current use of biodiesel fuels, concentrations of the supply, variation in consistency of supply, laboratory testing, examples of fuel issue where biodiesel are used, and an

increasing trend in the use of biodiesel blends.

In addition to locations where biodiesel blends are a purchased commodity, some of the railroads' general fuel supply does contain biodiesel blends of varying concentrations. If the current trend continues, there will be an increased use of biodiesel blends, possibly at higher concentrations.

Analytical test evaluation of plugged fuel filters, leaking wayside fueling systems seals, and suck/damaged locomotive fuel injectors have implicated biodiesel fuel as one of the contributing factors in the malfunctions.

The current fuel composition and future changes to railroad's fuel supply could require several adjustments to the railroads' fueling infrastructure, locomotive maintenance, and locomotive maintenance intervals.

Providing fuel products with consistent high quality and properties are paramount in overall railroads infrastructure and locomotive performance.

The general consensus of the LMOA FL&E committee, (and supported with yearly tracking) is that there will be an increased use of biodiesel, possibly at higher concentration.

With the advent of greater use of high pressure common rail fuel systems in new locomotives, fuel cleanliness and water content in the fuel are watch-points going forward. This may be addressed in a future paper.

ACKNOWLEDGEMENTS:

The authors wish to thank the LMOA FL&E committee members for their helpful comments on the paper and associated presentation. The authors are grateful to the three railroads for written responses to the survey questions and submitting data, the two railroads for their verbal comments, and the fourth railroad for additional input.

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APPENDIX:*EPA Requirement:*

“Effective June 1, 2007, the EPA requires most US-based refineries to produce Non Road, Locomotive, and Marine (NRLM) diesel fuel with a maximum sulfur concentration of 500 ppm. This requirement is delineated in 40CFR 80.510¹. This concentration was lowered from the previously allowable concentration specified by the railroads and/or locomotive manufacturers. US railroads often reference the ASTM International (originally known as the American Society for Testing and Materials) specification ASTM D 975 Diesel No. 2, which specified 5000-ppm maximum fuel sulfur. The goal of the EPA fuel sulfur reduction was to assist in the reduction of emissions of particulate matter from the locomotive, and by default the sulfur emissions would be reduced. 40CFR 80.510 additionally require US refineries to further reduce the fuel sulfur for locomotive fuel to a maximum of 15-ppm sulfur by June 2012. This future reduction is intended to allow the use of advanced after treatment technology if needed. The obvious goals of the regu-

lations are to complement the engines designs and fuel properties for a reduction in total emissions.”²

The ASTM specification list three No. 2 diesel categories S5000, S500, and S15 based on the fuel sulfur maximum content. The fuel are commonly referred to as High Sulfur Diesel (HSD) maximum of 5000-ppm, Low Sulfur Diesel (LSD) maximum of 500-ppm, and Ultra Low Sulfur Diesel (ULSD) with a maximum of 15-ppm sulfur.

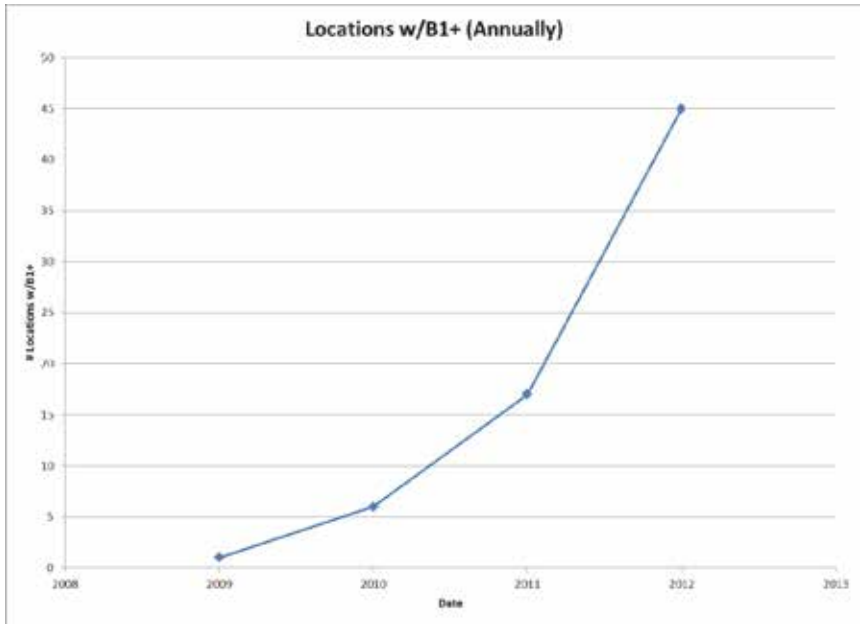


Figure 1: Number of Locations using Biodiesel

This chart represents the number of locations from which we received at least one sample which was tested to have at least B1 or greater. Fuel could have been DTL, tank car, truck, pipeline or storage tank.

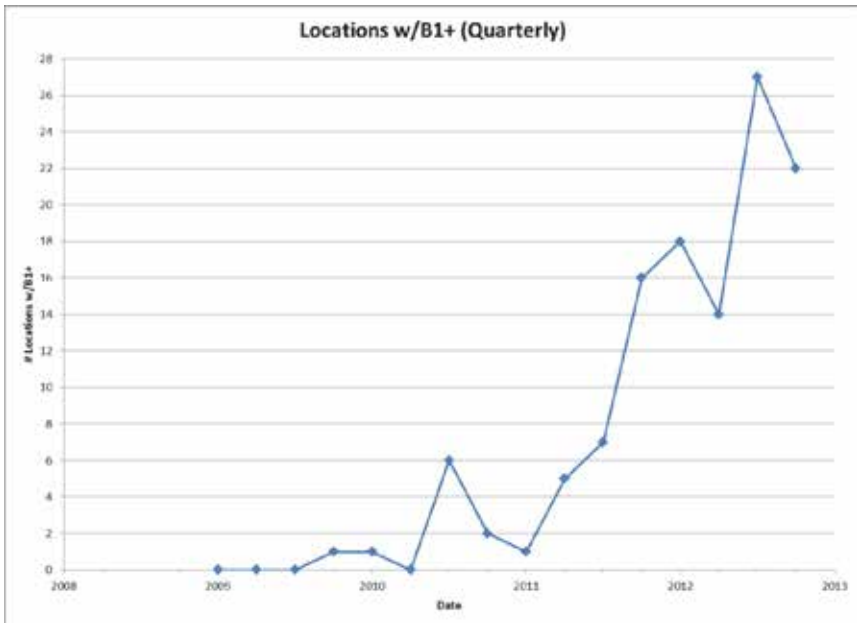


Figure 2: Number of Locations using Biodiesel by Quarter
 Same info as figure, 1 but broken down by quarter. The rate is clearly variable

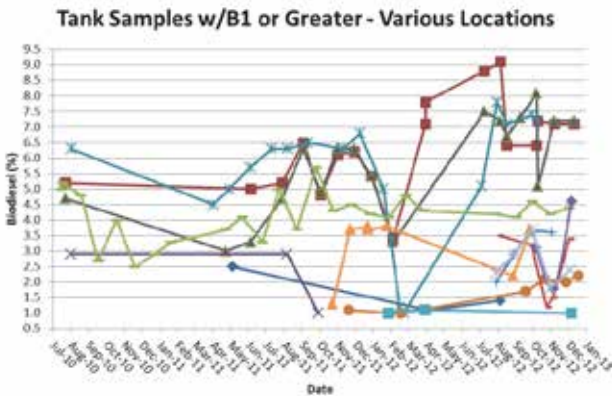


Figure 3: Concentration of biodiesel, B0 to B5 at those locations
 This chart displays the concentration of biodiesel received over time at 13 locations across the system. The biodiesel level is clearly not consistent over time. Also note, the data points are connected for clarity – this does not indicate the BXX percent followed the line specifically, especially if a long time interval is involved



*Figure 4: Additional images – Filter Plugging 2011-2012:
Monoglyceride crystals beginning to form in B100 biodiesel after being held
at 40F for 3 days*



*Figure 5: – end result, B100 held at 40F for 3 weeks. 40F was far above the classic
'cloud point' of the fuel*



Figure 6: Pasty residue recovered from plugged filters. Analysis revealed mainly palmitate (C16:0) and stearate (C18:0) monoglycerides.



Figure 7: Early Detection – Filter Plugging 2013

A ‘brown cloud’ of material was found to form during an in-house cold soak filter plugging test of mixed B5 fuel at approximately 40°F. Detection of this helped avert a major filter plugging incident. The fuel was found to fully meet all other applicable specifications for quality. ASTM D2500 cloud point was approximately 0°F.

Second ‘brown cloud’ issue noted in April 2013. Same fuel test parameters listed above. Fuel is approximately B5 concentration with 0.004% water by Carl Fischer water titration. ASTM D2500 cloud point was approximately 0°F.



Figure 8: HPCR Injector with sticking pilot valve

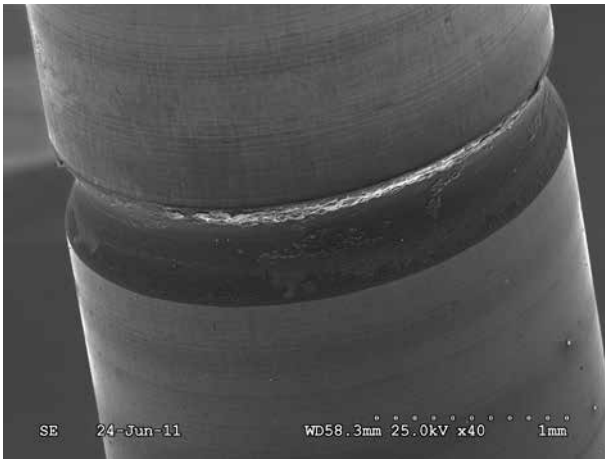


Figure 9: HPCR Injector with sticking pilot valve



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Locomotive Fuel & Lubricant Oil Filters 101

Prepared by:

Peter Whallon, Clark Filter

&

Jonathan George, Ph.D., Parker Filtration Canada

Introduction

The role of lubricating and fuel oil filters on diesel locomotives has been and will continue to be critical in the operation and maintenance of these costly and increasingly sophisticated machines. The applications and technology of locomotive filtration have changed significantly since the early days of dieselization as reflected in the continual evolution of element filtration media, element configuration and filter maintenance intervals over the past half-century.

The purpose of this paper is to provide a general overview of diesel locomotive lube and fuel filtration while focusing attention on the following topics:

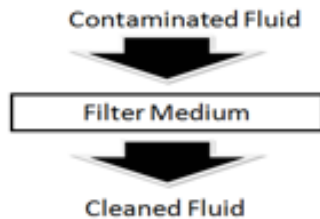
- A) Principles & Functions of Filtration
- B) Principles of Filter Testing
- C) Evaluation of Filter Performance
- D) Locomotive Filter Applications
- E) Future Trends & Challenges

Preface Statement

While it is not the purpose of this paper to prove through research or empirical data the correlation between filtration and locomotive reliability, it is generally accepted that proper filtration can and will reduce engine wear, engine failures and reduce unit exchange scrap rates.

A. Principles & Functions of Filtration

1. Filtration: The process of collecting solid particles from a contaminated fluid by passage of that fluid through a permeable medium where the particles are retained.



2. Function of Filtration: Remove particulate (insoluble contaminant) that contributes to the wear or deterioration of critical engine components.

3. Insoluble Contaminants

- a) Built-In: Residual from the fabrication process
 - Casting sand
 - Metal working chips
 - Weld slag
- b) Ingressed: Enter engine from external environment
 - Airborne dust & dirt
 - During routine maintenance activities

- c) Generated: Products of normal engine operation
 - Combustion soot
 - Wear metal particulate
 - Lube oil oxidation by-products
 - Lube oil acid neutralization by-products
 - NOTE: do not miss required oil change outs!

B. Principles of Filter Testing

1. What is a “Micron”?

- a) Measure of length (μm or μ)
- b) Common terminology
 - “micron”
 - “micrometer”
- c) Conversion factors
 - 1 micron = 1/1,000,000 meter = 1/25,400 inch
- d) Relative sizes
 - 40μ = smallest visible with naked eye
 - 75μ = diameter of average human hair

2. Filter Ratings

- a) Are Not:
 - Universally defined
 - Consistently applied by filter manufacturers
 - Well-served by terminology as “nominal”, “absolute”, “average”
 - Determined by media pore size
- b) Are:
 - Needed for commonality within an industry
 - Applicable only to a particular test procedure (measure of test results)
 - Best expressed in terms of “Filtration Ratio” (multi-pass test)

3. Multi-Pass Filter Test

- a) Developed in 1978 at Oklahoma State University
- b) Measures separation efficiency at selected particle sizes
- c) Measures dust-holding capacity at specified terminal pressure
- d) Most accurate & objective method for comparing filter performance

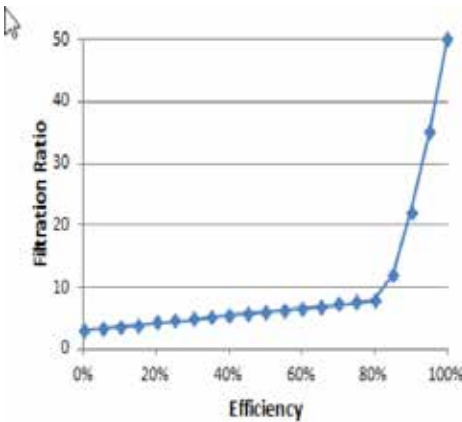
NOTE:

- laboratory test results do not necessarily relate directly to field performance
- test results best for purposes of filter comparison & product development

4. Filtration Ratio (“F.R.”)

- a) Determined by multi-pass test
- b) Best measure of a filter’s ability to remove particulate contamination
- c) Derived from the ratio of upstream to downstream particles

NOTE: Filtration Ratio is a severely non-linear function of efficiency



5. Filter Efficiency

$$\text{Filtration Ratio (F.R.)} = \frac{\# \text{ upstream particles} \geq \text{designated size}}{\# \text{ downstream particles} \geq \text{designated size}}$$

$$\text{Filter Efficiency} = (1 - 1/\text{F.R.}) \times 100$$

Example:

Calculate filter efficiency for particles ≥ 10 microns

Upstream count = 11,250 particles; Downstream count = 150 particles

$$\text{F.R.} = 11,250/150$$

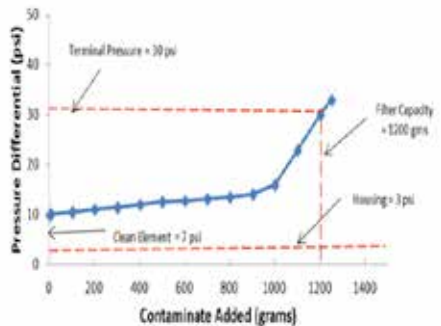
$$= 75$$

$$\text{Filter Efficiency} = (1 - 1/75) \times 100$$

$$= 98.7\%$$

6. Filter Capacity

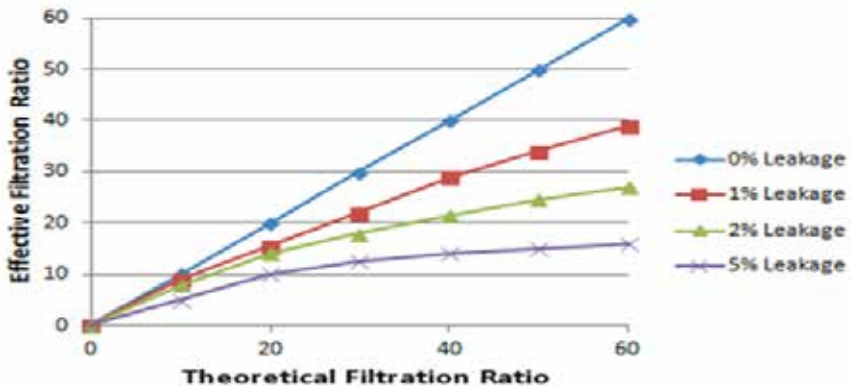
- a) Measure of a filter’s ability to maintain permeability during the filtration process
- b) Determined by pressure drop resulting from increased contaminant loading
- c) Amount of contaminant retained by filter at specified terminal pressure



3. Common Causes

- Filter media by-pass due to handling damage
- Defective element-to-housing interface seal
- Malfunctioning by-pass or relief valve
- Element by-pass due to construction defect

NOTE: Prevention of by-pass far more critical than achieving high filtration ratios



D. Locomotive Filter Applications

1. Lube Oil Strainers

- Primary Function
 - Protection for lube oil pumps
- Geometries
 - Cartridge
 - All-metal construction
- Filter Media
 - Wire mesh (fine or coarse)
- Service Interval
 - Cleanable



2. Turbo & Soak Back Filters

- a) Primary Function
 - Protection of EMD turbo-charger bearings
- b) Geometries
 - Spin-on
 - Cartridge
- c) Filter Media
 - Pleated paper
 - Typical micron size: 20μ
- d) Service Interval
 - 92-184 days



3. Main Lube Oil Filters

- a) Primary Function
 - Protect against engine and bearing wear
- b) Geometries
 - Cartridge (6"x30")
- c) Filter Media
 - Pleated paper
 - Typical micron size: 12μ , 20μ , 30μ
- d) Service Interval
 - 92-184 days



4. Fuel Strainers

- a) Primary Function
 - Protection of fuel transfer pump
- b) Geometries
 - Cartridge
 - Spin-on
- c) Filter Media
 - Pleated wire mesh
 - Typically 30-mesh ($\sim 600\mu$)
- d) Service Interval
 - 92-184 days



5. Primary Fuel Filters

- a) Primary Function
 - Protection of injector pumps & nozzles
- b) Geometries
 - Cartridge (10" O.D.)
 - Length: 30" or 45"
 - Cartridge segments: 1, 2 or 3
 - Filtration-type: single or double-pass
- c) Filter Media
 - Pleated paper
 - Typical micron size: 5μ , 12μ
- d) Service Interval
 - 92-184 days



6. Secondary Fuel Filters

- a) Primary Function
 - Protection of injector pumps & nozzles
- b) Geometries
 - Spin-on
 - Cartridge
- c) Filter Media
 - Pleated paper
 - Typical micron size: 5μ , 12μ
- d) Service Interval
 - 92-184 days



7. Wayside Fuel Filters

- a) Fuel Pumping Stations
 - Protection of locomotive injector pumps & nozzles
- b) Geometries
 - Cartridge (6", 10" O.D.)
 - Length: 30"
 - Cartridge segments: 1 or 2
 - Filtration-type: single or double-pass
- c) Filter Media
 - Pleated paper
 - Typical micron size: 10μ
- d) Service Interval
 - Determined by pressure drop and/or time interval



E. Future Trends & Challenges

1. Advanced fuel system technology will drive need for improved filtration

a) Common rail fuel injection systems require fuel with very low water content and will need to incorporate on-board water/fuel separators.

b) Common rail fuel systems will require fuel with high degree of particulate cleanliness via on-board filters with increased efficiency as much as five times greater than Tier 2.

2. Language of fuel filtration evolving from “Filtration Ratio” to “ISO Code”

3. ISO Code

a) Measure of filter performance testing per SAE J1985

b) Results reported in “particles per milliliter” at specific micron-sizes

c) Utilizes 3-number system to classify fluid cleanliness at 4μ, 6μ, 14μ

d) Example: ISO Code = “12/9/7”

- “12” designates level of fluid cleanliness at particle size 4μ and larger

- “9” designates level of fluid cleanliness at particle size 6μ and larger

- 7” designates level of fluid cleanliness at particle size 14μ and larger

ISO Cleanliness Code Table

	ISO NUMBER	Number of Particles Per Milliliter	
		MORE THAN	UP TO
@4u	14	80	160
	13	40	80
	12	20	40
	11	10	20
@6u	10	5	10
	9	2.5	5
	8	1.3	2.5
@14u	7	.64	1.3
	6	.32	.64

4. Challenges Ahead

- a) Will locomotive filtration needs change in the future?.....YES!
- b) Major factors affecting filtration system performance
 - Fuel types (i.e. ULSD, biodiesel, natural gas)
 - Cold weather issues
 - Water issues (greater tendency to attract & retain moisture)
 - Solvency issues (fuel system deposits, component compatibility)
 - Carboxylate soap deposits
 - Fuel injection technology requirements (high pressure common rail)
- c) New on-board and wayside filtration technologies
 - High-efficiency particulate removal
 - Water separation & removal

Summary

Quality lubricating and fuel oils, commonly considered the “lifeblood” of a diesel locomotive engine, are essential to achieving long and reliable performance from these high-output machines from which so much is demanded over the typical 20+ year life cycle. At the same time, the importance of good filtration of these critical engine fluids cannot be overstated relative to the needs of today’s railroads for long-term, dependable locomotive service.

Locomotive filtration technology has continued to evolve in accordance with changes and improvements in

diesel engine design. Those changes require improved quality of filtration to better protect the components and systems delivering ever-increasing levels of engine performance. New fuel formulations and advances in locomotive technology borne from low-emissions requirements have resulted in significant challenges for locomotive filtration. However, as the railroad filter supply community has proven capable in the past of meeting emerging industry and technology needs, it again welcomes the challenges that lie ahead.

Acknowledgements

The authors would like to thank all members of the Fuels, Lube & Environmental committee for their assistance and counsel in the preparation of this paper.

Generation 6 Locomotive Engine Oil Properties

Prepared by:

Thomas E. Gallagher, Chevron Oronite Company LLC

LMOA Generation 5 locomotive medium speed diesel engine oil performance standard was successfully defined in 1989 to effectively address changes in locomotive engine design, utilization and maintenance that had significantly changed from the introduction of the previous generation oil in 1976. Due to Environmental Protection Agency (EPA) fuel and emission regulations, locomotive engine design, utilization and maintenance have been significantly impacted. Chemical and physical performance attributes of locomotive engine oils were researched, developed and field tested to meet these compounding factors.

The 2009 paper presented by the Fuels, Lubricants and Environmental (FL&E) Committee of the Locomotive Maintenance Officer's Association (LMOA), titled "New Generation Oil Additive Technology for Locomotive Engines Operating on Low and Ultra-Low Sulfur Diesel Fuel" details a multi-year effort to identify and successfully field test a new low ash locomotive engine oil additive technology. The table below is taken from the referenced paper and has been updated to include the addition of two (2) new generations in the classification system.

LMOA Generation 6 locomotive engine oils are formulated to address

the consumption of low (≤ 500 ppm) and ultra-low (≤ 15 ppm) sulfur diesel via an optimized lubricant additive package with consideration for environmental emission concerns.

The FL&E committee defines Generation 6 diesel locomotive engine oil performance attributes and qualities per the following:

- The finished oil formulations must demonstrate good deposit and wear control, alkalinity retention, viscosity control, thermal & oxidative stability, engine cleanliness & sludge control in locomotives that have lower oil consumption resulting in longer residence time of the oil in the engine's sump
- The new finished oil formulation must be suitable for use in locomotive fleets with Tier 3 and earlier locomotive engine models
- The new locomotive engine oil additive technology must be tested to demonstrate acceptable compatibility with existing original engine manufacturers (OEMs) approved oil formulations

Table 1. LMOA Locomotive Engine Oil Generations: New GEN 6 & 7

LMOA Generation	Effective Year	Typical BN	Performance Milestones of Locomotive Engine Oil Advancements	Formulation Issues
1	1940	<7	Straight mineral oils	Lost alkalinity, lead corrosion, bearing failures
2	1964	7	Ashless dispersants, improved alkalinity with calcium detergents	Reduced sludge & better oil filtration
3	1968	10	Improved alkalinity retention, higher dispersant levels, calcium detergents	Reduced piston ring wear, reduced corrosion
4	1976	13	Improved alkalinity retention with improved detergents & dispersants	Increased protection for adverse engine operating conditions
5 / 4LL	1989	13 / 17 / 18	Improved drain intervals in low oil consumption engines	Longer life oils that meet LMOA definitions & requirements
6	2009	9 / 10	Optimized dispersant & detergent system for low sulfur diesel (≤ 500 ppm) & ultra low sulfur diesel fuel (≤ 15 ppm) for low oil consumption engines	Proper balance of lube oil alkalinity in consideration of fuel sulfur levels while maintaining established oil drain intervals; concurrent with reduction in sulfated ash in the oil
7	TBD	?	TBD – based on Tier 4 requirements	TBD – based on EPA Tier 4 requirements effective January 1, 2015

- Used oil analysis trending of the finished oil formulation must demonstrate the ability to maintain established locomotive maintenance intervals without breaching OEMs used oil condemning limits
- The finished oil formulations must pass all required tests by OEMs (e.g. oxidation, corrosion and friction tests)
- The finished oil formulation must also be field tested in accordance with the following:
 - o Field testing must be conducted in accordance with the procedures prescribed in the LMOA FL&E paper titled “Engine Lubricating Oil Evaluation Field Test Procedure” given in the year 2000
 - o The field test protocol must be reviewed and approved by the OEMs, host railroad and the additive company

- o The select locomotive engines must be operated in a service having a severity level acceptable to the OEMs
- o Resultant field test data must be reviewed by the OEMs for issuance of approval and recognition letters
- The use of a LMOA Generation 6 oil is not recommended for use in locomotives consuming diesel fuels with a sulfur content exceeding 500 ppm

LMOA Generation 7 locomotive engine oils will be required to address engine modifications necessary to meet 2015 EPA Tier 4 Emission Standards for locomotives. Reference Table 1. Engine design, metallurgy, and use of emission reduction technologies, (e.g. diesel oxidation catalysts, diesel particulate filters, exhaust gas recirculation, selective catalytic reduction, etc...) will significantly influence engine oil properties and performance attributes.

The FL&E committee will continue its efforts to ensure that the lubrication needs of modern locomotives are met.

Report on the Committee on New Technologies

Tuesday, October 1, 2013 at 8:45 A.M.



Chairman

Tom Mack

Chairman of the LMOA New Technologies Committee
Cincinnati, OH

Vice Chairman

Jeff Clapper

Supt-Motive Power
Wheeling & Lake Erie Rwy

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B. Wolff	Sales Engineer-Rail	MTU	Detroit, MI
C. Wyka	Senior Reliability Specialist	CN RR	Edmonton, Alberta

Note: Jason Smith will be replacing Tarek Elkhatib as UP replacement on this committee

PERSONAL HISTORY

Tom Mack

Tom Mack has worked as Vice President of Sales and Business Development for Motive Power & Equipment Solutions, Inc. since 2011.

Prior to joining MP&ES, Tom Mack 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 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 works with the AAR Natural Gas Fuel Tender Technical Advisory Group (AAR NGFT TAG). He also served on the SAE TC-7 Biodiesel in Rail committee.

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

The New Technologies Committee would like to express their sincere appreciation to MTU and Bruce Wolff for hosting our Winter meeting at the engine plant in Aiken, South Carolina.

We would also like to thank Motive Power & Equipment Solutions for hosting our Spring meeting in Cincinnati, Ohio and the Cincinnati Railroad Club for allowing us to meet in their facility in “Tower A” at the Cincinnati Union Terminal.



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LDARS and CMM

Prepared by:

Connie Nordhues

Nomad Digital Solutions

and

Tom Mack

Chairman of the LMOA New Technologies Committee

Since 1993 locomotive event recorders have been required for heavy and light-rail transportation systems. These event recorders have been an important tool in evaluating everything from locomotive performance to crew performance and are invaluable in crash investigation and recreation. In the 20 years since event recorders became mandatory locomotives have gone through major changes, especially in regard to the electronic systems carried on-board. Each discrete electronic device seems to have its own set of data that is collected. Even engines, high voltage inverters, and some electrical rotating equipment now provide a wealth of data, from temperature, to power outputs, that can be tracked. All of this information can have practical application if collected and reviewed.

While much of this data is available, not all of it is actually collected. What is collected may be transmitted via remote monitoring systems to a central site, but there are always intervals of time when data is not transmitted but still available and collected by onboard data acquisition systems. Where do we store all this data on the locomotive? Does it make sense to store data in multiple systems on

the locomotive and have to retrieve it from multiple locations? What about the new systems that record video or audio? These systems require huge amounts of data storage space. Most importantly, what if our locomotive is involved in an accident? Is the data collected by all these systems safe?

Because of the growth of electronic systems on locomotives, the AAR developed a new standard practice, Standard S-9101B adopted in 2011, to address Locomotive Data Acquisition and Recording System (LDARS) Architecture. This standard applies to new locomotives ordered after January 1, 2012, and states:

“The intent of this architecture standard is to provide requirements for the Locomotive Data Acquisition and Recording System (LDARS) to include the Event Data Acquisition Processor (EDAP) and Crashworthy Memory Module (CMM) storage functions and a standardized interface for retrieval of stored data. The EDAP and CMM requirements can be physical, logical, or electrical. The EDAP will be expressed as either a process or processor(s). A process is a functional and a processor is a physical (device or component) representation.”

In addition to the AAR S-9101 standard, the following also come into play:

- CFR Title 49 Part 229.135 – Event Recorders
- IEEE STD 1482.1-1999, IEEE Standard for Rail Transit Vehicle Event Recorders, 26 June 1999
- AAR Standard S-5702, “Railroad Electronics Environmental Requirements”

This paper is not designed to provide all the information contained in S-9101B, but it will acquaint the reader with some of the highlights and illustrate how this standard can be incorporated into a CMM device.

LDARS Overview

A Locomotive Data Acquisition and Recording System (LDARS) is actually based on two distinct functions that may or may not be combined. The first is the Event Data Acquisition Process (EDAP) which provides an interface to different systems onboard the locomotive and writes the data to the Crashworthy Memory Module (CMM). The CMM, or CHMM (Crash Hardened Memory Module) as it is sometimes called, is a protected storage device similar to the “Black Box” on an airplane that provides a high-survivability, protected storage repository for all the accumulated locomotive data.

The CMM must be able to survive extreme conditions. S-9109, Table 2.1 requires the following environmental conditions be able to be met by the CMM:

Condition	Requirement
Fire, high temperature	750 °C (1400 °F) for 60 minutes
Fire, low temperature	260 °C (500 °F) for 10 hours
Impact shock	55 g peak, 100 ms duration, 1/2 sine crash pulse, no less than 28 m/s velocity area under curve, separately in the direction of each of the three principal axes
Static crush	110 kN (25 000 lbf) for 5 minutes
Fluid immersion	Immersion in any of the following individually for 48 hours: • grade 1 and 2 diesel fuel • salt water • lubricating oil Followed by immersion in fire-extinguishing fluids for 10 minutes. Followed by 48 hours in a dry location without being otherwise disturbed.
Hydrostatic pressure	Immersion in salt water at a depth of 15 m (50 ft) for 48 hours at a nominal temperature of 25 °C (77 °F)

Figure 1: S-9109 Table 2.1

In addition to having to withstand external forces, the CMM must also be reliable. S-1909 requires that these devices have a minimum MTBF (Mean Time Between Failures) of 50,000 hours. Similar to the CMM, the EDAP should have a minimum MTBF of 30,000 hours.

The CMM needs to be sized according to the amount of data it will be storing. If a railroad wants to store PTC and/or digitized video data, a larger amount of memory will be needed. The amount of memory needed will also be affected by the number of days' worth of data that will be stored. Clearly a CMM storing seven days of data (the "desirable" amount of contiguous data stored per S-9109) will be significantly larger than a CMM that only stores two days of data (the minimum amount of contiguous data that should be stored per S-9109). In addition to the amount of data storage, the data that is currently stored in the CMM must be able to be retained for an extended period of time, preferably a year or more, once power is removed from the CMM unit.

CMM requirements are also addressed in the following official documents:

- IEEE STD 1482.1-1999, IEEE Standard for Rail Transit Vehicle Event Recorders, 26 June 1999
- AAR Standard S-9101, "Locomotive Electronics System Architecture"
- AAR Standard S-5512, "Locomotive Event Recorder Download Standard"
- AAR Standard S-5702, "Railroad

Electronics Environmental Requirements"

- 49 CFR 229, Appendix D—Criteria for Certification of Crashworthy Event Recorder Memory Module

There are also additional AAR standards such as S-9354, S-9355, and S-9356 that outline various messaging and communication protocols that may apply to the EDAP process.

To Combine or Not To Combine

Since LDARS includes two distinct functions, it is left up to the railroad to decide whether it is best to combine these two functions in one module or leave them as two separate but connected systems. This electronics architecture is not mandated. In essence this allows a railroad to choose between two different suppliers/manufacturers for the EDAP and CMM units. The S-9109 standard allows for either option, at the railroad's discretion.

In the case of a separate EDAP and CMM, the CMM can be looked at like an external hard drive on a computer. While some computers have a built in hard drive (the "combined" EDAP/CMM), sometimes it is easier to add a separate, external hard drive. Sometimes a computer user prefers one brand of computer but another brand of hard drive that may not be available from the OEM computer manufacturer. The functionality of the computer does not change whether it has an internal or external hard drive. Hence the S-9109 standard allows railroads to choose to use a single EDAP/CMM system vendor, or mix-and-match.

Data Acquisition and Writing To / Reading From the CMM

There is no specific data acquisition (sample rate) required for an EDAP system. This is because different events have different timing. For example, some events may only need to be monitored once per second, or even less. This might include engine temperatures, ambient temperatures, etc. Other data may be monitored every few milliseconds. Still other data may be event driven.

Once this data is acquired by a locomotive system (e.g. an engine monitoring/control system), it is up to that discrete system to deliver the information to the EDAP. The time between the discrete locomotive system obtaining a piece of data and that data being sent to the EDAP processor is known as Data Sample Latency. There is now specific standard for the maximum length of data latency before it is passed to the EDAP and CMM systems. There is thus always the chance some of this data could be lost in the event of a catastrophic event. In reality, this data loss should be minimal, as long as discrete locomotive systems do not hold or “cache” the data for excessive periods of time before passing it on to the EDAP. Manufacturers of locomotive electronic system should keep in mind, however, that their data needs to be regularly sent to the EDAP/CMM system and should not be retained just within their own system.

Data sent to the EDAP can be in different formats, but the main function of the EDAP is to “normalize” or

convert the data into a common format if possible. This common format is known as an EMP Class D message format. In this way the data sent to the CMM is for the most part in a standardized form which requires minimal processing by the CMM. This ensures that any data sent to the CMM can be as quickly as possible transferred to the “safe” section of the CMM, the crashworthy memory itself. While newer electronic systems can take into account an LDARS system, many older systems may not, or a system may be required to use an existing proprietary data format. EDAP allows for this variation of data.

All data fed to the LDARS should be time stamped from the originating system. What though if data coming from different sources has different times on it, due to slight variances in each systems internal clock setting? Every data item stored in the CMM is time-stamped. This time-stamp created by the LDARS system is based on a single, standard clock. In addition to this “standard” time stamp, the LDARS system is mandated to maintain the “relative time” of the source data, along with the “referenced” time of the LDARS. In this way raw data from the source system can be cross-referenced with data in the LDARS.

When data is written to the CMM, it is important that it is written in the right way. The CMM vendor is required to use a “data overwrite” scheme, not an “erase then add” scheme, where the oldest data is overwritten first. Since there are multiple data feeds to the CMM, the memory

has to logically be divided in such a way that no one type of data (e.g. video vs. audio vs. telemetry data) “hogs” the entire memory module. For example, since video data usually requires large amounts of memory, it would not necessarily be advantageous to have this video data take up too much CMM memory, thus reducing the amount of actual systems data stored. In essence different partitions can be allocated for different types of data feeds. Because of the different sizes of these partitions correlated with the size of the data elements, an LDARS system could potentially store more days’ worth of straight systems data (e.g. seven days of data), than video (e.g. three days of data). This is known as Time-to-Live (TTL) of the data elements, and these parameters must be decided on by each railroad. These TTL parameters will also affect the choice of what size CMM a railroad will decide to deploy on its locomotives. Railroads should, however, take into account a very practical suggestion stated in S-9109: “To extend the time between downloads, memory should be as large as practicality, economics, and reliability permit.”

While the data stored in and retrieved from the LDARS system’s CMM needs to be in a standardized format, the actual data stored in the CMM can be vendor specific, depending on the source. Since the CMM can conceivably store very large amounts of data (multi-Gigabyte capacity), the CMM unit should be equipped with one or more high-speed data interfaces. S-9109 suggests that at minimum

an 802.3 Ethernet 10 Base T connection be used. The standard, however, allows for a number of different interfaces, and the CMM can have more than one interface. S-9109 lists a number of different interfaces:

1. USB port
2. Ethernet port (M12)
3. On-board communication services
 - a. Wireless Ethernet
 - b. Digital Cell (as specified by the owning railroad)
 - c. S-5800 Railway Communications Specification
 - d. 220 PTC (TBD)

Since the S-9109 standard allows for a variety of interfaces, it is up to each railroad if they want to perform data downloads via an AAR S-9109 compliant LAN connection (e.g. 802.3 Ethernet 10/100Base-T), a direct cable connection (e.g. RS232, RS422, USB), or even via a wireless connection (such as 802-11b/g/n WiFi). Some CMM systems provide multiple connection options on their unit, thus giving the railroad a wide variety of choices from a single model CMM.

There are also multiple types of data access software interface options, though not all may be supported by a specific CMM manufacturer. These include:

- Interactive Access and Query
- Interactive Download Query
- Command Line Access and Query

The above three options can basically be further broken down into two functional forms – interactive and command line. To support these two different

forms of data access, data exchanges are built around standard IP and HTTP computer protocols. This means that in addition to a simple character-based command line access and query, an LDARS and/or CMM manufacturer can create a sophisticated interactive web browser based software system. The S-9109 standard states that the download interface should use HTML format, which is well known and commonly used by programmers. By using an HTTP/HTML interface the LDARS can be accessed directly through a web browser without any additional software being needed. Anyone who has set up their own WiFi router/hub is familiar with the use of an HTTP/HTML interface. By simply entering an IP address into the browser the user is connected to the device and presented with a setup screen where system parameters are set and data can be retrieved. There is no need to install any special software beyond the browser on the computer accessing the system. Additionally, the system being accessed (e.g. a WiFi router, or in this case, the LDARS or CMM system) can be securely password protected. Details for manufacturers developing the LDARS access and query software are found in S-9109.

Finally, LDARS and CMM systems are expected to provide remote diagnostic capability to support trouble shooting of a failed or failing system without having to remove the hardware. This includes the capability of connecting via a wireless connection to third party remote diagnostic systems connected to a central monitoring site.

Example of an Existing CMM system

So just what does the new CMM locomotive “Black Box” look like? S-9109 requires that the CMM be painted bright orange. 49 CFR 229, Appendix D states: “The CMM shall be painted international orange with retro-reflective material applied to the edges of each visible external surface and marked in accordance with FRA regulations.” (See Figure 2)



Figure 2: A Stand-Alone CMM

In Figure 2, note that this CMM is not part of a combined EDAP/CMM system. This CMM would be used with a stand-alone EDAP system. Together the two systems would make up the LDARS.

Also note that the CMM has multiple connections. These include:

- Power (can be isolated 74VDC, non-isolated 5VDC, or other voltages depending on manufacturer)
- USB
- Ethernet (100Base-T)
- RS-232
- RS-422

Any external connections, such as power connectors, Ethernet, or serial interfaces should use a robust MIL-spec connector. When discussing the download interface, S-9109 specifically mentions the use of an Ethernet M12 connection. The M12 connection is different from the RJ45 connection commonly used in the Ethernet networks found in a home or office. While both are adequately designed to maintain high data throughput and reliability, the RJ45 connections commonly found in stationary networks are not designed for the harsh mobile environment on a locomotive. Hence an M12 industrial Ethernet connection is preferred. The same goes for other connections on the CMM.

In addition to the connections shown above, the unit may also have:

- Ethernet (10Base-T – slower than 100Base-T)
- Wireless

In the unit shown in Figure 2, the communications/CPU portion of the CMM is contained in the smaller section at the front of the unit (the FEM or Front End Module), while the memory itself is in the larger section to the rear of the unit (the PMM or Protected Memory Module). Note that the larger section in the rear is made of a much thicker metal than the front section. And if you think about the size of even a high capacity, multi-gigabyte USB memory stick, it is clear that much of the space for the actual memory portion of the unit is simply steel and insulation. It is not necessary for the processor portion or connectors at the

front of the unit support a crash. As the architecture block diagram in Figure 3 shows, what is critical to survive the crash is the actual memory and front end processor for the memory itself which is housed in the PMM. This ensures that the data can be accessed and downloaded by the manufacturer or accident investigators. The multiple data access mechanisms and power supply in the front of the unit (the FEM) is only needed during normal operation.

Each manufacturer of a separate CMM or combined EDAP/CMM LDARS is at liberty to design their unit as they see fit. Hence each railroad does well to evaluate the different systems on the market. Some may have more or less data access. Some may provide for only hard-wired connections, some may include wireless.

As mentioned at the beginning of this paper, this paper is not intended to take the place of the information found in AAR S-9109. A railroad should familiarize themselves with not only the AAR S-9109 MSRP (S-9101B was Adopted in 2011) but should also consider evaluating the data access software provided by the manufacturer. While new locomotives built in accordance with the LDARS standards should have the EDAP and CMM already fully integrated into the locomotive design, with various onboard applications and locomotive control systems already integrated, older locomotives will not. Hence retrofitting existing locomotives with EDAP and CMM functionality will require some study and perhaps adaptation or

changes to systems already installed. Railroads will thus need to work closely with their equipment vendors and the LDARS supplier in regard to their support of any proprietary electronics systems that may already be installed on the locomotive fleet.

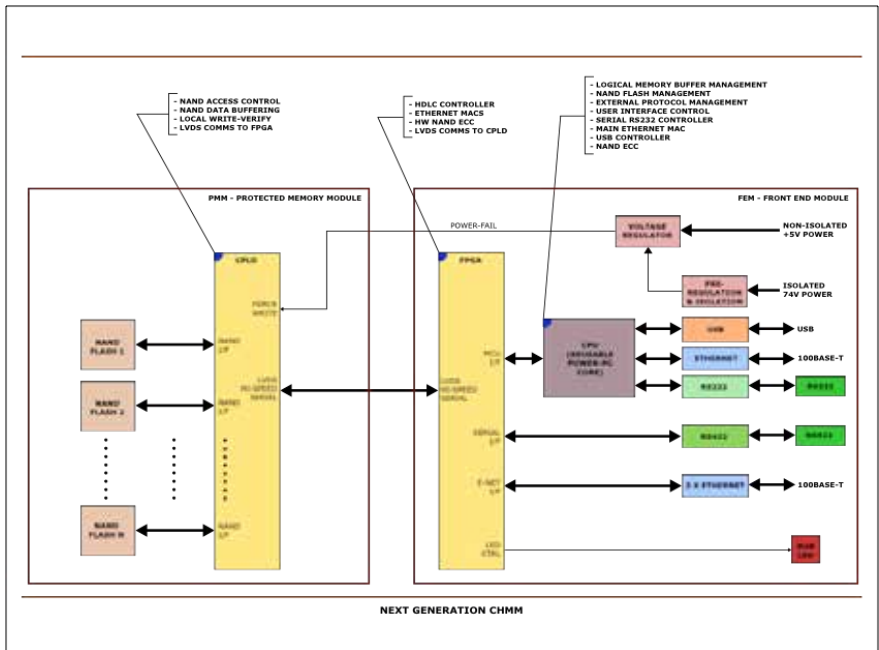


Figure 3: Stand-Alone CMM Block Diagram

Natural Gas Locomotives

Prepared by:

Tom Mack

Chairman of the LMOA New Technologies Committee

The use of natural gas as a transportation fuel is nothing new. Even for locomotives, experiments with propane fuel stretch all the way back to 1936 when the Plymouth Locomotive Company built a 450 HP propane fueled locomotive for the Joplin-Pittsburg Railroad in Missouri, which later worked for the Kansas City Public Service Company local freight railroad in the Kansas City area. (Interestingly this locomotive still exists and is on display at the Museum of Transport in Kirkwood, MO.) In 1953 Union Pacific even modified one of its massive 4,500 HP gas turbine locomotives to use propane, complete with a silver-painted propane fuel tender.

More recently, 1987 to 1995 Burlington Northern ran two converted EMD SD40-2's to run in dual fuel mode (natural gas and diesel). The natural gas was stored as Refrigerated Liquid Methane (RLM), which is basically the same as Liquefied Natural Gas (LNG). These locomotives ran in actual revenue service from 1992 to 1995. Starting in 1993 four LNG powered locomotives were used by the Union Pacific and Santa Fe railroads. All four LNG locomotives ended up on the BNSF in service in the Los Angeles, CA basin where locomotive emissions

come under close scrutiny. These locomotives operated for almost 20 years, and were just recently retired.

Because of continued high prices for diesel fuel (with no end in sight), coupled with low prices and high availability for domestic sourced natural gas, railroads are once again looking at this cheap domestic fuel as a viable mainstream alternative to diesel. One magazine writer even compared the upcoming move to natural gas for railroad locomotives as tantamount to the switch from steam diesel. While it is yet to be seen if a switch to natural gas will really match the magnitude of the switch from steam to diesel, there appears to be good reason for railroads to take a serious look at natural gas as a viable locomotive fuel.

This paper is not intended to present all the pros and cons of natural gas vs. diesel fuel. Nor is it intended to cover in detail every potential technology that can be applied to convert diesel locomotives to natural gas. This paper is expected to be the first of what will no doubt be a number of papers presented by LMOA committees on natural gas locomotive technologies, maintenance, and support, and as such will primarily cover basics of what will no doubt become a very popular topic, namely,

natural gas locomotives. As such, this paper will cover four basic areas:

- Natural gas as a locomotive fuel
- Economics of natural gas
- Natural gas locomotive emissions
- A primer on different natural gas locomotive technologies including:
 - o Fuel Storage
 - o Fuel Safety/Risks
 - o Engine Technologies
 - o On-board Fuel Storage and Fuel Tenders

Natural Gas as a Locomotive Fuel – Why Now?

There is no doubt that the move has been on for some time by railroads to investigate the potential of alternative fuels, including renewable fuels (e.g. biodiesel, renewable diesel, ethanol). Dependence on primarily foreign supplied diesel fuel has not only been very costly to the railroads, but the threat of a limited supply of crude oil due to political unrest or changing global demands is a strategic issue as well. The answer to all this would clearly be a domestic (i.e. North American) sourced fuel that is abundant and cost competitive to diesel. It would not hurt for this fuel to be cleaner than diesel, cheaper than diesel, and easily adaptable to use in existing railroad locomotive designs. Natural gas seems to meet all the qualifications. What is more, it appears that its abundance and low cost will continue for the foreseeable future. This is critical to make it worthwhile for railroads to take the plunge on new equipment which has not only a clear short-range ROI, but a long-range ROI as well.

But why natural gas and why is it viable today but not before? To answer the first question, we simply need to look at the amount of natural gas available and the abundant supply channels now in place.

One aspect of natural gas that quickly becomes apparent is that North America, and especially the United States, has huge reserves of natural gas even compared to the rest of the world. Of special interest is that as new technologies to remove natural gas (such as hydraulic fracturing) and new studies come into play, the estimated reserves of natural gas in North America have actually risen over the last 20 years, not declined. In fact, the Eni World Oil & Gas Review 2012 shows that estimated North American natural gas reserves have gone up from 6.6 trillion cubic meters in 1995, to almost 10.9 trillion cubic meters in 2011. That is a 54% increase in estimated reserves. (See Figure 1)

Put another way, based on BTU content, one gallon of diesel fuel contains ~129,500 BTU of energy. One cubic meter of natural gas contains 35,316 BTU of energy. The 10.9 trillion cubic meter reserve of natural gas is the equivalent of about 3.2 trillion gallons of diesel fuel.

Natural Gas Reserves - Areas and Aggregates									
(billion cubic metres as at 31st December)									
	1995	2000	2005	2008	2009	2010	2011	Δ y/y (2011-2010)	CAGR (2011-2000)
EUROPE	8,131	8,597	7,483	6,847	6,567	6,149	6,280		2.1%
RUSSIA and CENTRAL ASIA	51,405	51,574	52,685	58,588	59,516	59,516	60,979		2.5%
MIDDLE EAST	46,852	39,145	72,493	75,199	75,489	76,667	79,032		8.1%
AFRICA	9,930	12,458	14,223	14,705	14,736	15,529	14,534		-6.4%
ASIA - PACIFIC	11,522	12,247	14,133	16,128	16,098	16,288	16,503		1.3%
AMERICAS	14,525	14,448	14,648	16,470	17,362	18,317	18,760		2.4%
- North America	6,605	6,707	7,479	8,679	9,799	10,770	10,660		5.2%
- Latin America	7,920	7,741	7,229	7,791	7,569	8,007	7,900		-1.8%
WORLD	142,365	158,469	175,665	187,937	189,760	192,466	196,068		1.9%
									2.0%

Figure 1 – Natural Gas Reserves (Eni World Oil & Gas Review 2012)

A recent study of May 2013 by the Potential Gas Committee (PGC) at the Colorado School of Mines puts these reserve numbers even higher. The study and report had this to say in regard to U.S. natural gas reserves:

“Last month, the PGC released its 2012 estimates. Most observers were expecting the numbers to rise from 2010, but the magnitude of the increase was still eye-opening. Potential reserves in 2010 were estimated at 1,897.8 Tcf; for 2012, those numbers jumped to 2,383.9 Tcf, an increase of more than 25%. When you pull out the coalbed methane numbers (which barely moved) and consider only traditional gas resources, the increase is even more dramatic, from 1,739.2 Tcf to 2,225.6 Tcf, a jump of 28%.

“When you add in the EIA proven reserves, the PGC’s estimate of total U.S. future gas supply rose from 2,202.4 Tcf to 2,688.5 Tcf—quite a significant increase for just two years.

“In 2012, according to EIA figures, the U.S. consumed 25.5 Tcf of gas, basically keeping pace with the increase in resource estimates.”

Based on the above EIA consumption figures, the PGC natural gas reserve estimates would last the U.S. over 100 years. So even with increases of natural gas use, the supply estimates for natural gas are high enough to justify a long-term outlook on ROI on any natural gas vehicle investments.

In addition to the amount of natural gas available, it is important to take into account its location. When any fuel

source is located in just a few strategic areas, the chances for supply disruptions and/or price volatility jump dramatically. This has been seen in recent years when a U.S. refinery catches fire or has some other supply disruption – the price of diesel and gasoline takes a significant jump. Natural gas fields are very evenly distributed throughout the world (see Figure 2).

As Figure 3 shows, the distribution of natural gas fields throughout the U.S. is extremely balanced. Canada

and Mexico have similarly distributed fields. A key is that natural gas is readily available throughout the entire U.S., and not just because of the mature natural gas pipeline network already in place. Major gas fields can be found not just in the south or southwest (e.g. Texas), but large fields also exist in the Northeast (e.g. the Marcellus formation) and north-central states (e.g. the Bakken formation). These natural gas sources are well situated to supply natural gas to North American railroads.

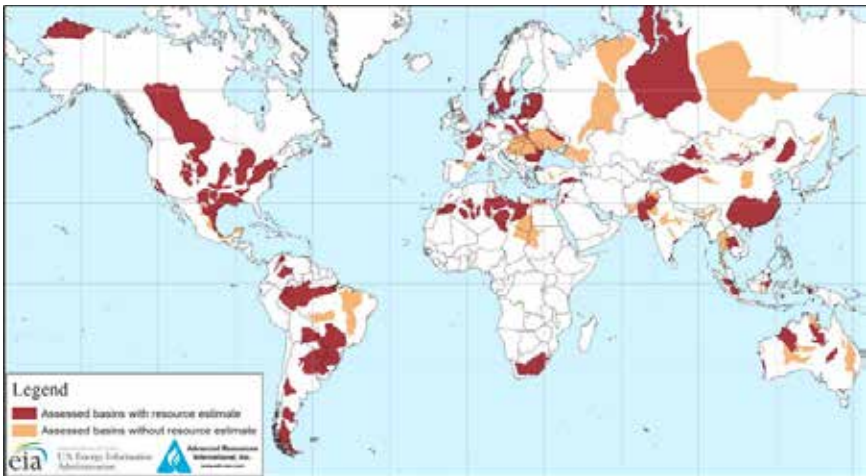


Figure 2 – Worldwide Gas Field Locations



Figure 3 – U.S. Gas Field Locations

Natural Gas Economics

Regardless of supply, cost factors must always come into play. For example, while proponents of the “hydrogen highway” liked to point out how abundant hydrogen is on earth, the cost to produce and transport the hydrogen has been a major setback to a practical move to hydrogen fueled vehicles. Natural gas prices, however, are extremely compelling to any transportation company considering its use as an alternative to diesel fuel.

Probably one of the most confusing aspects of natural gas is the way it is priced. Since natural gas is not a liquid, it is not measured in its basic form in terms of liquid gallons. Instead, natu-

ral gas is usually priced in “Therms”, or MMBtu (Million BTU’s). While natural gas prices have been as low as \$2.00 per MMBtu in 2012, prices in 2013 were back up at a more reasonable \$3.70 per MMBtu, and even broke the \$4.00 mark. While this may seem like a huge price fluctuation (which it was for natural gas suppliers), the \$2.00 per MMBtu price was undeniably a very low figure for the natural gas industry, and cannot really be used as a basis for calculating potential fuel costs. The current \$3.70 per MMBtu is probably a more realistic price base for future calculations.

But how does this \$3.70 per MMBtu correlate to our current diesel

fuel? First of all, in terms of raw energy content, each MMBtu of natural gas is the equivalent of about 7.72 gallons of diesel fuel (based on a diesel gallon energy content of 129,500 BTU). At \$3.70 per MMBtu, the price for natural gas extrapolates into a mere \$0.48 per Diesel Gallon Equivalent (DGE) of natural gas. In terms of raw energy content a 42 gallon barrel of oil contains 5,800,000 BTU of energy which is 44.79 DGE. At today's oil prices hovering at \$100 per barrel, the cost per DGE is \$2.23. That is over 4.5 times the raw energy cost of natural gas. With this huge price differential it is inevitable that the railroads take notice of natural gas as a potential locomotive fuel.

But what happens if prices fluctuate, as they often have? For now let's

leave the price of compression, liquefaction, or refining out of the equation. These prices tend to remain relatively stable anyway – the main contributor to pricing being the cost of the base natural gas or oil. Figure 4 illustrates how the BTU prices for diesel and natural gas both spiked in mid-2008. During that time oil hit a record \$148 per barrel. Natural gas hit over \$12 per MMBTU. While both energy sources took dramatic downturns through early 2009, oil quickly began its upward trend again, while natural gas remained relatively flat, at or below \$5.00 per MMBTU. In fact, while oil continued its upward swing to the \$100 per barrel we are seeing today, natural gas at one point dropped to below \$2.00 per MMBTU.

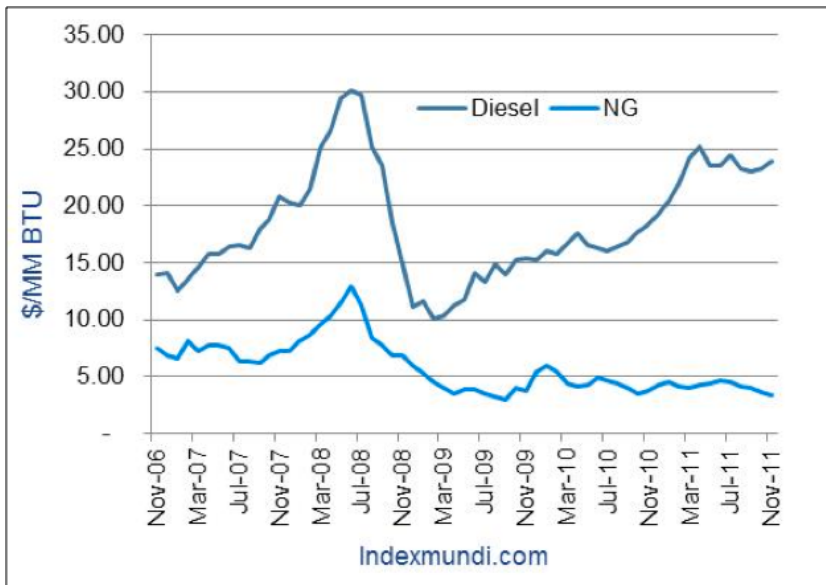


Figure 4 – Diesel and Gas Price Trend 2006-2011

Using the historical figures, if natural gas were to even double in price to \$7.50 per MMBTU, the price of a DGE of natural gas would still be less than one dollar, coming in at a mere \$0.97 per DGE. (Note that the chart in Figure 4 and all data since shows that natural gas prices above \$7.50 per MMBTU was truly an aberration, unlike crude oil prices that have hovered around \$100 per barrel since November of 2011.) If crude oil pushes back up to near its \$148 per barrel high, the base oil price for a DGE would jump to \$3.35. More importantly the price delta between the natural gas and diesel would go from \$1.75 per DGE to \$2.38 per DGE. Even if oil prices remain steady and natural gas prices double, the delta between natural gas and crude oil would still be \$1.26 per DGE. So while many people mention concern about natural gas prices rising, the real issue is with crude oil prices. Most analysts agree that natural gas will remain an incredibly price competitive fuel for the foreseeable future.

With all this price advantage, why didn't the railroads whole-heartedly adopt natural gas in the late 1980's or

early 1990's on the basis of the successful natural gas locomotive testing on the BN? A quick look at the price trends shown in Figure 5 shows that while there was a spike in oil prices in late 1990 (crude oil spiked to an "amazing" \$33 per barrel), the price of crude oil stayed relatively steady at around \$15-\$20 per barrel for almost 10 years. During that time the price of natural gas also remained relatively steady, but the price delta just simply did not exist. In 2001 through 2005 natural gas's competitiveness occasionally disappeared entirely with the price per MMBTU of natural gas eclipsing that of crude oil. But a very clear trend has emerged since 2006. While the price of natural gas has climbed steadily to maintain pricing at the \$100 per barrel mark, the price of natural gas has dropped and stayed low. There is no doubt that the advent of technologies such as hydraulic fracturing ("fracking") and discoveries of the vast natural gas reserves in North America have contributed to this trend, and analysts continue to point to continued low pricing for the foreseeable future.

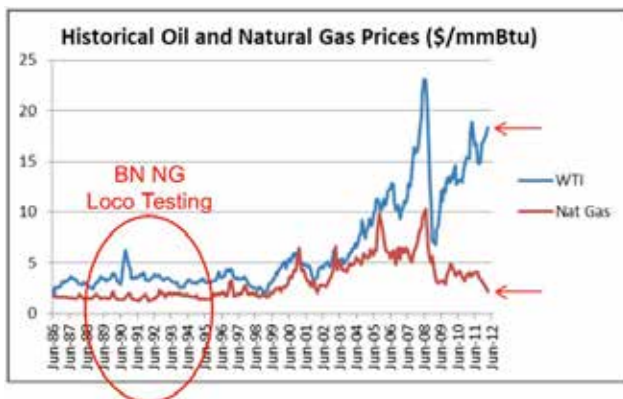


Figure 5 – Historical Oil and Natural Gas Prices During Railroad Locomotive Testing



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A final point to note that is of potential advantage to the large scale fleet operations of railroads is a willingness for gas suppliers to lock in long-term contracts. Because of the price competition in the market natural gas suppliers have been willing to lock in rates for five and even ten year contracts. These are contract terms that were previously unheard of.

Locomotive Criteria Emissions

While economics are an internal force that can certainly move a railroad to adopt natural gas, the fact remains that external forces, particularly in regard to EPA regulated criteria emissions (NOx, PM, HC, CO) have been the driving force in new locomotive engine technologies. New locomotives must meet current Tier 3 requirements and upcoming Tier 4 requirements, and if that means that locomotive manufacturers must sunset some age-old locomotive engine designs, or add complex aftertreatment devices that increase both capital and operational expenses, this is the price that must be paid to meet EPA regulations. So in this regard it is encouraging to note that natural gas powered locomotives can have two benefits in regard to these emissions.

The first is that the cost savings for the natural gas fuel itself can offset the incremental cost of new engine technologies and/or aftertreatment devices. For example, if a line haul locomotive cost an extra \$1M for a Tier 4 locomotive vs. a Tier 3 locomotive, just a cost savings of 50 cents or \$1 per DGE of fuel consumed could pay for the extra locomotive cost in less than five years.

Over the life of the locomotive the locomotive could potentially pay for itself in fuel savings alone.

This savings can also apply to switcher locomotives which have been consistently looked at as more of a cost of doing business than a revenue generator. With modern multi-genset locomotives or ECO repowers costing well over \$1M each, railroads have been hesitant to spend these huge sums on switcher fleets. But railroads have also recognized the need to replace their aging switchers with clean locomotives that benefit the local environment, especially around urban rail yards. Natural gas can have a huge impact on leveling the cost playing field for new, ultra-clean, switcher locomotives. It has been estimated that by moving to a modern fuel efficient Tier 3 or Tier 4 locomotive engine, and replacing just 60% of the diesel fuel used with natural gas (a dual fuel locomotive), an ultra-clean locomotive could pay for itself in 10-15 years. For the first time in recent history natural gas holds the potential to make new switcher locomotives cost effective and actually return an ROI to the railroads purchasing them.

The second benefit from natural gas locomotives is a definite positive impact on the criteria emissions produced from a straight natural gas or even dual fuel (diesel and natural gas combined) diesel engine. Studies have shown that the use of natural gas can reduce NOx levels. Some natural gas engines have publicized as much as a 10-15% drop in NOx emissions. While these reduction levels will not necessarily move an engine from one EPA

Tier level to the next (e.g. natural gas fuel will not necessarily clean up a Tier 3 locomotive engine to the point that it meets EPA Tier 4 levels), the additional NO_x reduction could benefit a railroad's or community's overall NO_x reduction plans. And since a railroad can quantify the savings on natural gas, those economic savings and emissions reductions may justify a railroad moving to a cleaner locomotive level, such as moving to Tier 3 locomotives instead of a Tier 0+ retrofit, or Tier 4 instead of Tier 3. In this way a railroad can maximize its NO_x reduction while minimizing cost.

When it comes to PM emissions, natural gas is definitely a game changer. A diesel engine re-designed to run on 100% natural gas will reduce PM emissions by about 85% just by switching from diesel fuel to natural gas. These percentages of reduction can be extrapolated with dual fuel natural gas engines as well. To illustrate, let's say we have a Tier 3 locomotive engine without a DPF system that produces 0.07 gr/bhp-hr of PM, well below the 0.10 gr/bhp-hr required to meet EPA Tier 3 emissions. If this engine were to run on a 50/50 mixture of diesel and natural gas, a rough estimate would be a 42.5% reduction in PM emissions. PM reductions would drop from 0.07 gr/bhp-hr to 0.04 gr-bhp/hr. Our Tier 3 locomotive engine with no PM aftertreatment is suddenly coming very close to EPA Tier 4 PM levels of 0.03 gr/bhp-hr! And we are reducing our PM while saving money on fuel.

Another aspect of PM management with natural gas is the size requirement

of a DPF system for a natural gas locomotive. If a DPF system is added, a smaller unit can potentially be fitted on the locomotive. With internal real estate on locomotives becoming more of an issue, the use of a smaller DPF may be a critical factor to moving a locomotive from some PM emissions to virtually zero PM emissions. Or if a larger size DPF is used, the number of regenerates the unit must go through to purge itself of built up PM can be reduced. This also means that the time between cleaning ash out of the PM system could be reduced. Lowered maintenance equals lower operational costs. Even replacement intervals on the DPF filter could be stretched, which also lowers locomotive operational costs.

Locomotive GHG Emissions

Another area of emissions that benefits from natural gas is greenhouse gas emissions (GHG). GHG emissions have been the topic of much debate, and we all recognize that trains, due to their inherent efficiency in moving a ton of freight on a low amount of fuel, are certainly environmentally friendly. But when it comes to GHG gas emissions, it is not simply the overall amount of GHG emissions that is looked at by the regulatory agencies, but the amount of GHG produced from a given amount of fuel. As such, upcoming GHG reduction requirements that it appears will be forthcoming from the EPA will push the transportation sector towards the adoption of more GHG emissions friendly fuels. This is another area where natural gas has an advantage over diesel fuel.

The state of California has always been known as being at the forefront of pushing for stricter emissions limits and cleaner vehicles. GHG emissions have been a major issue in California for year, especially since the passing of California Assembly Bill 32 in 2006 (also known as AB 32, the California Global Warming Solutions Act of 2006) and Assembly Bill 118 (AB 118) in 2007. AB 118 is directed toward the use and adoption of alternative and renewable fuels and vehicles. A key part of AB 118 deals with the curbing of GHG emissions through use of dif-

ferent alternative and renewable fuels. Under AB 32 California developed a Low Carbon Fuel Standard (LCFS) which assigned GHG carbon intensity values to various vehicle fuels. From these carbon intensities a GHG reduction equivalency can be extrapolated.

The EPA also has assigned carbon intensity values to various fuels (see Figure 6) and it is expected that under President Obama’s newest Climate Change initiative that a new federal standard will be proposed to assign carbon intensity values to a wide range of fuels.

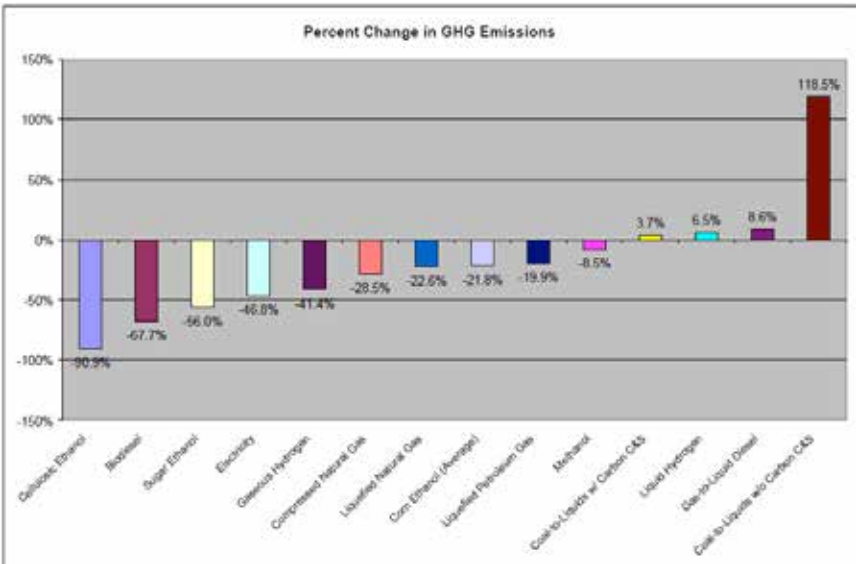


Figure 6 – US EPA estimates for percent change in lifecycle GHG emissions relative to petroleum fuel displaced (EPA420-F-07-035 April 2007)

Based on the current California LCFS, CNG fuel produces ~32% lower GHG emissions than diesel. Depending on the efficiency of the liquefaction process (80% or 90%) the GHG reduction for LNG ranges from about 16.9% to 27.6%. These percentages of reductions are quite significant in terms of GHG reduction goals set forth by many governmental and environmental groups.

Even if a locomotive is using a dual fuel engine (which runs on a combination of natural gas and diesel), significant GHG reduction can still be attained. It should also be noted that the use of a dual fuel engine does not change the engine's ability to utilize a

biodiesel blend to reduce GHG emissions even further. For example, if a diesel engine was originally designed to use a B20 biodiesel blend (20% biodiesel and 80% petroleum diesel), the dual version should still be able to use a B20 biodiesel blend. Thus, if a dual fuel engine used a 60/40 mix of CNG and diesel fuel, the 60% replacement with CNG would drop GHG emissions by 32% for that volume of fuel, and the 40% biodiesel remaining could drop GHG by emissions by anywhere from 3.3% to 17.6%. The combined GHG reduction for a natural gas dual fuel locomotive could thus be as high as 26.2%. (See Figure 7)

- Greenhouse Gas (GHG) Reduction*
 - Natural Gas
 - CNG
 - LCFS Reduction of ~32%
 - LNG
 - LCFS Reduction of 16.9% to 27.6%
 - Biodiesel
 - LCFS Reduction of 88.2% using waste oil
 - LCFS Reduction of 16.7% using Midwest Soy
 - without ILUC reduction is 78.8%
 - B20 reduction from 3.3% to 17.6%
 - Combined CNG/Biodiesel (Dual Fuel 60% ng / 40% b20)
 - GHG Reduction of 20.5% to 26.2%

* LCFS Source: Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline 11-28-2012

Figure 7 – Individual and Combined Fuel GHG Reduction

Fuel Storage Options

One of the biggest challenges presented to the adoption of natural gas is how to store the fuel. Since natural gas in its raw form is a gas and not a liquid, the fuel cannot be useably stored in its native state on a locomotive and/or tender. It must be either compressed or liquefied.

Before discussing these storage technologies, it should be noted that many natural gas engines, both straight natural gas and dual fuel, are ambivalent to the way in which the natural gas is stored. This is because the natural gas being introduced into the engine is in a gaseous state. So if the gas comes from a high pressure CNG tank, it simply needs to be regulated down to the standard low injection pressure, usually around 120psi-150psi. If the fuel is stored as LNG, it goes through a vaporizer to convert it from liquid to gas and is then regulated to the low pressure needed by the engine. So if the vaporizer is part of the fuel tank system, the same natural gas locomotive could use CNG or LNG fuel interchangeably. Some high pressure direct injection (HPDI) systems require LNG, but this is a requirement of the specific fuel injection technology, not natural gas engines as a whole. It should also be noted that because the BTU content of natural gas from LNG or CNG is basically the same, no perceivable difference in performance would be noted between an engine running on CNG or LNG. (Technically natural gas from CNG may have a slightly higher BTU value because it may contain up to 20% propane, ethane, and butane, which are

usually removed to create “dry gas” for liquefaction.)

When compressed, the gas is stored under high pressure in a storage cylinder. These cylinders can be made of metal (aluminum or steel) or a composite material and then wrapped with a steel or composite wrapping. Up until recently most on-road CNG systems were compressed to 3,600psi (250 barg). Because of the low BTU content per cubic foot of 3,600psi CNG compared to diesel, many people felt that this precluded CNG from being a viable locomotive fuel. But when used for powering locomotives in switching, local, or branch line service, 3,600psi tanks can be viable, especially on dual fuel powered locomotives.

LNG has the highest per volume BTU content of any natural gas storage technologies. This is because LNG is a true liquid state of natural gas. The BTU content of a gallon of LNG is approximately 59% that of a gallon of diesel. When used in a dual fuel engine, an LNG fueled locomotive having an average 70% natural gas for diesel substitution rate, can provide about 71% of the range of straight diesel. Considering that the fuel cost savings for a single line haul locomotive in long distance service can be hundreds of thousands of dollars per year, many railroads and locomotive manufacturers are giving LNG serious consideration, even if it involves storage in separate fuel tenders.

There are some additional issues with LNG that must be taken into consideration. One is the state of the fuel itself. LNG is an extremely cold

cryogenic liquid, which means that its temperature is well below the freezing point of water. The temperature of LNG is -260 degrees F (-162 degrees C). In order to keep the liquid this cold, it must be stored in vacuum insulated cryogenic tanks. And special handling is a must, since contact of liquids this cold with any part of a human body will cause immediate frost bite and severe tissue damage. Since there will always be some pressure in an LNG tank due to some “boil off” of the LNG in the tank, a crack in an LNG tank will result in a low pressure “spray” of extremely cold liquid. So while the escape of the gas itself may not be hazardous to personnel, contact with the super-cold liquid being expelled a potentially long distance can be.

The cost of LNG can also be significantly higher than CNG. This is because the LNG requires more complex liquefaction equipment that must be suitable for cryogenic conditions and there is an additional energy cost associated with liquefaction vs. straight compression. LNG can cost \$0.75 to \$1.00 more per DGE than CNG, and this extra cost must be weighed against the costs associated with shorter range or additional fueling stops associated with a CNG fueled locomotive.

A new natural gas storage option that is already being adapted to on-road vehicles is high pressure CNG. High pressure CNG utilizes high pressure wrapped tanks, usually of a Type 4 composite design. These tanks can handle pressures well in excess of 5,000psi. 5,000psi high pressure CNG tanks have been used for stationary storage for some time, and are now becoming available for mobile use. In fact, many of these same design tanks are already used for hydrogen fueled vehicles where pressures can range from 7,000psi on up to almost 10,000psi. So these high pressure tanks are already proven. Moving to 5,000psi CNG tanks moves the volumetric energy content of CNG vs. diesel from 25% to around 38%. Another way to look at this is that 5,000psi CNG is suddenly 64% the energy storage volume of LNG, vs. a paltry 42% for 3,600psi CNG. This can be a real game changer in the decision making process of whether to use CG or LNG in many shorter distance applications. New fueling station technology for 5,000psi CNG also uses less energy than previous 3,600psi fueling stations and keeps the CNG cylinders cooler during refueling, thus making it possible to consistently fill the CNG tanks to maximum capacity while also generating the least amount of heat build-up.

	3,600psi (250 barg) CNG	5,000psi (350 barg) CNG	LNG
BTU per Gallon (Diesel = 127,500)	32,400 BTU @ 3,0600 psi	48,090 BTU @ 5,000 psi	74,720 BTU per Gallon
Energy vs. Diesel	25% 58% lower than LNG	38% 50% higher than 3,600 psi CNG 36% lower than LNG	59%
Advantages	<ul style="list-style-type: none"> • Unlimited hold time • Does not require liquefaction • Most commonly used CNG option today • Simple fuel tanks and pressure management 	Same as 3,600 psi plus: <ul style="list-style-type: none"> • Increased on-board storage • Does not require cryogenic fueling • Decreased compression cost over 3,600 psi • Consistent "Full Fills" 	<ul style="list-style-type: none"> • Highest NG fuel density available • Smallest tank size requirement per DGE • Fewer tanks
Disadvantages	<ul style="list-style-type: none"> • Lowest onboard fuel capacity • Slower speed fill with standard fueling stations • Depending on fuel station, cost of compression can be high • Inconsistent "Full Fills" 	<ul style="list-style-type: none"> • Higher cost tanks than 3,600psi • Slight increase in tank diameter • Specialized fuel stations 	<ul style="list-style-type: none"> • Cryogenic liquid with safety implications • Boil off if stored too long • Complex tanks • High maintenance costs for cryogenic parts
Rail – Pro/Con	<ul style="list-style-type: none"> • Can be set up anywhere natural gas is available • Reduced range 	<ul style="list-style-type: none"> • Increases onboard storage capacity and refuel intervals • Reduced range vs. LNG 	<ul style="list-style-type: none"> • Boil off • Handling challenges

Figure 8 – Fuel Storage Options

Natural Gas Safety/Risks

As with the adoption of any new technology, concerns always arise regarding the safety of the technology. This also applies to adopting new fuels such as natural gas.

While the railroads have only experimented with natural gas locomotives, natural gas vehicles using both CNG and LNG fuel storage are nothing new. These vehicles have been in use transporting people and freight for decades. In fact, one of the most common applications of CNG fueled vehicle is in transit buses. These buses transport millions of passengers each year. Yet we simply do not hear of mass deaths due to CNG fueled buses exploding or otherwise causing harm. Add to this the estimated 15 million natural gas fueled cars and trucks worldwide, and it be-

comes very clear that natural gas is an inherently safe vehicle fuel.

One reason for the outstanding safety record of natural gas fueled vehicles is mature safety standards that have been in place and evolved over the decades of natural gas use. This includes not only safety standards for the vehicles and engine systems themselves, but also stringent standards for fuel storage systems (both stationary and mobile), handling, and refueling. In the United States these standards primarily fall under the auspices of the U.S. Department of Transportation, which regulates not only on-road vehicles, but railroads as well through the Federal Railroad Administration (FRA). While there are no specific regulations in place by the FRA for natural gas locomotives, many of the regulations already

in place cover aspects of natural gas locomotives. The US DOT has a very robust set of standards and guidelines as part of the Federal Motor Vehicle Safety Standards (US DOT FMVSS). In addition to these federal regulations, the National Fire Protection Association (NFPA) has published codes and standards under NFPA 52, the Vehicular Gaseous Fuel System Code. These requirements are very stringent and are perfectly adaptable to locomotive applications. Finally, there are the internal natural gas vehicle industry standards known as NGV Codes. In many cases, these NGV codes go above and beyond what is required by DOT and NFPA. So much so in fact, that many other countries outside the U.S. have adopted these NGV Codes into their natural gas vehicle requirements.

Another critical aspect is the flammability and characteristics of natural gas itself, especially as compared to diesel fuel. Figure 9 shows the flammability and risks associated with methane, the primary component of natural gas, compared to diesel fuel. Natural gas has a very limited range

of flammability. Natural gas is flammable only within about a 5-15% gas-to-air mixture. And, it has a very high ignition temperature. The high ignition temperature and the limited flammability range make accidental ignition or combustion unlikely. Natural gas is lighter than air. This means that generally when natural gas is accidentally released into the outside air it will rise and vent harmlessly into the atmosphere, thus dissipating from the site of a leak. When a gas-and-air mixture within the flammable range collects in a confined space, it can accidentally ignite upon a source of ignition. But this ignition source must be very high temperature. And when the natural gas ignites, the fire is limited to the gas in the area where the natural gas and air mix is within the flammability limit. Once it hits the higher natural gas concentration point the flame will discontinue propagation, unlike a major diesel spill which will continue to burn for hours as the liquid fuel pool continues to burn.

For example, one issue that has been raised is whether the exhaust manifolds, situated high up in the carbody

		Diesel Fuel	Methane
Lean Flammability Limit	% by volume of air	0.6	4.4-5.0
Upper flammability Limit	% by volume of air	7.5	15-17
Flash Point	C	> 62	
Autoignition Temp	C	210	580
Accidental Release	behavior	pools	lighter than air
Risk to ground water		high	low

Figure 9 – Natural Gas Safety/Risks

of a locomotive, would be a potential ignition source for any lighter-than-air natural gas that might accumulate there. Clearly the exhaust manifold/stacks constitute a heat source, but not really an ignition heat source for natural gas. The autoignition temperature for diesel fuel is 210 degrees C (410 degrees F). The autoignition temperature for natural gas is almost three times that, at 580 degrees C (1,076 degrees F). Autoignition temperature refers to the lowest temperature at which a substance will spontaneously ignite without an external source of ignition such as a spark or flame. So the exhaust system under the hood of a locomotive is considered a potential autoignition source.

According to a verification report published in 2005 by the EPA, the exhaust temperature of a 3,000 HP turbocharged EMD 16-645E3 engine is about 201 degrees F at high idle (223 degrees F at low idle) and goes up to a high of 732 degrees F at Notch 6 (Notch 8 is actually only 720 degrees F). So diesel fuel will ignite if sprayed on the exhaust manifold since the autoignition temperature for diesel is only 410 degrees F, well below the potential 732 degrees F manifold temperature. But even at the highest exhaust temperatures the EMD engine exhaust manifold would still be almost 350 degrees F below the autoignition temperature for natural gas. So natural gas is actually much safer from this standpoint than diesel fuel.

The bottom line is that there really is no consistent heat source under the hood of a locomotive for ignition of

natural gas. You would need to have an open flame or consistent spark source or a hot engine component producing a temperature of 1,076 degrees F or above to ignite the natural gas. This is just one example why natural gas can be safely used in locomotives.

Diesel and Natural Gas Engine Technologies

For railroads seeking to run locomotives there is a wide range of engine technologies that can run on straight diesel fuel, dual fuel (diesel and natural gas, or straight natural gas. As the table in Figure 10 shows, these three overall engine options cover a wide range of natural gas substitution, from no substitution (straight diesel) all the way up to 100% natural gas with no diesel fuel needed at all.

Our baseline is a 100% straight diesel engine. This is our stock off-the-shelf engine from any major locomotive manufacturer or OEM supplier of locomotive engines. These are tried and true engines, and we know what to expect from these engines.

The highest substitution rate of natural gas (100%) requires major conversion of the engines from their original diesel configuration. Most notably, the compression ratio is lowered dramatically, and thus the horsepower output is significantly decreased. For example, the four LNG locomotives used until recently by the BNSF were rated at only 1,200 HP, despite the fact that the stock V-16 diesel engine produced between 1,600 HP and 2,200 HP depending on configuration. A horsepower de-rate of between 25% to 40%

	← Less	Natural Gas Use	More →
	Straight Diesel	Dual Fuel (Diesel and NG)	Straight NG
Ignition Type	Compression	Compression	Spark
Compression/ Efficiency	High	High	Low
Engine Transient Response Time	Excellent	Excellent	Poor
Engine Power Output Compared to Diesel	N/A	Same	Lower power and torque
Raw Criteria Emissions	<ul style="list-style-type: none"> • PM – High • NOx – Medium to High • HC – Low • CO – Low 	<ul style="list-style-type: none"> • PM – Low • NOx – Medium • HC – High • CO – High 	<ul style="list-style-type: none"> • PM – Very Low • NOx – Medium • HC – Low • CO – Medium
Requires Change to Base Diesel Engine?	N/A	<ul style="list-style-type: none"> • No if in CAC circuit or pre-turbo • Yes if between turbo and intercoolers or port injection or micro-pilot 	• Yes
Substitution Rate: Diesel Replacement with Natural Gas	• 0%	<ul style="list-style-type: none"> • 40% to 80% average with fumigation • 98% or greater with micro-pilot ignition 	• 100%

Figure 10 – Diesel and Natural Gas Engine Technologies – Fuel Mix

is not uncommon with pure natural gas versions of diesel engines. These engines also depend on a spark plug to ignite the natural gas, so the engines must have modifications made to the heads as well. Some straight natural gas engines also suffer from poor or slower transient response times, and in some locomotive applications, such as kicking cars, this can be a definite problem.

In between these two extremes is the dual fuel engine, which runs on a mix of diesel fuel and natural gas. These engines may or may not require modification to the base diesel engine. The key to a dual fuel engine is that a certain percentage of the air introduced into the cylinder contains natural gas. When the diesel fuel is introduced into the cylinder, less is needed to produce the same amount of energy since the

natural gas in the air mix contributes the combustion energy output. The key is that the natural gas flow into the air mix must be metered and monitored so as to control the amount of diesel fuel injected into the cylinder, thus maintaining a given amount of horsepower at a given RPM. There are also issues of engine knock not normally associated with a diesel engine that must be monitored and controlled. Another advantage to many dual fuel engine systems is that if the locomotive runs out of natural gas or the natural gas fuel supply must be shut down due to a problem with natural gas dosing/injection system, the engine will continue to run on straight diesel. For many railroads this “fallback” option is an important criterion for considering a switch to natural gas.

	Single Point Manifold Injection	Port Injection	MicroPilot	High Pressure Direct Injection
Description	Natural gas injected into intake manifold either pre- or post-turbo	Natural gas injected at intake port during intake stroke	Small "MicroPilot" diesel injector is used to ignite natural gas injected during intake stroke	Natural gas injected directly into the cylinder at end of compression stroke
Natural Gas Replacement	• 40% - 80% average	• 60% - 80% average	• 95% to 99%	• 95%
Pros	<ul style="list-style-type: none"> • Supports 100% diesel "fallback" mode • Low pressure gas • Lowest cost 	<ul style="list-style-type: none"> • Supports 100% diesel "fallback" mode • Low pressure gas 	<ul style="list-style-type: none"> • High NG replacement value • Very good individual cylinder NG fuel control • Low pressure gas 	<ul style="list-style-type: none"> • High NG replacement value • Low knock sensitivity
Cons	<ul style="list-style-type: none"> • May have low or no natural gas substitution at idle or low power settings • Knock sensitivity • Air/Gas mix passes through turbo on some systems 	<ul style="list-style-type: none"> • Multiple injectors require engine modification • Knock sensitivity 	<ul style="list-style-type: none"> • No diesel "fallback" mode • Increased CO emissions • Engine itself must be modified 	<ul style="list-style-type: none"> • No diesel "fallback" mode • High pressure gas • Primarily LNG • High maintenance

Figure 11 – Natural Gas Engines – Dual Fuel Technologies

Within the dual fuel engine technologies there is a range of ways to introduce natural gas to the engine. Each of these technologies has its own pros and cons and must be taken into account when choosing a dual fuel system. Figure 11 outlines the high level breakdown of these systems.

The first and simplest system to convert a diesel engine to dual fuel involves a single point of gas injection. Sometimes known as fumigation, the gas manifold can be placed virtually anywhere along the air intake system. Some single point manifold systems place the gas inlet before the turbocharger. This means, however, that the gas/air mixture is actually going through the turbocharger and being heated and compressed. While the heated air/fuel mix coming out of the

turbocharger is nowhere near the 1,076 degrees F autoignition point of natural gas (typical turbocharger outlet temperatures are around 400 degrees F) the introduction of natural gas before the turbocharger has been safely done for years. But some customers may prefer the injection post turbocharger, and there are systems that are designed for injection of the gas after the turbocharger. Depending on the engine design, this natural gas injection can even be done post-intercooler or charge air cooler (CAC), thus taking advantage of a more stable air temperature. Many larger locomotive engines have the turbocharger and intercooler system closely connected to the intake manifold, so in these instances the gas injection must be placed between the turbo and the intercooler.

Single point gas injection systems have several advantages, price being just one of them. They require minimal to no changes to the actual diesel engine they are installed on, and because of this they normally have a full “fallback” mode where the engine can run on 100% diesel fuel. Thus failures of the natural gas supply or injection system will not stop the locomotive from running at normal power levels in all throttle notches. They are perfectly suited for low pressure gas applications, and can thus run on CNG or LNG fuel.

One of the negatives include a low overall natural gas substitution rate (less than 50%), although many newer systems that interact with the engine ECM can better control the diesel fuel injection and get substitution rates as high as 80% or 85% in higher throttle notches. Overall average natural gas substitution rates can be as high as 60%-65% on a switcher cycle locomotive. Other negatives include a higher knock sensitivity and the pre-turbo fuel injection discussed earlier.

A similar technique to single point gas injection is a multi-point injection system located near or at the engine intake ports. This has been successfully applied to both two-cycle and four-cycle locomotive engines. Most of the same pros and cons that apply to a single point gas injection system apply to a multi-port gas injection system. Of course, by nature of the location of the cylinder intake ports, multi-point gas injection systems are located post-turbocharger.

The multi-port gas injection system can provide a higher overall fuel

substitution rate in some cases, but also has the drawback of having zero or extremely low fuel substitution rates at idle or low throttle notches (N1-N3). These systems have therefore been used primarily for line haul applications, not switcher cycle locomotives. Since the injectors need to be fitted near the intake ports, modifications to the engine are required. These can range from minimal to major.

Very high natural gas substitution rates can be achieved with either a micropilot system or High Pressure Direct Injection (HPDI). The micropilot system uses a special low flow fuel injector which serves to ignite a high ratio of natural gas in the cylinder. In this case the fuel injector is designed to work more like a spark plug instead of a fuel injector. It is designed so as not clog despite the low fuel flows through the injector, and it requires a modified head from the original diesel engine. Micropilot diesel injection systems, when coupled with multi-port gas injection, can provide gas substitution rates of 95% to as high as 99% across the entire engine RPM and power range. But because they use a special injector, coupled with a modified cylinder head, there is no diesel “fallback” mode for most of these systems.

High Pressure Direct Injection is another high substitution rate technology that requires major modification to the engine. One of these systems is currently marketed by Westport. Westport HPDI technology uses natural gas as the primary fuel along with a small amount of diesel as a pilot ignition source, or “liquid spark plug”. At the

heart of the engine is a patented injector with a dual-concentric needle design. It allows for small quantities of diesel fuel and large quantities of natural gas to be delivered at high pressure to the combustion chamber. The natural gas is injected at the end of the compression stroke. (Non-HPDI systems discussed earlier bring the natural gas in with the air during the intake stroke.) As mentioned earlier, under the pressures found in the combustion chamber of a normal diesel engine, natural gas requires a higher ignition temperature than diesel. To assist with ignition, a small amount of diesel fuel is injected into the engine cylinder followed by the main natural gas fuel injection. The diesel acts as a pilot, rapidly igniting the hot combustion products, and thus the natural gas. HPDI replaces approximately 95% of the diesel fuel (by energy) with natural gas.

Because the natural gas is actually injected after the diesel fuel is injected and begins to ignite, very high pressures in the fuel lines are required. For this and other reasons some manufacturers, such as Westport, consider their systems to be designed only for use with LNG. So a customer of a particular HPDI system may be required to choose a particular fuel (i.e. LNG over CNG) just simply to support that natural gas engine technology, and not because the economics or range requirements require it.

The engine technologies outlined are just a broad overview of existing and upcoming technologies for locomotives. As this paper was being prepared at least one company has stated that they have

a fuel delivery system that will allow CNG to be used with HPDI systems. Some of these new technologies may allow an increase in fuel substitution rates that blur the lines even further of which engine technology is best suited for locomotive applications.

CNG and LNG Fuel Storage – On Board or Tender Cars

As so many times happens in all industries (railroads included), we many times come full circle in technologies applied to our business. For example, early steam locomotives required a tender to store fuel and water for any long range operation. In fact, very few operations had the luxury of dispensing with the tender and storing all the fuel and water on board the locomotive itself. The advent of the diesel locomotive with its on-board fuel tanks and no need for water was considered by many a huge advance over the steam locomotive. Today's modern high-horsepower locomotives carry 5,000 or 6,000 gallons of diesel fuel, reducing even trans-continental trips to a minimum number of fueling stops.

With the switch to natural gas fuel, interest has been renewed in tender cars, due to the lower BTU content of CNG and LNG compared to the same volume of diesel fuel. As a result the need for fuel tenders, FRA and AAR have both put together work groups made up of railroads, suppliers, and industry experts, to set the standards for the new generation of natural gas locomotives and tenders.

In October 2012 the FRA convened a workshop titled "Natural Gas

Locomotive Technology” at Argonne National Laboratory in Lemont, IL. It was organized by the FRA to develop a roadmap for the use of natural gas in rail applications. The workshop was attended by 55 participants spanning railroads, locomotive manufacturers, OEM suppliers, and research and federal organizations.

This group is now known as the Natural Gas Locomotive Research Task Force. The task force continues to meet to look at all aspects of locomotive and tender safety and technology. In addition to the FRA group, the AAR has created its own working group. Known as the Natural Gas Fuel Tender Technical Advisory Group (AAR NGFT TAG) this advisory group is looking primarily at locomotive fuel tender needs for line haul locomotives, including standards and safety for the delivery of the fuel (gaseous or liquefied) across connections from the tender to the locomotive. It is expected that these same standards and recommendations would be used for any interface between a natural gas locomotive and a separate natural gas fuel source, such as a slug that might be equipped with LNG or CNG fuel tanks.

One key aspect of an LNG tender is the location of the vaporizer that converts the LNG to gas. These vaporizers require large amounts of energy to convert the extremely cold liquid to a gaseous state. A diesel locomotive has a lot of waste heat that it must dispose of through the exhaust and radiator system. If this waste heat can be used to vaporize the LNG, that energy is actually being used more efficiently. The challenge is where to locate the vapor-

izer. If it is put on the tender car, then the hot coolant from the locomotive’s radiator circuit must be piped across between the locomotive and tender. And once the LNG is vaporized, it must be decided whether the gas that is piped back to the locomotive is high pressure gas (5,000 psi) or low pressure gas (125-150 psi). If the vaporizer is placed on the locomotive, there is no need to move high temperature engine coolant across to the LNG tender, but we must find a place on the locomotive to put the vaporizer. This is no easy task because of the limited real estate on today’s Tier 3 and upcoming Tier 4 locomotives! (One suggestion was to reduce the size of the diesel fuel tank and use that space for the vaporizer. Since a high percentage of the fuel for the locomotive is coming from the tender, the locomotive would not require the same amount of diesel fuel to get between existing fueling stops anyway.) If the vaporizer is on the locomotive then extremely cold cryogenic LNG must be passed through a connection between the tender and locomotive. This would require higher power cryogenic pumps and insulated cryogenic lines between the locomotive and tender. The AAR NGFT TAG continues to look at all these nuances of fuel tenders.

Another interesting caveat of the use of a fuel tender is its status as a hazardous materials car. If fuel is stored on board a locomotive it comes under the rules applying to fuel tanks, and thus a locomotive is not considered a hazardous materials car even if it is carrying thousands of gallons of diesel fuel. As soon as the fuel is

moved to a tender car it now falls under the jurisdiction of the HAZMAT rules governed by additional agencies beyond just the FRA. The Pipeline and Hazardous Materials Safety Administration (PHMSA) develops and maintains the regulations on the transportation of hazardous materials by rail, contained in Title 49 of the Code of Federal Regulations Parts 100-185. The FRA works with PHMSA to enforce the transportation of hazardous material by rail. Currently, natural gas cannot be transported by rail unless the rail carrier obtains a Special Permit. However, a Special Permit is not required for the use of natural gas as fuel for the locomotive but the locomotive being classified as a vehicle that carries natural gas or any other material being used to fuel attending locomotives is subject to FRA's statutory and regulatory authority related to locomotives contained in the Federal railroad safety statutes.

This brings up the option of storing the natural gas fuel on board the locomotive itself. Depending on the design of locomotive itself, it is entirely possible to place CNG or LNG tanks on a locomotive. While LNG would once again seem to be the natural gas fuel of choice, recent studies on locomotive duty cycles, dual fuel engine efficiency, and on-board space available for the fuel tank(s), has shown that CNG is a very viable fuel for switcher locomotives using as much as 50,000 to 60,000 gallons of fuel per year. On larger road switcher locomotives used for transfer or local service, the additional fuel space available on a longer frame lo-

comotive makes on-board CNG viable for these environments as well. By putting the natural gas fuel on board, the issues of moving fuel between a tender and the locomotive, adding the additional tender to the locomotive consist, and turning a locomotive-tender combination at the end of a line (to keep the tender from leading a single locomotive consist) are all eliminated. Additionally, whereas LNG may not be economical in terms of cost savings on a lower fuel consumption locomotive, the extra \$0.75 to \$1.00 per DGE savings of CNG over LNG could make the difference between staying with current diesel locomotives or moving to a natural gas alternative. One recent study by a major switching railroad suggests a savings of as much as \$100,000 per year by replacing older Tier 0 or Tier 0+ 1,500 HP switchers with new Tier 3 dual fuel CNG powered locomotives. With savings of this magnitude it is hard for a railroad not to consider natural gas as a fuel alternative.

Conclusion

There is little doubt that natural gas is here to stay. The Energy Information Agency (EIA) estimates that the supply of natural gas (NG) in America will last over 100 years thanks to fracking of shale rocks. Considering the cost differential between natural gas and diesel and that this differential does not appear to be collapsing in the foreseeable future, there is significant fuel savings opportunity in using natural gas in locomotive engines.

This white paper is not intended to present every possible natural en-

gine or locomotive technology. New advancements are being made every day in regard to natural gas storage systems, dual fuel and straight natural gas engine technologies, and natural gas exploration and drilling techniques. As these natural gas technologies and locomotives are developed, it is expected that a number of new white papers will be forthcoming from not only the LMOA New Technologies Committee, but other LMOA committees as well.

For many of us who work with locomotives every day, the steam to diesel transition era is something that

we never actually experienced. While a complete transition from diesel to natural gas may never materialize, the new natural gas technologies being presented for locomotives is certainly no less exciting in its economic, environmental, and even operational potential. Who knows, maybe in 2036 one of the first successful new technology natural gas locomotives of today will end up in the same museum next to the early Plymouth propane locomotive of 1936. That would make quite an interesting 100 year anniversary celebration, wouldn't it?

Remote Monitoring of Locomotive Systems

Prepared by:

Joe Whitmer

Southern Region Field Service Manager

MotivePower, Inc.

Your locomotive is miles away when it develops trouble or is running low on fuel. How would you know that there is a potential problem? Wouldn't it be helpful if your loco could let you know that it is low on fuel or that an engine parameter is out of range? This is where the world of remote diagnostics and fuel monitoring is becoming the hero.

There are several options out there today and here we plan to just touch on a couple of those options and what they may be able to accomplish for the railroad today.

The goal? Locomotive reporting for improved on-time performance and locomotive reliability.

One of the benefits of remote monitoring is the enhancement of reliability since with back office storage of locomotive alarms and records this information is readily available at a moment's notice. Performance improvements can be made with the real-time operational status of the roads locomotive. With this information, shop dwell time can be reduced by being able to preemptively take care of problems before they can shut you down. Road failures are reduced, keeping the operation running on time. Fuel levels and consumption can be monitored as well. With this

information the chances of locomotives running out of fuel on the main line can be reduced. With this remote information available in real-time, dispatch can decide whether a consist needs to go to the fuel rack or if it can be directly tied on another train without refueling.

Remote monitoring comes in various levels of capabilities:

The first level, or Basic, gives minimal feedback. Items include GPS location, locomotive speed, direction, and fuel level.

The next level would incorporate these basics and a few others. Event recorder logs can be remotely acquired for review when needed. The Locomotive Control Computer can pass alarms indicating faults on the road and sometimes data packs as well. Another up-and-coming type of monitoring is the video monitor. With the video monitor both stills and video clips can be downloaded remotely.

Ultimately, all these items can be monitored, but with a couple of more benefits. Back office data services can store historical data for tracking when and where faults occurred and if they are repeating. With this historical data performance reports can be compiled on the fleet identifying bad actors and units that need attention. Also, some

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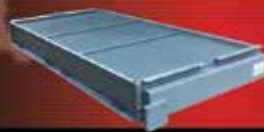
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plans from manufacturers of remote monitoring offer Help Desk services to get units over the road by assisting the crew on the unit.

System architecture can vary by vendor, but the basic layout is similar to Figure 1 below. The remote monitoring computer communicates with the various on-board systems gathering data. As shown in Figure 1 some systems such as Electronic Air Brake may feed into the Locomotive Control Computer and this information is then passed to the remote monitoring system. The remote monitoring computer will then pass this data on to its database using a few possible methods. These methods may include 802.11, cellular, and in some cases satellite. Cellular is used for the bulk of the communication on most systems with the extensive cellular network most readily available. It

can however have its dark spots and if this is the method of choice the system will need to store data until the next access to a cell is achieved.

Local data radio using 802.11 is also very popular, but is limited by distance. Most applications of this are installed at yard locations. As with cellular, with this protocol while the locomotive is out of communication range data will need to be stored and downloaded upon arrival. The most costly method of course is satellite data communication. This method can be limited in bandwidth and a clear view of the sky is required for reliable connection. The downside to most of these though is if a locomotive is in dark territory instantaneous downloads of event recorders cannot occur and will need to wait until the locomotive has come back to an area that has reliable

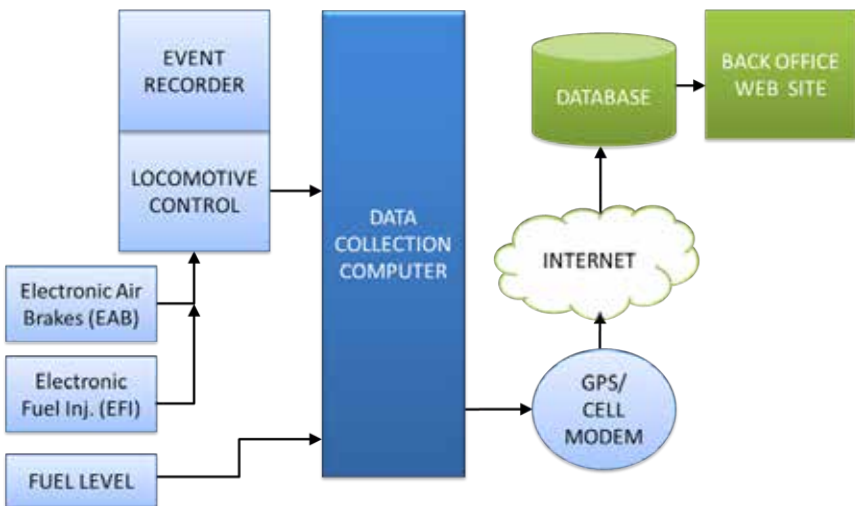


Figure 1 – Remote Monitoring Basic Layout



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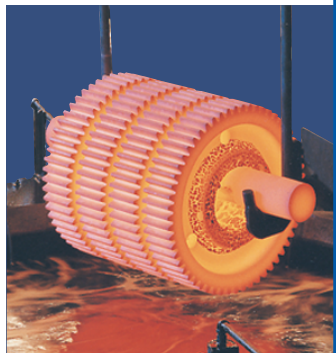
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service. So while Satellite is a possible solution, due to expense and bandwidth it is not very popular except in the most extreme situations.

Hardware used on the various systems can vary greatly. The Central Diagnostics System (CDS) by Wabtec uses a chassis in kind with what is currently used for PTC systems (see Figure 2). Actually with CDS, if the locomotive is already equipped with PTC, the CDS processor board can use the 'Business Application' slot that is available on this unit. This may be an option the end user can use to their advantage in not installing extra physical hardware and taking up space.



Figure 2 – Wabtec Central Diagnostics System (CDS)

Peaker Services offers a PLC based system that integrates with the engine control system. Peaker's system offers other flexibilities since it presents more engine related functions than most systems currently provide.

Wi-Tronix is currently known for its Wi-PU, which is a stand-alone processor unit. The Wi-PU contains multiple communication ports to interface

with many different systems. This can be advantageous to those looking to connect to systems with a locomotive equipped with different makes of systems that need to communicate to the outside world.



Figure 3 – Wi-Tronix WiPU

The downside for many of these systems though is that most to date do not have any direct interface to discrete signals and sensors. For most of these applications some type of third party interface or a PLC may be required.

Functions

By far, the most sought after goal for remote monitoring has been and still is GPS location. This in itself is a great resource. Locomotives have been 'lost' on railroads as long as anyone can remember and being able to locate them in short order has been a savior. It can be a great help for locating the locomotive when maintenance or crews need to locate it. Using the GPS information from the system plugged into the navigation GPS in a car and the crew can find it on that little known siding easily.



Figure 4 – GPS Map Location

The monitoring of fuel levels has probably become the Number 2 item that railroads want monitored. With real-time fuel information dispatchers can determine whether a train that pulls into the yard needs to have the fuel truck meet it and fuel up, or whether the power is ready to turn and take another train directly out of the yard. This can save a great deal of time and labor by not having to take the power to the barn for servicing that may not be required. Fuel levels are also monitored to ensure that the train will in fact make it to the next destination without refueling in a more remote location.

Event recorder data has come into its own in the last five years. Even DVR remote downloads have now become main stream. Though download bandwidth may limit the size of

the video download, it has become important to have this capability. With remote monitoring, not only can event recorder downloads happen while on the road, but rule infractions or incidents of emergency brake application can be immediately transmitted to transportation department officials. Most all of the remote monitoring systems can be set up with custom parameters to notify key personnel via email or even smart phone applications.

When remote monitoring first came into being many wanted to grasp the possibilities of what information could be gathered. At first because of bandwidth and technology issues this was limited to simple things like location and maybe two or three discrete signals. With today's advances most of these possibilities can be realized in diagnostics of most locomo-

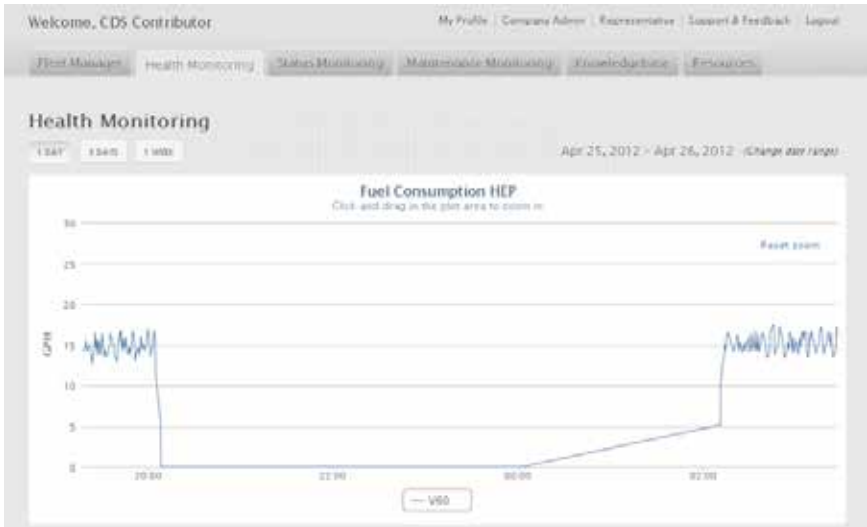


Figure 5 – Fuel consumption graph

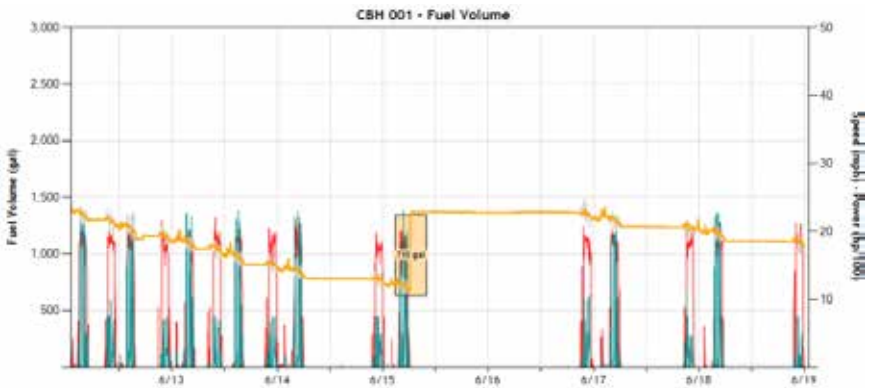


Figure 6 – Fuel Volume Graph

Time	Location	MP	Engine State	Throttle	Reverser	Heading	Speed	Altitude	Load	THP	BP	BC
5/8 1:10 PM	Seattle, WA	Seattle Yard	Running	Idle	Reverse	NNE	0.0 mph	20 ft	0 A	0 hp	111 PSI	1 PSI
5/8 1:05 PM	Seattle, WA	Seattle Yard	Running	Idle	Centered	NNE	0.0 mph	20 ft	0 A	0 hp	111 PSI	0 PSI
5/8 1:00 PM	Seattle, WA	Seattle Yard	Running	Idle	Centered	NNE	0.0 mph	20 ft	0 A	0 hp	111 PSI	54 PSI
5/8 12:55 PM	Seattle, WA	Seattle Yard	Shutdown	Idle	Centered	NNE	0.0 mph	20 ft	0 A	0 hp	112 PSI	0 PSI

Figure 7 – Real-time event recorder data



Figure 8 – DVR Snapshot

tive systems while the unit is on the move. Through a web-based interface a user can readily look at the locomotive status and verify that all systems are online and functioning in real-time. Real-time system diagnostics is beneficial to on-time performance. In reality the locomotive can transmit parameters that are out of range which in turn puts maintenance on alert for when the locomotive comes in for service so that repairs that may be needed can actually be planned events instead of being a surprise on arrival.

When problems occur on the road historical data can help isolate the problem making troubleshooting simpler and quicker. Graphs like Figure 11 show real-time trending while the locomotive is loading, giving the maintain-

er the information he needs to isolate any issues so the locomotive can continue on without any more delay than necessary.

With all of these features (and those that may not have yet been discovered) there is of course a cost. This breaks down into areas such as cell phone setup and the monthly fees that go along with them. If back office data is to be maintained, how will that be done? Will it be on-site and maintained by the railroad? Or as many are doing, will the railroad allow the supplying vendor to perform the back office data portion? Since these services come with a monthly fee, on top of any monitoring fee, decisions have to be made. Spare components are something else that needs to be considered in order to

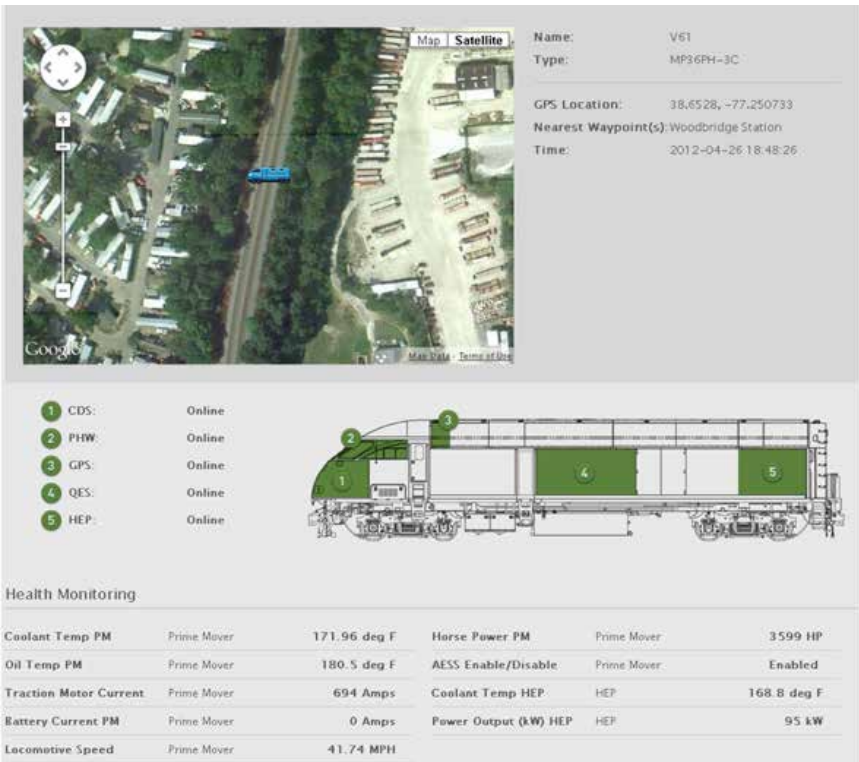


Figure 9 – Real-time Health Screen

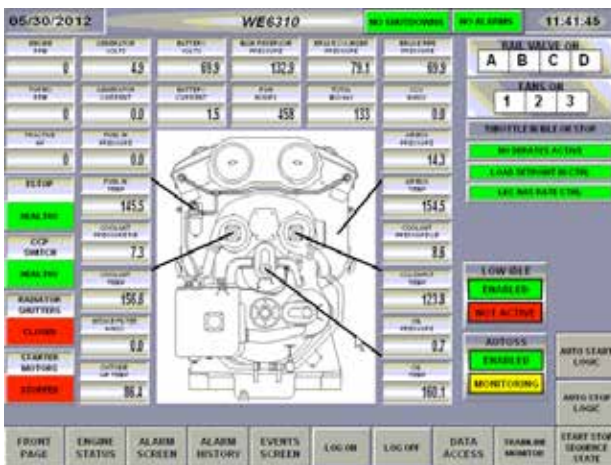


Figure 10 – Remote engine screen through PSI Viewer

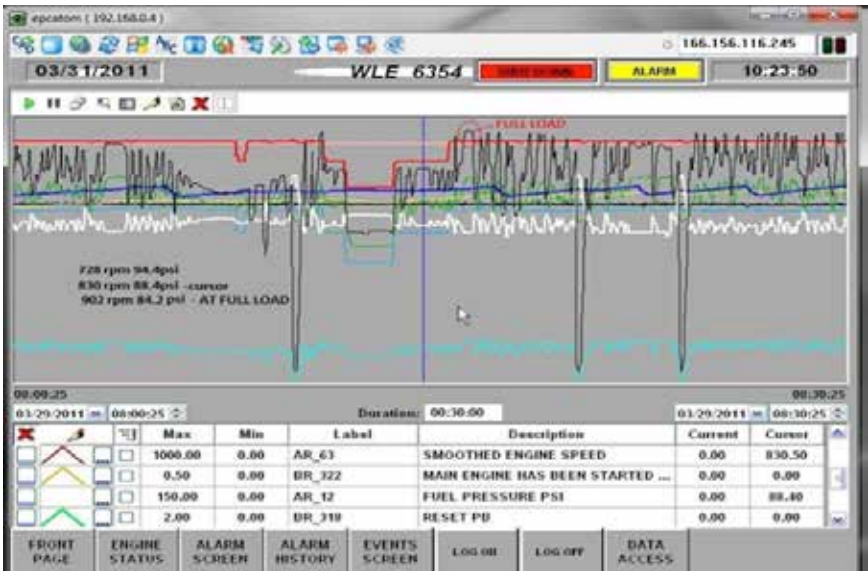


Figure 11 – Historical graphing of engine loading

keep the systems operating with allowances for failure. It goes without saying that reliability of the remote monitoring system is the key to keeping the locomotives reliable. If the remote system goes down, then the advantage has been lost.

Remote monitoring gives us long term data collection that will assist in historical analysis of locomotive performance and event data. With these tools individual locomotive as well as fleet performance can be determined. Trends of failures can be more easily seen when this data can be easily gathered. Real-time analysis of locomotive troubles can be done with this data in the hands of locomotive experts. The future of remote monitoring includes more and improved automated analysis tools to keep locomotives on line.

We have only touched on what remote monitoring is capable of here. But with all of these features remote monitoring has grown from something nice to have, to something we need to have for reliability, cost savings, fuel savings, and on-time performance. Only the future can tell what else we may be able to do with remote monitoring of locomotives – maybe even remote maintenance will someday act on those alerts?



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Extending Battery Life

*Prepared by:
David Brooks (ZTR Control Systems)*

Introduction

In the last few years, the introduction of automated engine start/stop systems (AESS) has saved the railroad industry millions of gallons of fuel. With this fuel savings comes an increased usage of the locomotive starting system that has, over time, reduced the achievable lifetime of batteries and starters. In addition to AESS systems, increased electrical content on locomotives, especially those active when the engine is not running, can also add additional strain to batteries. This paper will discuss:

- A brief summary of some of the available battery technologies.
- A brief comparison of those technologies in the locomotive application.
- The strains that AESS places on those batteries in more detail.
- Technologies that can help to prolong the life of batteries.

Available Battery Technologies

Although there are a plethora of battery technologies available today, only a handful of these are practical for use on locomotives. This is mainly due to the: large required capacity, duty cycle, electrical noise, high

vibration environment and large temperature range.

Flooded Lead-Acid Batteries

Flooded lead-acid batteries are one of the oldest battery technologies and still by far the most ubiquitous in the rail industry. They have proven themselves over many years to be dependable and relatively inexpensive. These batteries are relatively simple to charge with a couple of caveats. If the battery is allowed to deplete too far, the plates in the battery will sulfate. If the battery is overcharged for too long, the battery will suffer grid corrosion. These batteries will, over time, vent small amounts of gas and also require the addition of water to ensure electrolyte balance.

Sealed Lead-Acid Batteries

There are two main types of sealed lead-acid batteries: “Gel Cells” where the electrolyte is suspended in gel form and contained in plastic packets, and Absorbent Glass Mat (AGM) where the electrolyte is suspended in a specially designed glass mat.

These batteries contain a much smaller amount of electrolyte; hence they are also referred to as “acid-

starved". The same results of sulfation and grid corrosion can occur on these batteries as in the cases listed for vented lead-acid batteries. Normally gases created through these processes are recombined within the battery to form water. Gas can still be vented if significant overcharge or depletion occurs. Since water cannot be added to these batteries, this venting causes a permanent decrease in the capacity of the cell.

Nickel-Cadmium (NiCd) Batteries

NiCd batteries have a higher specific power (the battery capacity in Watt-hours divided by the battery weight) than any type of lead-acid battery. These batteries can withstand a much higher number of discharge cycles. The "memory effect" that most people associate with these batteries is not actually a decrease in the capacity of the cell. This effect is actually a voltage dip that can occur at a certain state of charge if the battery is repeatedly discharged to the same point and then recharged. This effect is highly unlikely to have a noticeable effect in the locomotive application as anything on the locomotive requiring battery power alone will not have sensitivity to minor fluctuations in voltage.

Unlike lead-acid batteries that retain their charge very well, NiCd batteries do suffer from a higher self-discharge rate than their lead-acid equivalent. NiCd batteries contain Cadmium, a toxic heavy metal that requires special disposal at designated facilities. Nine major facilities already exist worldwide that are capable of fully recycling all NiCd bat-

teries. NiCd batteries are quite rugged and can take a fair amount of abuse, both electrically and environmentally, without detriment to the battery life.

Nickel Metal Hydride (NiMH)

In low-power applications a NiMH battery will have 30-40% higher energy density than standard NiCd batteries. However, to maintain the required robustness for high power applications, the energy density is lowered (it is 30% lower than in consumer electronics). NiMH cells are generally environmentally friendly since only mildly toxic materials are used to construct them and the facilities to recycle them are more widespread. These batteries have a very high self-discharge rate of approximately 20% in the first day and 4% each day after. Elevated temperatures exacerbate this self-discharge. NiMH batteries, in general, do not tolerate high temperatures well in any circumstances.

Lithium Ion (Li-ion) Batteries

One of the newer battery technologies is lithium ion. Although there are several different types of Li-ion batteries, they will be discussed in general here. The major benefit of Li-ion batteries is that they have a very high specific energy per weight (over two times that of a NiCd battery). They also have excellent load characteristics with a flat discharge curve and a generally low self-discharge rate. Large scale usage of these batteries in electric / hybrid vehicles has driven the price of this technology down significantly. Li-ion batteries can suffer

from very dangerous failures modes (including thermal runaway with flames) if not cared for or charged/discharged correctly. Because of this, most Li-ion batteries are made with built-in protection to ensure that the conditions under which these failure modes occur do not happen.

Battery Energy Storage Comparison

The battery technologies in the paragraphs above are listed in order according to their energy density. This means that for a given weight/size, the lead acid battery technology stores significantly less energy than NiCd, which in turn stores significantly less energy than Lithium Ion type batteries.

Battery State of Charge/Discharge Characteristics Comparison

Depending on the type of battery used, the method of determining the state-of-charge of that battery differs dramatically. Today's AESS systems depend upon a drop in terminal voltages on lead acid batteries to determine their state-of-charge. With newer battery technologies, the terminal voltage drops very little through their full state-of-charge range right up until the battery is almost fully discharged. Using newer batteries with AESS systems will be challenging because of this. A benefit of the newer technologies over lead acid, however, is that they are able to maintain high power output even when they are in a depleted state of charge. This means that, in theory, these batteries could be allowed to deplete much more than a lead acid battery and still be able to

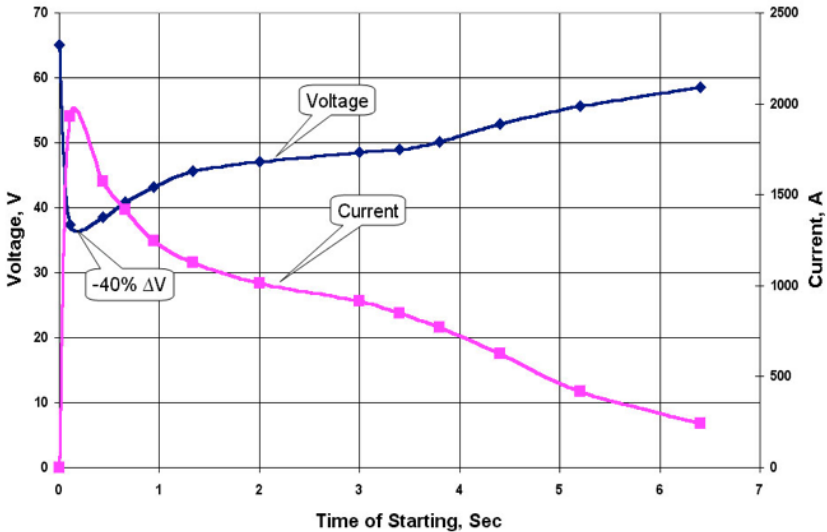
maintain the current required to crank the engine. This high power output, in addition to their higher energy density, makes them great for an AESS, with the caveat that the AESS system must be able to accurately determine their state of charge.

Battery Life in Locomotives

Battery life in locomotives has been reduced in the last several years due to the widespread application of AESS systems and the common use of lead-acid batteries. In the past, locomotives were only shut down and started up occasionally. With AESS systems they are now shut down and restarted several times a day.

In addition to the sheer number of cycles that the battery and starter have to go through, the health of the battery is further deteriorated by the fact that battery voltage is a condition for the AESS system to restart the engine. If all of the other conditions to keep the engine shut down are met, the AESS will keep the engine shut down until battery voltage falls below a set threshold. This is a critical requirement of the AESS system to ensure that the batteries are capable of starting the engine.

Starting of a typical locomotive engine requires a very high break-away current of over 2000 Amperes. If this power is being extracted from a battery that is already in a low state of charge it will only drive the battery further into depletion. This can be seen in Figure 1 with the dip of the battery voltage from its nominal 64VDC down to less than 40VDC when the engine crank is first initiated.



As was noted above, with lead-acid batteries, pushing the battery to a depletion state causes sulfation of the battery and further lowers its capacity. A lower capacity battery will lose its charge faster when the engine is shut down, driving more restarts from the AESS due to battery voltage, creating a vicious cycle of battery deterioration.

Technologies for Extending Battery Life

There are several technologies that exist in the market for extending the life of batteries used in locomotive applications. The technologies discussed in this paper are as follows:

- Auxiliary Power Units (APUs) with integrated battery chargers
- Discharge control systems (specifically automated battery disconnect)

- Crank assist systems (specifically integrated supercapacitor)
- Battery maintenance systems (specifically battery desulfators)

Auxiliary Power Unit (APU)

Auxiliary power units have been around for many years now. Not only do these APUs keep the engine warm, but some also maintain the charge on the battery. By not allowing the battery to deplete, APUs prevent sulfation of the battery and hence increase battery longevity. Even if the APU doesn't maintain the battery charge, the fact that the main engine is warm when it is started means the torque required to crank it is reduced. The down-side of APUs is their high purchase price and ongoing maintenance requirements.

Discharge Control Systems

Load Shedding With the number of electrical devices on each locomotive constantly increasing, the demands on the electrical system are increasing commensurately. A lot of these devices still continue to draw power from the battery system even when the engine is not running. This is in addition to loads that can be purposely or accidentally left on by the crew. These additional loads deplete the battery when the engine is not running causing additional restarts in the case of an AESS equipped locomotive and sulfation of the battery in the case of a non-AESS equipped locomotive. Load shedding systems can work in conjunction with AESS systems to deactivate battery loads when the locomotive is shutdown. This decreases the current draw on the battery and ensures that depletion of the battery is kept to a minimum.

Battery Disconnect One of the worse situations that can occur with a lead-acid battery occurs when it is allowed to discharge completely. Not only does this often cause an out-of-service situation with the locomotive and possible schedule delays, but it also causes excessive sulfation of the battery thus severely reducing its life.

With non-AESS equipped locomotives, leaving a locomotive shutdown without pulling the battery knife switch can lead to this situation. With AESS equipped locomotives, disabling the AESS equipment using the EFCO button to shut the engine down without pulling the battery knife switch can lead to this situation. Auto-

mated battery disconnect systems are a simple, low-cost way to ensure that if either of these situations occur, the knife switch is automatically opened after a period of time, thus saving battery life.

Crank Assist Systems (Supercapacitor)

As has been discussed above, cranking the locomotive prime mover with a battery, regardless of its state, puts a great deal of strain on the battery and can shorten its life. The vast majority of that strain occurs in the first second or two of cranking when the electrical current required to overcome the static friction of the stopped engine is extreme. In this situation, the series wound starter motor looks exactly like a short circuit to the battery, and it doesn't start producing back-emf to limit current flow until the motor starts turning. This "short circuit" characteristic puts the battery under extreme load.

Supercapacitors are devices that can store a significant amount of energy and release it very quickly without detriment to their life. These devices are good for hundreds of thousands of cycles.

A supercapacitor placed in parallel with the battery and properly integrated into the starting circuit can release its energy when the starting motor requires it (at the early high load "short circuit" phase) and remove some of the strain placed on the battery. Figure 2 and Figure 3 show the difference in voltage drop on the battery during the engine crank.

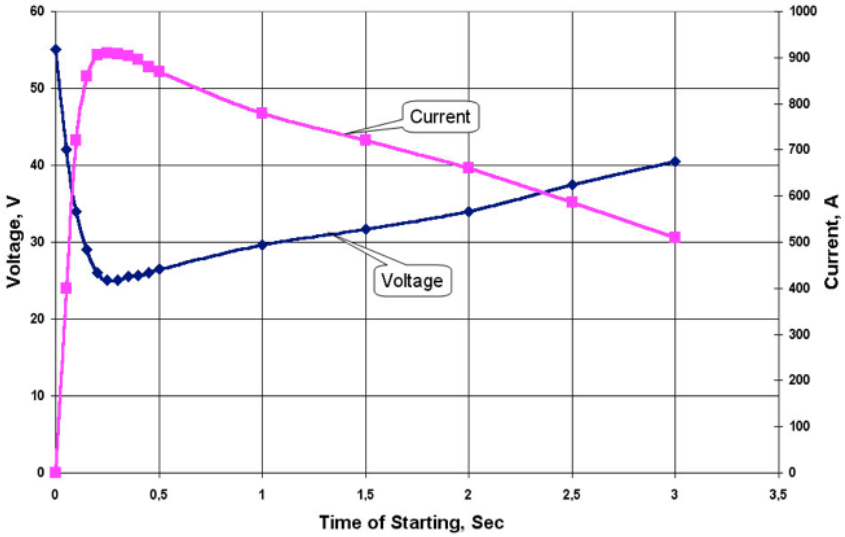


Figure 2 - Battery start with low state-of-charge batteries

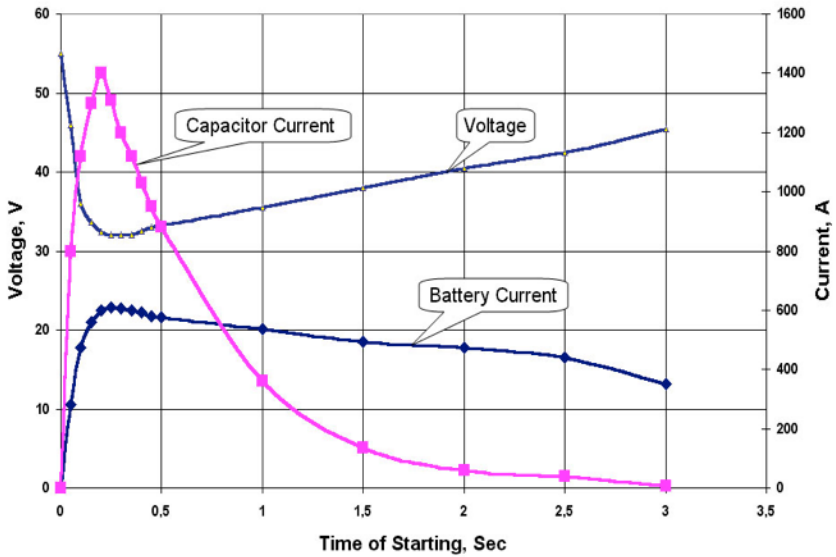


Figure 3- The same locomotive with the same batteries and a supercapacitor assist system

Battery Maintenance Systems (Desulfators)

Sulfation forms when a lead-acid battery is in a low state of charge. There are two types:

- Soft sulfation forms initially when a battery is in a low state of charge for a short period of time.
- Hard sulfation forms when a battery is left in a low state of charge for longer periods of time e.g. weeks / months.

Desulfation systems are only effective on soft sulfation. Desulfators work by applying high current pulses to the terminals of the battery for a relatively long period of time (24 hours). These pulses break down the sulfate crystals that are formed on the battery plates. Desulfators can be either permanently applied or used as a “rehabilitator”. Desulfator functionality can also be included as an integrated part of the battery charging system. Although this technology has shown success in automotive application, there is little evidence of great success using these devices on locomotive battery sets.

Multiple Phase Charging Systems

All batteries benefit from being charged under their ideal conditions. Although lead-acid batteries can be charged using a constant current limited supply, this does not represent their ideal charging condition. The newer battery technologies (including NiCd, Li-ion, and NiMH) require specific charging parameters to be held in order to prevent severe battery damage or even catastrophic failure. Depending on the battery type, these charging

systems may need to provide:

- Constant voltage
- Constant current
- Full discharge
- Trickle charge timers

These systems may need to sense:

- Charging current
- Battery temperature and change in temperature over time (dT/dt)
- Change in charging voltage over time (dV/dt) (NDV for NiCd)

Most experts recommend a 3-stage system for lead-acid batteries (see Figure 4):

- **Stage 1 – Constant Current (Bulk Charge):** Current is sent to batteries at the maximum safe rate they will accept until voltage rises to near full charge level (80-90% charge).
- **Stage 2 – Topping or Absorption Charge:** Voltage remains constant but current gradually tapers off.
- **Stage 3 - Float Charge:** After the batteries reach full charge, charging voltage is reduced to a lower level to reduce gassing and grid corrosion thus prolonging battery life. This is often referred to as a “maintenance” or “trickle” charge.

Conclusions

There are several suitable choices for battery technologies on locomotives. There is no one stand apart solution that is easily discernible as the clear choice for overall cost effectiveness and performance. The best choices involve either a higher up-front cost or a combination of technologies to achieve greater longevity.

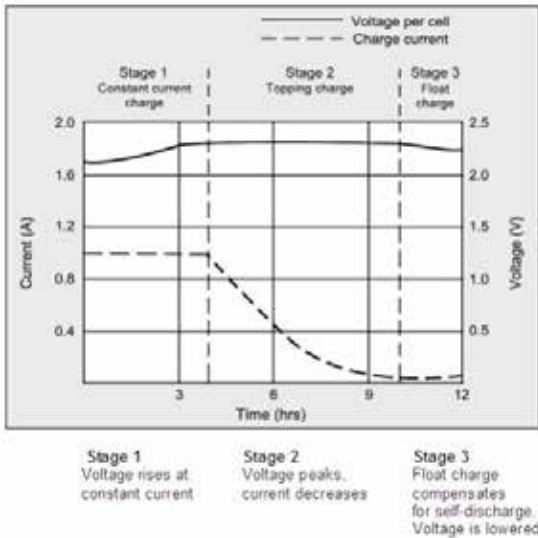


Figure 4 - Three phase charging algorithm¹

Plausible alternatives to a stand-alone lead acid battery are:

- NiCad batteries with the required charging system.
- Sealed or Vented lead acid batteries with a multi-stage charging system, supercapacitor, and automatic battery disconnect.
- Li-ion batteries with appropriate and robust safety and protection systems, charging system, and automatic battery disconnect.

Continuous improvements in battery technologies are occurring constantly as new technologies arise and older technologies improve. Many of these technologies may not be suitable in a locomotive environment or cost effective for railroads, but some will be. It will benefit railroads to stay abreast

of these new technologies and consider which may be right for them for their current and future locomotive fleets, especially those equipped with AESS systems.

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Acknowledgements

Philip Hess – NS
 Christopher Miller – UP
 Jeff Clapper – Wheeling and Lake Erie Rwy. Co.
 Bruce Kehe – CSS&SB
 Jeremy Smith – BNSF
 Viktor Gvelesiani – ZTR Control Systems

Report on the Committee on Diesel Electrical Maintenance

Tuesday, October 1, 2013 at 10:30 A.M.



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Tom Nudds

Training and Development Manager
ZTR Control Systems
London, Ontario

Vice Chairman

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<i>(Past President)</i>			

Note: E. Grecu, Via Rail, will be joining the committee replacing Ron Bartels

PERSONAL HISTORY

Tom Nudds

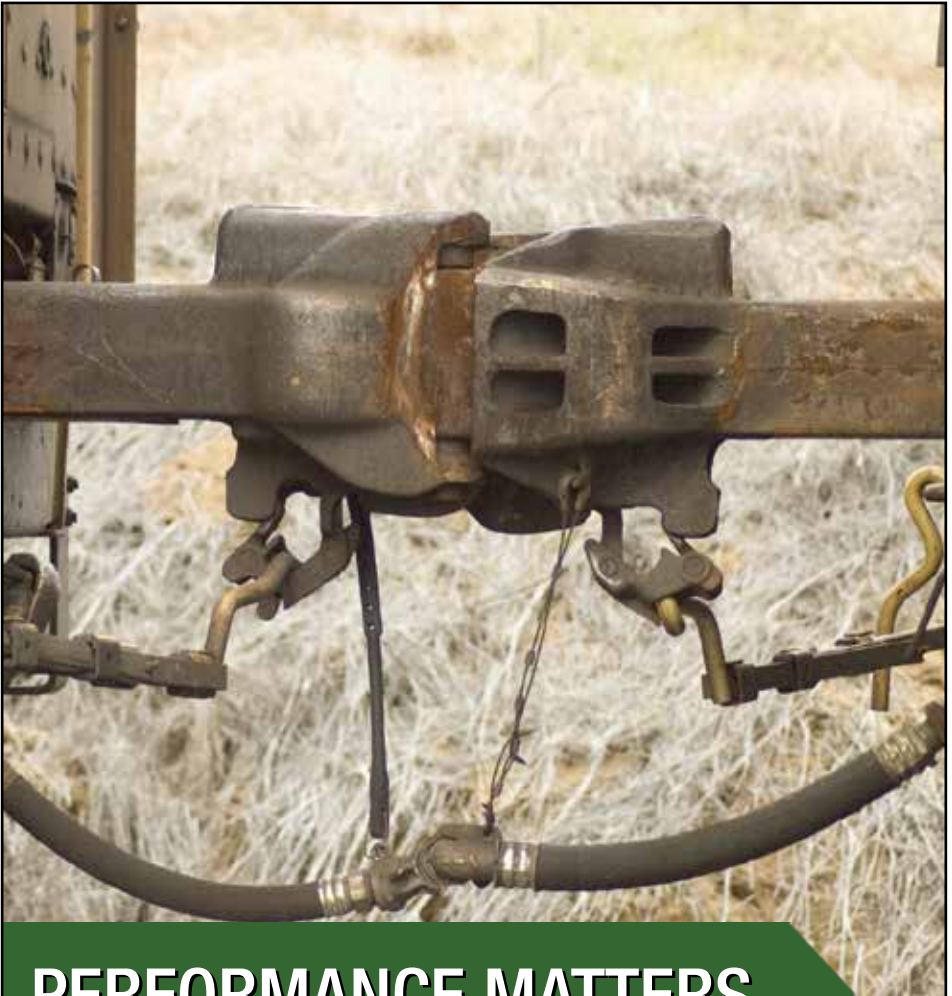
Training and Development Manager
ZTR Control Systems

Tom was born in London Ontario and attended Fanshawe College there. He joined General Motors Diesel (EMD London) in 1971 and was at GMD for 17 years. His work experience includes Locomotive and Titan electrical assembly, Locomotive Test, Armoured Vehicle Test, Production Supervisor, Quality Assurance, Receiving Inspection Supervisor and Locomotive Test Supervisor. In 1988, Tom joined four other former GMD employees to start a company called Trac Rail which became ZTR Control Systems. His position currently is Training and Development Manager at ZTR.

Tom lives in London with his wife Mary Lou, a Bouvier Des Flandres and two Siamese Cats. He has two children and four grandchildren. Tom enjoys his motorcycle, photography and IPSC shooting sports.

The Diesel Electrical Maintenance Committee would like to extend their sincere gratitude to the UPRR Jenks Shop in Little Rock, AR for hosting their February 2013 meeting. The committee toured the Jenks shop and then a tour of GNB Battery in Fort Smith. Thank you Mark Henry for arranging the Jenks tour and Chris Adams for arranging the GNB tour.

They would also like to thank Stuart Olson for arranging Wabtec Railway Electronics to host their July 2013 meeting in Germantown, MD and the tour of their excellent facility there.



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Locomotive Diagnostics

Prepared by:
Amarjit Soora, ZTR Control Systems

Introduction

Diagnostics is the art of practice of diagnosis:

“The identification of the nature and cause of anything”¹

While the above is applicable and holds true in just about every industry, in the locomotive world this focuses on reducing downtime. The sooner we can identify the problem, the sooner the locomotive will be in revenue service.

Workforce Optimization

All organizations strive to achieve the highest possible productivity. However, productivity is not simple to measure when dealing with problem solving and troubleshooting.

There are two obvious undesirable situations: untrained (low skill) workforce and overqualified workforce. In case of the former the inability to solve problems and in case of the latter the high cost of skill glut leads to loss of productivity. Somewhere between these extremes is the sweet spot that everyone is trying to find, where the training costs and skill level combine themselves into an “ideal workforce”.

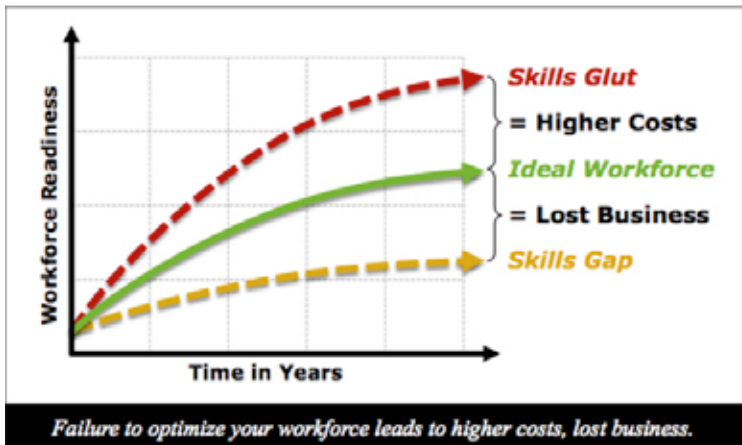
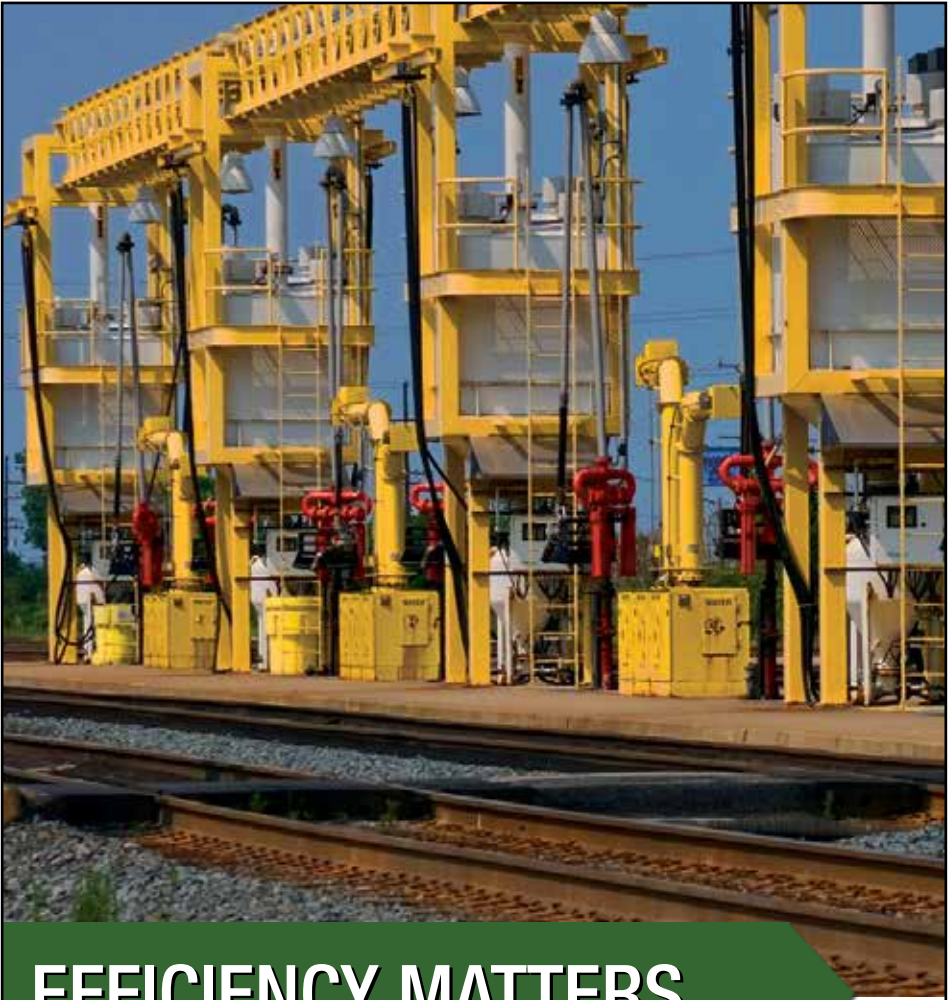


Figure 1. Workforce Readiness vs. Time



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Most companies find this optimum by trial and error and once found this balance is carefully maintained. However, changes in the environment (such as demographic shifts, or technological breakthroughs) can upset this balance.

High attrition rate of baby-boomers in recent years suggests a potential skill gap that could only be filled with a substantial investment in training and time if companies continue using traditional methods.

Traditional methods rely on specialized training and practical experience. In the case of retiring baby-boomers, this means a significant outflow of skills that took a long time to develop. New recruits will either have to go through more intense (and expensive) training, or will just have to be patient and wait until the skill gap closes itself over time. Neither choice appears to be very attractive.

Technology can help to solve this problem. Advanced diagnostics systems (if implemented correctly) can augment the current skill level and bring the workforce to its ideal skill level without having to wait or invest into additional training.

Modern locomotives equipped with microprocessor control systems are addressing these issues to some degree through the use of:

- Extensive data logging
- HMI diagnostics
- OEM provided diagnostics (data analyzed by OEM)
- Wireless connectivity

However, older locomotives (which more frequently require atten-

tion) do not provide such luxury to the maintenance personnel.

Pre-microprocessor Diagnostics

An example of this on pre-micro locomotives is the EMD Dash 2 system.

In order to perform real time diagnostics, the unit was equipped with a test panel with electrical “test connections” to various points on the locomotive (generator positive/negative, alternator winding etc.). With a multimeter in hand the technician would measure the millivolt (mV) signals and, using predefined formulas, determine the actual reading.

With respect to historical information, the dash 2 system was equipped with an annunciator panel. There were a limited number of conditions that would cause transmission of an electrical signal to the annunciator panel such as the following:

- Hot Engine
- Engine Air Filter Restriction
- Grid Open Circuit
- Motor Excitation
- Grid Overcurrent
- Ground Relay
- Excitation Limit

The technician would open the dash 2 door and if an LED was illuminated it meant a fault had occurred. The limitation with this setup is that it only indicates an incident type occurred but no record of when or how often.

Early Microprocessor Systems

One of the first improvements with these systems was text based on-board diagnostics (HMI) that included his-



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torical information and provided fault codes.

However, these systems were typically not user friendly as they required the technician to look up the code and then determine the correlated fault. Often the displays in these units had small limits with respect to lines and characters i.e. 4 line x 16 characters.

These systems still require highly skilled and experienced personnel to interpret the fault codes and diagnose problems.

PC Based

Eventually more user-friendly PC based diagnostics was introduced that offered a blend of historical data with meaningful descriptions, guides on how to resolve the issue and locomotive performance reports.

Real time diagnostics to aid in the diagnosis of the fault as it was occurring also became more intuitive (figure 2).

With the pre-micro systems, the technician needed to setup meters and perform calculations to observe real time parameters. With these PC systems bar graphs, charts and other graphics were used not only for the historical information but for the real time performance parameters as well (speed, horsepower, traction system voltages and currents). As previously mentioned, although this could be done via a multimeter and calculations, this method was more efficient while providing more information at the same time! (figure 3)

Through time PC based diagnostic systems have evolved to provide more and more intuitive problem solving

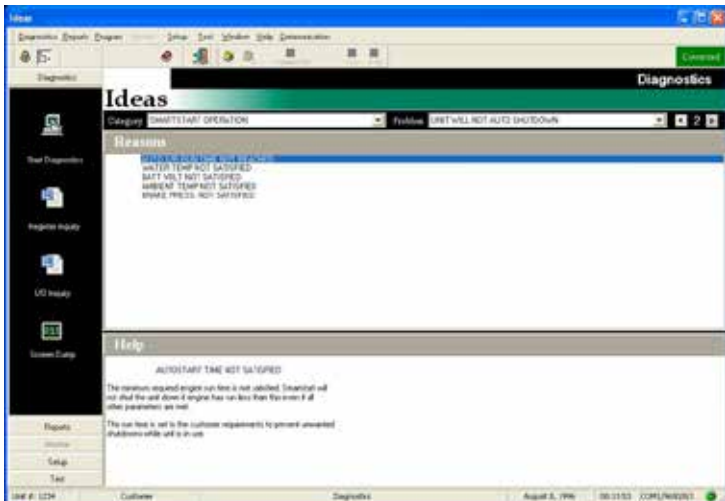
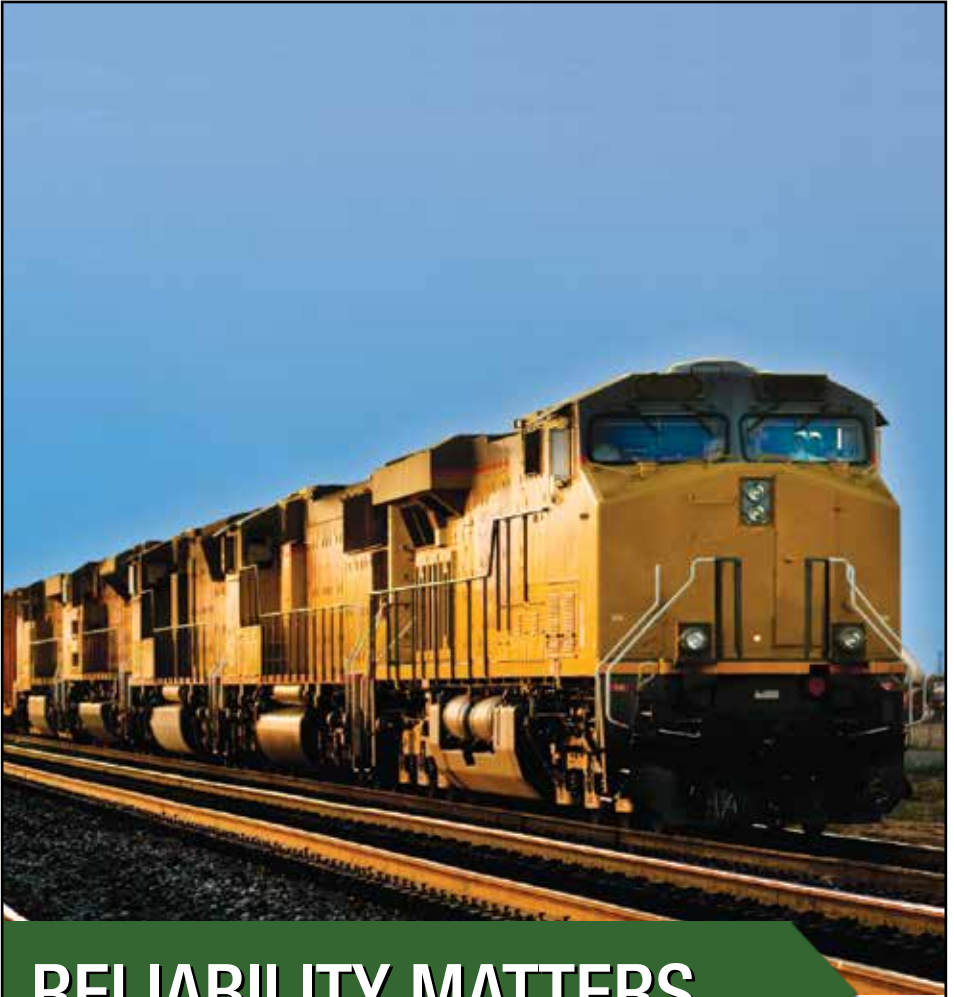


Figure 2. PC based diagnostics



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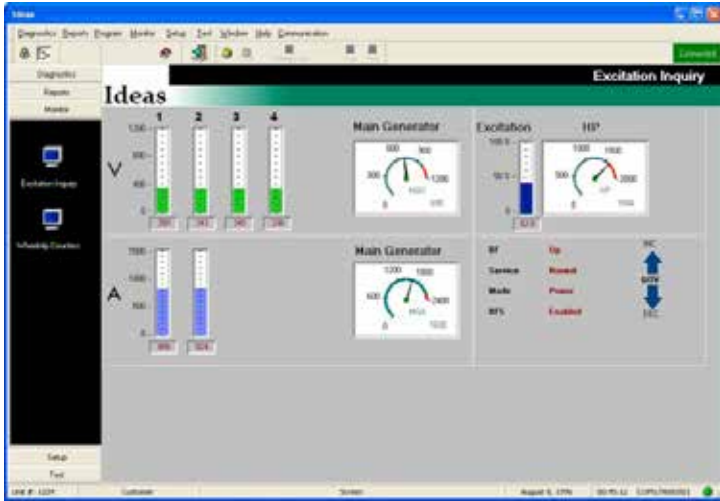


Figure 3. PC based performance monitor

techniques. An example of this are the interactive troubleshooting flow diagrams (see figure 4):

- User states the problem (i.e. unit is not moving)
- System provides possible reasons and highlights which reasons could (under current conditions) be causing this problem
- User attempts to clear these conditions using interactive help procedures, or drill down further
- The system monitors and updates visualizations in real time to indicate favourable outcome

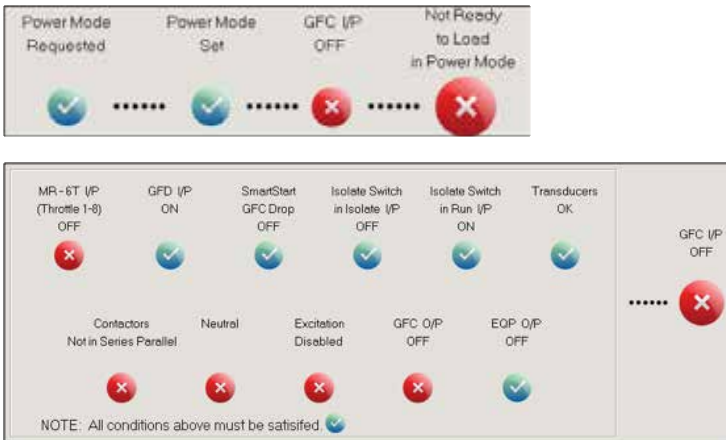


Figure 4. Modern PC diagnostics

HMI Diagnostics

Greater availability and variety of ruggedized displays has allowed HMI's to become more integral to diagnostics.

The obvious advantage of HMI's are they are always there when you need to troubleshoot:

- No need for a portable computer
- No specialized cables and adapters
- No software compatibility issues
- No IT restrictions

Significantly advanced graphical, processing and memory capabilities bring HMI's close to laptops and tablets – it's not surprising that modern HMI's are often preferred to PC-based diagnostics.

Greater processing and communication capabilities open doors for HMI based diagnostic systems to pool information from various computerized “aftermarket” systems to provide one stop shop for troubleshooting help.

We previously touched on first generation HMI diagnostics that were not user friendly – is it possible to replace these? The answer is yes.

Using published protocols, some aftermarket replacements are now also available to replace first generation systems. Below is a capture of such a replacement for the GE Dash 8 DID panel:



Figure 5. Modernized replacement for DID panel

Aside from addressing the user-friendly aspects, another benefit is a modernized replacement for previously obsolete panels.

Various Options

With the increasing numbers of suppliers and microprocessor platforms available, the railroads (AAR) should be driving towards common open (this is critical) protocols allowing greater interchangeability of the equipment.

Moving forward

We earlier discussed the importance of being able to diagnose the problem on the locomotive quickly so that it can be repaired and back in revenue service fast. And there are many tools at the railroad's disposal, whether it is a laptop, HMI or remote access.

However, the locomotive being down in the first place costs money.

Through the implementation of prognostics and predicting potential failures, the chance of certain road failure types would be minimized. While this does involve accumulation of large amounts of data and processing power, modernized locomotives have both. Today's control systems monitor almost every performance parameter on the locomotive and often have a wide range of interface options (RS232, CAN bus etc). With this information available, prognostics systems can compare desired performance against

actual, monitor for degradation in performance and, ultimately, predict failure times.

While predicting the failure of every component on a locomotive is not cost effective, there are obvious benefits to predicting the failure or degrading performance of major components such as engines, generators and other rotating equipment.

Final Comments

In conclusion, we are talking about a two tier approach – being able to predict problems before they occur and, if the failure occurs, being able to diagnose and repair in a time effect fashion.

Even though modern designs should provide increased attention to prognostics, when considering locomotive modernization programs, it is important to keep in mind the skill level of maintenance personnel today and implement diagnostics accordingly. In most cases it means microprocessor systems with onboard diagnostics with intuitive navigation and messaging, including capability to wirelessly integrate into back office maintenance systems.

References

1. <http://en.wikipedia.org/wiki/Diagnosis>

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Positive Train Control (PTC) - Onboard Segment An Update and Recommendations

Prepared by:

Bob Ralph – Norfolk Southern Railroad

Jason Fox – Union Pacific Railroad

FRA regulation 49 CFR 236 parts H and I require all railroads that meet certain traffic conditions to equip lead locomotives on all trains with a communications based train control system. In order for this system to be interoperable between territories and railroads the Interoperable Train Control group was formed to develop and approve standards for an interoperable train control system to meet this requirement. This paper will discuss some of the lessons learned from this effort. For those just starting to equip locomotives, this paper will give recommendations on what to prepare for. For those who have not yet turned on a PTC system, this paper will present some of the issues expected in your future.

Types of Installations

When considering onboard equipment there are two categories of installation types. The first category is equipment installations on newly purchased locomotives. The second category is a retrofit of PTC equipment to railroad owned locomotives.

Locomotive Original Equipment Manufacturers (OEM) are working with railroads and PTC equipment suppliers to install equipment on newly

built locomotives. This installation type allows a unique opportunity to relocate other equipment to allocate space for the PTC equipment. Railroads should work with the locomotive OEMs to determine what options are available to move equipment so that the PTC equipment can be placed in a reliable, maintainable location. All OEM locomotive schematics illustrate PTC equipment placement and wiring termination landing points.

The second category of installation type is a retrofit of PTC equipment on each railroad's legacy fleet. This is where PTC equipment is installed on a locomotive that is currently owned and operated by a railroad. It is expensive to relocate existing equipment. Finding a location for all of the PTC equipment poses a challenge. Some of the challenges are discussed below. Retrofit installations require a separate PTC schematic that must be used in addition to the locomotive schematic. Railroads need to work to getting existing locomotive schematics revised to show newly installed PTC equipment.

Why start now?

Both UP & NS chose to determine equipment location and install the PTC equipment in-house with shop forces performing the installation and testing the system, and validating the installation during final system checkout. Although PTC is not required until the end of 2015, the installations have been started years in advance. Spreading the installation out over several years will allow each railroad to reduce the impact the installation has on locomotive availability. Additionally, the manpower required to install and test equipment on several thousand locomotives over a shorter time frame would be massive and unrealistic.

Starting installations early allows each railroad to develop a trained work force for the PTC system. By the time PTC is deployed, each railroad will have several hundred craftpersons extremely familiar with the installation and operation of the PTC equipment. This built-in knowledge of the PTC system will be invaluable as the need to troubleshoot and maintain the PTC equipment increases.

Early installation of PTC equipment has allowed railroads to adapt energy management systems in development and testing to use the same computer platform as PTC. Energy management systems present fuel saving opportunities to railroads allowing them to get some return on the investment of PTC equipment. By using PTC equipment as the platform to run energy management, railroads are gaining real-time operational experience with the equipment. Failure modes are be-

ing discovered and troubleshooting and repair processes are being developed for the PTC equipment today. This will be discussed in detail later.

The experience a railroad gains by running energy management systems on the same computer platform as PTC will provide a glimpse into what tools and reports will be required to manage the complicated systems on the locomotives. These tools require additional time and resources to develop. Many tools can be developed and implemented before PTC systems become active.

The implementation of PTC involves a delicate balance of trying to get ahead of the installation curve to prevent surprises when the system is turned on and waiting for new equipment to be released to railroads at the time of installation. Managing this balance will prevent unnecessary shopping of locomotives to install equipment that was not ready when first installed. Having key tools and reports in place as well as an experienced staff of trained people will be the future key to PTC success.

Variations in installations

The first important lesson learned from this effort was the realization of just how many variations of locomotives exist. Both Union Pacific and Norfolk Southern have 23 different locomotive models that will require PTC equipment.

Further complicating the challenge different locomotive models present is the variation within each locomotive model. The physical location and placement equipment and even wiring loca-

Norfolk Southern	
SD40-2	GP60
D9-40CW	SD60I
GP38-2	D8-32B
ES40DC	SD60M
SD60	GP38-3
D8-40CW	GP59
SD70M-2	ES44AC
D9-40C	SD40-E
GP40-2	SD70ACE
D8-40C	PR43C
SD70	F7A
SD70M	

Union Pacific	
C40-8	GP60
C40-8W	GS21B
C41-8W	MP20GP
C44/60AC	RP20GE
C44-9W	SD 40
C44AC	SD59MX
C44ACCTE	SD60
EVO (C45ACCTE)	SD60M
GP15-1	SD70ACe
GP38-2	SD70M
GP39-2	SD9043
GP40-2	

Table 1: Locomotive Models Requiring PTC Equipment

tions can vary based on the Model Year or Locomotive Build Order. Sometimes a given Model Year can have two or three different Build Orders. The Build Orders could have different locomotive configurations that impact PTC equipment installation.

Anyone familiar with the history of railroads should not be surprised that locomotives have been acquired through mergers and these locomotives may have different cab configurations. Various modifications have been performed on these locomotives throughout the years. The documentation of these modifications range from poor to very poor. Another contributor to the variation of locomotive configuration is the changing FRA standards that were required at the time of locomotive manufacture or changes required since manufacture.

These factors create variations in the locomotive instructions and drive the above mentioned 23 different models to over 250 locomotive varia-

tions that must have PTC equipment installed. Some of the different locomotive configurations vary by only a few wire connections but many require new and unique placement of the PTC equipment. It is noted that the older locomotives are more unique and less documented. The older the locomotive, the more each locomotive is an individual and like no other unit.

Another major contributor to the variation in PTC equipment installations is these installations are performed at many different locations. It would be unreasonable to think several thousand locomotives could be routed through one location on each railroad to receive PTC equipment installation.

Union Pacific is performing installations at a rate of 140 locomotives per month at nine installation locations. Norfolk Southern is performing installation at a rate of 72 locomotives per month at eight installation locations.



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Juniata	Hinkle
	West Colton

Table 2: PTC Equipment Installation Locations

To reduce the variation that installations across multiple locations can introduce, standard work and standard installation processes should be developed and implemented. These standard work documents will give detailed instructions on equipment location, wire termination points and cable routing. Using standard work documents ensures that the PTC equipment is installed in the same way regardless of the installation site, thus reducing variability.

When starting PTC equipment installations on a new model, the best practice is to sort all of the locomotives in that model into the known groups of similar configurations. A good place to start is grouping locomotives by units from the same build order group and by original purchasing railroads. There is a good chance each locomotive from the same build order will have similar cab configurations. Knowing the original purchasing railroad will allow you to group multiple build orders together. It is likely a railroad desired to keep the same general cab configurations across multiple orders.

Once the locomotives are grouped within the model, a prototype installation can be performed. This installation is fully documented with a standard work document. This standard work document is verified on one more locomotive, and then released for all of the locomotives within that group.

Now the standard work document can be used to survey locomotives from other groups. If it is determined the document can be applied to a new group, it is released to those locomotives. If there are enough differences to require significant changes to the standard work documents, then a locomotive from that group is scheduled for a prototype installation and the new process is documented.

This structured approach reduces the number of unexpected cab and locomotive configurations the PTC equipment installation team must encounter. This approach will not eliminate unexpected configurations. Any unexpected configuration is handled through a continuous improvement technique called “stop the line”. When a “stop the line” event occurs, the unexpected configuration is noted with supervisors and a solution is developed and documented. This will ensure that similar configurations encountered in the future are not unexpected and this solution can be shared with other installation locations.

Equipment Location Considerations

We have discussed the extraordinary variability in locomotives that leads to locating equipment in different locations in the fleet; we must discuss other considerations to be taken when

determining where equipment will be located. Each piece of equipment must be placed in an environment that meets the design specifications. Temperature, humidity, salt spray, EMI, and vibration must all be evaluated before deciding on a location for a piece of equipment.

Screens must be placed so that the operating crews can 'naturally' see them. Maintenance and service personnel require equipment be placed where it can be accessed, replaced and status indicators can be seen by the craftperson. One interesting challenge is the need to provision for equipment that is not released to a production environment. For example, each railroad knows a 220MHz radio will be required. It is only in the last year railroads actually have known what it looked like for installation.

The variation in locomotive configuration has driven the need to install equipment in many different locations. The installation of the Train Management Computer (TMC) and Onboard Network (OBN) equipment in the short nose vestibules are desirable when there is space. Often, under desk areas must be utilized. Keep in mind environmental considerations; this equipment requires air flow to keep it from overheating. Other unique locations include Dash 2 control card areas and short nose sand box inserts for those applications with no other space available.

In most locomotives, a large Computer Display Unit (CDU) screen is being added where there was no thought to ever having a computer. The CDU must not block the windshield view and

must be simple and easy to access/view from the normal seating location. The equipment must also not cause a knee knocker condition for crews and shop folks.

Locomotive departments have been trying for years to reduce the operator control Christmas Tree Effect of added electronics competing for crew's attentions. In some cases, this newly installed equipment is mounted right back in the way of crew communications. There is often no other location for equipment placement given these constraints.

No part of the PTC system is more challenging than the communications. The system is required to use less than perfect communications paths to view the track ahead and to know where the dispatcher intends the train to go. To achieve this goal the system requires many redundant radio paths to work across any given track with many varied communications paths. Each of these paths requires radio modems and each modem has its own set of antenna requirements. These communication systems should not interfere with or prevent communications by the other systems contained within the locomotive.

The following consideration should be made when determining antenna locations

- The antenna(s) each need a clear view of the sky and clear forward view of the horizon.
- Each antenna requires a properly sized ground plane with no obstructions.
- Certain antennae tend to transmit at high power (voice radio and

220MHz radios) that will tend to interfere with other radios. There is no coordination of transmissions, so expect simultaneous transmit and receive conditions by different systems.

- The GPS antennae need to be spaced at least 1 meter apart for train control. There are benefits to mounting them on the locomotive center line.
- Each antennae needs to have a way to route the transmission line back to the radio modems, without being subjected to excessive heat, noise sources, or distance.
- There will be more antennae added in the future, plan for rework. Some railroads have opted to install an array of antenna farms to provide flexibility in antennae arrangement, maintainability, and a migration path for future expansion with minimal rework.

A First and Second Touch, and Third and Fourth.....

The scope of the PTC equipment installation today includes only a portion of the equipment that will be required to operate a PTC system. The installation and checkout of antennae, cables, the Train Management Computer (TMC), and Computer Display Unit (CDU) has been coined as the First Touch.

Equipment such as a Locomotive Data Acquisition Recording System (LDARS) compliant crash hardened memory, 220MHz radio, and Locomotive Interface Gateway (LIG) are being developed or tested. The requirements and solution for a limited reduction

penalty application are still being developed and tested. The software required to operate the equipment in the PTC system is being developed. As this new equipment and solutions are deployed, a Second Touch will be initiated where these items are installed on the locomotive and a more extensive test of the system is performed.

As more is learned and developed regarding PTC, more equipment will be added and more changes will need to be made to existing equipment. Some of the equipment does not yet exist for production purposes and some of the pieces already deployed have either become obsolete or have been recalled for upgrades. Until the PTC system solution is stabilized, there will be changes to the system that railroads must implement to create a reliable and effective system. While it is each railroads goal to commission PTC after the Second Touch, do not be surprised if several touches are required before PTC is ready for deployment.

There is a lot of work in bringing all units up to a common platform. A case study in this is the antenna array on Norfolk Southern locomotives. Originally, the PTC installation required six new antennae. These antennae were mounted directly on the cab roof. As the system evolved, the need for more diversity, more frequency bands, and higher gain antenna has driven the number of antennae up to thirteen.

The requirement of additional antennae has driven Norfolk Southern to re-evaluate how the antennae are mounted to the cab roof. An antenna array ("farm") solution has been imple-

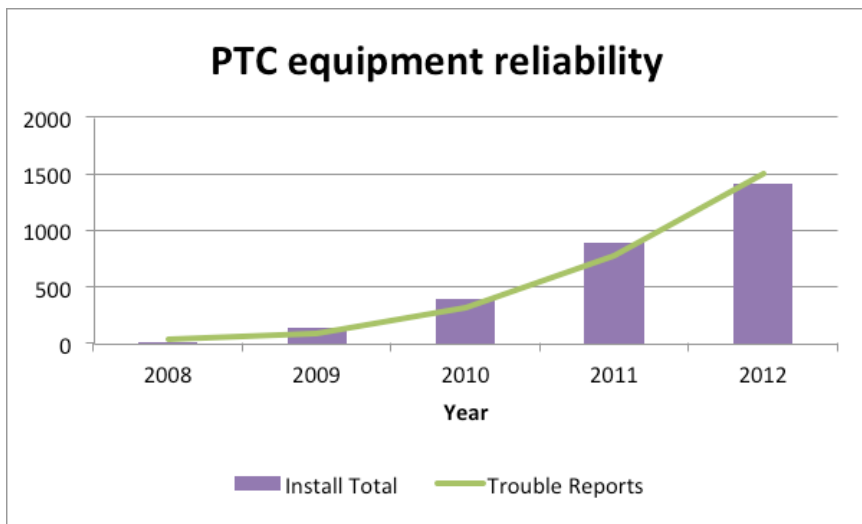


Chart 1: PTC equipment Installs and Trouble Reports (NS)

mented where enclosures are mounted to the cab roof and the antennae are mounted to the box. This solution has several benefits. Because the antennae are mounted to the box and not the roof, the cable can be bundled together and routed through a single (or at most two) hole in the roof. Minimizing the number of holes in the roof will greatly reduce the risk of water leaks into the cab. The clamshell design of the antenna farm allows each antenna to be serviced without removing the headliner in the cab.

The Second Touch will be used to upgrade locomotives with the 6-antenna solution to the 13-antenna farm solution. This solution also permits a single re-engineered solution as additional or different antennae are added in the future.

Failures & Mitigation

With new equipment come new issues. The Norfolk Southern has offered a glimpse into what they have learned from the nearly 1500 locomotives with an Energy Management System using the same computer platform as PTC. Note from Chart 1 that the number of trouble reports each year have followed the number of installations. This shows that reliability is not improving. As more systems are installed the problems are increasing; this product is still evolving.

Table 3 lays out the distribution of issues found with the equipment and the root causes. To date, the equipment has required more repairs than anticipated. Upgrading early installations and obsolete equipment upgrades are leading factors in Trouble Reports. Software bugs have confused crews and exasper-

ated the crew training issues are a reality. Another reality every railroad will have to deal with is vandalism. Vandals are causing cracked screens and failures resulting from tampered wiring. Currently these systems spend a great deal of time in the hands of crews with no idea what the equipment is for. They are curious.

Issue	%	Cause
No trouble Found	34%	Unknown causes
Software Not Ready	14%	Early deployment costs
Communication Equip	14%	OBNs, leased service, antenna, back office
Software Issues	13%	Ready but bugs discovered
Screens	7%	Failures and vandals
Reset	7%	Power cycle cleared issue
Wiring	5%	Mostly vandals
Antenna	3%	Water, tree strikes
TMC	2%	Software loads, cards failed etc.

Table 3: Distribution of PTC Equipment Failures (NS)

The above distribution of failures seems to follow a trend. Root causes can be identified and corrective actions can be put in place. We are hoping this indicates mostly early teething problems. However, the failures will be monitored closely and much development, refining and training still needs to be done.

Troubleshooting

Several railroads have collaborated with the PTC equipment manufacturer to develop PTC troubleshooting guides. These guides were written and verified on locomotives; not in a conference room. The guides were created, and then faults were induced on locomotives. The guides were then verified that they could be used to lead a craftsperson to find, repair, and test clear the fault.

The guides were written at very generic level. They have been submitted to the AAR and will likely be released as a recommended practice. Each railroad will be free to take the guides and customize them to their specific needs.

Recommendations

Most all railroads are faced with the FRA mandate to implement Positive Train Control. Early installation of equipment will ease the pain later. Operating hours of the equipment now will give railroads the experience needed to know what tools and reports will be needed so that they can better manage the system when PTC goes live. These tools/reports should be able to allow the railroad to plan repairs to minimize locomotive downtime.

When installing PTC equipment, take a structured approach to the installation process. Learn as much as possible about where the locomotives came from and their configuration to minimize the variability of installations on similar models. Use standard work processes to ensure that each installation is performed the same way.

When selecting equipment locations, be sure to consider environmental design constraints of the equipment. Consider how the operating crews and maintenance personnel will interact with the equipment. To aid troubleshooting, plan to update locomotive schematics with the wiring related to PTC equipment.

Be aware that the communication system is extremely important in a communications based train control system. Redundant communications paths should be built into the system. Paths should be able to fail without affecting PTC performance. Proactive warnings are needed for timely testing/repair of these paths. Where possible, develop a solution that will permit a one-time engineered solution to any other antenna to be added without having to re-engineer 250 different installations.

Because of equipment availability, early installations will lead to multiple

touches of the locomotives to get all of the equipment installed. Expect each locomotive will need to be touched 2-4 times before PTC can be commissioned. After PTC equipment is installed, expect 2-3 additional trouble reports per year per locomotive due to failures of the system. This additional work needs to be factored into future servicing staffing levels.

PTC is early in its development at present. It is not going to be easy, especially not at first. There are still many lessons being learned. Railroads are working with OEMs and PTC equipment suppliers to improve availability, reliability and serviceability. There is much field testing of this equipment yet to be done and it is not ready for prime time yet. With proper planning, testing, and documentation, this system will get better as time goes on but not without it being a learning experience for all railroads.

Locomotive Battery Storage and Maintenance

A Recommended Best Practice

Prepared by:
Chris Adams, TPSC

The goal of this paper is to assist users in improving locomotive reliability through the proper storage and maintenance of the locomotives batteries.

Over the past five years GNB service centers throughout North America have had a growing number of locomotive batteries come in for repair and return work that are simply discharged and or low on electrolyte. The problem runs industry wide and makes no distinction as to the battery make or model. To understand this trend we must consider how the operating practices for locomotives have changed during the same time. Historically locomotives were started infrequently and allowed to run for days or even weeks at a time. This practice allowed the onboard charging system, which was set up to provide a “trickle charge”, to slowly return the battery to a full state of charge and to maintain full state of charge. In addition to the significantly longer run times for locomotives the ancillary electrical demands were considerably smaller than they are today. In today’s operating environment locomotives

are equipped with automatic start stop systems (AESS) that are designed to start up and shut down the locomotive multiple times each day in order to conserve fuel and to limit emissions. Additionally newer locomotives now operate multiple computers, heaters, air conditioners, PTC, and other electrical loads that were not present in the past and some of these loads remain on even when the unit is shut down. Paradoxically multiple starts and constant electrical loads puts more demand on the battery requiring more energy to be put back to the battery than the AESS programming permits.

A battery is an electrochemical storage device. It stores chemical energy which is then converted to electrical energy. What a battery is not is an energy producing device; it can only give back what was previously put into it. Think of your bank account. If you didn’t make any deposits eventually you wouldn’t be able to make a withdrawal.

The basic chemical reaction which takes place within a lead acid battery...



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As the battery is discharged the lead oxide on the positive plate reacts with the sulfuric acid to form lead sulfate and electrons. Meanwhile the lead from the negative plate is reacting with sulfate ions to produce lead sulfate and two positive charges. By supplying energy (to recharge the battery) these reactions are reversed and the lead sulfate is broken down with oxygen from ionized water with lead oxide being deposited on the positive plate and lead being deposited on the negative plate. Note that the recharging process is not a perfect reversal due to unwanted chemical reactions and physical damage to the active chemicals. Examples are corrosion which consumes some of the active materials, chemical loss through evaporation, and sulfation of the plates which blocks some of the active material from being able to participate in the reactions.

Sulfation

Note that lead sulfate is the byproduct of the chemical reaction at both the positive and negative plates. Sulfation is the depositing of lead sulfate onto the battery plates. Initially this lead sulfate is in an amorphous state which is easily broken down by the input of energy during the recharging process. If however the battery is not recharged immediately after it is discharged the amorphous lead sulfate begins to transform into a solid crystalline structure which is difficult to break down during the recharging process. If the battery is left in a depleted state for long enough the crystalline lead sulfate will no longer be able to be broken down during the

recharging process and eventually can lead to cracking of the plates and the destruction of the battery.

The production of lead sulfate cannot be avoided but sulfation can almost completely be avoided by simply fully recharging the battery immediately after it has been discharged. We accept that this may not always be possible and fortunately there is a technology that can, in many instances, reverse the sulfation. The equipment is utilized in conjunction with the battery charger and through pulse technology is able to break down the crystalline lead sulfate such that the battery charger's energy is able to break it down and return its constituents to the positive and negative plates. But like the process of sulfation, desulfating a battery takes time, in severe cases several days are needed to return the plates to working condition.

Deficit Charging is simply not putting back as much as you take out of the battery. Over time this deficit will accumulate until the battery is so depleted that it can no longer perform its primary function of starting the locomotive. Compounding the problem is that typically deficit charging occurs over time which allows the amorphous lead sulfate to become crystalline lead sulfate and "sulfating" the plates. It also leads to electrolyte stratification which can result in accelerated corrosion at the layers of higher acid concentration and reduced reaction efficiency at the layers that have a lower acid concentration. Both rob the battery of some of its potential.

Finally batteries "self-discharge". Unlike almost all other locomotive

components, batteries have a shelf life, if they are not properly stored and periodically charged they will go dead of their own accord. This is due unwanted chemical reactions occurring within the cell and which are unavoidable. The self-discharge rate depends on the battery type, chemistry and temperature.

Recommended Best Practices for Battery Storage

1. Store batteries indoors in a well-ventilated space.
2. Apply an equalization or freshening charge every 90 days that batteries remain in storage.

Flooded type batteries must be stored in a well-ventilated because they are designed to gas during the recharge process. The VRLA batteries do not need to be stored in a well-ventilated space because of their recombinant design. This is where the evolved oxygen at the positive plate recombines with the ready to evolve hydrogen at the negative plates creating water and preventing water loss through the gassing process experienced by flooded batteries.

An equalization or freshening charge should be applied every 90 days when temperatures do not exceed 77 degrees F. Like essentially all chemical reactions, the rate of self-discharge increases with temperature. For every 18 degree F increase in temperature the rate of self-discharge doubles! Batteries stored outdoors in direct sunlight during summer months could require a freshening charge as frequently as every 30 days. Additionally a battery

at an elevated temperature will not be able to accept a charge as quickly because the applied current will have to be limited in order to not overheat the battery.

Recommended Best Practices for Battery Maintenance

At each shop visit:

1. Check the batteries state of charge
2. add distilled for deionized water if necessary
3. charge the batteries

Check the charge level for each 16 cell tray, the State Of Charge or (S.O.C.). To complete this initial step, the battery needs to be on stable open circuit preferably with NO LOAD present – the max load allowed is 5 amps per 100 Amp Hours of the batteries nominal capacity. For a 650 AH battery, the max load present should be no more than 32.5 amps. With the knife switch “open” simply use a digital volt meter and measure the open circuit volts for each tray across the negative and positive terminals. For flooded batteries add distilled or deionized water to the manufacturer’s recommended fill point if needed. For all batteries apply a boost charge if the SOC is low by 15% or more (<32.96 Volts Flooded, <33.92 Volts VRLA).

Recommended Annually:

1. Replace the Batteries
2. Check the onboard charging system

At first glance this recommended best practice may seem drastic and/or costly but consider that by replacing

the battery with a fully charged (new or serviced) battery there is no need to check the vent caps on flooded type, no need to inspect the inter-cell connectors, or the terminal connections, no need to charge or water the battery, and no delaying the unit while the battery is recharged. Furthermore, when the locomotive is returned to service you can be confident that the battery is good, that barring some other failure of the systems the unit will start. Although this recommendation requires that the shop maintain a supply of fully charged batteries, it does eliminate 5 of the 6 steps that make up the alternative below and most of the batteries removed could be recharged at a charging station set up at the shop location, avoiding the expense of sending the batteries to a repair and return servicing center.

Recommended Annually (An Alternative):

1. Clean the battery
2. Check the terminal and inter-cell connections
3. Water if necessary (Flooded type)
4. Check the on board charging system
5. Perform a 20 second engine cranking test
6. Complete a final boost charge

Determining the State of Health (SOH) of a battery by the discharge or load test method provides one of the most accurate estimations of the battery's capacity and remaining life. However this method is time consuming, requires additional equipment, requires that the battery be removed from the locomotive, and most significantly

leaves the battery completely drained at its conclusion. Necessitating that the battery be fully recharged before it can be returned to service. Because of these limitations a surrogate test was sought that would be able to be performed on a battery while it was on the locomotive, could ideally be done in under 30 minutes, and would return a result that could, with reasonable certainty, define a battery fit to be returned to service. The test chosen was a 20 second engine cranking test.

20 Second Engine Cranking Test

This is a suggested surrogate test for the state of health for flooded lead acid type cells with nominal specific gravity of 1.250 and VRLA batteries. The following steps would be completed at annual shop visits or when a fault suggests that the batteries may be weak or under charged and/or under watered. The following work is to be completed with the batteries remaining onboard the locomotive.

- 1) Check the State Of Charge (S.O.C.).

To complete this initial step, the battery needs to be on stable open circuit preferably with NO LOAD present – the max load allowed is 5 amps per 100 Amp Hours of the batteries nominal capacity. For a 650 AH battery, the max load present should be no more than 32.5 amps. With the knife switch “open” simply use a digital volt meter and measure the open circuit volts for each tray across the negative and positive terminals. If the SOC is below 50% (31.84 Volts Flooded and 32.80 Volts VRLA) the batteries should

- be replaced with fully charged new or serviced batteries. If at or above 50% SOC proceed with the 20 second test.
- 2) Disable the ignition of the locomotive.
 - 3) Attach digital volt meters with a MAX/MIN volt hold function to the terminals of each battery.
 - 4) Crank the engine for 20 seconds. The 20 second cranking test is intended to capture engine cranking performance.
 - 5) Record the tray volts during the engine roll, not during the engine breakaway by activating the MIN volts hold following the first 5 seconds of the test.
 - 6) Minimum voltage reading should be greater than or equal to 24.0 Volts per battery/tray.
 - 7) Maximum Voltage differential between the two batteries should not exceed 2.4 volts.

Samples of the 20 Second Engine Cranking Test

RR	Unit Number	Locomotive Model	Year Built	Horsepower	Front Battery		Rear Battery		Engine RPM during Test
					Starting Voltage	Min Volts During Test	Starting Voltage	Min Volts During Test	
BNSF	6661	ES44AC	2010	4400	33.05	29.04	33.00	28.92	154
BNSF	6612	ES44C4	2009	4400	0.571	No Test	9.70	No Test	
BNSF	7824	EC44DC	2009	4400	33.01	27.68	33.04	27.28	154
BNSF	6761	ES44C4	2010	4400	32.74	28.68	32.73	28.56	142
BNSF	6643	ES44C4	2010	4400	32.23	27.96	32.56	25.16	143
BNSF	6710	ES44C4	2010	4400	33.07	28.92	33.00	28.9	
BNSF	6988	ES44C4	2010	4400	32.18	27.56	32.46	27.74	124

Note that all of the batteries observed in these tests were of the flooded design. The results are listed in the columns headed Starting Voltage for the Front Battery & Rear Battery in the table above. What do we see from these S.O.C. values? First, unit 6612 has a completely dead battery with both trays below the condemning low voltage limit of one (1) volt per cell or 16 volts per tray. Both battery trays should be replaced.

Second, for the balance of the trays the S.O.C. ranges from a low of 60% (32.18 or 2.01 volts per cell) to a high of 85% (33.07 or 2.06 volts per cell). All of the trays are at or above a 50%

S.O.C. (1.99 VPC) and the trays on each unit are separated by less than 1.0 volt overall. The 6 remaining units can be moved on to the next step – a 20 second engine cranking test.

What do we see in the Min Volts during Test columns? First, all of the trays completed the test with end volts above the low limit of 24.0 (1.5 VPC). Second, the rear tray on unit 6643 fell below the front tray by 2.8 volts, more than the 2.4 volts allowed – look for a low cell or a high resistance connection if time permits.

Finally, the locomotive onboard control and status monitoring systems may reveal other useful info. In this

case, engine RPM during the roll easily exceeded 100.

In conclusion for railroads to achieve their desired levels of locomotive reliability they must take an active role in how batteries are stored and how they are maintained. Batteries store energy, they don't make it. Keep flooded batteries watered, keep all batteries fully charged, and they will be ready when you need them.

Constitution and By-Laws Locomotion Maintenance Officers Association

Revised September 22, 2003

Article I – Title:

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

Article II – Purpose of the Association

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

Article III – Membership

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

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

to approval of the General Executive Committee.

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

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

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

Pre-Convention Report and Annual Proceedings.

Article IV- Officers

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

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

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

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

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

Article V- Officer, Nomination, and Election of

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

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

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

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

Article VI- Officers- Duties of

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

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

The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secre-

tary-Treasurer and contact advertisers to underwrite the cost of the **Annual Proceedings**.

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

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

Section 3-The Secretary-Treasurer shall:

A. Keep all the records of the Association.

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

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

D. Furnishing security bond in amount of \$5000 of behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.

Section 4-The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.

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

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

D. Promote Association activities and monitor membership levels within

their assigned areas of responsibility.

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

Section 5-Duties of General Executive Committee:

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

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

C. Serve as the Auditing and Finance Committee.

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

E. Exercise general supervision over all Association activities.

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

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

H. Approve the schedule for the Annual program.

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

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

Article VII-Technical Committees

The technical committees will consist of:

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

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

Section 3-Committee members as follows:

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

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

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

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

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

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

Article VIII-Proceedings

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

Section 2-Those present at any meeting called on not less than thirty

days advance written notice shall constitute a quorum

Article IX-Rules of Order

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

Article X-Amendments

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



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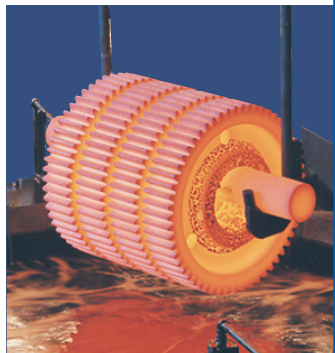
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