LMOA

Locomotive Maintenance Officers Association

Proceedings of the 76th Annual Meeting

SEPTEMBER 22 – 23, 2014

Montreal, Canada

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2014 TOC and Index

2013 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 2013.

NAME	COMMITTEE
Tom Mack, VeRail Technologies	New Technologies Committee
Jason Fox, Union Pacific RR	Diesel Electrical Maintenance Committee
Pete Whallon, Clark Filter, Inc	Fuel, Lubricants & Environmental Committee
Michael Hartung, Norfolk Southern	Diesel Material Control Committee
James Sherbrook, Sherpower	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 Executive Board of LMOA wishes to express their sincere appreciation to PowerRail Distribution Inc. and The PowerRail Team for hosting and sponsoring the LMOA Joint Technical Committee Meeting in Scranton, PA on May 5th and 6th, 2014 and for providing lunches on both days. A special thanks goes to our 1st VP, Bob Harvilla, for making all of the arrangements which made our meetings a terrific success. We also wish to thank PowerRail for allowing the six technical committees to tour their facility in Duryea, PA.

The technical committees also had the opportunity to tour Steamtown Rail Museum in Scranton.

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 Convention Center in Indianapolis, Indiana on Tuesday, October 1, 2013.

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

PAST PRESIDENTS

1939 & 1949	F.B. DOWLEY (Deceased) Shop Supt., C. & O. Ry.
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1949	J. W. HAWTHORNE (Deceased) Vice-Pres.- Equipment, Seabord Coast Line R.R.
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1959	E.V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry.
1960	W.E. LEHR (Deceased) Chief Mechanical Officer, Pennsylvania R.R.
1961	O.L. HOPE (Deceased) Asst. Chief Mechanical Officer, Missouri Pacific R.R.
1962	R.E. HARRISON (Deceased) Manager-Maintenance Planning & Control, Southern Pacific Co.
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1964	H.N. CHASTAIN (Deceased) General Manager-Mechanical, A.T. & S.F. Ry.
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1977	T.A. TENNYSON (Deceased) Asst, Manager Engineering-Technical, Southern Pacific Transportation Co.
1978	E.E. DENT (Deceased) Superintendent Motive Power, Missouri Pacific Railroad
1979	E.T. HARLEY, Retired Senior Vice President Equipment, Trailer Train Company, 289 Belmont Road, King of Prussia, PA 19406
1980	J.H.LONG (Deceased) Manager-Locomotive Department, Chessie Systems
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1982	N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
1983	F.D. BRUNER (Deceased), Asst. Chief Mechanical Officer, R&D, Union Pacific RR
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1985	D.M.WALKER, Retired, Asst. Shop Manager, Norfolk Southern Corp, 793 Windsor St, Atlanta, GA 30315
1986	D.H.PROPP, Retired, Burlington Northern RR, 10501 W. 153rd St, Overland Park, KS 66221
1987	D.L.WARD (Deceased), Coordinated-Quality Safety & Tech Trng, Burlington Northern RR
1988	D.G. GOEHRING, Retired, Supt. Locomotive Maintenance, National RR Passenger Corp, 1408 Monroe, Lewisburg, PA 17837
1989	W.A.BROWN, Retired, I&M Rail Link, 9047 NE 109th St. Kansas City, MO 64157
1990	P.F.HOERATH, Retired, Sr. Mech. Engr. Shop, Conrail 1534 Frankstown Rd, Hollidaysburg, PA 16648
1991	D.D.HUDGENS, Retired, Sr Mgr R&D, Union Pacific, 16711 Pine St., Omaha, NE 68130
1992	K.A.KELLER, Retired, Supt. Locomotive Maint, Reading RR, 241 E. Chestnut, Cleona, PA 17042
1993	W.R.DOYLE, Project Manager, Sound Transit, Seattle, WA 98104
1994	M.A.COLES, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
1995	C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
1996	G.J.BRUNO, Retired, Supt.-Mechanical, Amtrak 14142 S.E. 154th Pl, Renton, WA
1997	D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
1998	H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
1999	JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak 1130 Walnut Ave, Osawatomie, KS 66067
2000	RON LODOWSKI, Retired Production Mgr, CSX Transportation, Selkirk, NY 12158
2001	LOU CALA, Retired, Duncansville, PA 16635
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2007	LES WHITE, Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
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2009	DENNIS NOTT, Northwestern Consulting, Boise, ID 83703
2010	BOB REYNOLDS, Sales Manager, Amglo Kemlite Laboratories, Calgary, Alberta T24 2V8
2011	JACK KUHNS, V.P. Sales, Graham White, Salem, VA 24153
2012	RON BARTELS, Sr. Manager - Equipment Reliability and Electrical Engineering, Via Rail-Canada, Montreal, Quebec
2013	R. BRAD QUEEN, Manager of Locomotive Utilization - RCO, BNSF Railway, Fort Worth, TX

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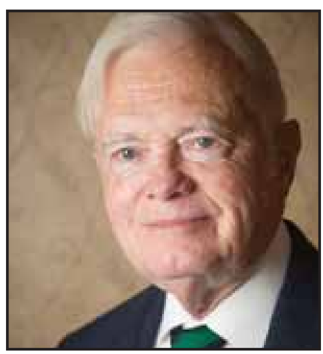

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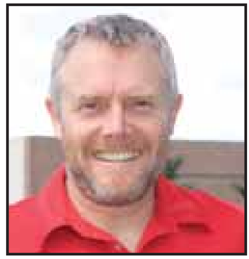

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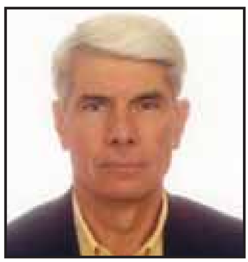

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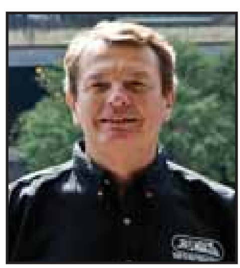

RON SULEWSKI
VP–Sales & Marketing
Rail Products International Inc
St. Louis, MO

2nd VP Bob Harvilla presents President's gavel to newly elected President Dave Rutkowski.

Past President Dennis Nott presents newly elected 3rd VP Jeff Cutright with his LMOA blazer. Past President Bob Reynolds congratulates Jeff on his nomination as 3rd VP.

Executive Committee: Past President Bob Runyon, newly elected President Dave Rutkowski, Past President Dennis Nott; back row (left to right) – newly elected 1st VP Bob Harvilla, Past President Les White, Past President Bob Reynolds and newly elected 3rd VP Jeff Cutright.

2013 State of the Union Address

President Brad Queen's State of the Union Address

Monday Afternoon, September 30, 2013

Good afternoon ladies and gentlemen, LMOA members and the Executive Committee. It is a great honor to both welcome and thank you for attending the 2013 Locomotive Maintenance Officers Association (LMOA) technical sessions here in Indianapolis.

I am also extremely honored to have served as the LMOA's President for the 2012-2013 term of an organization that dates back to 1939. Reflect on that for just a moment; it is hard to imagine all that has changed.

Before going too much further, I want to personally thank our Secretary/Treasurer, Ron Pondel, for his dedication, behind the scenes support, and tremendous leadership to this organization.

A tremendous thanks also goes out to the suppliers and railroads which have supported and sponsored committee meetings during the year. The sponsorship from these companies continues to help the LMOA keep our rail industry well informed with documened best practices, challenges such as Positive Train Control, and new trending industry innovations.

Also special thanks to PowerRail Distribution for their efforts on maintaining and updating our LMOA website and archiving as many of our past technical papers as possible into one place on our website. We are planning to eventually provide these archived past presentations on our website with searchable topics to our members or to those who wish to subscribe.

This year (2013) the LMOA Joint Technical Committee session was held at the Pullman Plaza Hotel in Huntington, WV on May 7th which was well attended by our committee members. We also graciously thank the CSX Huntington Shops and Magnetech Industrial Services for hosting and sponsoring the joint session in addition to their informative facility tours that we were able to take advantage of. We do not want to forget the hard work that Mike Drylie of the CSX and David Rutkowski of the Providence & Worcester RR put into making all of the arrangements come together. Lastly, special thanks go to PowerRail Distribution and to Gary Fadale for providing ideal lunches during the session.

We want to recognize the efforts of the LMOA Fuel, Lubricants and Environmental Committee with the letter they submitted to Jim Grady, Vice President of the AAR, regarding biodiesel usage and detailed concerns regarding the use of elevated biodiesel levels greater than 5% biodiesel.

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 such a long time. We appreciate your sponsorship. Also, a very special thank you to Graham White for their continued support. Their financial contribution helped to defray expenses incurred for audio-visual equipment during this convention. Lastly, thanks to all the vendors who are displaying this year and to all the companies that hosted individual committee meetings through the season. Well done to all

As the LMOA continues, we are always looking to evolve from the norm. Please do not hesitate to approach a member of our Executive Committee with your thoughts or ideas so they can be voiced during our Tuesday afternoon executive committee meeting.

As I wrap up my term as the President of LMOA, I would like to reflect on one of the key benefits that the LMOA has helped prepare me with. “Managing No”. How many of us have had a major project or an idea flawlessly worked out. Everyone was briefed beforehand of the concept. Questions were asked, deadlines were set. Everything is a GO. You meet with the departments involved. NO, everthing is a complete re-write. Has this ever happened to anyone sitting here today? How well did you conceal the disappointment in your voice, masked your facial expressions, or even controlled your body language? What was the reaction of your performance to your team, peers, boss, or AVP? How many times in your career do you get to practice for such a performance?

Believe it or not, there is a great solution in overcoming this exact type of situation; the LMOA. We go through this drill every year when preparing for technical presentations. The LMOA members deal with involving other members from different railroads and suppliers, both large and small. The logistics are, at time, impossible. On their own time, members will coordinate conference calls to work on these presentations. Their committees will meet at railroad locations with their teams to do continuous drafting of these technical papers. Then meet together at the annual joint committee meeting to do a practice review with all the LMOA sub committees and possibly some CMOs in the room. Some of these papers get re-written the night before the final presentation.

I remember my first paper in 2000 that I did. By the time I was done presenting my paper for the first time in front my team, there were so many suggestions that I felt it was a complete re-write. Not only did I have concern about not getting it right, I was frustrated with all the time I put into it. But with my divers’ support team comprised of knowledgeable experts and leaders from the rail industry, I was able to get back on track.. These fellow LMOA members used their own personal time to provide their technical advice, project management skills, and re-established the vision that made it work. This successful and rewarding experience was invaluable to my future endeavors with the BNSF.

That is the LMOA. Now, serving as President, I was fortunate to witness these examples in all of our different sub technical committees at our Joint Committee meeting this year. The ways our teams were coaching others was just such a tremendous experience to witness. Not very many folks like to speak in front of large groups or audiences and to explain a topic you may not be quite the expert on and do this within 30 minutes. By going through these exercises in the LMOA, our members gain a valuable skillset in project management, people skills and presentation skills.

With this as an example, we commissioned a group of members and a member's spouse to come up with a technical presentation preparation document/template for the LMOA. Thank you to Mary Volkmann (wife of Past President Tad Volkmann), Dwight Beebe, and Past President Jack Kuhns for volunteering their time to do this. It is an extremely valuable tool.

Please be assured that we will continue to provide, sponsor and reach out to future leaders to take on the LMOA experience. 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.

I would encourage all railway executives, managers, shop personnel and railroad suppliers to be supportive and to encourage 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 education knowledge
- Experience of speaking or presenting in front of a knowledgeable audience
- Ability to meet and follow through on a deadline
- Expanded people skills

Tomorrow, I will pass on the gavel to David Rutkowski, CMO of the Providence and Worcester RR. I look forward to seeing everyone here today and again at our 2014 Convention that will be held on September 21st through 23rd in Montreal.

Acceptance speech

Dave Rutkowski
Tuesday Morning, October 1, 2013

Thank you Brad,

Ladies and Gentleman, Members of the Executive Committee, Mr. Secretary, and Fellow LMOA members. I am honored to be your President of the Locomotive Maintenance Officers Association (LMOA) 2014. We will be celebrating 75 years of existence next year. Our President 75 years ago was F.B. Dowley who was the Shop Superintendent at the Chesapeake and Ohio Railway (C & O Railway) in Huntington, WV. By the way our joint committee meeting this year was in Huntington, WV and a thank you to CSXT. Even back in 1939 our by-laws stated the purpose of the Association was to improve the interest of its members through education and to supply locomotive maintenance information to their employers. It also is to exchange knowledge and information with members of the Association and to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad Industry.

We have six committees that educate the members and the industry through technical papers by providing Best Practices, New Technologies, and Technological Changes that are published in book form and distributed to members annually. We also have a website www.lmoarail.com that I encourage you to visit.

My first LMOA Diesel Mechanical Committee meeting experience was in the year 2000 in Winnipeg, MB. Jay Holley, CSXT, was our Chairman and Tad Volkmann, UP, was our Regional Executive. I remember Jay telling the Committee that “this is a working committee and don’t think you’re going to be here just to be here. You must participate”. Being the new kid on this committee meant it’s “Technical Paper Time”. At the time I was working for the St. Lawrence and Atlantic Railroad as Chief Mechanical Officer in Auburn, ME. My fleet of locomotives consisted of 4 - GP40-2’s, 6 - GP-9’s, 2 – SW – 1 switchers and 11 Alco MLW 420’s. After telling the committee my locomotive roster Tad Volkmann had a grin on his face. His look was that of a man in deep thought. He was thinking new guy equals a technical paper. Tad asked me “how do you maintain your Alco locomotives in the 21 century?” The rest was history with my first paper “Maintaining Your Alco Locomotive in the 21st Century”.

I eventually rose through the ranks. I was selected as Chairman of the Mechanical Committee and then their Regional Executive. I was nominated for 3rd VP, 2nd VP and then 1st VP. I now stand before you as your President. I have learned that interaction and networking with my peers in the rail industry was indispensable. Sharing ideas and meeting vendors for products and pricing has always help my budgetary bottom line. We will continue to help the industry through technical papers and the sharing of ideas.

I envision challenges for all of us. One of those challenges will be with Positive Train Control or (PTC). There is potential that PTC will affect us all. And most importantly, locomotive reliability. I have experienced this first hand with ACSES or Advanced Civil Speed Enforcement System. You could have a situation where you have a brand new locomotive and if it does not pass the PTC day test it must not be used in the lead. We will be addressing this issue in coming years.

The Shop Safety, Processes & Equipment Committee, Diesel Material Control, Diesel Mechanical, Fuel , Lubricants and Environmental Committees had presented informative and educational technical papers yesterday. Please enjoy the exhibits and our two remaining committee's technical papers (The New Technologies and Diesel Electrical Committees) which are next.

I thank you for your time and want to note that I am here today with the support of my wonderful and loving wife Katarina, who has stood by me throughout my career and supported me, my great son Kristofer, who has recently entered into the railroad supply industry and the Providence and Worcester Railroad, who encourages participation in this great organization. I want to extend an invitation to next year's convention to all of you. We will reconvene in 2014 at the RSI/CMA Convention in Montreal, Quebec. I hope I will see you all there.

Thank you and enjoy the rest of the exhibits and technical sessions

Report on the Committee on Fuel, Lubricants and Environmental

September 22, 2014 at 9:00 AM

Chairman

Tom Gallagher

Global RR Technical Liaison

Chevron Oronite

Commerce, MI

Vice Chairman

Virginia Wiszniewski

Researcher

Exxon Mobil Research & Engineering

Paulsboro, NY

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D. Bills	Vice President	Red Giant Oils	Council Bluffs, IA
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E. Davis	RR & Spcl Sales Asst.	American Refining Group	Bradford, PA
B. Dittmeier	Customer Tech Service	Afton Chemical	Richmond, VA
B. Fischer	Customer Tech Service	Afton Chemical	Richmond, VA
S. Fritz, P.E.	Mgr-Medium Speed Diesel Engines	Southwest Research Institute	San Antonio, TX
J. George	R&D Director	Camfil-Farr	Laval, Quebec
F. Girshick	Technologist	Infineum USA, L.P.	Linden, NJ
L. Haley	Chief Chemist	Norfolk Southern	Chattanooga, TN
J. Hasterlo	Mgr-Mechanical Engineer-Facility and Equipment	Union Pacific RR	Omaha, NE
S. Koshy	Mechanical Engineer	Amtrak	Wilmington, DE
N. Kuzhiyil	Sr. Lube & Fuel Technician	GE Transportation	Erie, PA
G. Lau	Senior Reliability Specialist	Canadian National	Edmonton, Alberta
D. Mattey	Key Account Manager	Alfa Laval Inc.	Hermitage, PA
D. McAndrew		Dennis McAndrew, Inc.	Waterford, PA
J. McDonald	Off. Of Transportation & Air Quality	EPA	Ann Arbor, MI
D. Meyerkord	Senior Project Engineer	Electro Motive Diesels Inc.	LaGrange, IL
C. Ruch	Asst. Director–Tech. R&D	BNSF	Topeka, KS
T. Savage	Business & Lab Manager	ALS Laboratory Group	Kansas City, KS
M. Stanfill	Dir-Environmental Engrg & Program Development	BNSF	Topeka, KS
W. Strickland	Mgr-Test & Lab Services	CSX Transportation	Jacksonville, FL
D. Tuttle	Mgr-RR&Marine Sales	American Refining	Atlanta, GA
K. Wazney	Chemist/Testing Specialist	Canadian Pacific	Winnipeg, Manitoba
P. Whallon	Director-RR Sales	Clark Filter Co	Lancaster, PA

PERSONAL HISTORY

Tom Gallagher

Thomas E. Gallagher was born and raised in New York City. He is a graduate of the United States Merchant Marine Academy located in Kings Point, NY. Tom worked in the Nuclear Engineering Department of the Charleston Naval Shipyard in Charleston, SC for 3 plus years prior to accepting a technical service engineer position with Chevron International Oil Company addressing fuel and lubricant related issues for equipment onboard merchant vessels from offices located in Stamford, CT and Media, PA. In 1996, he accepted a position with Chevron Oronite as technical sales representative and was based in Rolling Meadows, IL and Lexington, KY locations during the following 6 years.

Tom assumed the responsibilities of Global Railroad Technical Liaison for Oronite in 2000 and has had the pleasure of actively participating in the Fuels, Lubricants & Environmental Committee for the past 14 years. His current position affords Tom the opportunity to work with N. American & International Railroads, OEMs and oil companies to effectively address the research and development requirements of additive technology solutions for emerging emission and fuel regulations in order to advance locomotive engine oil performance attributes and standards.

Tom is a retired Lieutenant of the United States Naval Reserve. He and his family reside in Commerce, MI.

The Fuel, Lubricants and Environmental Committee would like to express their sincere Appreciation to Red Giant Oils and David Bills for hosting and coordinating their winter meeting and for arranging a tour of the Durham Museum. Committee met at Union Pacific headquarters in Omaha on February 6, 2014 which was arranged by John Hasterlo and Tom Kennedy who deserve the committee's gratitude.

The committee had a number of teleconferences during the season which were well attended. Committee members from Exxon Mobil, Innospec and Oronite hosted the teleconferences which aided the committee's collective efforts to successfully complete our work.

Fuel Filtration Considerations in the Changing Landscape of Engines and Fuels in Railroad Applications

Prepared by:
Najeeb Kuzhiyil, GE Transportation, Erie Pennsylvania USA
Gregory Obrecht, Ford Motor Company, Dearborn Michigan USA
Rick Chapman, Innospec Fuel Specialties USA
Jonathan George, Parker Filtration Canada

Abstract

The onset of high pressure common rail (HPCR) fuel injection systems and ultra-low sulfur diesel (ULSD) fuel brought in associated fuel filter clogging and injector fouling issues. While the automotive industry has learned to get around these issues, the railroad industry has recently started implementing HPCR fuel injection systems and is transitioning to ULSD fuels. This paper reviews the technological changes in railroad engines and discusses case studies where filtration problems were experienced and suitable engineering solutions were implemented.

Introduction

Regulatory requirements for improved air quality have necessitated development of more efficient, lower emission engines. Diesel engines in the automotive and on-highway industry have seen significant changes in fuel injection technology; from mechanical injectors in the 1980s to electronic injectors in the 1990s and then to the High Pressure Common Rail (HPCR) injectors in the 2000s [1,2]. HPCR systems have typically increased fuel injection pressures about 5 to 10 times more than conventional injectors. The consequent tighter clearances and higher stress on components warranted much cleaner fuel in terms of particulate and other contaminants [3,4]. In order to obtain the required level of cleanliness, much finer fuel filters need to be employed.

During these years, significant changes were made to diesel fuels primarily due to emission considerations. Reduction in sulfur content has been the major change impacting fuel composition. Sulfur content of number 2 diesel fuel in the US prior to 1994 was up to 5000 ppm and is referred to as high sulfur diesel (HSD). After 1994, it was reduced to less than 500 ppm and became commonly known as Low Sulfur Diesel, or LSD [5,6]. Further, sulfur level was decreased to less than 15 ppm in 2006 and this fuel became known as Ultra Low Sulfur Diesel, or ULSD for on-road vehicles. The required reduction in railroad's fuel sulfur content lagged behind on-road vehicles by several years. These efforts to reduce fuel sulfur content has been driven by legislation to improve air quality by controlling sulfur oxides emissions as well as limiting the detrimental effects of sulfur on emission after-treatment equipment such as diesel oxidation catalysts.

Reduction in sulfur content led to poorer lubricity and less fuel stability under HPCR operating conditions. ULSD itself is much more stable than LSD according to traditional stability tests such as ASTM D2274 and ASTM D6468. The severe refinery hydro-treating necessary to reduce sulfur also removes compounds that provide lubricity to the pumps, injectors and valves [7]. Lubricity enhancement additives, or lubricity improvers, now compensate for this loss of lubricity. The addition of even small amounts of biodiesel can also improve lubricity. This hydro-treatment essentially converts most of the olefins and aromatics into saturates such as paraffin and cyclo-paraffin which have lesser solubility than the parent unsaturated compounds. The poor solubility of ULSD can lead to separation of oxidation products and other heavier molecules from the fuel rather easily.

In recent years, blending of biodiesel into diesel fuel has brought about multiple effects to fuel quality in the US. ASTM International specification for diesel fuels, D975, specifies up to 5% biodiesel can be blended with regular No.2 diesel. Many OEMs in the automotive industry now have engines that can use biodiesel blends of up to 20% while some have restricted use up to 5%. Biodiesel not only improves lubricity of the ULSD, but at the same time significantly decreases oxidation stability of the fuel. Biodiesel is also hygroscopic and does not allow water separation from the fuel easily in storage tanks or in vehicle on-board water separators. Increased water content can cause increased fuel oxidation and microbial growth in storage tanks and in vehicle fuel tanks resulting in slimy, microbial sludge which in turn can cause filter clogging. In addition, biodiesel can cause metal carboxylate salts (soaps) to form by providing carboxylic acid free radicals that can react with sodium ions (from sodium hydroxide used as a catalyst in the biodiesel manufacturing process, or from refinery caustic or salt excursions). These carboxylate salts are well known for their ability to clog fuel filters and cause injector sticking. The ill effects of biodiesel become more pronounced in affecting its quality; biodiesel made from various feedstocks behave differently and the purity of the fatty acid esters depends heavily on the manufacturing process.

In the railroad industry, ULSD was introduced in around 2007 and is mandated from 2015 onward. Most of the number 2 diesel consumed in the railroad industry currently is ULSD. Since the ASTM D975 specification allows up to 5% biodiesel without notice, varying amounts of biodiesel (sometimes more than 5%) have been seen in different parts of the country. In some states, above 10% biodiesel are available that could be blended with diesel fuel to make fuels that meet D975. Within the State of Illinois, it is common to see 11% biodiesel blends due to a State tax credit requiring a minimum of 10% biodiesel.

With the advent of HPCR fuel injection systems, associated finer filters and ULSD fuels, the automotive industry has faced many challenges. Injector sticking and fuel filter clogging became two of the most common problems to occur [8-10].

In 2012, railroad OEMs introduced Tier 3 emission compliant locomotives with HPCR fuel systems for the first time in the history of the industry. Before 2012, there were prototype Tier 3 units running in revenue service. Similar to the automotive industry, the railroad industry also faced fuel filter clogging in the field.

HPCR fuel injection system requires very high fuel cleanliness. Conventional micron rating for the filters has been replaced by ISO 4406 classification to rate the fine filters.

ISO 4406 Cleanliness Code

ISO 4406 was introduced to define the level of cleanliness in a fluid. It is widely used to describe fluids in systems such as hydraulics which are closed loop systems where particulate contamination can build up and cause component wear and damage.

The ISO 4406 cleanliness code is based on the number of particles given in one milliliter of fluid for the particle sizes of >4 μm, >6μm, and >14μ. Using a particle counter, the number of particles is determined for 4, 6, and 14 microns and the corresponding code number is assigned as described in Table 1. For instance, an ISO code of 20/18/15 would mean the fluid contains between 5,000 – 10,000 particles >4 μm, between 1300 – 2500 particles >6

μm, and between 160 – 320 particles >14 μm per milliliter. Through experience and testing, cleanliness levels can be correlated to acceptable component life and damage, and cleanliness specifications using the ISO 4406 code can be defined.

Using ISO 4406 can be helpful when defining the filtration requirements needed for a system. If the cleanliness code is known for a dirty fluid and the cleanliness requirements for the system are known, the level of filtration required to clean the fluid can already be estimated.

Historically in the rail industry, ISO codes have not been used to describe the fuel or lubricating oil requirements. The industry has always accepted filter micron ratings and this system has worked well. The introduction of emissions treatment technologies and the need for clean combustion to meet the EPA emissions requirements has now driven suggested fuel cleanliness requirements for diesel fuel. This is not only true for the rail industry but impacts all diesel engine technologies. In the on-road and off-road diesel engine segment, a cleanliness level of 18/16/13 at the pump for diesel fuel has been suggested by the Worldwide Fuel Charter.

(http://www.acea.be/uploads/publications/Worldwide_Fuel_Charter_5ed_2013.pdf)

However, at least one fuel quality survey has shown that approximately 44% of diesel fuel may be over this suggested limit [11]. This only underlines the need for better filtration.

For the advanced fuel injection systems operating at high pressures described in the previous section, the fuel cleanliness requirement has been determined to be approximately 12/9/7. Looking at the codes for particles of 4 microns, this is suggesting that we can expect the need for a filtration system to clean the diesel fuel from an ISO code of approximately 18 to the required level of 12. By referring to the minimum number of particles per level in Table 1, this would mean reducing the number of particles from 1300 particles/ml down to 20 particles/ml. This represents a minimum filter efficiency of approximately 98.5% at 4 microns while maintaining the required 184 day maintenance cycle. The result is a very efficient filter for locomotives that did not previously exist.

Table 1. Number of particles per milliliter of fluid and corresponding ISO 4406 code number.

Code Number	Particles per ml	
	More than	Less or equal
22	20000	40000
21	10000	20000
20	5000	10000
19	2500	5000
18	1300	2500
17	640	1300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.5	5
8	1.25	2.5
7	0.64	1.25
6	0.32	0.64
5	0.16	0.32

Case Study

Filter clogging was reported in locomotives fitted with HPCR systems in revenue service at a Class I railroad in the US. The filters were changed every 184 days as a standard maintenance practice. In the reported cases, the filters clogged between 120 days to 150 days service. The filters used in these units had lower micron ratings when compared to the regular filters in the units without the HPCR system. A root cause analysis was carried out of which a schematic representation is given in figure 1.

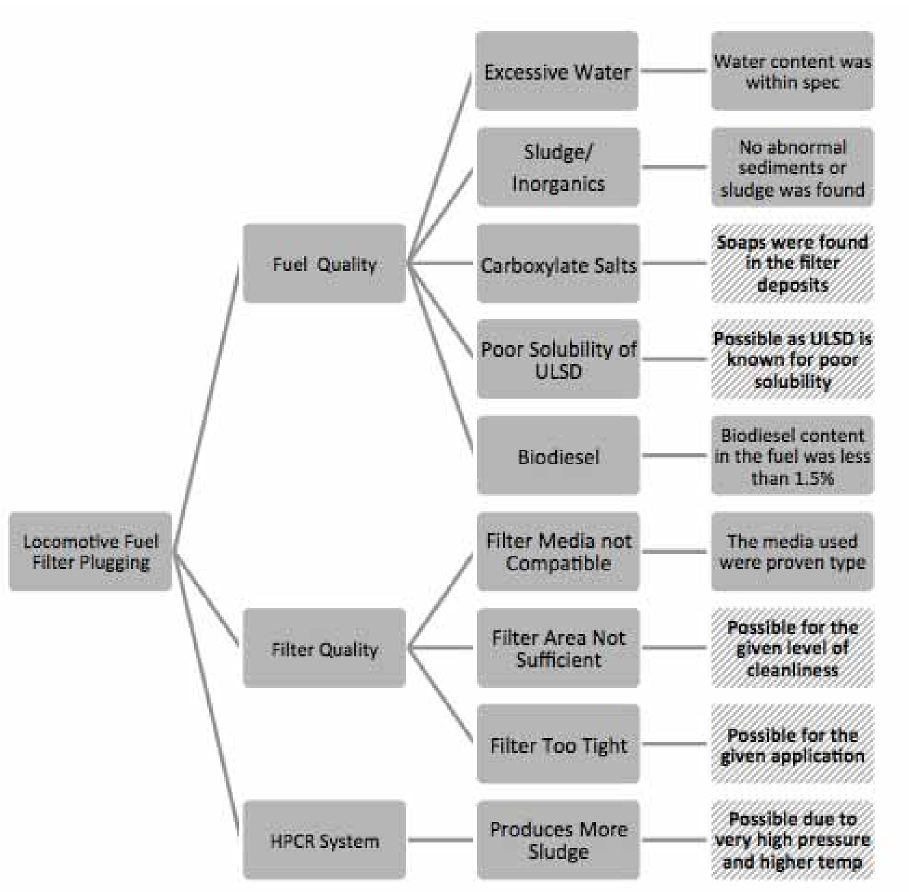

Figure 1. Schematic of the root cause analysis of the filter clogging problem

The quality of the fuel used in these units, the differences of the new filter from the regular filter and the dynamics of the HPCR system were identified for detailed analysis. Relevant properties of these components were tested and examined.

Fuel quality: Various fuel samples were collected from the units that reported filter clogging. All of them met the ASTM D975 spec. No excess water was found in any of the fuel samples. Sediments were within the limits and no sludge was found in the samples. No excessive use of biodiesel was found; the fuel samples did not contain more than 1.5% biodiesel.

The deposits looked greasy and contained normal fuel oxidation products. The deposits did not look different from the deposits seen on a regular filter, but the quantity of the filter deposits was much higher. The clogged filters had so much deposit that it could be scooped with a spatula from the surface of the filter. The FTIR (Fourier Transform Infrared) spectrum of the filter deposits revealed the presence of carboxylate salts which is common in filter deposits. It is possible that the carboxylate salts are the root cause of the clogging, but the fact that the regular filters on other units using the same fuel did not clog, indicates that the finer filters on the Tier 3 units contributes to clogging. Also, it is known that ULSD has lower solubility than LSD and HSD. The lower solubility helps the fuel oxidation products and carboxylate salts to separate from the fuel easily.

Filter quality: HPCR fuel injection systems require much improved fuel cleanliness than the current requirement. The new filter designed to meet the improved cleanliness requirement is much finer than the current filter and thus can retain finer particles and hence the amount of filter deposit loading on the filter surface could increase. At the same time, a finer filter typically means the filter media fibers are closer together so they may more easily clog with a lesser amount of sticky materials. The filtration area of the filter was not changed from the previous design levels while there is a chance that a higher level of cleanliness may require larger filtration area.

HPCR system: The HPCR system pressurizes the fuel to the range of 1600 to 2200 bar (23200 – 31900 psi). The compression and fuel circulation through the system increases the temperature of the fuel to approximately 125°C (257°F). In the locomotive, the duty cycle is such that most of the fuel going through the injection system is returned to the fuel tank. Typically a higher rate of fuel return leads to more fuel degradation [12].This returned fuel contains degradation products and free radicals which will affect the fuel in the fuel tank – this may be exacerbated by the approximate 3 days between refueling. It is well known that HPCR systems typically increase the amount of deposits formed in the fuel system. Carboxylate salts (or soaps) in the fuel, oxidation products, lower solubility of ULSD, finer filters and HPCR system effects can all have individual as well as combined effects on the fuel filtration. In order to determine the interaction of these various factors, experi-

ments were conducted in the field with the interchange of filters.

Experiment with the interchange of filters: To determine whether finer filtration is a factor in clogging, the regular, coarser filter was fitted to 3 locomotives with HPCR systems. These filters completed 184 days without any operational problems. On inspection, it was found the amounts of deposit on them were as good as the ones without HPCR systems. This experiment showed that tighter filtration is an influencing factor in clogging.

In another experiment, a new tighter filter was installed in 3 locomotives with a unit injection system. All the filters completed 184 days without any operational problems. On inspection, it was found the filters had similar amounts of deposit as the coarser filters. This experiment indicated the HPCR system contributes to the filter clogging.

In both of the above experiments, ULSD fuel was used, indicating there was no evidence to support or reject the hypothesis that the poor solubility of ULSD was contributing to the filter clogging.

As it was clear the tighter filter and HPCR system effects tend to increase the amount of filter deposits, the most evident solution to the filter clogging problem available was to increase the filtration area. The filter was redesigned to increase the filtration area that was tested in the field. All the redesigned filters passed the 184 days test without clogging or increased differential pressure.

Conclusion

Filter clogging occurred in the locomotives fitted with a HPCR fuel injection system. It was found that finer filters were clogging while coarser filters did not. Also, it was clear the HPCR system contributed to more deposits and subsequent clogging of the filters. It was concluded that the higher level of cleanliness and the HPCR system together required more filtration area to hold the increased amount of filter deposits. Redesigned filters with increased filtration area successfully completed the field tests.

Acknowledgement

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Diesel Fuel Troubleshooting Guide

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Most railroads monitor their fuel supply in some way. The changing nature of locomotive engines and diesel fuel likely means that railroads must further scrutinize their fuel monitoring practices. High Pressure Common Rail (HPCR) fuel injection systems-- such as those found in Tier 3 and Tier 4 locomotive engines- have additional fuel requirements and are becoming more common . Railroad diesel fuel with its increased biodiesel and renewable diesel fuel has also changed. significantly in recent years . As a result, improved ways of monitoring fuel quality are warranted. This Diesel Fuel Troubleshooting Guide is designed to provide the fuel user with recommendations and best practices for monitoring diesel fuel and investigating any fuel related issues in railroad applications.

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1. INTRODUCTION

Diesel fuel supply is possibly the single most important commodity to railroads in terms of costs, profits, and operations. Therefore, to help control cost, maintain or increase profits, and help maximize operations, most railroads monitor their fuel supply. Each railroad has their own system which might include certificates of analysis (CoA) from suppliers, in-house fuel quality testing/verification, and other quality control processes. Because it is such an important part of railroad operations, monitoring of fuel quality and associated system elements have been utilized by the railroad industry for some time, and have been recognized as a viable technique to help mitigate operational difficulties

Additionally, recent years have seen multiple regulatory-driven fuel changes including:

- Decreased sulfur content
- Limits on aromatics content
- Introduction of renewable fuels such as biodiesel (fatty acid methyl ester or FAME) and renewable diesel (hydrotreated biological oils)

The overall health of a railroad's fuel operations considers both wayside tank farms and locomotive fuel system components. These will continue to be fundamental parameters moving forward in an environment with changing equipment and fuel options. The goal of this guide is to provide best practices and recommendations for monitoring and investigating diesel fuel related issues in railroad applications.

2. BACKGROUND

Fuel related problems can manifest themselves through a number of scenarios (e.g., wayside and locomotive filter plugging, leaking seals, loss of engine power and/or hard starting). While this can be due to a number of causes, it is important to note that if only one engine is having a problem it is unlikely that the problem is fuel related. Fuel with excessive particulates and/or water can also lead to engine failures such as valve problems, ring, liner and component wear. Additionally, finer filtration may be needed to protect newer HPCR engines. The use of finer filtration is a "Catch-22" situation – finer filters offer more protection against contaminate-affected wear, but a plugged filter can also potentially lead to some very major failures on locomotive engines. The use of finer filtration must therefore be carefully evaluated.

Experience from centrally-fueled fleets has shown that when a number of engines exhibit similar symptoms, a potential problem with the fuel source is likely. Newer technologies such HPCR with their extremely small component clearances may be more sensitive to particulate, water, carboxylate soap, or other contaminants. What has been acceptable filtration for non-HPCR engines may not be sufficient for new engines types that require filtration of very fine particles (e.g., ISO Code 4406 of 12/9/7)[1]. As the Rail Industry moves toward more HPCR and Tier 3, Tier 4 engines, improved filtration such as this will likely become necessary for wayside and

Figure 1. Proper Diesel Fuel Placard

on-board applications and should help to prevent engine operating problems.

The Locomotive Maintenance Officers Association (LMOA) Fuels, Lubes, and Environment (FL&E) Committee has written several papers on different aspects of diesel fuel consumed by the railroads. Those past informative papers were technical in nature, and not written as a fuel user guide[2]. The main goal of this paper is to provide user friendly flow charts for identifying potential fuel related issues.

3. FUEL RECEIPT BEST PRACTICES

Purchase only the fuel or fuel(s) that are endorsed by equipment manufacturers. Upon receipt, the CoA and Bill of Lading accompanying a fuel delivery should be checked against expected fuel properties (i.e. those specified by a fuel purchasing contract) and expected fuel type and delivery size. Check the tank car or tank truck placard (if applicable) to verify that the delivery is diesel fuel (See Figure 1).

The American Petroleum Institute's API RP 1640, "Product Quality in Light Product Storage and Handling Operations,"[3] is a resource for determining what tests to run on a new batch of diesel fuel upon receipt, or what tests to run on a fuel storage tank after a newly delivered batch of fuel is added to it.

4. STORAGE & HANDLING BEST PRACTICES

The manufacturer or supplier of a diesel fuel should be the first source for storage and handling guidance on purchased fuel. Additionally there are several relevant diesel fuel handling guides available within the fuel industry, including the American Petroleum Institute's RP 1640, "Product Quality in Light Product Storage and Handling Operations,"[3] and the Coordinating Research Council's (CRC) soon to be released "Diesel Fuel Storage & Handling Guide"[4]. Both of these documents are resources for diesel fuel storage and handling best practices.

5. RAILROAD DIESEL FUEL DISTRIBUTION CHAIN

Due to wide geographic operating regions and relatively large fuel consumption, railroad fuel distribution and supply chains are quite varied (Figure 2). For example, upper Midwest locations typically receive fuel containing substantial quantities of biodiesel, with delivery in trucks or tanks, while other locations may receive pipeline deliveries of fuel with minimal biodiesel. Remote locations with no pipeline access may rely on multiple tank car deliveries for large amounts of fuel, or local tank trucks for smaller direct-to-locomotive (DTL) fueling events. Locations near a refinery may have a direct pipeline de-

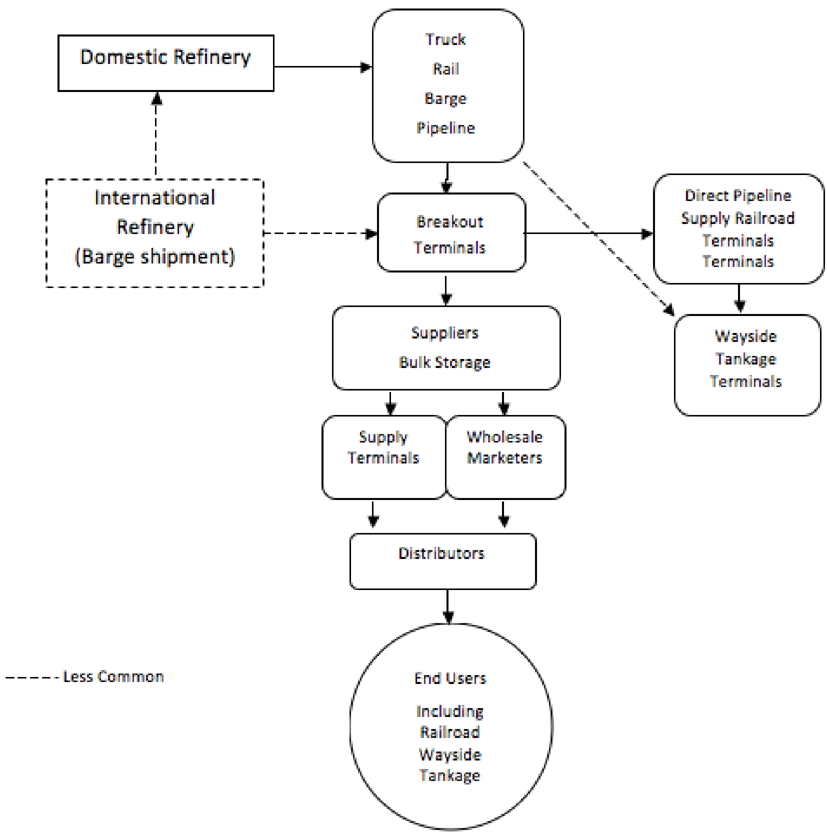

Figure 2. Railroad Diesel Fuel Distribution Chain

livery with no 'middle man' transport of the fuel at all. The varied nature of this fuel distribution system could potentially cause fuel quality challenges such as insufficient lubricity, conductivity, cold operability, etc. Lubricity, conductivity, and cold flow additives are generally incorporated at product terminals; if fuel is direct supplied it becomes the railroad's responsibility to add these additives if it's determined that they are necessary.

A clear understanding of fuel supply chain can help to avoid, and if necessary investigate, possible fuel issues. It is also important to contact fuel suppliers when fuel issues are encountered, particularly for recent fuel deliveries, to determine whether any of their other customers are experiencing fuel issues at the same time.

6. IDENTIFYING DIESEL FUEL ISSUES

A fuel monitoring program can help to identify issues with bulk diesel fuel through routine testing and appearance checks. Beyond out-of-range test results, perceptible symptoms of a diesel fuel issue may include abnormal appearance (haze, free water, particulate, wax – see Figure 3) or unusual odor.

In an engine, fuel related problems can manifest themselves through a loss of power, increased fuel consumption, and/or hard starting. Additionally, filter plugging can potentially lead to fuel starvation. It is important to note that engine problems may be caused by multiple factors including hardware issues, fuel issues, etc. Experience from centrally-fueled fleets suggests that when a number of engines exhibit similar symptoms, a potential problem with the fuel should be investigated.

Figure 3."Clear & Bright" Diesel Sample vs. Diesel with Suspended Particulate (last two pictures illuminated with flashlight)

7. DISCUSSION:

This paper provides recommendations based on:

A. **Problem Categories**: Problem categories may present with different "symptoms." Different confirmatory tests may be needed to aid in understanding root cause of the problem. These categories will be discussed further in the Appendix.
   a. Contamination
   b. Deposit formation: e.g. soaps, carbonaceous, lacquer
   c. Fuel choice
   d. Fuel qualities/properties
   e. Fuel supply chain/sourcing
   f. Engine technologies

B. **Tiered Approach**: This approach is based on assessing fuel concerns on a severity scale and taking corresponding action. Such a technique may help facilitate preventing the progression of an issue. For example, water in fuel may be considered without consequence if below specified limits (i.e. proposed D975 limits). Water at increasing levels may have significant consequences, such as degrading the quality of stored fuel, corroding metal in fuel storage equipment, or deteriorated engine operation.

C. **Fuel Monitoring Program**: A program for prevention and early detection of issues can be of significant utility. Buying fuel from proven, quality-oriented suppliers may help to lessen the possibility of fuel issues. "Good housekeeping," meaning consistent maintenance of fuel storage tanks to avoid accumulation of water, dirt, fuel degradation products, etc., is critical. Both pre and post fuel storage tank filtration can help to prevent water and many common contaminants from entering the locomotive fuel tank, and should be considered. Fuel monitoring program elements may include the following:
   a. Sampling: Representative sampling at specified locations/frequencies.
   b. Testing: A program of routine analysis on samples from fuel deliveries, post-receipt tank contents, stored fuel, etc. Routine analysis is important to establish and document a baseline, which then allows identification of outliers or trends. To define a testing program, refer to fuel supplier guidance or fuel industry references such as API RP 1640.
   c. Analyzing: Assessing test results versus baselines, references or standards/specifications.
   d. Reporting: Reporting deviations from baseline, exceptions, or unusual findings.
   e. Tracking: Time based trending of key parameters (e.g. wayside fuel filter changes, etc.).

D. **Troubleshooting Techniques**:
   a. Query-based flow charts and checklists with key indicators.
   b. Determine deviations from baselines/references.

8. FUEL AND ENGINE OPERABILITY COMPLAINTS INVESTIGATIONAL FLOW CHARTS

When operability complaints or fuel monitoring program complaints are encountered, consider use of the decision tree in Figure 4 to aid in investigating the potential root cause. Figure 5 is to aid in the investigation of fuel issues, while figure 6 is for fuel filter issue investigations.

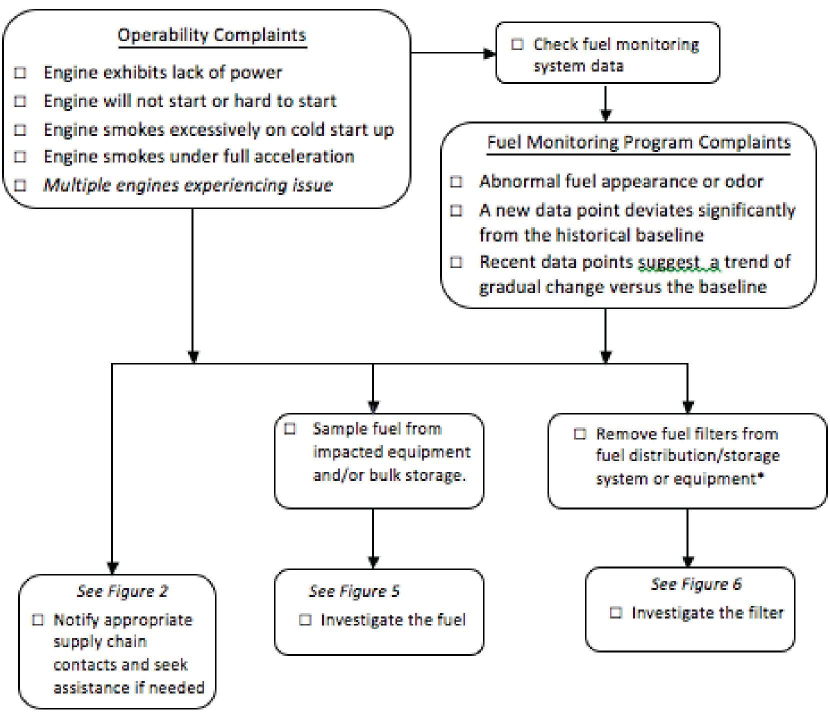

Figure 4. Investigational Flow Chart

**Note that a filter may "concentrate" fuel-borne solids (degradation product, contaminants, etc.) making them easier to detect versus in bulk fuel. As a result, consider evaluating fuel filters during an investigation into unusual results from a fuel monitoring program, even when there are no operability complaints.*

PROTECT
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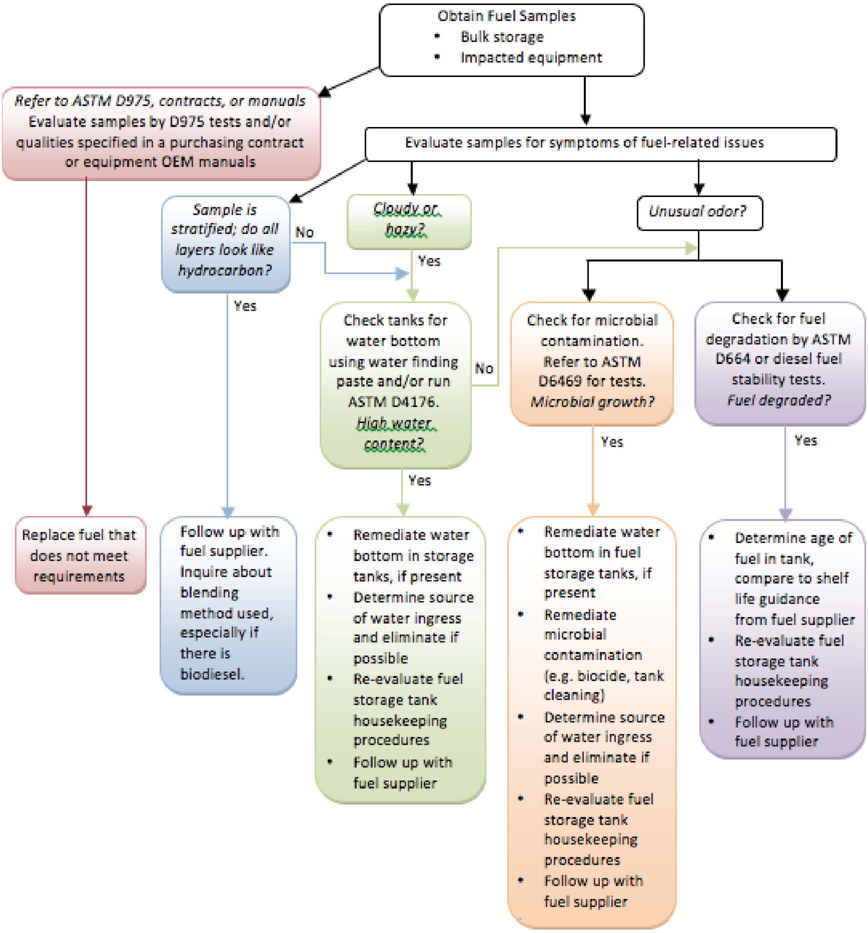


Figure 5. Investigating the Fuel

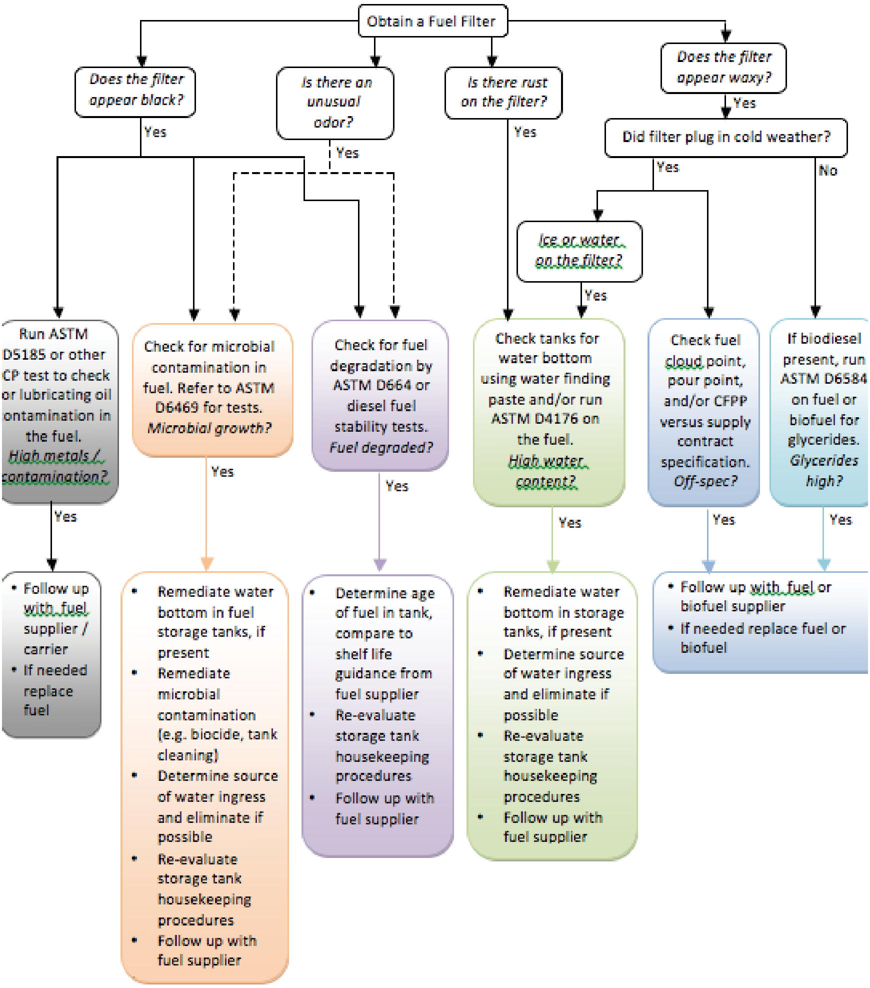


Figure 6. Investigate the Fuel Filter

9. APPENDIX

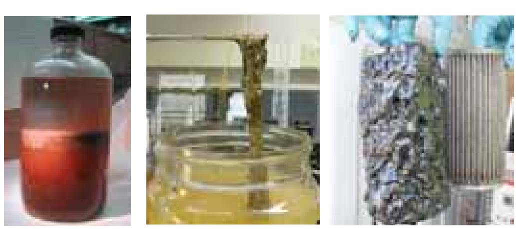
A. PROBLEM CATEGORIZATION:

a. Contamination

i. **Water** – Too much water can make fuel hazy. Excess water is more often observed in the winter or after temperature fluctuation. When fuel cools, dissolved water can drop out causing hazy fuel and/or free water at the bottom of the fuel tank. Too much water can lead to many fuel related problems in addition to premature filter plugging. ULSD does not hold as much water as higher sulfur diesel blends; as a result, there may be more water present in fuel distribution and storage systems. Checking for water in fuel and frequent draining of wayside and locomotive tanks can limit fuel-water problems (See Figure 7)

Figure 7. Wet, Hazy Diesel Fuel

ii. **Microbiological** – Fuel "bugs" are either bacteria or fungi. These organisms need two things: a food source (fuel) and water. Bugs are often found in the interface between these two layers in a fuel system (a.k.a. "rag layer"). They are often slimy or greasy, have a distinct smell, and will plug filters rapidly. They can be eradicated with use of a biocide additive – it is recommended that biological material be removed from tankage before refueling (e.g. by filtration or tank cleaning). Effective water management and fuel housekeeping will usually minimize the occurrence of microbial growth. For more information on detecting and treating microbial contamination refer to ASTM D6469 (see Figures 8-10).



Figures 8-10. Diesel Fuel and Filter with Microbial Contamination

iii. **Particulates** – Too much particulate matter can plug filters. Particulate matter in fuel is usually dirt, fine rust, or oxidized fuel, but can be other contaminants as well. A magnet held to the contaminant will usually indicate rust, but to be sure of the root cause laboratory analysis is usually necessary. Evaluating fuel sources and/or improved fuel housekeeping will often resolve the problem (see Figure 11).

Figure 11. Wet, Dirty (Particulate) Diesel Fuel

iv. **Contaminants from fuel manufacturing** – On limited occasions, unintended excursions of production may allow contaminants to be delivered downstream. Potential contaminants are water, rust, dirt, sodium hydroxide (“caustic” or NaOH), sodium chloride, sodium sulfate and other compounds. These contaminants are often not detected by diesel fuel specification tests and may be difficult to ascertain.

v. **Wax** – Wax formation can occur when ambient temperatures drop below typical conditions. This is normally linked to the winter season, when fuel may be exposed to unusually low temperatures (below the fuel Cloud Point). As the fuel drops below the cloud point, wax may precipitate out of solution and a light yellow suspension may be observed. This waxy deposit can plug fuel filters. The cause can be related to using the incorrect fuel for the season (e.g. using summer fuel in the winter or using a Southern sourced fuel in colder Northern climates) or if a region experiences unusually low temperatures. Wax problems can be minimized by using fuel preheaters on the locomotive, blending No.1 diesel fuel, or by the use of cold flow additives which alter the wax crystal size so filters may not plug as easily (see Figure 12).

Figure 12. Fuel Filter Plugged with Wax

vi. **Unsheared Pipeline Drag Reducing Agent (DRA)** – This problem can occur in fuel which was in a pipeline at some point in the supply chain. DRA is normally sheared by pipeline pumps. Unsheared or insufficiently sheared DRA contamination however may present itself as rapid, repeated filter plugging. When examined, pinching the filter pleats together and slowly peeling apart may reveal multiple 'strings' of the unsheared ultra-high molecular weight polymer DRA spanning the gap (see Figures 13, 14).

Figure 13. Unsheared DRA

Figure 14. DRA Plugged Filter

b. DEPOSIT FORMATION[5, 6, 7]

i. **Metal Carboxylate Soaps and Other Soft Particle Contaminants**[5]– Too many soft or amorphous particles can cause filter plugging and engine starvation. This type of contaminant can have many causes. Among them may be biodiesel related contaminants and additive interactions leading to soap formation (i.e. metal carboxylate). These soaps can also deposit internally within fuel injectors and cause sticking problems resulting in engine no-start or over-fuelling. Additionally, when additives such as monoacid lubricity improvers and corrosion inhibitors react with sodium based contaminants to form soaps, their protecting ability is diminished[9]. Unfortunately, these causes are often hard to detect and may necessitate a change of fuel, change of the fuel additive, and/or the use of more efficient fuel filters to minimize problems. Using more efficient fuel filters will likely result in increased filter changes (see Figure 15).

Figure 15. Metal Carboxylate Soap Plugged Filter

ii. **Fuel Injector Carbonaceous Deposits**[8, 10] – These deposits may be an indication of high pressure and temperature degradation and/or oxidation occurring with some ULSD fuels. It's basically "cooking" the fuel and can result in HPCR fuel injection system deposits. These deposits can prematurely plug filters or disable injectors and can appear in fuel that otherwise pass all known stability tests (e.g. ASTM D2274, ASTM D6468, etc.). Several injector manufacturers have redesigned injectors in an effort to eliminate this phenomenon, but at this time the only known way to prevent these problems in fuels subject to the phenomenon is with the use of special High Pressure Fuel Injection (HPFI) stabilizer type additives. Traditional, non-HPCR deposits also exist, but these are typically confined to the injector nozzle area (see Figure 16).

Figure 16. Injector Nozzle Carbon Deposits

iii. **Fuel Injector Lacquer Deposits**[11] – These deposits are primarily seen with HPCR engines in parts of the world where use of diesel detergent is common. They are thought to be related to by-products of the manufacture of poly isobutylene succinimide (PIBSI) detergent additive, but only lesser quality, lower molecular weight ones. These deposits generally do not plug filters, but disable injectors by laying down a shiny, dark colored deposit on internal injector parts that causes the injector to stick.

c. FUEL CHOICE – Use only the fuel or fuel(s) that are endorsed by equipment manufacturers. Contact OEMs or refer to OEM manuals to determine recommended fuels.

d. FUEL QUALITY - Diesel fuel for railroad use should meet all relevant specifications (e.g. ASTM D975) and be "fit for purpose." Acknowledging some diesel contaminants are not governed by such specifications, it may be necessary to check additional fuel properties to ensure the fuel remains of acceptable quality. In addition to ASTM D975 specified properties, additional properties may be specified in a fuel purchasing contract (for example, a certain sulphur level or cold temperature operability i.e. CFPP). Finally, proper housekeeping, including good water management techniques, should always be practiced as excessive, free water can lead to a multitude of fuel problems such as microbial contamination and corrosion. Fuels containing biodiesel have a potential for increased water related issues since biodiesel has a greater affinity for water.

e. FUEL SUPPLY CHAIN / SOURCING - Understanding the fuel supply chain can assist in tracking sources of problems. For example, a certain supplier may experience a fuel issue, and a consumer using that fuel supplier exclusively may experience the full extent of the issue, while a consumer using two or three other sources of fuel at the same time may not experience the full extent of the issue due to fuel dilution. For instance, fuel which is transported in pipelines at any point in the distribution chain may be subject to unsheared DRA contamination, while fuel transported only in tank cars or trucks may not be subject to this form of contamination. Note that even if fuel suppliers meet Certificate of Analysis (CoA) requirements, fuel contamination may still cause issues with the fuel. It is important to engage fuel suppliers immediately when potential fuel-related issues are experienced.

f. ENGINE TECHNOLOGIES – Commercial diesel engines are designed for compatibility with ASTM D975 diesel fuel. Some newer technologies such as High Pressure Common Rail (HPCR) experience higher pressures and temperatures in fuel injectors, and also have tighter clearances, making them more sensitive to variability in fuel quality.

B. TEST PARAMETERS

TABLE 1: RELEVANT TEST PARAMETERS, METHODS, WARNINGS and COMMENTS

#	PARAMETER	TEST METHOD	WARNING	POTENTIAL ISSUES	COMMENT
1	Appearance	Visual	Fail ASTM D975 workmanship clause: Fuel has particulate, haze, or phase separation	Fuel may contain water, dirt, rust, microbial contamination, degradation product, etc.	
2	Flash Point	ASTM D93	Outside of ASTM D975 limits	Contamination with lighter hydrocarbons such as gasoline	Safety concern
3	Water and sediment	ASTM D2709	Outside of ASTM D975 limits	Fuel system issues, emulsions, ice (winter), microbial growth	
4	Distillation	ASTM D86	Outside of ASTM D975 limits	Potentially poor engine operation	
5	Viscosity	ASTM D445	Outside of ASTM D975 limits	Poor atomization, poor combustion	
		1300			
6	Ash	ASTM D482	Outside of ASTM D975 limits	Wear	
7	Sulfur	ASTM D5453, ASTM D7039, or ASTM D7220	<15 mg/kg for equipment requiring ULSD	Excess sulfur may damage catalyst in emissions after-treatment devices and/or accelerate corrosion in EGR systems	For equipment requiring ULSD
8	Copper Strip Corrosion	ASTM D130	Outside of ASTM D975 limits	Damage to copper, bronze, or brass parts in the fuel system	
9	Cetane Number	ASTM D618, ASTM D6890, ASTM D7170	Outside of ASTM D975 limits	Poor combustion, poor cold start	Cold weather issue
10	Cloud Point / LTFT / CFPP	ASTM D97 / ASTM 4539 / ASTM D6371	Outside of ASTM D975 limits	Cold operability problems: Wax plugging of fuel filter; 'gelling' of fuel	Cold weather issue
11	Carbon Residue	ASTM D524	Outside of ASTM D975 limits	Fuel deposit-forming tendency	
12	Lubricity	ASTM D6079, or ASTM D7688	Outside of ASTM D975 limits	Fuel pump wear; from insufficient lubricity additive	
13	Conductivity	ASTM D2624, or ASTM D4308	Outside of ASTM D975 limits	Fuel handling issue; from insufficient conductivity additive	Safety concern
14	Biofuel content	ASTM D7371 or EN 14078	Outside of ASTM D975 limits		
15	Storage stability	ASTM D2274 or ASTM D5304 or ASTM D7545		Insufficient stability leads to accumulation of fuel degradation product	See ASTM D975 section X3
16	Thermal stability	ASTM D6468		Insufficient stability leads to accumulation of fuel degradation product	See ASTM D975 section X3
17	Acid Number	ASTM D664		Acid number can be used as an indicator of fuel degradation	
18	Karl Fischer Water	ASTM D4176		Fuel system issues, emulsions, ice (winter), microbial growth	Alternative to ASTM D2709 for water content

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11. ACKNOWLEDGEMENTS

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Richard L. Chapman
June 18, 2014

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Locomotive Biodiesel Updates

Prepared by:
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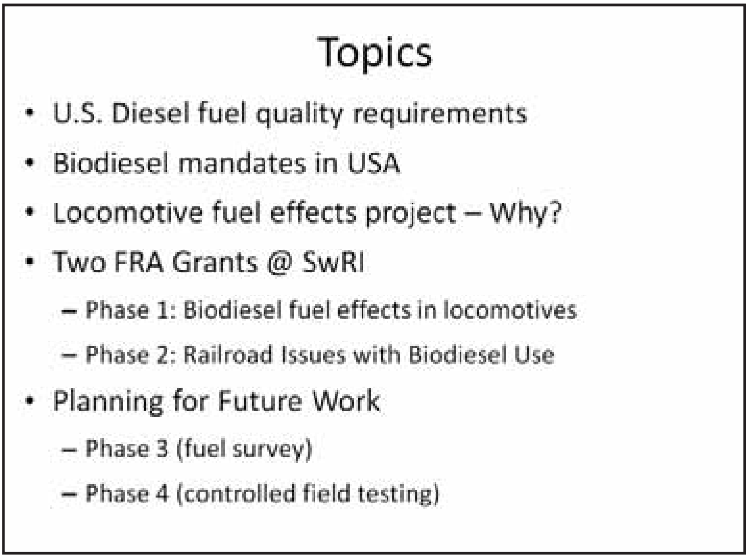
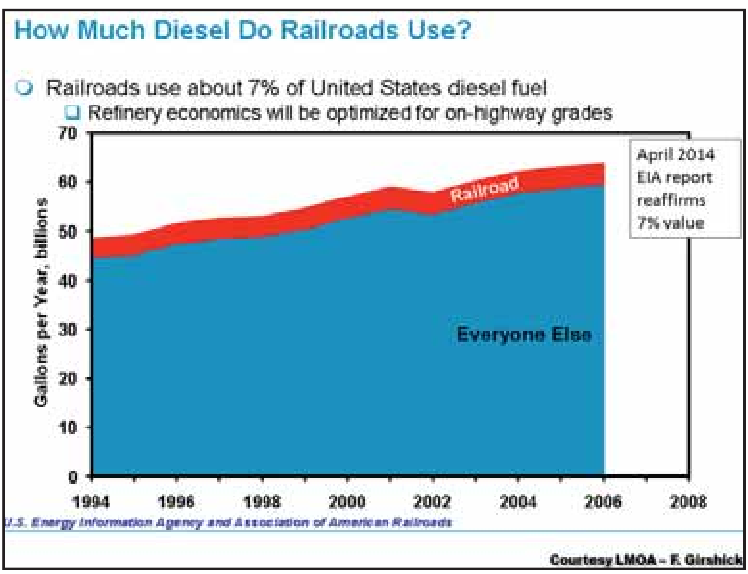


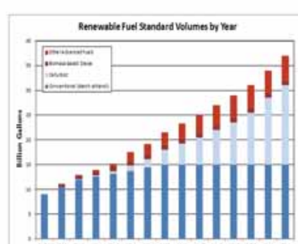


EPA Diesel Fuel Regulations

- Nonroad diesel not regulated by EPA until June 2007
- EPA Nonroad diesel regulations
  - Including locomotive and marine diesel – nationwide
  - Effective June 1, 2007
    - 500 ppm Sulfur maximum
    - Cetane > 40
    - Aromatics < 35% volume
  - Effective June 1, 2010
    - 15 ppm Sulfur maximum (except Locomotive and Marine)
- June 2012
  - Locomotive and marine diesel ULSD, 15 ppm max Sulfur
  - Transmix provisions for "L&M fuel"
    - Up to 500 ppm S

Why RR Interest in Biodiesel?

- ASTM D975 "Standard Specification for Diesel Fuel Oils"
  - Revised in 2008 to allow up to 5% Biodiesel
  - B100 must meet ASTM D6751
- EISA - Energy Independence and Security Act of 2007
  - Based on the EPA standard, each refiner, importer and non-oxygenate blender of gasoline or diesel determines the minimum volume of renewable fuel
    - Must ensure is used as a transportation fuel
    - 1.8 Billion gallons B100 (minimum) in 2013
- Biodiesel is in RR fuel today ......



DOT-FRA Locomotive Biodiesel Study

Public Law 110-432
Oct. 16, 2008
DOT to investigate biodiesel

Interestingly, the word "biofuel" is not found in this document

SEC. 404. LOCOMOTIVE BIOFUEL STUDY.

(a) IN GENERAL.—The Secretary, in consultation with the Secretary of Energy and the Administrator of the Environmental Protection Agency, shall conduct a study to determine the extent to which freight railroads, Amtrak, and other passenger rail operators could use biofuel blends to power locomotives and other vehicles that can operate on diesel fuel, as appropriate.

(b) DEFINITION.—In this section, the term "biofuel" has the meaning given such term by section 9001 of the Farm Security and Rural Investment Act of 2002 (7 U.S.C. 8101).

(c) FACTORS.—In conducting the study, the Secretary shall consider—

(1) the energy intensity of various biofuel blends compared to diesel fuel;

(2) environmental and energy effects of using various biofuel blends compared to diesel fuel, including emission effects;

(3) the cost of purchasing biofuel blends;

(4) whether sufficient biofuel is readily available;

(5) any public benefits derived from the use of such fuels; and

(6) the effect of biofuel use on locomotive and other vehicle performance and warranty specifications.

(d) LOCOMOTIVE TESTING.—As part of the study, the Secretary shall test locomotive engine performance and emissions using blends of biofuel and diesel fuel in order to recommend premium locomotive biofuel blends.

(e) REPORT.—Within 1 year after the date of enactment of this Act, the Secretary shall issue the results of this study to the Committee on Transportation and Infrastructure of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.

FRA Phase 1 – Locomotive Fuel Effects

- SAE TC7 Fuels - Subcommittee Oversight
  - Dr. Manuch Nikanjam – Chair
- Scope: Two line-haul freight locomotives
  - Tier 2 EMD SD70ACe & Tier 1+ GE DASH9-44CW
  - 1 batch of B100 – Soy based (ASTM D6751)
    - 1,800 gallons provided by NBB
    - Maximize expected NO_x impact
  - Two baseline fuels
    - ULSD EPA Certification Diesel Fuel (10,000 gallons)
    - CARB ULSD fuel (10,000 gallons)
  - Blend B5 and B20

FRA Phase 1 Project Scope

- 6 fuels total
  - EPA0 = EPA ULSD Cert.
  - CARB0 = CARB ULSD (commercially available)
  - EPA5
  - CARB5
  - EPA20
  - CARB20
- Triplicate FTP tests on each fuel
  - FTP = Federal Test Procedure for locomotives, 40 CFR Part 92
- Randomized test sequence
- 6 fuels x triplicate tests x 2 locomotives = 36 FTP tests

FRA Phase 1 Study Results

SAE INTERNATIONAL

Locomotive Emissions Measurements for Various Blends of Biodiesel Fuel	2013-24-0106 Published 09/08/2013

Steven G. Fritz and John C. Hedrick
Southwest Research Institute

James A. Rutherford
Chevron Oronite Company, LLC

doi:10.4271/2013-24-0106

FRA Phase 1 Conclusions

- General emissions trends similar to other locomotive studies and other diesel engine applications
- CARB0 fuel had lower NO_X than EPA0
- 5% biodiesel blends not significantly different from base fuels for any emissions
  - *For these two locomotive models tested, if the question is posed "Will B5 increase NO_X emissions?" The answer can be "no."*

FRA Phase 1 - Acknowledgements

- U.S Federal Railroad Administration
  - Grant FR-RRD-12-009
- SAE TC7 – Fuels
  - Locomotive Biodiesel Subcommittee
    - Dr. Manuch Nikanjam – Chair
- National Biodiesel Board
  - Provided B100 fuel
- BNSF Railway Company
- Co-Authors
  - John Hedrick – SwRI
  - Dr. James Rutherford - Chevron

FRA Phase 2 – In-Use Operation Issues

- Scope based on SAE TC7 Fuels - Subcommittee input to FRA
- Phase 2 FRA Grant awarded to SwRI
  - Project date 8/1/2012 to 9/30/2014
  - Agreement No. FR-RRD-0047-12-01-00
  - $500k
- LMOA FL&E Technical Steering Committee
  - LMOA = Locomotive Maintenance Officers Association
  - FL&E = Fuels, Lubes, and Environment Committee

FRA Phase 2 Tasks

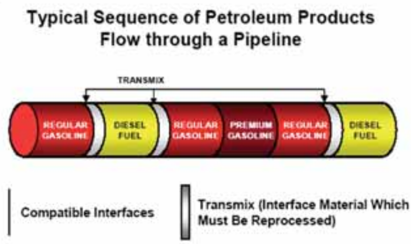
1. Investigation of Existing Issues with Biodiesel Use in Commercial Railroad Operation
2. Identify / Evaluate Potential Solutions to Fuel-Related Problems
3. Definition and Design of a Comprehensive and Systematic Program for Engine Durability Assessment
4. Laboratory Testing (Materials Compatibility)
5. Literature Survey

Future Planning: FRA Phase 3 and 4 Working Toward B20 Acceptance

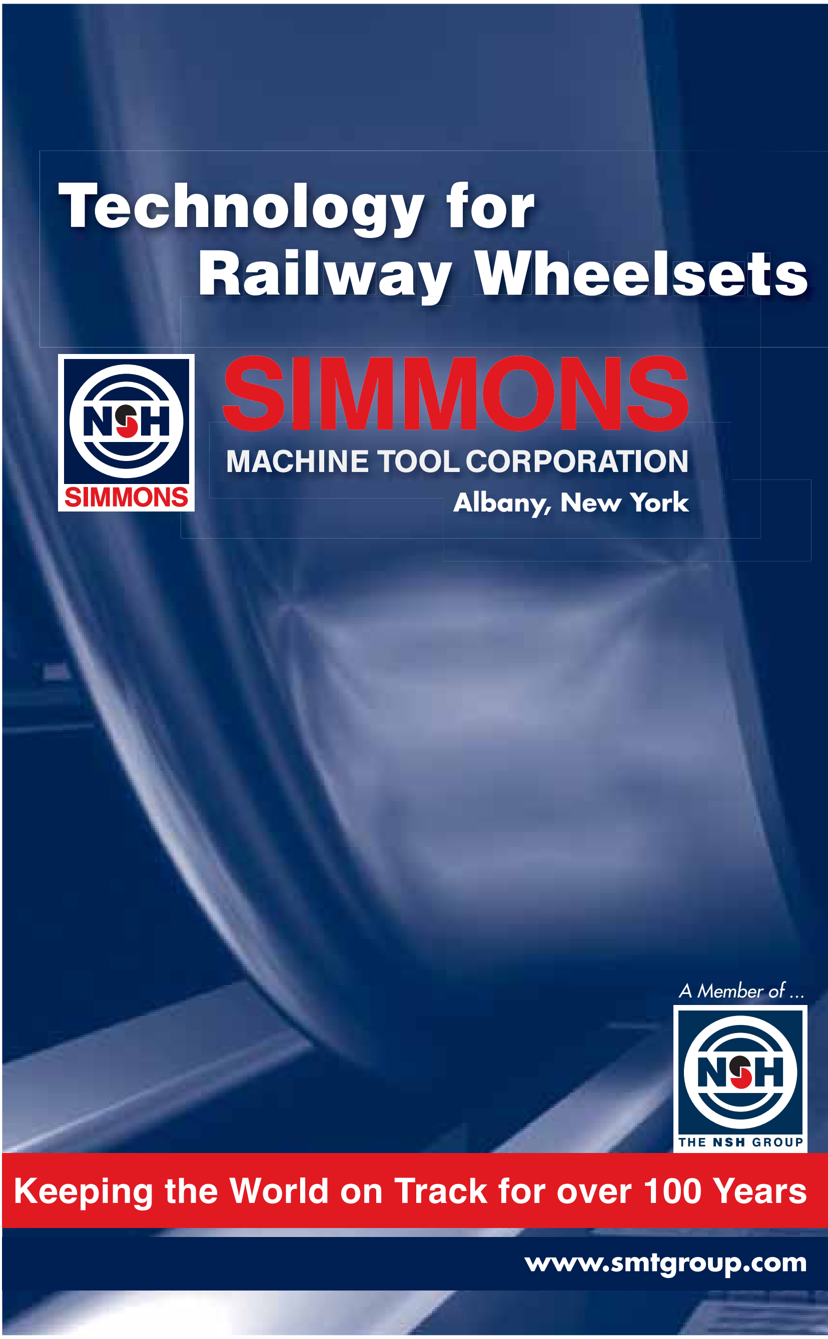
- RR diesel fuel survey (Phase 3?)
- Comprehensive RR program? (Phase 4?)
  - Multi-year, Multi-locomotive, Multi Tier
  - Captive service? Hot? Cold? Fueling.....
  - FRA "Phase 4" funding available
    - Likely to be a relatively small fraction of total RR commitment
- Tier 3 locomotives? Common rail on GE
- Tier 4 locomotives?

Transmix

- Is the interfacial mix in distillate fuel pipelines between two dissimilar products that is cut out and isolated.
- Can be up to 500 ppm S
- Permitted for use in certain locomotives per EPA Direct Final Rule September 2012



- Bottom Line: Locomotive fuel with sulfur levels > 15 ppm available with appropriate handling / storage
- LMOA FL&E Committee following issue



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Cold Soak Filter Plugging Test

Prepared by:
Corey Ruch, BNSF Railway

ABSTRACT

Cold weather related wayside filter plugging has been recently noted in the fuel supplies of several major North American Railroads. Fuel was generally identified as a B5 to B10 biodiesel blend, but similar issues could affect other fuel blends as well. Review of fuel supplier provided Certificate of Analysis' (CoA's) as well as in-house quality assurance tests did not reveal any issue with the fuel supply prior to the incident. Most notably all cloud point (CP), pour point (PP) and other cold-weather related parameters were 'nominal' or within expected ranges and specifications which suggested the issue was tied to a new, or unknown / untested fuel property. This paper discusses the forensic research which identified alkali metal soap formation as the filter plugging material, and suggests a relatively quick/easy screening test to determine if fuel may be subject to cold weather filter plugging, even when the classic cloud point / pour point numbers are within acceptable ranges.

BACKGROUND

In the winter of 2011 / 2012 at least two major North American railroads experienced wayside filter plugging issues in the upper Midwest region. Examination of the wayside filters revealed a dark-amber, pasty-like material which did not appear consistent with the typical 'wax crystal' material observed when the fuel is cooled below the cloud point and wax accumulates on the filter media.

In one instance, the substance was isolated and tested for various parameters such as melting point and solubility, as well as examination with gas chromatography/mass spectroscopy (GC/MS) and inductively coupled plasma (ICP).

IDENTIFICATION

A sample of the filter plugging material was removed from an affected filter. The sample was washed with heptane to remove excess diesel fuel. The plugging material was found to be insoluble in heptane (a non-polar alkane solvent with similar solubility characteristics to diesel fuel). Further analysis of the heptane-washed sample revealed the material was soluble in polar solvents such as isopropyl alcohol. The sample was then dissolved in alcohol and filtered through a 0.5 micron filter to remove solid / insoluble contaminants. The alcohol was then evaporated to reveal a soft white to off-white flaky material.

Melting point analysis of the purified material revealed a melting range around 157º-159ºF (70º-71ºC)

Further analysis with GC-MS revealed various transesterified species, however the largest contributors were Palmitate (C16:0) and Stearate (C18:0). (In the CXX:Y format, XX denotes the number of carbons in the chain and Y represents the degree of unsaturation.) ICP results revealed mainly sodium and magnesium metals present with no substantial calcium or potassium detected.

This evidence combined to indicate a carboxylate metal soap had formed in the fuel. Since the bulk material had a melting range approximately 160ºF, the material would not simply 're-melt' when the fuel warmed, as one might expect when dealing with a classic cloud point issue. (i.e. a paraffinic wax forming as the fuel cools below the cloud point, then melting and restoring 'normal' fuel properties as the fuel warms above the cloud point.

MAIN ISSUE

The fuel plugging material had been identified, however, various fuel samples submitted for analysis were found to pass all routinely applied screening tests including (most notably) cloud point, as well as pour point, Karl Fischer water titration, particulate examination, etc. CoA's from fuel suppliers indicated the fuel passed all applicable tests as well. This suggested a new test would be needed to detect this cold filter plugging issue in fuel.

RESEARCH

A literature search of several publications was conducted. Canadian, European Union and American (ASTM) standards were examined. The most closely related standard to detect this issue was determined to be ASTM D7501 – Determination of Fuel Filter Blocking Potential of Biodiesel (B100) Blend Stock by Cold Soak Filtration Test. However this method was found to have several drawbacks.

- Basically a test for B100, but railroads typically get fuel as B5-B11
- Complex to run as a screening test
- Requires user to "Erase Thermal History" by warming fuel before the test - this doesn't happen in normal railroad fuel use.
- Allowed to "Re warm" test fuel before final filtering in an effort to 'pass' the given test – again this doesn't happen in the typical railroad fuel infrastructure.

In summary, the ASTM test is good from a laboratory nature, precision, repeatability, etc, but not indicative of the way railroads – or most others – use fuel. Most often in the winter season, the fuel would be bought cold, delivered cold, stored cold, filtered cold, dispensed cold, etc.

LABORATORY TESTING

Laboratory experimentation was conducted to determine if the ASTM D7501 specification could be used as a framework for a simplified 'screening' test. This screening test would ideally have several beneficial properties, but would retain the sensitivity and selectivity of the original test:

- Eliminate the 'conditioning' and 'reheating' of fuel because they are not representative of real world use.
- Eliminate the '24 hour 'sitting' time to speed sample test rate.
- Eliminate inert atmosphere / inert gas usage as the sample is not heated, there is no risk of additional oxidation.
- Use standard laboratory glassware and procedures for ease of testing.

Based on these requirements a test was developed based on the ASTM D7501 framework and amended to the following procedure:

- Measure 300mL of fuel, as received, into a 400mL beaker
- Transfer fuel and beaker directly into a circulating air chiller for 24 hours at 35ºF / 2ºC
- At the end of the 24h cold soak period, remove beaker from chiller and briskly stir for 5 seconds to disperse and suspend any particulates.
- Immediately filter fuel through a #1 Watman glass filter (0.45 microns) under 15" Hg vacuum using a standard laboratory vacuum filtration apparatus.
- Record time to pass complete 300mL sample through filter.

Using this procedure two sets of experiments were performed. One experiment focused on repeatability of the procedure by obtaining a 5 gallon fuel sample and testing multiple aliquots of this sample 17 times over the course of 2 weeks. A second experiment examined the sensitivity of the procedure by testing 256 samples from across the United States, over a timespan of several months. Results of these experiments are discussed below.

DATA

Data for the fuel sample which was tested 17 times over the course of two weeks is displayed in Table 1, below. The sub-samples of identical fuel were found to have a maximum filter time of 118s and a minimum filter time of 100s, leading to an average time of 110s, standard deviation of 4.90 and a max-min difference of 18s. This testing suggested the sample repeatability would fall within acceptable limits for differentiating 'good' and 'bad' samples of fuel.

Test	Filter Time (sec)
1	114
2	110
3	102
4	118
5	109
6	100
7	107
8	107
9	107
10	105
11	111
12	113
13	112
14	116
15	115
16	113
17	112

Average	110
Std Dev	4.90
Min	100
Max	118
Max-Min	18

Data obtained from testing 256 different samples of fuel from across the country is displayed in Charts 1-4 below. A discussion of the data follows each chart.

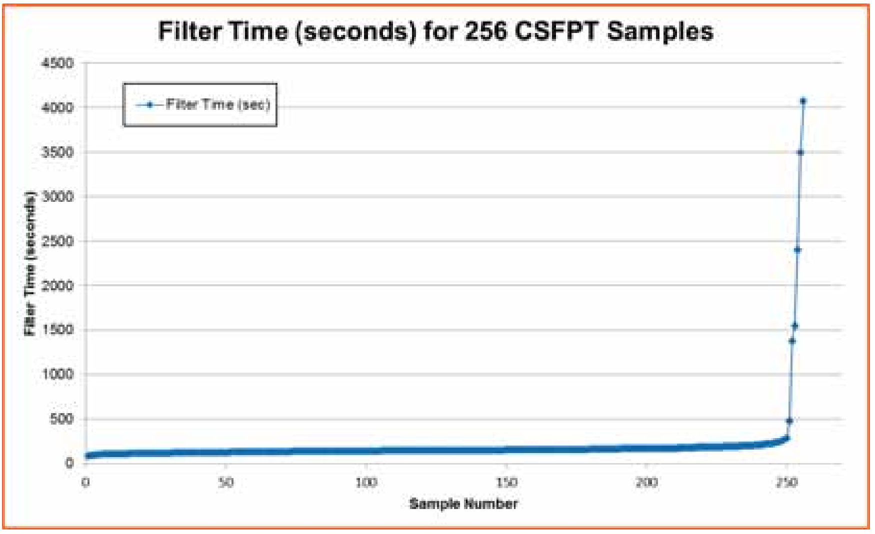


CHART 1 – Filter time of 256 samples (numbered 1-256) was arranged from shortest filter time to longest and plotted on a graph. Shortest filter times (left) were found to be sub 100s range. The longest filter times (right) were found to be 4000s+. The sharp 'hockey stick' indicated a good differentiation between two different sample groups. The majority of samples were found to filter in 300s or less, which indicated they passed relatively easy through the filter. However, several outlying samples took 500s or more, which indicated a substantial plugging of the filter.

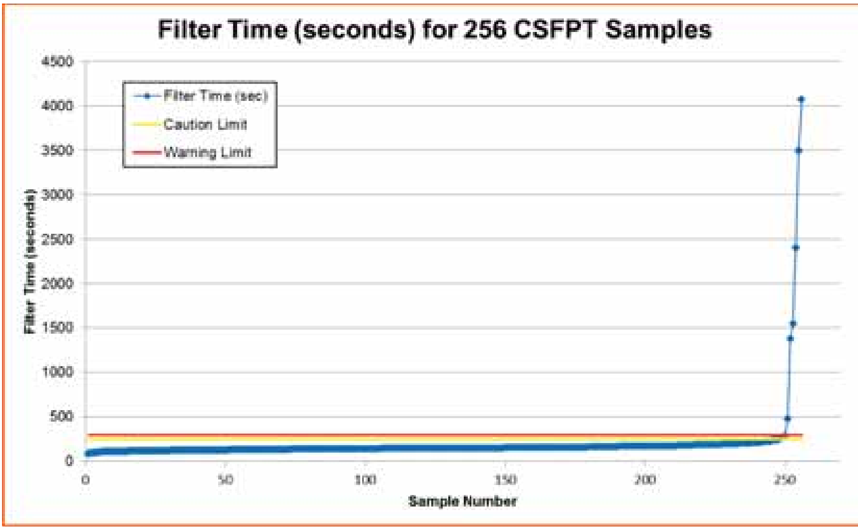


CHART 2 – The 'hockey stick' formation suggested a limit near the point of the outlying samples. Based on close examination of this point, a caution limit of 250s filter time was applied and a warning limit of 300s filter time was applied. In summary, any fuel sample taking over 250s to filter during the test would be cause for close attention and additional monitoring. Any fuel sample taking over 300s to filter during the test would generally be an 'outlier' or a worst-of-the-worst (WOW) fuel sample and require close attention / pose the risk of fuel filter plugging.

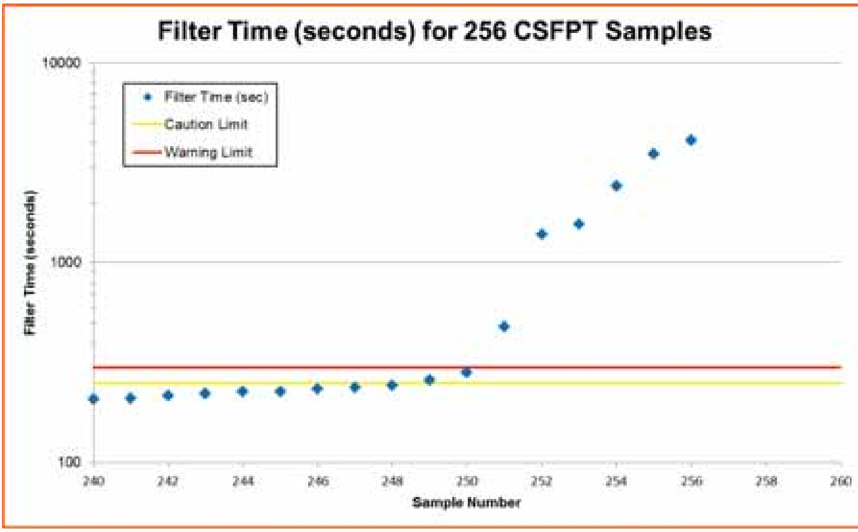


CHART 3 – Detail of the shaded area displayed in Chart 2. Note the logarithmic Y scale. This chart shows the sharp differentiation between the 248 samples which passed the test, 2 samples which were found in the 'caution' zone and 6 samples which failed the test with filter times approximately 500s – 4000s.

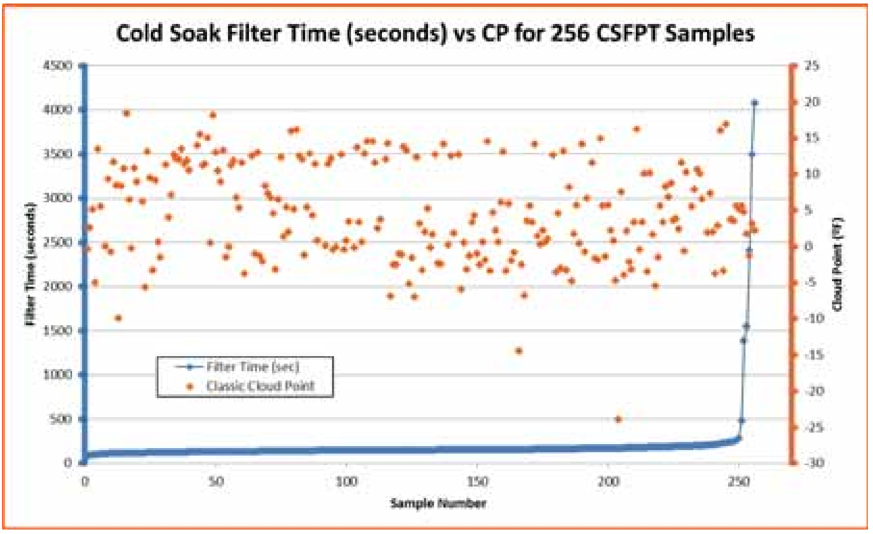


CHART 4 – To determine if the new cold soak filter test was simply duplicating data which might be obtained through a classic cloud point (CP) test, the cloud point of the same 256 samples was also determined. Chart 4 displays the classic cloud point temperature (orange) compared to the cold soak filter test time (blue). As noted on the chart, some of the samples which displayed very fast filter times (left) also displayed very high CP (in the 12-20ºF range). Conversely several of the very long cold soak filter time samples (right) displayed very low CP (around 0-5ºF). This indicated there was no correlation between the classic cloud point and the new cold soak filter plugging test. To state another way – even a fuel sample displaying sub 0ºF CP could cause filter plugging when cold soaked at 35ºF for a period of time. The classic CP test could not be used as a surrogate for cold soak testing, as each test describes a different parameter of the cold weather fuel performance.

SUMMARY

In summary, various railroads have encountered fuel plugging issues even when the base diesel fuel, base biofuel and resulting blended fuel appear to meet all general specifications. Various 'Cold Soak Filter Plugging' tests are available, however they are cumbersome and time consuming to run. Further, various aspects such as heating of the fuel do not represent 'real world' usage and may allow some fuels to pass the test when they would otherwise plug a filter under 'real world' conditions.

ASTM D7501 was used as a framework for an abbreviated test which we believe more closely represents 'real world' fuel use conditions and allows quickly screening large numbers of fuel samples encountered at a typical railroad laboratory.

The new Cold Soak Filter Plugging Test (CSFPT) demonstrated in this literature can provide a relatively quick and easy screening method to identify fuels which may have an increased tendency to cause filter plugging in cold weather.

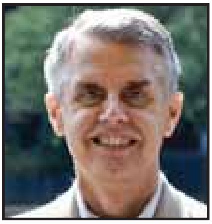
Some fuels are identified as having increased filter plugging potential even though all classic tests (cloud point, pour point, etc) show the fuel fully passing all specifications.

Test provides sensitivity to fuel 'at that time', 'at that location', however, shipping fuel to different locations and/or exposing it to different conditions may alter the outcome of the test (but would represent the filterability of the fuel in the new environment)

This paper/presentation provides some basic description and information concerning a new test for cold fuel filterability. It does not represent, nor is intended to be a complete/rigorous scientific investigation into all possible factors which may affect the test outcome.

Report on the Committee on New Technologies

Monday, September 22, 2014, 10:30 AM



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J. Smith	Mgr-Mechanical Engineering	Union Pacific	Melrose Park, IL
K. Ulbick	Sales Manager	Peaker Services, Inc	Brighton, MI
B. Wolff	Sales Engineer-Rail	MTU	Detroit, MI
C. Wyka	Senior Reliability Specialist	CN RR	Edmonton, Alberta

PERSONAL HISTORY

Tom Mack

Tom Mack has served as Chief Technology Officer of VeRail Technologies, Inc. since September 2013. VeRail's focus is bringing leading edge natural gas locomotives and technologies to railroads around the world.

Prior to VeRail, Tom served as Vice President of Sales and Business Development for Motive Power & Equipment Solutions, Inc. (dba/MP&ES) of Greenville, SC. Prior to MP&ES he founded Alternative Hybrid Locomotive Technologies (AHL-TECH) in November 2005. Tom assembled a team of innovators from the locomotive, biofuels, software, and energy storage industries to design the world's first ethanol hybrid locomotive. While the AHL-TECH hybrid never became reality, the designs incorporated into the locomotive and the computer models developed, along with the experience gathered from the project, have given Tom a unique insight into alternative fuels use in locomotives, locomotive new technologies, and the locomotive market.

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

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

The New Technologies Committee would like to express their sincere appreciation to the BNSF for hosting our December 2013 Committee Meeting at their Fort Worth, TX headquarters. We would also like to thank GE for allowing us to tour their new locomotive plant in Fort Worth.

The Committee also wishes to express their appreciation to Miller Ingenuity for hosting the committee's meeting at their Winona, Minnesota facility in March 2014.

End of the Line for the MU Jumper Multiple Locomotive Unit Control: A Discussion of Past, Present and Future

Prepared by:
Adam Bennett – R.J. Corman Railpower Locomotives
David Brooks – ZTR Control Systems
Keith Gilbert – Miller Ingenuity
Jason Smith – Union Pacific Railroad

Introduction and Scope

The ability to combine the effort of several locomotives to pull tremendous loads provides a great deal of power and flexibility for all railroads. Rail in general is the most efficient land based method of transporting freight. With this added power and flexibility comes the ability to haul trains with greater efficiency of fuel, time and manpower. The connection that makes this all possible in North America is the MU or Multiple Unit connection. In this paper we will:

- Discuss the existing MU connection and explore some of the things that has made it successful and allowed it to maintain currency as well as some of the things that have made it cumbersome.
- Present how the detriments of the cable affect modern railroads by looking at the experience and current statistics of a class 1 railroad.
- Discuss some existing and potential solutions that could be considered for use as a replacement to this aging technology.
- Briefly discuss the Association of American Railroads (AAR) initiative that is currently underway to create a new and more powerful standard in the not-too-distant future.

The 27 Pin Standard: Why it is successful…

The 27 Pin Multiple Unit Control standard has an established and proven track record. The 27 pin connector for electrical interface operates in conjunction with train and consist-only pneumatic connectors for Multiple Unit consist control, with connections typically located at each end of the locomotive. While Multiple Unit locomotive control concepts were invented around 1895, initial systems were purely pneumatic-based. The AAR standards, endorsed by railroads and manufacturers, enable any modern locomotive in North America to be connected with any other modern North American locomotive. AAR Standard S-512, consisting of a 27-Point Control Plug and Receptacle, adopted in 1969, has had many revisions since then, including dynamic brake status reporting in 2007.

The MU connections enable up to 8 locomotives to be controlled from one locomotive. This locomotive, the lead unit, is configured to control the trailing locomotives, typically from the control stand. Control voltage of the lead unit is passed down trainlines to operate locomotive functions. Basic control includes direction of movement (forward or reverse) and engine throttle settings (eight discreet notch settings). Due to swapping of direction trainlines within each locomotive and MU jumper, the locomotives operate in the same movement direction regardless of locomotive orientation. The 27 pin connector, sockets, pins, and wires are sized to support eight contiguous locomotives. The silver-plated pins and sockets are 20 amp rated with 12 and 14 gauge connecting wires, each pin is one trainline. See the chart below for a list of trainlines and their specified function.

Pin	Function	Abbreviation
1	Power Reduction Setup	PRS
2	Alarm Signal	SG
3	D Throttle	DV
4	Control Negative	N
5	Emergency Sanding	ES
6	Generator Field	GF
7	C Throttle	CV
8	Forward	FO
9	Reverse	RE
10	Wheel Slip	WS
11	Spare	--
12	B Throttle	BV
13	Positive Control	PC
14	Parking Brake Applied Status	PB
15	A Throttle	AV
16	Engine Run	ER
17	Dynamic Brake Setup	B
18	Unit Selector Circuit	US
19	2nd Negative	NN
20	Dynamic Brake Warning	BW
21	Dynamic Brake	BG
22	Compressor Synchronization	CC
23	Manual Sand	SA
24	Dynamic Brake Excitation	BC/PRC
25	Headlight	HL
26	Spare	--
27	Spare	--

The 27 Pin Standard: What holds it back.

In exchange for simplicity, the 27 Pin Multiple Unit Control fulfills very limited functions and can be cumbersome. The simple control interface is limited to basic consist operations, and requires manual setup for lead verses trail locomotives. This includes control stand switches, headlight setup, and air brake modes. Some railroads employ separate setup crews that make up the train's power. Often proper setup is bypassed to save time, including leaving the control switch up on all locomotives. In a proper setup, the lead unit supplies control voltage to the trailing locomotives, connected point-to-point down the trainlines. Even with 12 gauge wire, voltage drop on TL13 (PC) eventually leads to possible contactor drop-out on farthest locomotives or tripping of control breakers on the lead locomotive.

The 27 pin connector limits new functionality. For example the connection does not support distributed power or power sharing between consist locomotives. Digital communications are limited to a low-bandwidth dynamic brake status reporting feature; even that is only required for locomotives equipped with dynamic brake and therefore cannot be depended on for general digital communications. The standard has allowed for spare pins/ sockets and wires, but inconsistent use has hampered some equipment interchange. For example, the use of spare pin 11 for slow speed control, pin 19 as spare negative return, and use of spares for ditch light control similar to head light setup and control.

The standard equipment can be quite cumbersome. The plugs are cast aluminum and the jumper weighs about 20 pounds. The plug weight and moderate insertion force, combined with lifting the receptacle cover, while leaning to a high and inward location, can lead to job-related injuries. Some lever-based designs are available to ease ergonomic issues, but these are non-standard and atypical. The MU jumper is designed to be rugged, yet still is a common source of failures. Inner liner, braid reinforcement, and neoprene outer jacket are flexible to -40 degrees Fahrenheit and resist oil, chemicals, etc. The conductors are rated for 1000V dielectric isolation at 60Hz for one minute. The standard specifies a minimum 50 pound crimp pullout strength.

The 27 Pin Standard: A Class I Railroad Perspective

Reliability

27 pin MU connections have a multitude of failure modes which affect locomotive reliability. The failure of the MU system often results in a locomotive being unable to complete its mission, causing operationally impactful and expensive train delays. The nature of the failures is such that they often occur while the locomotive is in operation on a road line, thereby exacerbating the operational impact and expense through cascading train delays. Examples of these types of failures include loss of power in the locomotive consist, loss of dynamic braking control in the locomotive consist, electrical protection shutdown (tripped breakers), and airbrake control issues.

The root cause of most MU reliability issues lies in the 27 pin cable, connectors, and receptacles. Although the cables and connectors are considered to be heavy duty, the operational environment is so severe that problems inevitably occur. Some of the various failures that occur are:

- shorted cables or connectors
- open pin connections
- intermittent connections
- oxidized connectors
- defective receptacles
- defective terminal board connections
- physical damage to cables and connectors

Because the intermittent nature of the electrical connection failures, locomotive repair personnel are often unable to recreate MU issues. This results in a good probability that there are many MU related failures that are not accounted for.

Cost

Known MU failure costs generally consist of:

- Costs related to operational deficiencies due to train failures
- Material costs for repair/replacement of the 27 pin MU system components
- Associated labor costs for troubleshooting efforts and repair/replacement of components.

As an example of the costs related to operation, maintenance, or repair of the 27 pin MU, a large class I railroad reported that in 2013 the MU cable was directly responsible for more than 30 train failures on a line of road. The operational cost of these failures alone are estimated to be nearly half a million dollars.

In addition to these defined failures, there were an additional 250 repair events related to MU cable failures and an annual purchase of over 2500 of the physical 27 pin cables (one of the highest failure rates of any locomotive component). When factoring in these costs and the estimated costs of hidden (intermittent) failures, the total cost to this railroad for MU failures is likely more than a million dollars per year.

Based on the above, it is a safe estimate that failures of the 27 pin MU system cost the railroad industry several million dollars annually.

Overall Railroad Perspective

The railroad perspective of the 27 pin MU system is that it is antiquated technology. There is a need for added system functionality due to rapidly developing new technologies. In an era where service quality is one of the most important business objectives, the system is unacceptably unreliable and extremely costly. Given these issues, the current strength of the rail industry, and the economic opportunity for investment in new or improved technology, the time to develop and implement the next generation MU is now.

Newer Advances Using the MU Standard Cable or Other Wired Connections

Powerline Carrier

Powerline carrier technologies allow for communication signals superimposed on the same conductors as power and low frequency control signals. The technology is similar in concept to the telephone industry's digital subscriber line (DSL) communication. With DSL, there are low frequency legacy signals (48V talk voltage, >100V AC ring voltage, 6kHz of analog voice bandwidth) providing normal functionality. Riding at frequencies on top of this are a set of carrier signals that are modulated to transmit DSL data with rates in the MB/s range. There is currently broadband over power line (BPL) equipment on the market that can provide data connections in the MB/s rate for electric utility customers to receive broadband internet access. On a locomotive, DSL or BPL style modems could be configured with a hardware link toward each MU connection. The same point to point (PPP) protocol used by internet service providers to tunnel IP networking over DSL and cell network USB internet adapters could then be applied to the high bandwidth locomotive connection to tunnel internet protocol (IP) networking between locomotives, providing a flexible communication link with MB/s bandwidth.

Just one specific example of a trainline overlay system that has been around for quite some time in the locomotive industry is the Bach-Simpson Priority Alarm system.

Introduced in 1991, this system allows transit operators such as GO Transit to send certain key Alarms or Messages from the train to the Operating Crew using existing trainline wires that do not have to be dedicated to Priority Alarm usage.

Typical Alarms

- Smoke Detected
- Heat Detected (Fire)
- Dragging Parking Brake
- Doors Closed (left or right side)
- Doors Open (left or right side)
- Passenger Assist

The above list is typical but by no means the limit. The system is very flexible and can be factory configured to suit a wide variety of application needs.

Priority Alarm consists of several different enclosures that can be installed in the control cab(s) of a transit consist. These are comprised of a display head, a master control unit, a remote alarm unit and various alarm reset panels. Reference the following diagrams for a typical system configuration.

As stated above, the system reads signals that are multiplexed onto a designated trainline wire within the MU jumper using the trainline #4 wire as its common return. It is very important to note that as discussed above with all powerline carrier systems, the trainline wire selected can already have a designated purpose and signal. The multiplexed signal does not inhibit or interfere with a 0 - 74 VDC signal. In other words, Priority Alarm does not need a

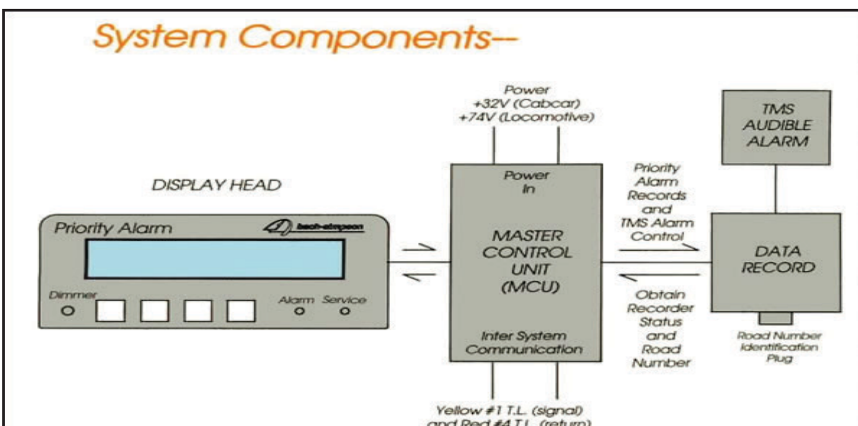

FIG. 2: MASTER CONTROL SUBSYSTEM BLOCK DIAGRAM


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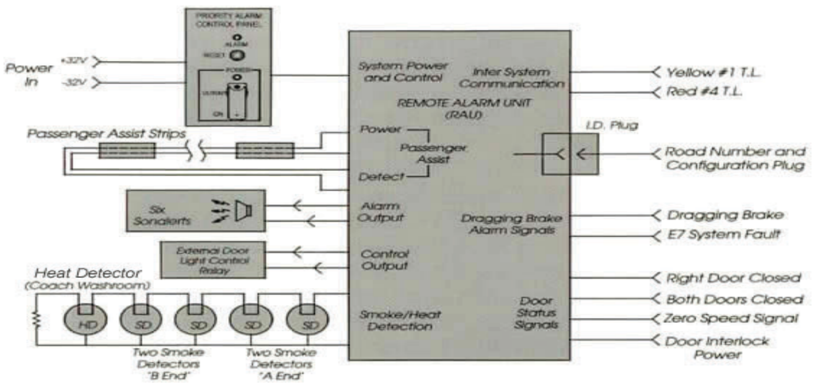


FIG. 3: REMOTE ALARM SUBSYSTEM BLOCK DIAGRAM

dedicated wire within the MU jumper system.

Dynamic Brake Status Reporting

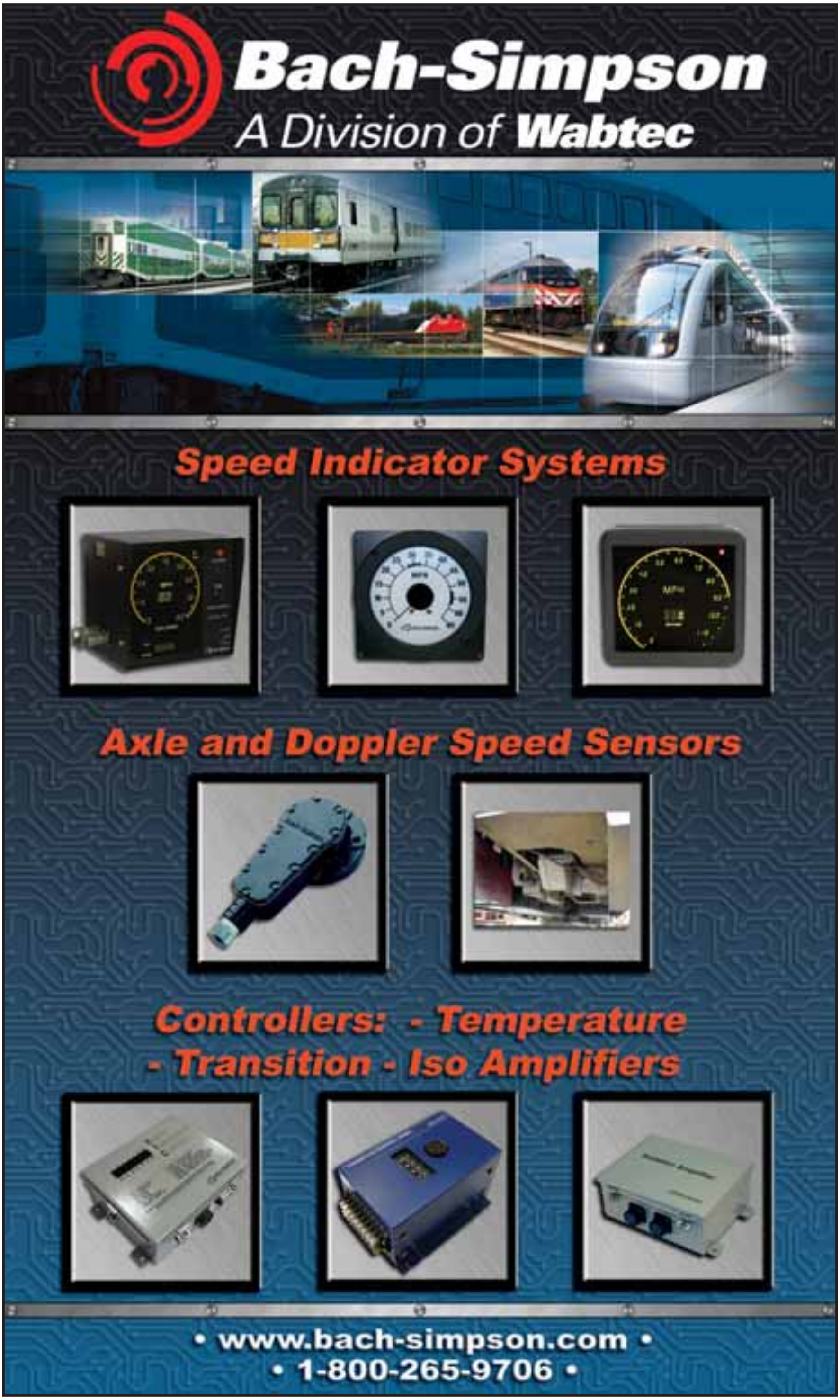
In an attempt to bring digital communications to the 27 Pin Multiple Unit Control standard, dynamic brake status reporting was added in 2007. The trainline modem technology uses a control network power line carrier system that creates a relatively low bandwidth link between locomotives for sharing parameters using a serial interface between the modem equipment and the locomotive control system. The trainline modems are used for a very specific set of functions related to monitoring the status of dynamic braking systems of the locomotives in a consist. Currently this communication is used for displaying information to an operator, not for real time control.

AAR Standard S-5509, Locomotive dynamic brake status reporting, specifies the data passed between locomotives and the connection scheme. The data provides dynamic brake status and other information to the lead locomotive in a consist. The locomotive equipment is typically limited to 9600 baud due to serial port interface requirements to older microprocessor-based locomotives. The system reports:

- The number of locomotives contributing to dynamic brake.
- Cumulative tractive or dynamic brake effort of the consist.
- Dynamic brake status of each locomotive including cutout, fault, or isolated.

Electronically Controlled Pneumatic (ECP) Systems

ECP Brake systems (AAR Standard S-4230: Intra-train communication specification for cable-based freight train control systems), also uses powerline carrier technology for digital communication. These systems are primarily used for control of electronically controlled pneumatic (ECP) brakes and remote multiple units, and use the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same LonWorks network protocol and transceiver specification as dynamic brake status reporting, but with different carrier frequencies and voltages. ECP brake systems do not operate on the 27 Pin Multiple Unit control but with separate cables and power supplies down the entire length of the train, not limited to the locomotive consist.

Wireless MU Connection Possibilities

When we think about wireless connections, there have been a plethora of technologies developed over the years. Just looking at the top of a PTC equipped locomotive with its forest of antennae mounted on the roof you recognize that the industry is fully embracing these technologies.

Now, with PTC and the increasing desire for better tracking of locomotives and their valuable data, locomotive wireless communication has exploded.

In order to at least meet the current functionality of the hardwired MU connection, a wireless replacement must:

- Allow locomotives to be placed in any position in the consist facing any direction.
- Be interoperable across all types of locomotives and different railroads.
- Be able to synchronize the activity of the connected locomotives such that traction and braking activities are all acting together.
- Allow for control of at least 8 locomotives.
- Maintain interoperability with existing 27 pin standard equipped locomotives.

To transcend the current wired connection, here are some features the locomotive wireless MU system could add:

- Automatically determine whether it is in lead or trail and set itself up to operate in that role.
- The lead locomotive could then, using the wireless replacement to DB health monitoring, be able to view all of the connected locomotives and determine their contribution to tractive effort and braking.
- One further step would be to allow the lead locomotive to cut in and cut out trailing locomotives individually or perform power/braking effort matching operations instead of notch/handle matching.
- If trailing units were AESS equipped with appropriate settings, the trailing locomotives, when cut out, could shut down if not in use and start up when needed. Functionality like this could save fuel in operations where locomotive output must be matched to the ruling grade and the remainder of the trip requires substantially less power.
- This wireless connection could also be used for off-locomotive data download.
- The wireless device could be designed such that it fits directly onto the existing MU wiring location and provide a pass through connector for coupling to units that are not wirelessly equipped. This could reduce

installation time and support backwards interoperability.

Following are some existing technologies that could accomplish some of these things and other technologies that could be adapted to the task.

Distributed Power (DPU)

Distributed Power System (DPU) is a technology that allows locomotives to operate at various positions throughout a train consist by monitoring and relaying control commands through wireless RF communication. In essence the DPU radio commands replace the command signals typically carried over 27 pin MU. DPU has been in use since the 1960's and is used extensively throughout the railroad industry.

Typical DPU systems utilize UHF radios for transmitting and receiving commands between lead (controlling) and remote locomotives. The radio signals are typically strong enough to transmit the length of the train and have a range of 2-5 miles depending on various conditions. The systems use typical road numbers as identification and require setup on both lead and remote locomotives (either through software or hardware dial) in order to ensure communication to the correct locomotives. Various frequencies and channels are used to ensure the DPU locomotives of a single train can operate without interference from other DPU trains.

The main benefit of the DPU technology as a model for next generation MU is that it is a well-developed and established technology for the industry. Railroad employees have extensive experience using or working on the DPU systems.

Some detriments of utilizing DPU technology would be limited functionality, frequent radio signal issues (communication loss), manual setup, and data security concerns.

Although others have produced DPU systems, the market is essentially dominated by the series of Locotrol Distributed Power systems from General Electric. The Locotrol system employs proprietary and patented technology. If used for general consist control, in order for the North American rail industry to maintain the interoperability of locomotives and allow fair competition, there would need to be a non-patented standard written to allow competitive OEMs and aftermarket suppliers to also produce systems with the same interface.

End of Train Devices

End of train (EOT) and Head of Train (HOT) devices have evolved to include two way radio communications between the lead locomotive and rear of the train. Specifically the EOT monitors brake pipe pressure and sends that info back to the lead locomotive. The EOT also has the capability to open the brake pipe to ensure brakes apply quickly on the whole train in an emergency situation. The radios operate on UHF or VHF frequency similar to DPU and use an ID code or address that is set manually on the head end device. Given the similarity to DPU systems, EOT/HOTs have the same pros and cons for being a model for next generation MU.

Bluetooth

Bluetooth is a short range communication protocol operating in the range of 2400 – 2483.5 MHz. This operating range is divided up into 79 channels (40 channels in Bluetooth v4.0). The radio technology used is referred to as frequency-hopping spread spectrum.

The Bluetooth technology was developed for and used mainly in consumer electronics and is specifically focused on portable devices such as cell phones, music players etc. A licensed technology, the specification for the protocols and interfaces is overseen by the "Bluetooth Special Interests Group". Not as well known about Bluetooth is that that the standard allows for three classes for ranges of 100m, 10m and 1m. At 100m, locomotive to locomotive communication does become conceivable, at least as far as range is concerned.

Because of the nature of the protocol, Bluetooth requires a mating / discovery process to establish a secure master / slave link between devices.

All things considered, this technology would be a very unlikely candidate for use in a locomotive MU system.

WiFi

Most people are familiar with WiFi as it is mainly used in homes and office as the de facto standard for wireless networking. WiFi is actually a series of protocols based on the IEEE 802.11 standard and overseen by the WiFi Alliance.

WiFi is generally used in a fixed structure architecture using routers and access points, but can also support a node to node ad hoc structure. Range on WiFi systems can vary drastically based on the transceivers used and the output power. Earlier encryption schemes used on WiFi networks such as Wired Equivalent Privacy (WEP) have been demonstrated to lack security. Later encryption methodologies such as WiFi Protected Access (WPA) and WPA2 have proven far more secure and have been around since 2003.

Dedicated Short Range Communications (DSRC)

DSRC is a two-way short/medium range wireless method of communication. It is setup to provide very high data transmission rates allowing it to be used for active safety applications. DSRC uses 75MHz in the 5.9GHz band.

This standard is currently being developed and used for information transfer between vehicles for accident avoidance, traffic management etc. This protocol, capable of use in a dynamically changing ad hoc network, would transfer information such as the path history of the vehicle, vehicle speed, GPS, heading etc.

Not only can this protocol be used for communications from vehicle to vehicle (V2V), there are applications for data transmission between vehicles and infrastructure (V2I). The SAE and IEEE standards ensure interoperability in vehicular applications. VANET (Vehicular Ad hoc NETwork) is a specific implementation of a DSRC ad hoc network.

DSRC has seen very limited application on locomotives for fuel monitoring and yard data transfer, but could be worth looking at for much more.

Some Other Wireless Concepts

Wireless Ad Hoc networking

The term ad hoc is a Latin term that literally means "for this" and logically "for this purpose only". In the locomotive world, MUing together two or more locomotives is this type of connection: for the purpose of pulling this load over this route.

In general ad hoc networks are decentralized in the fact that they have no routers or any managed infrastructure. Each node can route information to other directly connected nodes based on its limited knowledge of the dynamically changing network. These links and data routes can be formed without setup and allow for scalability and redundancy. Because of this certain specifically designed protocols must be used in these networks.

The use of ad hoc networks for MU connections on locomotives could eliminate the need to set up consists the way that they need to be today and could allow automatic formation of the locomotive network based on the units that are coupled together. The question of how to omit locomotives on adjacent tracks or non-coupled units on the same track could be a difficult one to tackle. Due to the safety implications and mission-critical nature of the MU connection, it is likely that redundancy in the system will be necessary.

Security in Wireless Networks

Due to the accessibility of wireless networks to devices not physically connected, security becomes a much larger issue in these systems. The MU interconnect is inherently secure due to its required physical connection. Password type security keys protect our home networks, but the interoperability requirement of locomotives mean that any common key required for communication would eventually become public knowledge. These issues mean that operator interaction may still be required to confirm or setup consist / train power content on at least the lead, if not all controlled locomotives. There is the possibility of limiting the accessibility to the inter-locomotive communication with the use of highly directional wireless antennas. These directional antennas if placed at both ends of a locomotive, could not only limit access to the communications, but it could also allow the MU systems on the locomotive to automatically determine lead vs. trail and direction of the locomotives in consist.

AAR Initiative

Some time ago an AAR sub committee was formed at the request of one or more of the Class I railroads to determine a viable next generation alternative to the 27 pin MU. The key parts of the initiative are the elimination of the physical 27 pin connector, and the addition of added functionality to the system. At this point the desired added functionality by the railroads is for a universal upload/download box to allow a single point of wireless or wired transfer of all software and data needed for locomotive systems.

The goal is to have the industry decide upon and develop specs for both a wired and wireless MU alternative and the separate "universal upload/download" box that will provide the added functionality desired for the system. All class 1 railroads are involved and all are committed to selecting a new industry standard technology.

Several vendors were asked to give proposals or demos of a next generation MU system using already developed or established technologies (including DPU, Trainline Modem, ECP interface, PTC data radio, and perhaps others). The idea is that an existing technology could be used and further developed to IEEE or SAE standards. The system must utilize existing standards for communications and data security of other large industries.

As of the writing of this paper, a second vendor demo is scheduled for September 2014 at TTCI. After this demo, the railroads will discuss which path they want to develop further and define AAR specifications for. An implementation plan would be developed to decide on how to phase in the new technology and phase out the old. Some level of compatibility between current and next generation systems must be included to ensure interoperability. Class 1s are progressing under the assumption that small regional or shortline RR will not initially adopt the new standard or retrofit.

Conclusions

Given the current experiences in the industry, it is evident that the 27 pin MU connector is no longer the best solution for railroads today. At 45 years old, this cable has supported the industry well and will likely continue for some time. However, the time for a step forward is at hand.

In general, moving forward with a hard cable type connection for a new solution would have many of the same reliability issues that are faced by the current hard connection. That being said, wireless connectivity could come with a whole new set of difficult to diagnose issues. Intelligent design of the MU systems and intuitive on-board diagnostics could greatly alleviate that concern.

All of the technology exists to design and implement a wireless solution for control of multiple units in consist operation. The challenge of seamless and automated connection of locomotives still has several design issues that would need to be overcome including security and automated locomotive setup algorithms. Many of these concerns could be simply avoided by using a manual setup procedure and existing technology, but is that the best solution moving forward? It will be very interesting to see what comes from the AAR initiative this year and what will be chosen as the new industry standard… given the precedent, this new standard could be around for 45 years!

Natural Gas Economics and Fueling for Locomotives

Prepared by:
Tom Mack
Chief Technology Officer, VeRail Technologies, Inc.

As reported in the LMOA New Technologies Committee's 2013 paper on natural gas in locomotives, 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. More recently, in 1987 to 1995 Burlington Northern ran two converted EMD SD40-2's to run in dual fuel mode (natural gas and diesel). Today it seems like a new article comes out every week about railroads looking to switch from diesel fuel to natural gas.

While the switch from diesel to natural gas (or a combination of diesel and natural gas) makes a lot of sense, there is much more to this switch than meets the eye. While the economics of the fuel itself certainly make sense, and it appears the price differential will make sense for many years to come, the railroads are aware of the fact that there are many other factors that will affect the overall economics and logistics of a switch to natural gas.

In this paper we will attempt to delve into the basic economics of natural gas, and what it takes to support a natural gas powered locomotive, whether it be a straight natural gas or a dual fuel (diesel and natural gas) locomotive. To accomplish this, this paper will cover three basic areas:

- Natural Gas Pricing
  - o Industrial Pricing
  - o Direct Purchase
- Henry Hub
- Transportation Costs
  - o Wells to Wheels – Actual Cost Model

- Locomotive Fuel Storage Systems
  - o LNG
  - o CNG
  - o Separate Tender
  - o Onboard Locomotive Storage

- Refueling
  - o Systems
  - o Delivery Logistics
  - o Economics

Natural Gas – An Overview of North American Supply

In LMOA's 2013 paper on natural gas locomotives, it was pointed out that a study and report in May 2013 by the Potential Gas Committee (PGC) at the Colorado School of Mines 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. More recently, in an interview with The Motley Fool, world-renowned oil and gas tycoon T. Boone Pickens also reiterated the 100 year supply of natural gas. Based on these numbers, the projected gas supplies would be the equivalent of almost 3 trillion gallons of diesel fuel.

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. While the U.S. was starting to feel comfortable regarding its own energy security, recent events in June of 2014 in regard to turmoil in Iraq have sent shock waves through the energy and especially the petroleum sectors. So as Figure 1 shows, the distribution of natural gas fields throughout the U.S. is extremely balanced and reassuring for future supply demands. 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.

The distribution of natural gas throughout North America also plays well for the critical aspect of natural economics. Without a balanced and mature distribution network, natural gas would not be nearly as attractive as it is to the railroad market.

Natural Gas Economics

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, natural 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 climbed to a more "reasonable" $3.70 per MMBtu, and even broke the $4.00

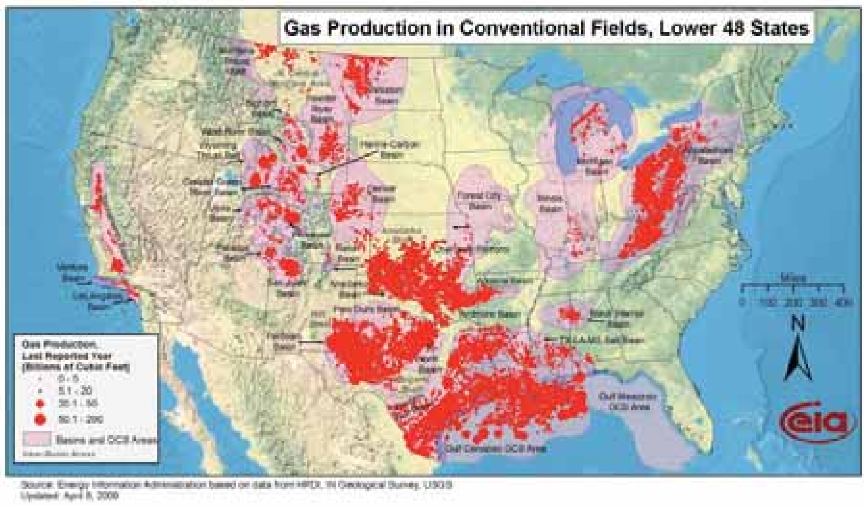

Figure 1 – U.S. Gas Field and Well Locations

mark. In 2014 prices have gone as high as $8.12 per MMBTU in February 2014, but almost immediately settled back down to under $6.00 per MMBTU. Much of this price fluctuation was attributed directly to the extremely harsh winter of 2013-2014 experienced in North America. Since many homes use natural gas for heating, and a major shift is being made from older coal fired electric generating plants to new clean natural gas plants, this spike is not entirely unexpected nor is it unexplainable. In March 2014 natural gas prices fell back down to the mid-$4.00 range, with prices from March through June fluctuating between a low of $4.33 per MMBTU and a high of $4.83 per MMBTU, a very tight spread on either side of the average of $4.51 per MMBTU.

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 $4.50 per MMBtu is probably a more realistic price base for future calculations.

But how does this $4.50 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). While the conversion factors from raw natural gas priced per actual MMBTU to Diesel Gallon Equivalents (DGEs) is not a precise calculation (depending on heating values used for the natural gas per MMBTU and heating value used for one gallon of diesel fuel), at $4.50 per MMBTU, the price for natural gas extrapolates into a mere $0.58 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 above $100 per barrel, the cost per DGE is $2.23. That is over 4.5 times the raw energy cost of natural gas. With increasing turmoil again in the Middle East, the price of Brent crude, a benchmark used to price international oils, was at $113.58 a barrel on the ICE Futures exchange in London. At that price, the raw energy cost per DGE for oil is $2.53, almost 4-1/2 times the base BTU cost for natural gas.

Using the historical figures, if natural gas were to spike 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. 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 very price competitive to oil for the foreseeable future.

Natural Gas Pricing

But just how is natural gas priced to an end user like a railroad? Railroads are very familiar with how to buy diesel fuel. For large railroads, they can buy diesel fuel through wholesale outlets. Smaller railroads can buy in bulk for their own fueling facility, or may buy through a local oil company and have the diesel delivered directly to the locomotive. Except for railroads using natural gas in their physical plant (e.g. to heat buildings), buying natural gas a vehicle fuel is probably a new experience. So while we think in units of diesel gallons, we buy natural gas in units of MMBTU. Once we have a conversion between MMBTU and DGE established, then we have to decide just where we will buy our natural gas, and there are several options for railroads.

Industrial Pricing – Medium to large scale buyers usually buy their natural gas at industrial pricing, which is lower than residential pricing. In this scenario the buyer usually buys from the natural gas utility, which delivers the natural gas to the point of use via the utility's pipeline distribution system. The price of gas per MMBTU therefore includes the "delivery charge" for the natural gas. A railroad that uses natural gas to heat buildings, shops, etc. would simply buy additional natural gas from its local utility to be delivered to the railroad's fueling terminal.

A typical industrial price for an MMBTU of natural gas might be around $5.60 per MMBTU, about $1.00 more per MMBTU than the Henry Hub price (see next section on Direct Purchase).

Direct Purchase – The largest users of natural gas can buy directly from the actual natural gas producers. These producers pipe their natural gas into the nation's network of pipelines for delivery to the final customer. As such, the producers themselves do not charge for the transport of the natural gas to the end user.

In order to set a standard pricing scheme, the Henry Hub price is used. According to Wikipedia, "The Henry Hub is a distribution hub on the natural gas pipeline system in Erath, Louisiana, owned by Sabine Pipe Line LLC, a subsidiary of Chevron Corporation. Due to its importance, it lends its name to the pricing point for natural gas futures contracts traded on the New York Mercantile Exchange (NYMEX) and the OTC swaps traded on Intercontinental Exchange (ICE)… Spot and future natural gas prices set at Henry Hub are denominated in $/MMBTU (millions of British thermal units) and are generally seen to be the primary price set for the North American natural gas market. North American unregulated wellhead prices are closely correlated to those set at Henry Hub."

As noted earlier in this paper, prices from March through June 2014 fluctuated between a low of $4.33 per MMBTU and a high of $4.83 per MMBTU, a very tight spread on either side of the average of $4.51 per MMBTU. While this price is lower than industrial pricing, the natural gas buyer must pay the pipeline company a transportation fee to get the gas to its final destination. While this is an additional cost per MMBTU, direct purchase plus transportation costs can be a cheaper purchasing option than purchase directly from the local utility, and for a railroad buying natural gas for multiple locations, it can be a better option logistically as well.

Multi-Year Gas Contracts – This option can be used with purchases either through a utility provider or direct purchase from the gas producers. The multi-year contract pricing allows a railroad to better quantify it multiyear costs to convert to natural gas, which will include other capital expenditures for both the locomotive conversions and refueling systems. As with any commodity, the length of time offered in a multi-year contract will vary depending on the volatility of the markets and how "hungry" the supplier may be to lock in multi-year contracts to cover risk. It is not unusual in today's market to negotiate five year contracts, and even 10-year contracts were being made during the early natural gas expansion in key gas fields.

Corporate Owned or Co-op Wells – While the idea of owning one's own wells tends to be sold as an investment option, for a very large user of natural gas the potential savings in owning its own wells can be very feasible. While there is definite risk in such ownership (it is an investment), the savings potential can be significant. To reduce risk, an alternative is to buy into a well or group of wells through a co-op arrangement.

Some railroads may also already own land and its associated mineral rights. Depending on the location of this land, it may be in a railroad's interest to explore the natural gas potential for land already owned. Ownership of the land on which natural gas wells are drilled does not negate the option of offering Co-op wells vs. wells owned singularly by the railroad.


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As with buying natural gas at the Henry Hub price, the railroad will need to pay for transportation of the natural gas to its final destination. This may involve having to run significant pipeline to a main branch or feeder line of the national natural gas pipeline grid.

Captive Flared Gas – While many natural gas wells are drilled specifically to tap natural gas, a large amount of natural gas produced is actually a by-product of oil wells. Unlike a natural gas well that (currently) needs to be connected via pipeline to the national gas pipeline network, many oil wells simply pump their output to local storage tanks, which are then offloaded to trucks, which take the crude oil to a central terminal, where it is distributed either by pipelines or by the growing Crude By Rail (CBR) network. For those oil wells which are not close to a pipeline, and therefore store their crude oil output in local storage tanks until offloaded, there is a problem with what to do with the natural gas by-product of the well. The natural gas cannot be simply discharged into the atmosphere. In addition to its past issues methane release is also now closely watched because it is a potent greenhouse gas. Up until now, the answer to this methane problem is to simply burn it at the well. This is known as flaring.

As the number of oil wells drilled in the United States has increased, so has the amount of natural gas being flared off at the wells. It is currently estimated that in North Dakota alone, $1 Billion USD worth of natural gas is being flared off annually. This is the equivalent of over 1.5 billion gallons of diesel fuel, Another way to look at this problem is that the equivalent of almost half the annual consumption of diesel fuel by Class I railroads in the United States is simply being burned off every year at oil wells across North Dakota. Because of this, North Dakota changed its policy on June 1, 2014 to require energy companies to submit a plan to capture any natural gas that could be released by a new oil well when filing for permits for the well. Without a plan, applications for new wells will not be approved.

There is an opportunity for railroads to become involved with the oil well owners to purchase this flared gas and utilize in locomotives or other equipment. Whether oil companies may be willing to work with the railroads to take what is currently considered a waste product from oil production and make it available at a reasonable price, either directly or through some capital cost sharing to capture the flared gas, remains to be seen. But it is clear that there is a huge and existing source of flared gas that will be available to the market and railroads could be a viable consumer of this flared gas supply.

Wells-to-Wheels – Actual Cost Model

While the price of natural gas is, and will no doubt continue to be, very competitive as compared to diesel fuel, the pricing discussed so far in this paper is for the “raw” or base cost of natural gas. There is much more to the pricing model than simply buying natural gas. We must take into consideration what it will cost to get the base product onto our locomotives as a fuel to ultimately turn the wheels!

The pricing considered so far takes into account actual gas being delivered via pipeline to a point on the railroad where it will be used in locomotives. Since we cannot expect to run long hoses from the natural gas pipeline to our locomotives, we must change the gas into a form that can be stored on the locomotive or a fuel tender, such as compressed natural gas (CNG) or Liquefied Natural Gas (LNG). Thus we will have additional costs involved in our wells to wheels model for the compression or liquefaction equipment, stationary storage tanks, energy costs to convert the gas to a storable fuel, and maintenance on our refueling station and equipment. These costs must all be factored into the final cost of the natural gas fuel.

Cost of gas and transportation – As mentioned earlier, our first line item in our wells to wheels calculation will be the natural gas itself and any additional delivery costs to our refueling facility.

Compressor system or liquefaction plant – If a railroad plans on setting up its own refueling station, it must choose between whether its fuel of choice is CNG or LNG. Based on this decision the railroad will need to purchase the compression or liquefaction equipment. This is a capital cost that must be amortized over the projected life of the station. In addition to the projected amortized cost of the station itself, is the expected annual fuel quantity that will be dispensed. For example, using simple math, if a railroad spends $10M on a 10,000 gallon per day LNG plant, and the expected lifespan of the plant is 20 years, the annual cost of the plant is $500,000. If the railroad expects to use the full 10,000 gallon per day capacity of the plant (which could fuel twenty-two 300,000 gallon per year dual fuel locomotives with a 55% natural gas substitution rate), then the annual cost for the plant is only $0.14 per DGE. But if we are only refueling three locomotives, the annual cost for same the plant is $1.01 per DGE. That is a substantial difference towards the end cost of the fuel. At this rate the cost to liquefy the natural gas is almost twice that of the base natural gas itself. So it is critical to put together a good model of expected fuel usage when considering the size and cost of the compressor system for CNG or liquefaction plant for LNG in order to develop a viable wells-to-wheels model.

Compression or liquefaction cost – The cost to compress or liquefy the natural gas will be directly linked to the equipment purchased. The equipment dealer should be able to supply a projected energy input for the compression or liquefaction of the natural gas, either as a cost per MMBTU, cost be cubic feet converted, or even cost per DGE. While these numbers may change as the equipment ages, most manufacturers will be able to provide some quantitative analysis of the operational costs of their equipment. By applying a kilowatt-hour (kWh) for each DGE converted, the wells-to-wheels model becomes more precise. This cost is usually constant regardless of whether the plant is used at full nameplate capacity or partial capacity.

Maintenance – In order to complete a true wells-to-wheels model the annual maintenance on the compressor or liquefaction plant must be factored in. While this cost may be based on the nameplate capacity of the plant, most maintenance costs are projected by the manufacturers based on the actual amount of natural gas processed. So the maintenance costs should fairly constant and be able to be applied on a per DGE basis.

One caveat about maintenance costs in a per-DGE model: If a railroad is currently dispensing its own diesel fuel, the cost to dispense the fuel, including maintenance of refueling facilities, is usually not included in diesel cost projections. The same should be true of a CNG or LNG refueling station. In order to create a good cost comparison model for diesel vs. natural gas, costs for maintenance and operation of current refueling facilities must be factored in against costs for new natural gas refueling facilities.

Natural Gas Costs for Locomotives – A Government Perspective

While there are no official government studies on the costs of actual natural gas fueling equipment, maintenance, or locomotive conversion option, the United States Energy Information Administration (EIA) published a paper in April 2014 entitled "Potential of liquefied natural gas use as a railroad fuel". (This paper can be found at www.eia.gov/forecasts/aeo/liq_nat_gas.cfm.) While the paper specifically looks at LNG as a locomotive fuel, much of the information has applicability to CNG and natural gas in general.

The first key point from the EIA paper is the projection that the spread between energy equivalency costs of crude oil to natural gas will remain relatively high, thus making natural gas an economically attractive fuel for years to come. The oil to gas price ratio through 2040 is expected to be between 3.2x to 3.4x (see Figure 2). In other words, the same amount of natural gas energy as found in a barrel of oil will cost less than 1/3 the price of crude oil. Each will need further processing and transportation, but with this wide price spread natural gas definitely is worth watching.

A word of caution: The 7.1x ratio from 2012 is considered by many experts to be an anomaly. This spread was seen when oil prices remained high and natural gas dropped to nearly $2.00 per MMBTU, an unusually low price and probably not economically sustainable for the natural gas industry. So this ratio should not be taken as a potential future benchmark.

The second key aspect of the paper is its projections on how much natural gas (expressed as LNG in the EIA paper) could potentially be used by the railroads by 2040 (see Figure 3). The paper bases its premise on current fuel usage in the United States by Class I railroads and potential substitution rates advertised by natural gas engine manufacturers. The fuel usage numbers are published each year by the U.S. Department of Transportation, Surface Transportation Board (STB). These

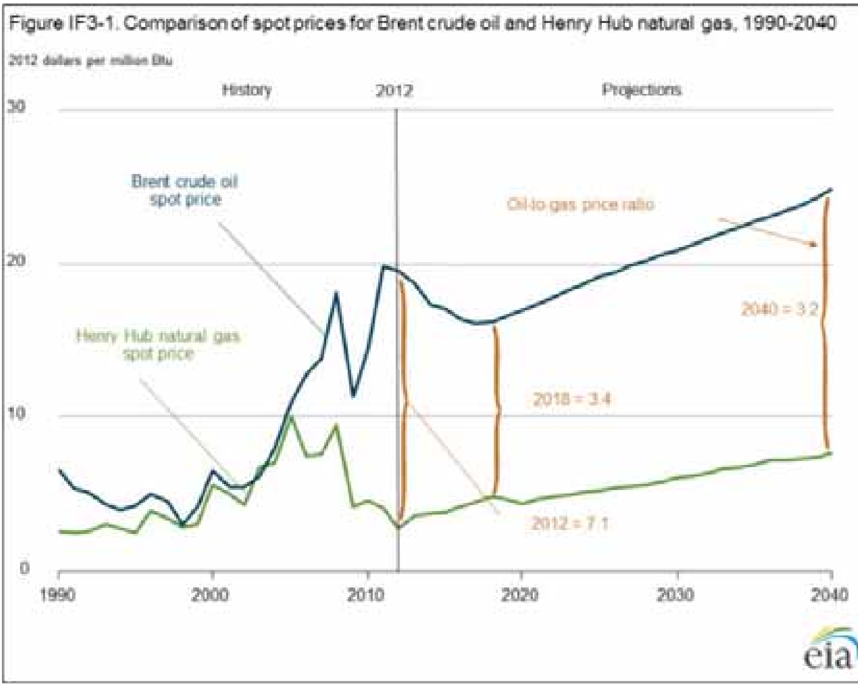


Figure 2 – Comparison of Crude Oil and Natural Gas Prices, 1990-2040

numbers show that in 2012 Class I railroads in the United States used just slightly more than 3.6 billion gallons of diesel fuel. Based on the historical diesel fuel usage and projected traffic increases, three scenarios were created, each with the assumption that natural gas locomotives will go through an initial trial period from 2017 to 2020, and begin to attain widespread adoption thereafter:

1. The reference point scenario wherein railroads would convert 35% of their diesel fuel usage to natural gas by 2040. This would involve railroads converting to using approximately 1.2B DGE annually of natural gas by 2040.This could be accomplished by purchasing 35% of new locomotives as straight natural gas locomotives (an unlikely scenario at this point), or converting 60% of the new and existing locomotive fleet to dual fuel locomotives with a 50% to 60% average natural gas substitution rate.

2. The low conversion rate point assumes that just slightly less than 500M DGE of natural gas will be used annually by the Class I railroads by 2040. This scenario was developed by the EIA using an

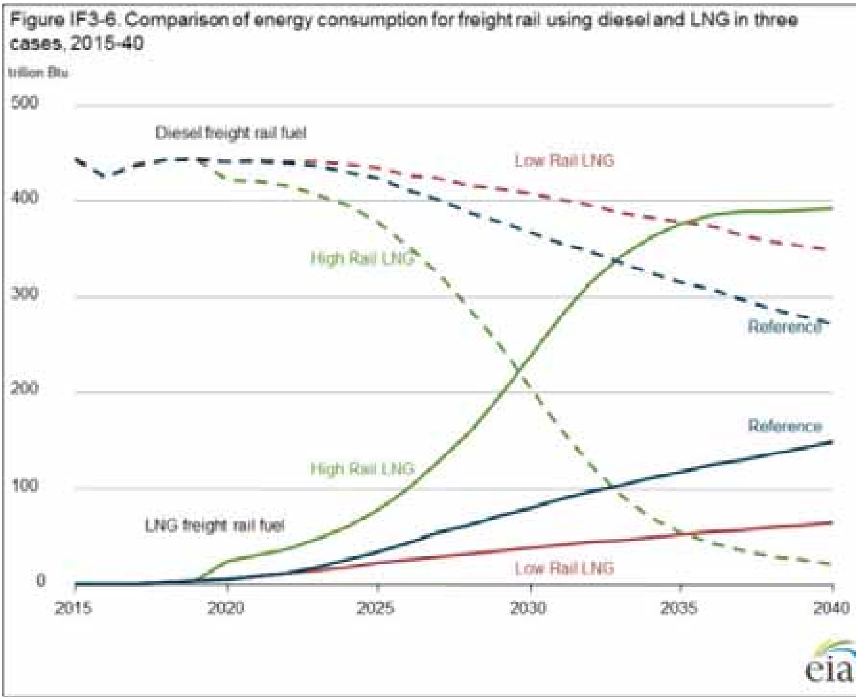


Figure 3 – Three Projected Comparisons of Diesel and Natural Gas Consumption, 2015-2040

average 80% natural gas substitution dual fuel engine model. In this scenario the Class I's would only need 20% of the locomotive fleet converted to dual fuel locomotives, and overall natural gas substitution would be approximately 16% of annual diesel consumption.

3. The final scenario is a high conversion rate which assumes a full scale adoption of the highest substitution rate technologies. These substitution rates are projected to be 95%. In this scenario the railroads would basically make a full switch from diesel to natural gas, because the 5% diesel usage is only as a pilot ignition source and the natural gas engines used would not be able to "fallback" to 100% diesel as in a true dual fuel engine. In this scenario railroads would use approximately 3.1B DGE of natural gas annually. Interestingly, to support this "total conversion" scenario, the overall U.S. production of natural gas would have to increase less than 1% from current levels. So while this scenario might seem unlikely at this point from a business standpoint, it is certainly feasible from a natural gas supply standpoint.

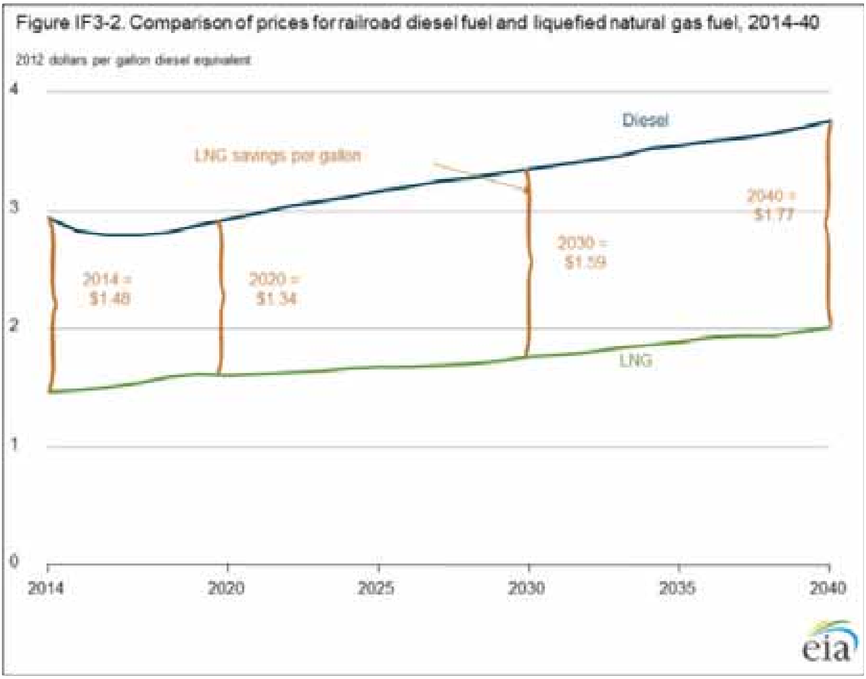


Figure 4 – Price Comparison Projection for Diesel and LNG, 2014-2040

The EIA analysis also includes projections on the price differential for LNG to diesel. The differential is projected at between $1.34 to $1.77 per DGE. This closely matches independent price comparisons and projections carried out by the LMOA New Technologies Committee in preparing this paper.

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 usably 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

	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	• 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: • Increased on-board storage • Does not require cryogenic fueling • Decreased compression cost over 3,600 psi • Consistent "Full Fills"	• Highest NG fuel density available • Smallest tank size requirement per DGE • Fewer tanks
Disadvantages	• Lowest onboard fuel capacity • Slower speed fill with standard fueling stations • Depending on fuel station, cost of compression can be high • Inconsistent "Full Fills"	• Higher cost tanks than 3,600psi • Slight increase in tank diameter • Specialized fuel stations	• Cryogenic liquid with safety implications • Boil off if stored too long • Complex tanks • High maintenance costs for cryogenic parts
Rail – Pro/Con	• Can be set up anywhere natural gas is available • Reduced range	• Increases onboard storage capacity and refuel intervals • Reduced range vs. LNG	• Boil off • Handling challenges

Figure 5 – Fuel Storage Options

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.

Natural Gas Fuel Storage Containers for Locomotives

LNG and CNG use two very distinctly different types of containers. The LNG container is a cryogenic liquid storage vessel, whereas the CNG container is a high pressure gas storage vessel. We will look at each type of container.

Since LNG is a cryogenic liquid with a temperature of -260 degrees F, It cannot be stored in a standard non-insulated steel tank, like a diesel fuel tank. The cryogenic tank which stores the LNG must have a very high level of insulation, and the only way to achieve the high level of insulation needed is to create a vacuum insulated container, wherein the LNG is stored in an inner stainless steel tank, and a vacuum is created between the inner storage tank and an outer protective tank. Externally, there is nothing obviously different in an LNG tank to a non-insulated tank (see Figure 6). But internally these tanks must meet stringent requirements, including the ability to take pressures of 120 psi. This pressure rating is needed because LNG after a period of time will begin to “boil off” in the tank, creating a pressure build-up in the storage vessel. This also means that a puncture to the LNG tank will not necessarily produce a simple leak from the tank, but can produce a high pressure stream of a very cold cryogenic liquid spraying into the surrounding area. Also, because LNG is a liquid, it requires a head space within the tank of at least 10% of the tank volume. Thus an LNG tank which is rated for 10,000 water gallons would only be filled with about 9,000 gallons of LNG. Additionally, it must be remembered that it takes approximately 1.7 gallons of LNG to supply the same energy volume as 1 gallon of diesel fuel. So a 10,000 gallon capacity LNG tank would hold the LNG equivalent of almost 5,300 gallons of diesel fuel.

Figure 6 – Stainless Steel LNG Vacuum Tank

Figure 7 – Type 4 CNG Cylinders

Unlike an LNG tank, which is designed to hold an actual liquid, a CNG tank is a high pressure gas containment vessel, often called a gas cylinder. For many years the standard pressure for CNG cylinders has been 3,600 PSI. Because a gas tends to heat up as it is compressed, the cylinder must be able to take a higher pressure when it is filled. So while a CNG cylinder may be rated for a particular working pressure, say 3,600 PSI, during filling the pressure may get to almost 4,500 PSI. As the cylinder cools, that pressure will come down to or below the 3,600 psi rating.

There are four basic types of gas storage cylinders available. These are:

- Type 1 – All metal (aluminum or steel) cylinders
- Type 2 – A metal cylinder which is reinforced by steel or composite "hoop" wrap around middle section of the cylinder
- Type 3 – A cylinder made up of a metal inner liner reinforced by composite wrap around the entire tank, including the ends
- Type 4 – A cylinder made up of a plastic inner liner reinforced by composite wrap around the entire tank, including the ends

Type 1 tanks resemble a common scuba tank. Type 3 and Type 4 look identical externally and are usually black in color with the reinforcing fibers clearly visible as seen in Figure 7.

A new generation of high pressure cylinders is now entering the CNG vehicle market. These 4,500 to 5,000 PSI cylinders support a higher working pressure than standard 3,600 PSI cylinders. One manufacturer refers to this new high-pressure fuel storage as HDCNG, which stands for High-Density CNG. The storage capacity of the HDCNG cylinders is a major step forward for locomotive CNG use since in most cases 3,600 PSI CNG storage was just not capable of storing enough fuel energy.

The future for even higher pressure CNG storage vessels exists since several of the composite Type 4 cylinder manufacturers are already offering higher pressure cylinder options for storing hydrogen. These next-generation gas cylinders are capable of supporting 8,000 PSI and even as high as 10,000 PSI working pressures.

Fuel Tenders and Onboard Storage

If properly certified, either LNG tanks or CNG cylinders can be used to store fuel for use on a locomotive. The use of high capacity fuel tenders has garnered much attention for supplying natural gas to high horsepower line haul locomotives. One reason for looking seriously at tenders on line haul locomotives is that there just is not enough space on today's high horsepower road power to store a sufficient amount of LNG or CNG. In 2012 the AAR formed the Natural Gas Fuel Tender Technical Advisory Group (AAR NGFT TAG) which is made up of representatives from the AAR, Class I railroads, and other railroads such as Amtrak and FEC. This TAG is tasked with defining the specifications for future natural gas fuel tenders.

Current LNG fuel tenders (and there are very few in existence at this point) are based on either cryogenic tank car or intermodal well car designs. In the intermodal well car design a modified LNG ISO container is used as the actual LNG storage vessel. Unlike a regular freight car, the fuel tenders must meet enhanced crashworthiness requirements since they will be part of the actual locomotive consist. Additional connections for MU pass-through, gas, hot coolant from the locomotive (used to vaporize the LNG from a liquid to gaseous state), electric, and communication will also be needed.

A CNG fuel tender will need the same connections but would not require the coolant connection since the natural gas is already stored in a gaseous state. It will need to reduce pressure in the gas coming from the high pressure storage cylinders to the low pressure specified in the final fuel tender specifications.

Since a fuel tender car will be part of the locomotive consist, and potentially between two locomotives, these tender cars may also require locomotive brake systems, so that the tender's brakes can be applied through use of the independent locomotive brakes, an so that air can be bailed off from the tender car as well as the locomotives in the consist.

It should be noted that since these are separate cars, and are not powered, when a tender car is not part of the locomotive consist it comes under the definitions of a hazardous materials car. Therefore, when not in a consist, these fuel tender cars will come under PHMSA jurisdiction. This must be taken into account in the design and handling of these cars.

When a Fuel Tender is Not a Tender Car

Some railroads are experimenting with or considering storing natural gas on a slug unit instead of a tender car. In this case, the fuel tender is not considered a tender car as it comes under the regulations applying to locomotives. It must meet any current FRA regulations for locomotives, and no doubt FRA will introduce additional locomotive regulations for natural gas locomotives. But it is not considered a tender car when not in consist, so it does not come under PHMSA regulations.

Some safety advantages to using a slug as a fuel tender include the fact that locomotives already meet high crashworthiness and safety standards. Their frames are already designed to take the high buff and draw stresses produced in a locomotive consist. And they already provide for the MU, electrical, and locomotive brake connections that will need to be added for tender cars.

Storing Natural Gas Directly On the Locomotive

Just as we can put natural gas storage on board a slug,(without an engine) we can also put natural gas storage directly on our locomotive (with an engine). The locomotive still comes under the normal FRA regulations, such as 49 CFR Part 229 safety requirements, and FRA will no doubt be making additions to Part 229 specific to natural gas locomotives. It is not expected, however, that changes will have to be made to the safety standards for things like locomotive frame or cab crashworthiness to support onboard natural gas fuel storage. Also, since the fuel is contained on the locomotive, there is no need for any special connections between the locomotive and a fuel tender car or slug. Like the slug, these are still locomotives when not in consist, and therefor do not come under PHMSA jurisdiction.

There are multiple mounting options for natural gas fuel tanks, and these will need to be identified by the locomotive manufacturers based on the current or planned designs. Some possibilities include:

- With the diesel fuel tank under the frame. In this case the existing diesel fuel tank could be shortened and an LNG tank or tanks added in a separate contain. Or a single container which meets fuel tank crashworthiness requirements could contain the diesel fuel in one area and the natural gas in another.

- In the locomotive hood above the frame. On some locomotives there may be enough room in the hood area to put a sufficient amount of LNG or CNG to provide sufficient operation between refueling. In many cases, however, current locomotive designs are limited in the amount of space they have available for additional fuel. It must also be remembered that an LNG system will also require space for a vaporizer to convert the liquid into a gas.

- Under a sub-floor below the engines but above the frame. This requires a major redesign or retrofit of the locomotives and would not support taller locomotive engines, many of which are actually mounted between the existing locomotive frame rails.

Many times the first question that comes up in regard to putting natural gas on board the locomotive has to do with how much is needed. This is actually less a matter of range and more a matter of refueling intervals. For example, if a railroad normally refuels its switcher locomotives every week, and the current fuel usage is around 50,000 gallons per year, the locomotive is using around 1,000 gallons of diesel fuel per week. If the locomotive is converted to a dual fuel natural gas system with an average 60% substitution rate, the locomotive will only need 600 DGE of onboard fuel storage to maintain the current refueling interval of one week. Any more natural gas storage beyond that will simply lengthen the interval between refueling. For example, if the natural gas fuel capacity is increased by 300 gallons, the refueling interval will be stretched to every 1-1/2 weeks based on average fuel consumption of the locomotive. So unless we are already expecting to increase the fuel usage in a locomotive, it is quite simple to calculate the onboard storage requirements based on current fuel usage.

Getting the Gas from the Pipeline Onto the Locomotive, Part I – Converting Gas to LNG or CNG

Since natural gas comes out of the ground in a gaseous form, and is transported via pipeline to its destination as a gas, how can a railroad get the gas to a state where it can be loaded on a locomotive or fuel tender?

To liquefy natural gas several steps must be taken. First, all "impurities", such as dust, acid gases, helium, heavy hydrocarbons (such as Propane, Butane, Benzene, etc.), carbon dioxide, mercaptan (added to odorize normally odorless natural gas), and water must be removed. These impurities will freeze instead of liquefy, so they must be removed before the methane (the main constituent of natural gas) can be liquefied. (Because LNG is mainly methane with other natural gas constituents removed, it is also referred to as Refrigerated Liquid Methane, or RLM. Despite the name difference, it is LNG.) The gas has to be refrigerated, and when it reaches -260 degrees F it becomes a liquid. Because of the additional steps needed to produce LNG, the cost of an LNG plant and the per-DGE production is more expensive than CNG. Depending on the processes used, a DGE of LNG can take two times more energy to produce than a DGE of CNG. This is why LNG is commonly more expensive per DGE than CNG.

Another cost factor to keep in mind with LNG is that there is an economy of scale that must be met to make an LNG plant practical. Even the "smallest" LNG plants are designed to produce anywhere from 6,000 to 10,000 gallons of LNG per day. Plants below this capacity are not just not economical to manufacture at this time. While a 6,000 or 10,000 gallon per day plant does not have to operate at full nameplate capacity, as discussed earlier in this paper, the capital cost for the plant is still the same. Therefore, if a 6,000 gallon per day plant is only utilized at 2,000 gallons per day, the cost factor for the plant in calculating a per DGE cost for LNG will be triple what it would be if the LNG plant were running at or near capacity.

A couple of examples of current "small" liquefaction plat offerings are:

- GE's LNG In a Box™
  - o Available in sizes from 10,000 to 50,000 gallons per day LNG production (5,882 to 29,412 DGE per day)
- 2.1M to 10.7M DGE per year capacity
- 146-730 30,000 gallon/14,706 DGE LNG Tender fills
- Assumes 30,000 gallon capacity tender filled with 25,000 gallons (14,706 DGE) of LNG
- Dresser-Rand LNGo™
  - o 6,000 gallon per day and up (scalable)
- 1.3M DGE per year and up
- 87 30,000 gallon/14,706 DGE LNG Tender fills or more

The costs for these plants vary and may or may not include storage tanks for the LNG. While final pricing must be obtained from the manufacturer, current goals appear to be pricing at around $900 to $1,000 per 1,000 gallons of daily nameplate capacity. Thus a 6,000 gallon per day plant would be in the neighborhood of $6M, and a 10,000 GE plant in the neighborhood of $10M. Published reports have listed the energy input to produce 1 gallon of LNG at around 1.4 kilowatt-hours (which is about 2.4 kWh for 1 DGE of LNG).

An alternative to installing a dedicated LNG plant is to buy LNG from an existing large-scale LNG plant. These plants produce tens-of-thousands to hundreds-of-thousands of gallons of LNG per day. 34 of the existing large-scale LNG plants in the U.S. have the capability to offload LNG into tanker trucks that could then supply the LNG directly to a locomotive refueling station where it is either directly loaded into an LNG fuel tender or is stored in an on-site LNG tank for later loading into the locomotive or fuel tender. It should also be noted that while only seven of the 34 LNG plants that offer offload to trailers are considered producers of "vehicle grade" LNG (meaning it meets on-road truck engine manufacturer specifications for methane content, etc.), the producers of locomotive and off-road engines have not mentioned a requirement for "vehicle grade" LNG to be used in their engines. Pricing for offloaded LNG can be quite attractive, with one LNG supplier quoting $1.33 to $1.38 per DGE if a buyer uses their own trailer and picks up the LNG at the LNG plant.

Producing CNG is a less complicated process than producing LNG. First, there is no need to remove all the additional constituents of natural gas, such as heavy hydrocarbons or even the mercaptan odorizer. While the gas will go through a dryer to remove water, the natural gas from the pipeline can be used "as is" from the pipeline. Also, because the heavy hydrocarbons are not removed (which have a higher BTU content than methane), the overall per cubic foot BTU content of the natural gas stored as CNG can be higher than natural gas stored as LNG.

In its simplest form, producing CNG is just a matter of drying the input natural gas and using a compressor to store the gas in CNG cylinders. While the gas can be actually compressed directly into CNG cylinders on board a locomotive for fuel tender, this is a very slow process, so can only be used when a locomotive or fuel tender can sit for many hours while it is refueled. Thus a direct "slow fill" method is not practical for most locomotive applications.

Because the "direct to vehicle" slow fill method is not practical for most refueling applications, a set of stationary storage tanks are used. These can be filled at a slow fill rate during the interval between locomotive refueling then these filled stationary cylinders are used to fill the locomotive or fuel tender at a "fast" rate during refueling. In order to fill the stationary tanks faster, a gas cooler may be inserted between the compressor and tank. This allows the stationary tank set to be more quickly filled between locomotive refueling without building up dangerously high heat and associated pressure in the tank. During the refueling process the gas from the stationary tanks may be chilled even further, thus making the transfer of gas from the stationary CNG storage cylinders to the locomotive or tender much faster and efficient.

The same overall CNG compression scheme is used for 5,000 PSI HDCNG systems. In these systems the CNG storage tanks must be rated for the higher working pressure and a higher pressure compressor needs to be utilized to fill the stationary CNG storage cylinders. It is also not uncommon to use an additional gas chiller between the stationary storage cylinders and the locomotive or tender CNG cylinders in order to further avoid heat buildup in the vehicle storage cylinders during a fast fill with HDCNG.

A key to CNG facilities is that they tend to be much more scalable to install as compared to an LNG plant. The addition of extra compressors and/or stationary CNG storage cylinders is also much more flexible and adaptable to different refueling needs and schedules. For example, if a railroad starts with just a few locomotives the initial CNG plant can be sized for just the initial locomotive fueling requirements. As the fleet grows, more or higher capacity compressors can be added, and if necessary, additional storage cylinders added. Because of this scalability the initial capital expenditure costs for a CNG system can be much better controlled than the cost of an LNG plant. In many cases, because of the gas cooling systems utilized with a 5,000 PSI HDCNG system, the refueling time for a HDCNG fueling system can be less than that for a traditional 3,600 PSI station.

Transferring Fuel from Station to Locomotive

How does a railroad go about actually refueling the locomotive or tender?

Since LNG is a liquid, the refueling process is similar to that of diesel in that a liquid is transferred from one tank to another. This can be done at relatively high flow rates. Trucks currently refuel at rated flow rates of around 50 DGE per minute (85 LNG gallons per minute), but in-field refill times indicate the actual rate is probably even higher, at around 70 DGE per minute (119 LNG GPM). These fill rates are rising, with

Figure 8 – LNG Refueling Hose and Protective Equipment

200 DGE fill rates forthcoming. Larger LNG facilities that fill large tankers are already filling at flow rates of 250-300 LNG gallons per minute.

While LNG is dispensed through a regular hose, this hose must be insulated for the cryogenic liquid. Because LNG is an extremely cryogenic liquid, care must be taken to protect the person refueling the vehicle, so heavy gloves, aprons, and face shields are required to protect refueling personal from possible burns should any liquid spill or splatter during refueling (see Figure 8).

Since CNG is not a liquid, it is transferred through a high pressure hose from the fill station to the vehicle. Flow rates for the gas, even at high pressure, are slower than for LNG. A typical truck refueling system transfers CNG at about 10 DGE per minute. Since the high pressure hoses used for CNG refueling are smaller than the insulated liquid hoses used for LNG, the fuel rate can be increased by bundling multiple hoses together. For example, four CNG hoses bundled together would result in a 40 DGE per minute fill rate. At this rate, a 1,000 DGE fill of a locomotive would take less than 30 minutes.

Unlike LNG, special protective gear is not required when refueling with CNG (see Figure 9). This is because CNG is not a cryogenic liquid, so it will not drip or splatter from the hose. Most railroads however, already require personal protective equipment (PPE) such as hard hats, eye protection, and gloves, during diesel refueling, and this same PPE would protect personnel during CNG refueling.

Figure 9 – Typical CNG Refueling

Thermal Challenges with CNG – The "Full Fill" Dilemma

A problem that has plagued CNG vehicle fuel systems in the past is the ability to get an actual full fill of fuel to the onboard CNG cylinders. As CNG is transferred to the vehicle CNG cylinders, the pressure in the cylinder rises, and this pressure rise produces heat as a by-product. This heat causes two problems: First, the heat must be controlled so as not to damage the CNG cylinders themselves. Second, the hotter the gas in a cylinder, the higher its pressure will be, but its actual density per cubic foot will be lower. Thus, when a hot CNG cylinder cools, the amount of actual natural gas in the cylinder will be lower than expected. Thus when refueling with CNG, it can be very difficult to get an actual full fill of gas.

Because of the heat build-up in a CNG cylinder, the cylinder will have a working or service limit (the maximum pressure at which gas can be stored at ambient temperature), but can be filled to 1.25 times that limit (i.e. a 3,600 PSI rated CNG cylinder can be pressurized to 4,500 PSI during refueling, but it must be no higher than 3,600 PSI when it cools to ambient temperature). What will many times happen is that a tank will actually drop to a pressure will below the 3,600 PSI working pressure. That means the tank was not fully filled.

To avoid this problem, which is exacerbated when filling to higher working pressures such as 5,000 PSI, a mechanism must be incorporated into the fill to reduce as much as possible the temperature rise and resulting pressure rise beyond the working limit in the CNG cylinder. One way this can be done is by filling the cylinder as slowly as possible, thus minimizing the amount of temperature rise and giving the cylinder ample time for the built up heat to dissipate during the fill. But as mentioned earlier, slow fill of a large quantity of CNG onto a locomotive or tender car just is not practical in most railroad operations. So other means of heat control and dissipation have been developed to overcome the thermal problem, support fast fills of high pressure CNG systems, and ensure near 100% full fills every time. These technologies include:

- Cooling/chilling the gas before it enters the CNG cylinder
- Patented valves and fill nozzle systems that chill the gas as it enters the cylinder
- Patented hot gas recycling
- In-cylinder temperature and/or pressure probes to monitor and intelligently control temperature and pressure rise in the cylinder

Other Considerations and Potentials for Locomotive Refueling

Beyond the simple technical and economic dynamics of producing and storing CNG and LNG, and moving from a refueling station to the locomotive or tender car, come logistics challenges in refueling locomotives or tender cars. Today diesel refueling is carried out through both stationary and mobile refueling stations. Some railroads opt for central refueling stations where the locomotives are always brought to the diesel fuel. Others have no permanent fueling facilities but take the diesel fuel to the locomotive by truck. These trucks could be owned by the railroad, but in many cases a third party fuel company is used. Depending on how a railroad operates now, and depending on a railroad's natural gas conversion strategy, both stationary and/or mobile natural gas refueling will still no doubt be needed.

By far stationary natural gas refueling, be it for either LNG or CNG, is the most common refueling method used today. Trucks or cars go to a CNG, LNG, or dual CNG and LNG fueling station for a fill up. Since this is the most common refueling option for on-road vehicles, it is also the most robust and refined method for refueling that can be shifted to the railroad environment. Unfortunately, to set up a stationary refueling station means that a railroad must make a committed investment in natural gas refueling infrastructure. If a railroad simply wants to use or trial one or two natural gas locomotives, the cost for the refueling infrastructure may be far more than any cost saving on natural gas will justify. Also, as noted earlier, the choice of natural gas fuel (whether CNG, HDCNG, or LNG), will have a direct impact on the capital cost of the initial station, with LNG production infrastructure being more costly due to the entry level size of even a small LNG plant.

It might seem, therefore, that the most logical choice is to start with mobile refueling. But because there is not a large market at this point (or any market in many places) for mobile CNG or LNG refueling, trying to find a mobile natural gas refueling vendor may be impossible! And what if a mobile refueling vendor does exist? Do they supply just LNG, just CNG, or both? What if the fuel they provide (e.g. LNG) is not our fuel of choice (e.g. CNG)? The logistics of mobile refueling could be very difficult to overcome, actually more problematic than the locomotive or tender car technologies themselves!

There are some indications that a mobile natural gas refueling market may be starting to emerge. One major LNG tank manufacturer has introduced a semi-trailer mounted LNG mobile fueling station. The refueler would fill its onboard LNG tank at a local LNG plant, and then drive to the vehicles that require refueling. According to the manufacturer, the new LNG mobile refueler's unique design includes an efficient, cooled submerged pump, an engine generator that runs on natural gas vapor from the LNG tank, a 6,000 gallon vacuum-insulated LNG tank, front and rear methane detectors, a flame detector at the rear, explosion proof night lighting, an optional external on-load pump, a PLC logic controller that automates fueling procedures, and an information screen with operator-friendly instructions, helpful messages, and pump information. The new LNG mobile refueler was designed with the expansion of the LNG-powered vehicle market in mind.

If a railroad decides to build its own stationary LNG or CNG refueling station, it is important to consider price payback for the station and remember that economies of scale do come into play. The more locomotives that are being refueled, or will be refueled, the lower the per-DGE cost of the fuel produced. Also, railroads would do well to look at other outlets for the fuel. For example, if a refueling station is in place, could it also be used to refuel other railroad vehicles, such as trucks, cars, or MOW equipment that can be converted to dual fuel or straight natural gas?

Railroads may also want to consider a Railroad-Private Partnership (RPP). A RPP would be similar to a PPP (Public/Private Partnership), but instead of government involvement, the railroad could approach local truck or car fleet owners to assess their interest in using CNG or LNG available at the railroad's facility. For example, in many areas a large amount of truck traffic is found around the railroad yard, especially if an intermodal terminal is involved. Would these truck operators be likely to convert their trucks to natural gas if a fueling station was available? If so, the economy of scale for an LNG or CNG station may be provided through this RPP arrangement, whereas a natural gas refueling facility just serving the railroad would not be economical.

Another option would be an RPPP (Railroad-Public-Private Partnership). In this scenario, the railroad is still the driving entity for establishing a natural gas refueling facility, but the government is also involved. In many states, money is available to build natural gas refueling stations. Some states have committed millions of dollars for building alternative fuel refueling stations, including electric recharging stations and hydrogen refueling stations. When this money is available, a railroad may want to look seriously at taking advantage of it. In this scenario, opening such a station to public use, even if refueling is limited to partnering truck fleets, may be a major contributing factor to securing funding for a major percentage of the cost for a natural gas refueling facility.

Conclusion

A year ago, the first LMOA New Technologies Committee paper on natural gas for locomotives noted that there is little doubt that natural gas is here to stay. Just in the year since that paper was written, many of the economic projections of that paper have proven true, with the price of oil rising and the price of natural gas remaining relatively steady. What was not foreseen was the sudden and major unrest in the Middle East which are once again threatening to push crude oil prices to all-time highs, the situation in Ukraine and its effect on Russian natural gas supplies to Europe, and the recently signed $400 billion dollar Russian natural gas supply agreement with China. Many economic forecasters look at these issues and predict that price of oil will only rise, and natural gas pricing will remain as economically attractive as it is, perhaps even more so.

It is hopefully clear from this paper that the use of natural gas in locomotives and its storage is a mature technology that can be adopted by railroads right now. While the economics for each railroad must be carefully weighed, and the refueling logistics must be taken into account, it is expected that 2015 will see the first widespread rollout and testing of a new generation of natural gas locomotives in North America. LMOA will continue to follow these developments and report on them in future.

What are my Natural Gas Engine Choices?

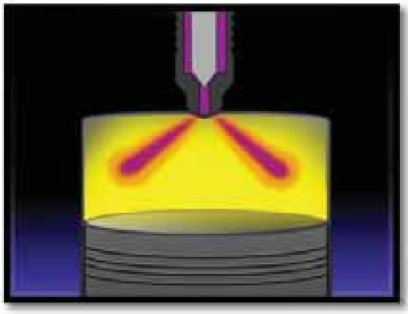
Kurt Ulbick, Peaker Services, Inc.

Introduction:

With the cost of diesel fuel on a steady rise the railroads are looking for ways to reduce their fuel cost; enter natural gas. Railroads have experimented with natural gas for about eighty years, but it has never really caught on. This is due mainly to the fact that diesel fueled engines performed better and the cost difference was not significant. In recent years diesel fuel prices have risen steadily, which has made natural gas much more attractive. The recent abundance of natural gas from hydraulic fracturing of shale deposits has resulted in a significant price advantage over diesel. One question that has therefore arisen is "What is the best type of engine to use in railroad service?" This can vary due to the application that it will operate in. We are going to look at various types of engines and some of the equipment associated with these engines. The paper attempts to deliver an accurate evaluation, contrasting some of the advantages and disadvantages of different approaches. Since this is a developing market, some information may become quickly outdated.

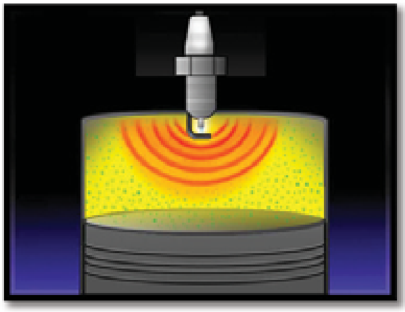
Types of ignition systems:

We first look at a range of alternative methods by which the fuel is ignited in diesel, natural gas and dual fuel engines, with some features of each.



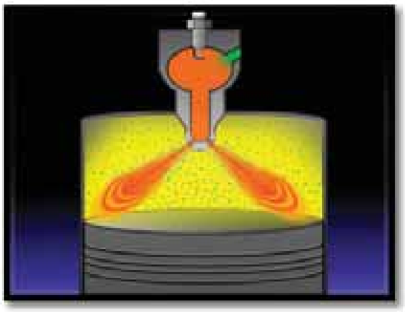
Diesel
Figure 1

This is the old standard. Reliable service, well understood technology, and excellent transient response.



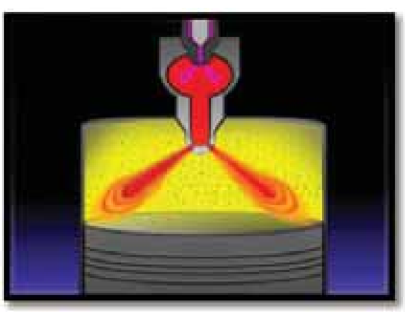
Open Chamber Spark Ignited NG
Figure 2

100% natural gas is mixed with air at low pressure. Lean burn to avoid engine knock. Very clean airbox and oil has very little PM build up. Combustion efficiency and transient response is poor. System can be expensive to install.



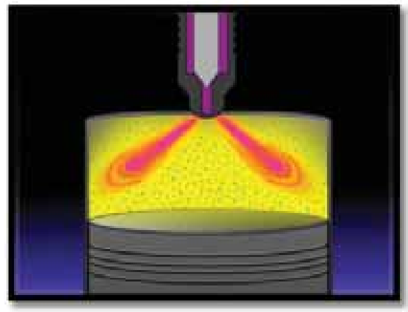
Pre-Chamber Spark Ignited NG
Figure 3

100% natural gas is mixed with air at low pressure. Lean burn to avoid engine knock. This type of ignition uses a rich gas mixture ignited by a spark plug to provide a torch ignition source for lean combustion mixtures, creating a better burn and transient response improves.



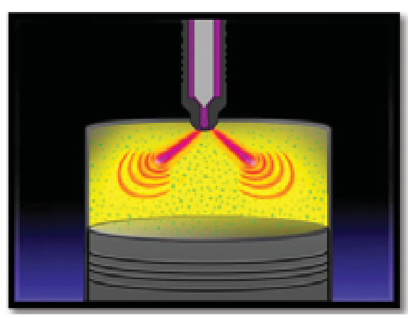
Micro Pilot Pre-Chamber Dual Fuel
Figure 4

Predominantly fueled by gas. A small amount of diesel fuel is injected into a pre-chamber which creates a more intense flame which ignites the gas. No sparkplug to foul but can be hard to start. Combustion efficiency is high and transient response is excellent.



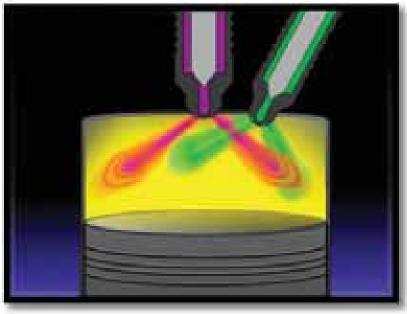
Dual Fuel
Figure 5

Predominantly fueled by gas. A small amount of diesel fuel is used as the pilot fuel. Gas is injected under low pressure and as the gas/air mixture is compressed diesel fuel is injected. The diesel ignites and causes gas to ignite. Combustion efficiency is high and transient response is excellent.



Micro Pilot Open Chamber Dual Fuel
Figure 6

Low pressure system with up to 99 percent gas substitutuion. Can only operate in the dual mode (no straight diesel fallback). Combustion efficiency is high and transient response is excellent.



High Pressure Gas Injection Pilot Ignited Dual Fuel
Figure 7

High pressure system with up to 95 percent gas substitution. Can only operate in the dual mode. A complex technology which requires liquid natural gas. Combustion efficiency is high and transient response is excellent.

Delivering fuel to the power assembly:

Fuel can be put into the power assembly in a number of ways. Fumigation, port injection, low pressure direct injection, and high pressure direct injection.

Fumigation - On a four stroke engine it is accomplished by piping gas into the air intake system, either pre- or post-turbocharger. This is a very simple and relatively inexpensive solution. See figure 8

Port Injection - Similar to fumigation in the sense that fuel is injected into an air stream, but the natural gas is injected at each cylinder. See figure 9 which shows gas being injected into the air intake ports of the power assembly. This is a process used in two stroke diesels engines.

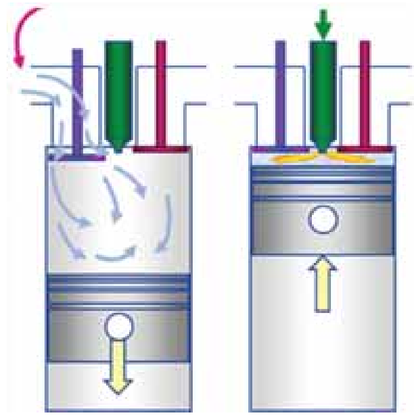


Figure 8

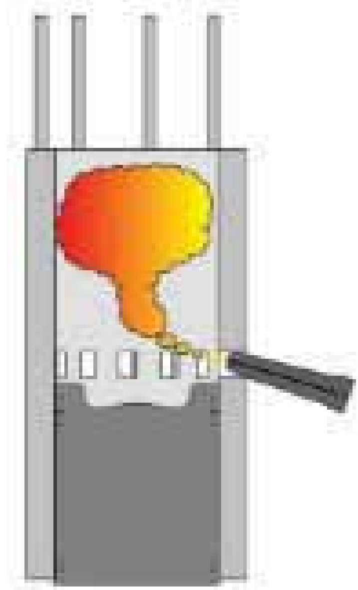


Figure 9

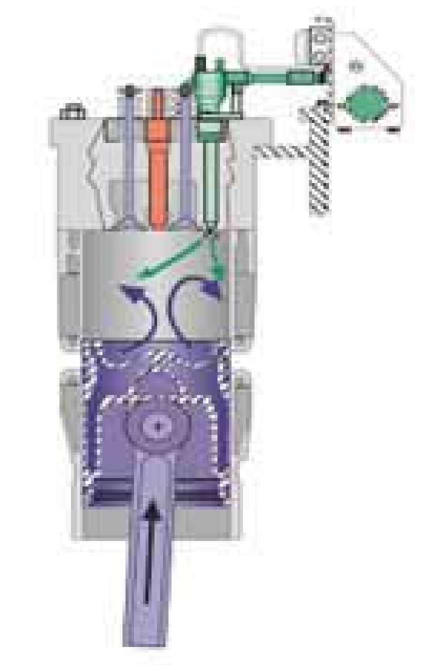


Figure 10

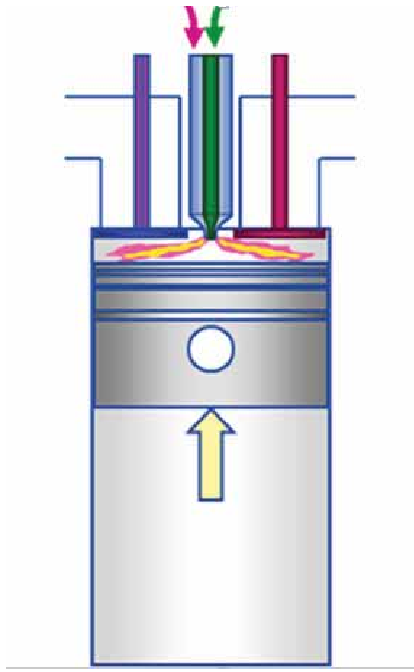


Figure 11

Low Pressure Direct Injecton - Gas is injected under low (100–200 psi) pressure directly into the cylinder during the compression stroke. Low pressure injection (figure 10) involves the admission of the natural gas into the combustion chamber when the piston is near the bottom of its travel. Pressure within the chamber is relatively low, esentially the same as manifold air pressure or airbox pressure.

High Pressure Direct Injection (HPDI) - (Figure 11) Gas injection entails forcing the gas into the already compressed air along with the pilot fuel near the top of the compression piston stroke. This requires that the gas be injected under high (3000+psig) pressure.

Gas Piping

Gas Pipe Routing

Figure 12 and 13 shows a general overhead view layout of the gas supply lines, in terms of the individual component placement within the chain. Though it is important that the order of components is maintained, their actual positioning and pipe routing should be designed to best fit the system environment. A-H is known as the gas train, and are the components required to be in the gas line.

Fig. 12: List of in-line gas supply components

A. Manual shut-off valve Fuel filter assembly
B. Vent valve
C. Regulator
D. Differential Pressure sensor
E. Port for regulator sensor line
F. Gas cutoff valve (GCOV)
G. Gas flow control valve (GFCV)
H. Gas headers (manifold)
I. Load blocks

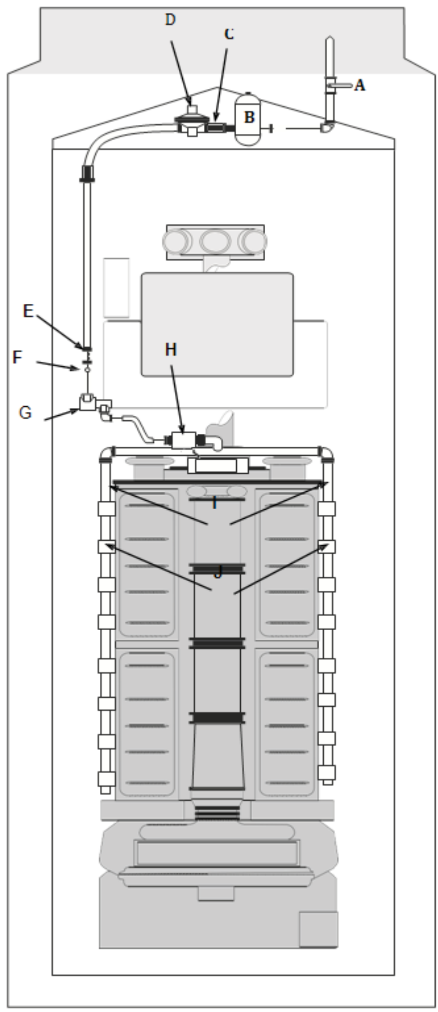


Figure 12

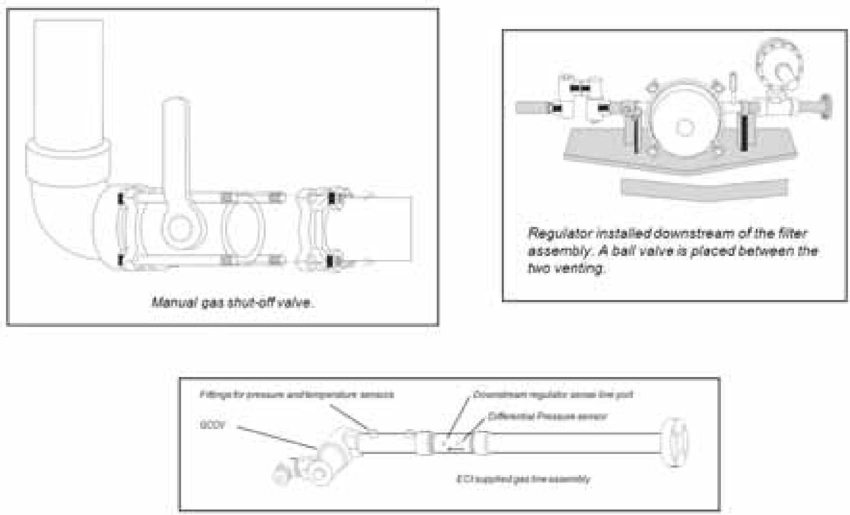
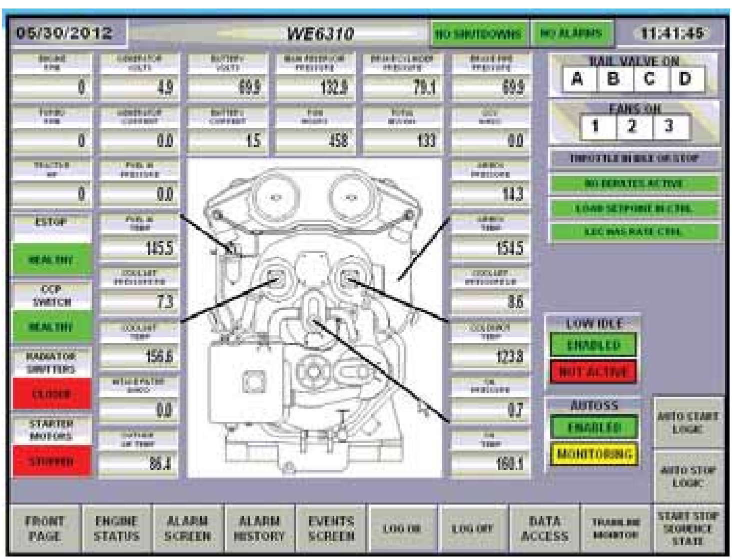


Figure 13



Engine Monitor

The engine monitoring system (HMI) is used to display all necessary elements of the engine's performance. With the addition of natural gas to the platform there will be more inputs required, which makes an HMI very helpful since it can be designed with multiple inputs.

Hardware

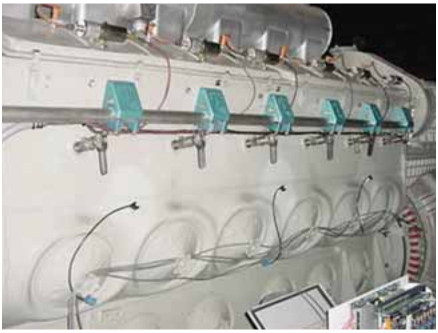
The following pictures show some of the hardware used in the installation of natural gas on locomotives. On the actual installations you will notice that additional hardware does not seem to be too intrusive.

Gas Valve

ECU

Dual Injector Installation

Diesel and Natural Gas



Spark ignited natural gas on an EMD engine

Gas manifold on a GE engine

Natural gas port injection on an EMD engine (test unit)

Dual fuel installation in an EMD locomotive

Feature	Diesel Fuel	Natural Gas Spark Ignited	Low Pressure Duel Fuel Direct Inj	Inlet Air/Port Dual Fuel Injection	High Pressure Direct Injection (HPDI)
Description	High pressure direct injection EUI or mechanical	100% Low pressure natural gas spark ignition	Low pressure EUI gas and diesel injectors	Gas injection – at air inlet ports with diesel pilot	High pressure gas with diesel pilot
Application	All locomotives	Switching, non-attainment areas	All locomotives	All locomotives	All locomotives
Diesel Bbck-up	n/a	No	Yes	Yes	No
Good/Bad	Known product, High fuel cost	Lower fuel cost, Reduced HP	True dual fuel, good gas substitution	Less cost to install, good gas substitution	High gas substitution, tier 4 potential technically no combustion knock
Estimated gas substitution	n/a	100%	60%-90%	50%-75%	90% +
Cost to install	n/a	$$$$	$$$	$$	$$$$$
Potential tier level	3-4	3	3	3	3-4

The consequences of Cleaner Fuel

Including natural gas as a fuel is challenging, but some of the advantages are quite nice:

✓ Cleaner lube oil
✓ Reduced engine wear
✓ Infers longer engine life
✓ Longer times between overhauls, better return on investment
✓ Lower environmental impact – goodwill with neighbors

Safety aspects of Natural Gas

Natural gas, when handled properly, poses no greater risk than more familiar petroleum fuels. Methane, the primary component of natural gas, is a very stable fuel. Its flammability limits (least and greatest volume percentage of gas in air that will result in an ignitable mixture) are quite narrow - between 5% and 15%. At 1350°F, its hot surface ignition temperature is 600° higher than that of gasoline: a striking match will ignite it, but the coal of a cigarette will not.

Natural gas presents the greatest safety risk when leaks occur in confined areas. Confinement of gas allows large, local, flammable or detonable vapor clouds to form, and increases the possibility of ignition. Once ignited, pressure will build in an enclosed area, speeding up flame travel to potentially explosive levels. This risk is easily eliminated by providing good ventilation.

Natural gas is actually nontoxic. It will not cause immediate physical damage or death upon inhalation. It is classified as a simple asphixiant, that is, it is no replacement for oxygen. A gas/air mixture containing greater than 40% gas by volume will not support life. Therefore, personnel responding to a leak in an enclosed area require self-contained breathing apparatus (SCBA) and an electronic methane level detector.

Conclusion:

Natural gas engine technology is expanding , growing, and developing as we speak. In this overview we were able to see some of the types of engines currently available. The choices vary by performance, cost to install, and cost to operate. These are significant challenges and will take careful study. The potential payback to the bottom line and benefit to the environment make this a very interesting prospect.

Report on the Committee on Diesel Electrical Maintenance

Monday, September 22, 2014 at 1:30 PM

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Tom Nudds

Manager-Training & Development
ZTR Control Systems
London, Ontario

Vice Chairman

Keith Mellin

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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 Siemens for hosting the Committee's meeting at their Sacramento, California Locomotive Shop in February 2014. The Committee toured their facilities and got a chance to see the latest Amtrak electric locomotives being built as well as enjoy Siemens' hospitality. Thank you Steve Mueting for arranging the meeting and use of the facilities.

We would also like to thank Keith Mellin for arranging our July 2014 meeting at Peaker Services in Brighton, Michigan and the tour of their facilities.

FRA Requirements for Headlights, Ditch Lights & Other Lighting

Prepared by:
Bob Reynolds, Sales Representative, Amglo Kemlite Laboratories, Inc.

The following subjects will be covered in this paper:

a. A Brief History of Headlights and Ditch lights
b. Requirements for Headlights and Ditch lights
c. Requirements for Step, Walkway, Number and Engine Area Lights
d. Requirements for Cab Lighting such as Reading Lights, Electrical Compartments
e. Requirements for Emergency Lighting
f. Troubleshooting and Maintenance

This paper is meant to provide a brief history of locomotive headlights leading up to the presently used sealed beam lamp, the Federal Railroad Administration (FRA) requirements and changes in lighting technology. Please refer to the current FRA rule 229.129 for more information.

History:

Early steam engines used a small firebox to create light for the headlight and number light. A large reflector focused the light down the track for the crew to see the track ahead. Not only did the fireman have to keep the main firebox burning, but he had to periodically fuel the headlight.

There was a period of time in the early 1900s when carbon pile lamps were used. The problem was the light output was too bright. There wasn't any way to dim the lamp, consequently causing passing trains to be blinded by the intense bright light. During rain storms the engine crews were blinded by their own light because it reflected back off the rain.

The modern steam locomotive had either a mechanically driven or steam driven generator that produced 32 volts. The generator powered a headlight that was a typical A19, 30 volt light bulb. A reflector was used to focus the light on the track.

Early diesel locomotives employed a similar light bulb and reflector. Although the battery and charging system operated at a nominal 72 to 75 volts, the same 30 volt steam engine bulb was used to be compatible. Later on diesel locomotives were built with a PAR56 sealed beam lamp. The new lamp also operated at 30 volts and consumed 200 watts. The 30 volt lamps required large resistors to drop the voltage down from 75 volts. The term PAR 56 stands for parabolic aluminized reflector with a diameter of 56 eights of an inch or 7 inches. It would have been better for these new lamps to operate at

75 volts, but I guess it was meant to be a replacement for systems using the 30 volt lamp. Most diesel locomotives that originally had 30 volt A19 lamps were converted to sealed beam lamps. Many 'A' and 'B' units that had A19 lamps for back up lighting were also converted to seal beam lamps.

The FRA created a rule in 1980 to use a standard sealed beam 30 volt lamp for headlights that has a minimum light output of 200,000 candela at the beam center. The amount of light output was used to replace vague, previous wording that the light output must be sufficient to see a man standing 800 feet in front of the locomotive. This 'spot' light output is very focused to mostly illuminate the center of the track. The center of the track is where the train crew needs to primarily see obstructions and track switches. In the 1970s there were a number of train derailments in mountainous territory due to rock slides or other debris on the track. It was determined that if locomotives had better lighting, train crews could see better around curves and take advanced action to stop before hitting obstructions. Thus the 'auxiliary light' rule was created by the FRA in 1997 to standardize their use. The term 'ditch light' is more commonly used to describe the two lights that are located on either side of the front of the locomotive.

The ditch lights were not meant to be dimmed. The ditch lights are turned on when the train is operating and are shut off temporarily when trains pass each other. This requirement created the 75 volt, 350 watt lamp eliminating dropping resistors. This simplified the application of the lamps and saved power. The FRA added a description of the 75 volt lamp in the 1997 rule. The rule stated that it must produce 200,000 candela or produce at least 3,000 candela at 7.5 degrees and at least 400 candela at an angle of 20 degrees from the centerline of the locomotive when the light is aimed parallel to the tracks.

Requirements for Headlights & Ditch lights

The FRA and Transport Canada each regulate the operation of railroads in their jurisdiction. The Canadian rules are generally the same as US rules for locomotive lighting.

The locomotive headlight is an important device that enables the safe operation of trains through public areas such as road crossings. The FRA considers the headlight to have conspicuity; that is for the train to be conspicuous to pedestrians, motorists, track workers and other trains. The headlight must provide sufficient light for train crews to operate their trains over various terrains.

In 2006 the FRA issued a technical clarification to headlight rule 229.129. A newer technology, developed in 2004 for locomotives, was available to extend the life of headlights and ditch lights. The technology is halogen lighting; the same proven type that automobiles changed to in the 1980s. Aircraft have been successfully using halogen landing lights for a long time. The FRA provided type acceptance for qualified halogen lamps. The halogen light output exceeds the 200,000 candela re-

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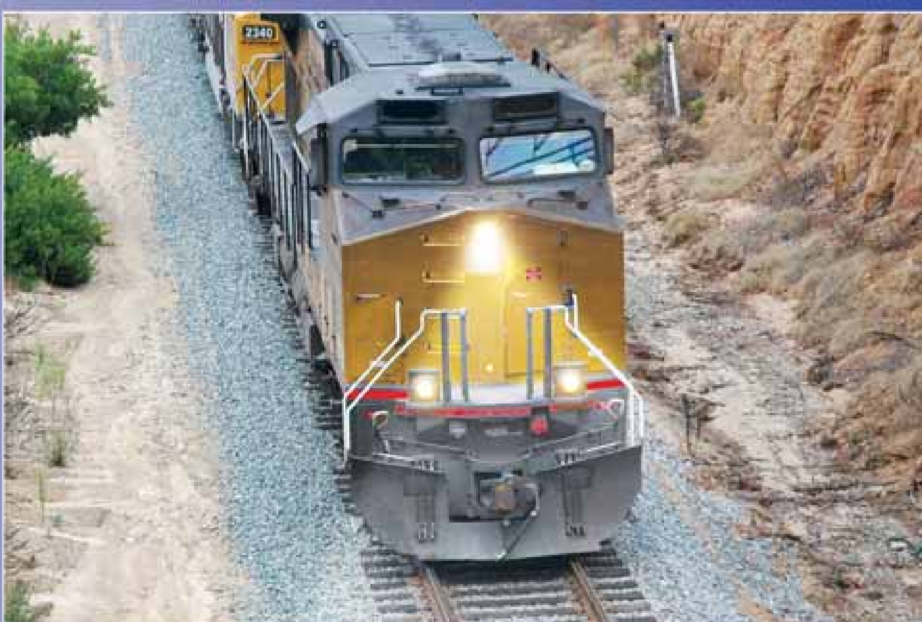

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quirement for the life of the lamp and, as a result, the FRA permits locomotives to operate with a burnt headlight beyond a calendar day inspection providing the remaining lamp is halogen.

Halogen lamps have the filament enclosed in a glass tube called halogen capsules or commonly ‘the burner’. An ordinary incandescent lamp has a ‘bare’ filament; it does not have a glass tube. Over time, when the lamp is powered, the filament on an incandescent lamp will ‘dissolve’. The dissolving filament coats the lens and reduces the light output. The filament also weakens and begins to sag. The effect of the sag is that the light beam is reflected slightly upward.

The halogen headlights and ditch lights are completely interchangeable with the simple incandescent.

The filament on a halogen lamp also dissolves over time. The halogen gases, under a certain pressure inside the burner cause the filament particles to be deposited back on the filament. This is what gives the halogen lamp an extended life compared to the simple incandescent lamp. The lens on the halogen lamps also stays clean as the filament is contained inside the glass tube. This results in no loss of light output for the life of the lamp. To summarize, a halogen lamp:

a. Has a longer rated service life – up to 4000 hours (depending on manufacturer) as compared to 500 hours for a simple incandescent lamp
b. Full 200,000 candela light output for the life of the lamp
c. Same rated power consumption (depending on manufacturer)

Class 1 railroads and many short line and transit railroads have switched to the halogen technology. Longer life means less overall work to change lamps, fewer lamps discarded and going into landfills, less ordering, handling and stocking. Many railroads have also switched from 30 volt headlights to 75 volt headlight to eliminate the power wasting dropping resistors. Another benefit is a standard lamp that can be used on both headlights and ditch lights.

Some railroads alternately flash the ditch lights on approach to a crossing to further draw the attention of the train to pedestrians and motorists. The flashing is triggered by either the horn or the bell.

Via Rail Canada has a third headlight on the front of their locomotives. The third headlight is a High Intensity Discharge (HID) lamp that has a very focused narrow beam. The beam provides more light farther down the track for the operating crew on passenger trains operating at 100 mph. There is no regulatory requirements for this type of lamp.

All railroads are concerned with saving fuel. One halogen lamp manufacturer has developed a 75 volt, 300 watt PAR 56 lamp. It consumes 50 watts less than the 350 watt lamp. The light output meets the required 200,000 candela and is FRA type accepted. The 50 watts per lamp can really add up to a lot of power saved. Power produced on the locomotive for lighting comes from an auxiliary generator which consumes fuel.

Requirements for Step, Walkway, Number and Engine Area Lights

The FRA has stated that there must be sufficient illumination for gauge lights, step lights, walkway lights, number lights, engine lighting and other lighting. Transport Canada made a requirement for the conductor's reading light when cabooses were eliminated in the late 1980s. The conductors reading light in Canada must have at least 220 lumens of light. This is accomplished by using two incandescent lamps or a single light emitting diode (LED). Halogen lamps are available to replace the typical A19/E27 lamps used for step lights, engine room lights and number lights. The benefit is much longer life and no loss of light output for the life of the lamp.

LED technology is fairly new to locomotives, but is now widely used for step lights and number lights. The benefit of LED lights is longer life and lower power consumption. The life of an LED is perceived to be in the order of 50,000 hours, but time will tell if this is true. There have been some quality issues such as domes falling off the lamps, premature failures of individual LEDs burning out or dimming. Some LED engine room lights fail due to the high heat in the summer months. In some cases the number lights were so bright, the numbers could not be read. The technology is new for locomotives. It is suggested to use high quality LED lamps from a reliable long time manufacturer of lighting products.

There are a few LED headlights in use on locomotives. The problem with all LEDs is they must operate from an electrically noisy electrical system. Locomotives have a large number of inductive devices that produce voltage spikes that can damage electronic devices. The LED lights have electronics that drop the voltage from 75 volts to 2 volts per individual LED. The circuit is a switching type that must be immune to noise 'spikes' and at the same time not create electromagnetic or radio frequency interference. There was a case of an LED number light that interfered with the voice radio communications on a locomotive.

If individual LEDs are burnt or weak on a LED headlight it will have a reduced output and will not comply with the FRA 200,000 candela output. As stated earlier, the headlight is an important safety device and must meet the requirements at all times. Here are other issues on LED headlights that must be addressed:

a. The headlight indicators on the locomotive may not be able to show if an LED headlight is operating or not.

b. The lens of the LED lamp will not be able to melt the ice and snow in the winter. A heater will be required with a thermostat. The heater or thermostat could fail, and the train crew will not know if the headlight is coated with ice and snow. The added heating element, when switched on, will consume an additional amount of power and fuel.

c. a LED headlight was noted to have a light flicker when the locomotive was idling.

d. On PAR lamps the glass lens is bonded to the reflector whereas the electronics in LED lamps could be contaminated by condensation or other contaminants found in the railroad environment.

e. A Halogen lamp damaged from mishaps or incidents can be inexpensively changed. A LED headlight is more costly to change.

f. Some LED lamps are very heavy and tend to unscrew and fall out of sockets due to locomotive vibration.

Requirements for Cab Lighting such as Gauge lights, Reading Lights, Electrical Compartments

Just as for step lights, the FRA has stated that there must be sufficient illumination for gauge lights, cab reading lights, electrical compartments and toilet compartments. The same lamp used on the number and steps lights is typically used for electrical compartments and passageways. The ceiling lights, reading lights and toilet compartment lights are typically 75 volt, 30 watt lamps. These incandescent lamps have a rated life of 1000 hours. There are LED replacements that consume just a few watts of power and give much longer life.

Requirements for Emergency Lighting

The FRA created a rule (238.115) to have emergency lighting whenever an emergency brake application occurs. A red light is contained in the center cab light fixture and at passageways. The red light provides the minimum amount of light to permit cab egress. The minimum amount of light does not disturb the night vision of the crew when the emergency brake application occurs.

The FRA requirement covers all new locomotives built after August 2006. It refers to details in the AAR standard S-580 for locomotive crashworthiness.

Troubleshooting and Maintenance

There is not a lot of work for maintaining locomotive lighting. Some of the problems encountered with lighting are:

a. Electrical grounds in step light sockets.
b. Tripping headlight breakers could be due to a headlight switch left ON in a trail locomotive in a multiple unit consist.
c. A weak headlight – likely a 75 volt lamp was installed in a 30 volt fixture.
d. A headlight that burns out as soon as turned on – likely a 30 volt lamp installed in a 75 volt fixture.

For more information on troubleshooting and other technical information, visit your lamp manufacturer's website.

Acknowledgement

I would like to thank the LMOA Electrical Committee for their comments and suggestions on the content of this paper.

Investigating Distributed Power Failures

Prepared by:
Jason Fox, Union Pacific Railroad

Abstract

The use of Distributed Power (DP) is increasing. Comm Loss Idle Down events are how the system safely responds to unconfirmed Brake Pipe activity. Undesired Emergencies (UDE) also occur on Distributed Power trains. The DP system is blamed but not usually the source of the UDEs. Testing helps identify what messages are available in the Distributed Power system log that can help the crews pinpoint the real source of the UDE. Clarifying messages, improving DP logs, and standardized training and job aides are keys to reducing delays on Distributed Power trains.

Distributed Power (DP) is a system that allows train crews the ability to control a locomotive consist placed in a remote position in the train. This can be either at some point in the middle of the train or at the end. While Union Pacific's Distributed Power system allows for up to 4 remote locomotive consists, current DP trains will be configured with either one or two remote locomotive consists.

Distributed Power uses two paths for the lead locomotive to communicate with the remote controlling locomotives. The first is a 450MHz radio link. There are redundant radios that will communicate all of the throttle and braking commands from the lead locomotive to the remote locomotive(s). The second path is an air link via the Brake Pipe. This is a safety link and must be established before DP is operational. This link is what the DP system uses to verify that the braking commands are being executed and to allow the DP system to communicate to the remote locomotives while in a radio communication loss situation.

A radio communication loss is a relatively common occurrence and the Distributed Power system has been designed to operate safely in a radio communication loss. The most common cause of a radio communication loss is environmental interference. Tunnels, mountains, canyons, and trees can prevent the transmitted radio signal from being received by the DP radio. Other causes can be failed radios, filters, antennae or other hardware.

When the train is in a radio communication loss event, the remote locomotive(s) will continue to perform the command that was requested in the last received message for up to 90 minutes. For example, if after the engineer requests Throttle 4 the train enters

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Figure 1: Yellow COMM indicator on DP Operation Screen

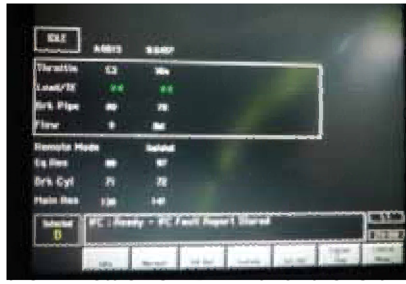


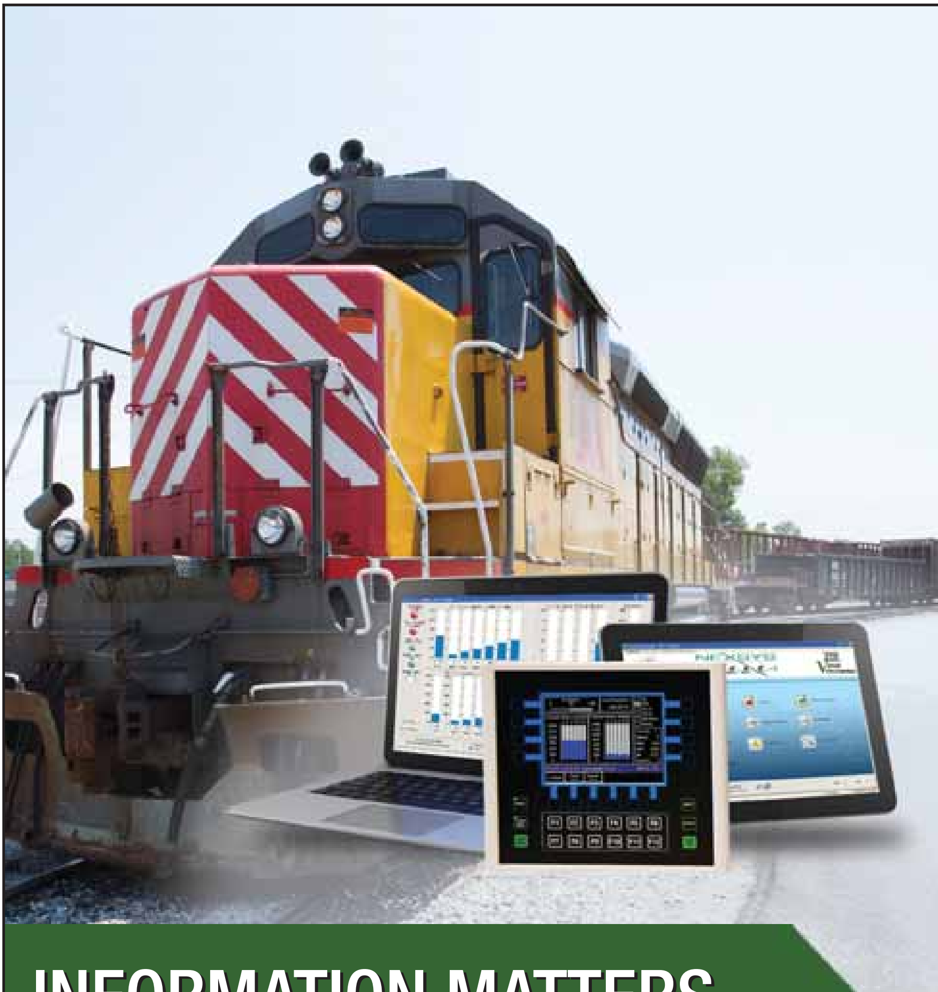
Figure 2: DP Operation Screen with Throttle at Idle, Flow at Out, and Remote Mode at Isolated

a radio communication loss, a Yellow COMM light will illuminate on the DP operation screen (Figure 1) and the remote locomotives will remain in Throttle 4. If, while in radio communication loss, the engineer requests Throttle 6 the remote will remain in Throttle 4. The DP Operation Screen on the crew display will continue to display the last status update that is received; in this case Throttle 4.

When the Lead locomotive determines that a status update has been missed, it will begin to repeat that update request at a faster rate, attempting to reestablish communication. Once radio communication is reestablished the remote locomotive will then receive the command to change to Throttle 6 and the remote will execute that command. The DP Operation Screen will update the status as appropriate.

The air link is used as a mechanism for the engineer, if needed, to stop the remote locomotive(s) from loading while in a communication loss. If, while in a radio communication loss, the engineer makes an 8lb or greater reduction in the Brake Pipe the remote locomotive(s) will cut its brake valve valve has been cut out until radio communication has been restored. For this reason it is important that the crew understand this function of the DP system and pay close attention to brake handle movements when in radio communication loss.

The crew also needs to understand the procedure to restore remote DP system to NORMAL and cut in the brake valve. From the Control Menu, the operator must select Normal and then Execute the command. This will change the remote mode from Isolate to Normal. The crew can now control the throttle of the remote from the lead. However, the brake valve is still not cut in. The remote must see a three psi rise in the brake pipe for the brake valve to cut in. Because temperature and train length can have a significant impact on the ability of that three psi rise to propagate down the brake pipe, the best way to ensure that the brake valve cuts in is to make a full service application and then release. The brake value should cut in within 3 minutes. This process will be referred to as NEAR for the re-



mainder of this paper: Normalize, Execute, Application, and Release.

Need for testing

As of the beginning of 2014, Union Pacific has a fleet of over 3400 DP equipped locomotives. Because DP allows better handling of longer trains, the number of DP trains and DP equipped locomotives is growing. All new locomotives are being equipped with DP and Union Pacific is exploring opportunities where DP can be retrofitted to existing locomotives. Operating Practices is continually exploring opportunities to reconfigure a conventional train into a DP train in order to make it longer and improve train handling.

As DP trains are added to the railroad, the opportunities to familiarize crews with Distributed Power messages and proper defect reporting increases. The number of reported Distributed Power failures is on the rise. Crews report that "the remote put my train into emergency" or "my remote will not stop idling down". Mechanical investigations result in No Defect Found reports or technicians changing out good components. This is costly as it ties up valuable diesel shop time and forces the material department to keep extra inventory on hand.

Crews become confused and frustrated when they experience undesired emergency applications and loss of remote loading. Improper troubleshooting and handling of these events can cause train stalls and DP trains are unnecessarily conventionalized. This will lead to recrews and cause train delays across the entire system. It is no wonder that some railroad personnel have reduced confidence in the Distributed Power system.

The fact is that very few conditions result in a remote locomotive being the source of an emergency application. Conditions where the remote idles down are known and can be prevented or recovered by crews that are educated on how Distributed Power is designed to operate.

Crews are not the only railroad personnel that need to be educated. Mechanical forces and train dispatchers must understand how Distributed Power is designed to safely handle communication loss conditions. One senior member of the dispatching team incorrectly reported that when a communication loss occurs the remote puts the train into emergency. This paper will discuss what conditions will cause DP to request an emergency.

This paper is an attempt at documenting behaviors of the DP system. Some common DP behaviors will be explained along with the messages that the DP system gives the crew to help them determine why the system responded as it did. This paper will help the reader understand that DP operates in a safe and reliable manner, even in a communication loss condition, and how to recover full functionality of a train when Distributed Power determines it must operated in a reduced mode (i.e. idle down). Additionally, some recommendations for improvement to the Distributed Power system have been outlined in this paper.

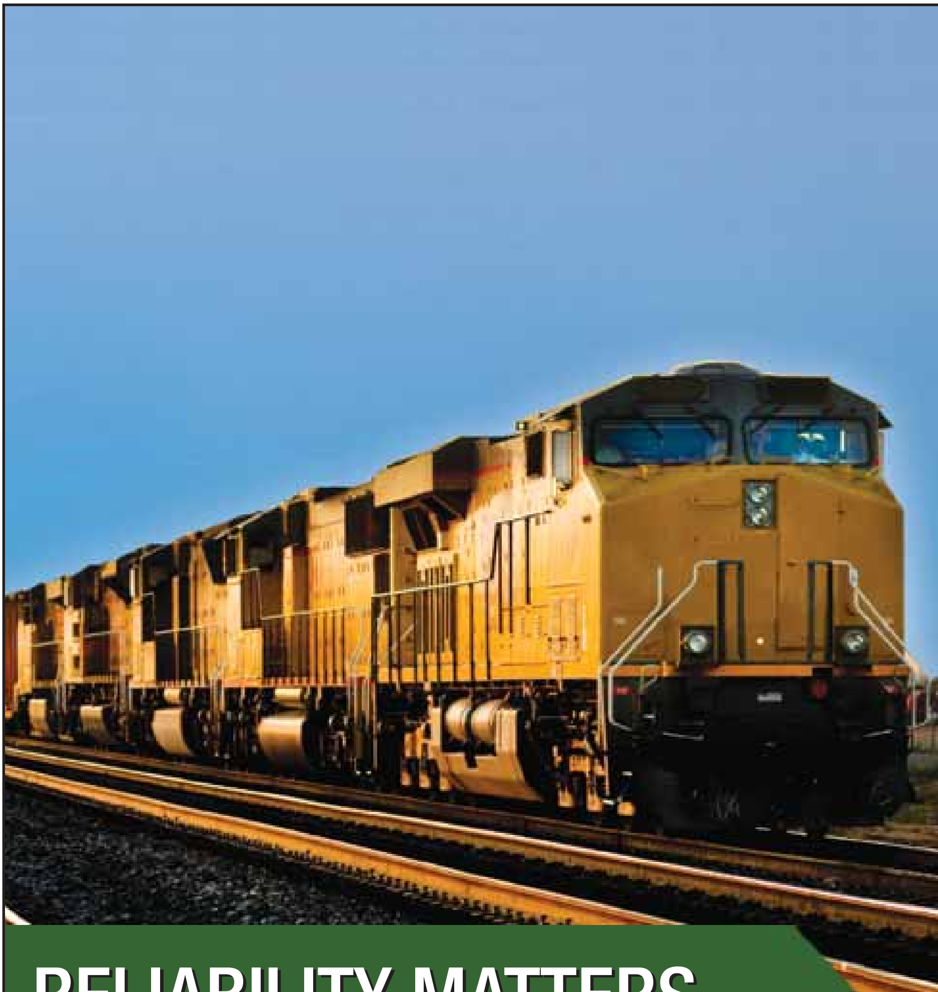


Figure 3: Test train configuration (Graphics)

Overview of the Test

Members of the Union Pacific Mechanical, Transportation, and Operating Practices departments recognized the need to improve the understanding of the Distributed Power system. With the help of local Manager of Operating Practices, a 115 car test train was set up in South Morrill, NE.

UP6815 was added to the head end of the train as the Lead locomotive and UP6437 was added to the rear end of the train as the Remote locomotive. This made a 1x0x1 test train of approximately 6,400 feet. With a test train built, the team could then place the train in various normal and abnormal operating conditions so that the DP system response could be documented.

It is important to note that over the years DP has been integrated with many different locomotive models on many different railroads. The Union Pacific alone has nine different versions (called baselines) of Distributed Power software. While the DP system manufacturer has made every attempt to keep the messages standard, slight differences in the displays and messages available to the crew have been unavoidable. In the age of interoperability, it is important to remember that while messages may be slightly different, the general theory of operation is the same.

It is important to note that this test is not intended to be a comprehensive study of Distributed Power Communication Loss events. It is intended to capture the messages that the crews see during some of the most common Communication Loss and Undesired Emergency events.

Idle Down Conditions

The first behavior that we wanted to test was the Comm Loss Idle Down (CLID) feature. The conditions that result in a CLID are if any of the following events occur during a Communication Loss

- Operator makes a reduction in the brake pipe
- The remote Brake Valve is cut out in a sustained communication loss
- The remote detects a Brake Pipe Rise
- The remote detects an Unexpected Flow

In short, an easy way to think about CLID is that any time the Remote detects a change in the brake pipe it will ‘ask’ the Lead locomotive via the radio link if a Brake Pipe change was requested. If the Remote does not get a response then it will Idle down, Isolate itself and cutout the Brake Valve.

In order to simulate a Communication loss, the DP Radio breaker was opened. To restore communication, the DP Radio breaker was closed.

Comm Loss Idle Down, basic

Recall that the basic Comm Loss Idle Down occurs when an operator makes a reduction in the brake pipe during a communication loss. During testing of this condition it was noted that during the communication loss, the Yellow COMM icon illuminates and the DP Operations Screen remained frozen with the last status update the Lead received from the remote. (Figure 1) When communication is restored, the Remote status is updated and the screen shows the current state of the remote. The remote will notch up or down in 3 second intervals to the current commanded state.

If a Comm Loss Idle Down event has occurred, the crew can recognize it by reviewing the following fields on the remote column of the Distributed Power Operation screen once communication has been restored. Flow will say OUT. Remote Mode will say ISOLATED. Throttle will say IDLE. (Figure 2)

There are messages stored in the System Log and Event Log what will confirm that a Comm Loss Idle Down event has occurred. The System Log will show the message “B-Comm Loss Idle Down”. (Figure 4) The Event Log will show three messages: “Comm Loss”, “Radio Fail”, “Comm Good”.

If the approved railroad operating rules has forced the crew to stop the train during a DP communication loss, then crew members or mechanical forces can confirm that a Comm Loss is active on the remote by the [COMM LOSS] message that is displayed on the DP screen. (Figure 5)

Figure 4: System Log showing "B-Comm Loss Idle Down"

Figure 5: Remote DP screen showing Comm Loss

Once communications has been restored the crew should perform the NEAR process to get full control of the remote locomotive. Recall that NEAR is the Normalize, Execute, Application, and Release.

Brake Valve Cutout in a Sustained Communication Loss

A safety feature of Distributed Power is that anytime a train has experienced a Sustained Comm Loss (approximately 45 secs or greater) and the Brake Valve is Cut out on the remote, the remote will declare a Comm Loss Idle Down. The thought here is that when the brake valve is cutout, the system does not have full control of the brake pipe, the safest thing to do is to idle down the remote in this situation.

There are two main reasons that a crew will be running with the Brake Valve Cutout on the remote unit. First, the crew has experienced a Comm Loss Idle Down where the remote is set to Idle, Isolated and the Brake Valve is cutout. Once communication is restored, some crews will only perform half of the recovery process. They will Normalize and Execute but forget to make an Application and Release. The Normalize and Execute will change the Remote mode from Isolated to Normal and allow the remote throttle to be commanded by the lead unit. The Brake Valve is not cut in at this point. If they remembered to make the Application and Release, sometimes the application will not be deep enough for the remote to see the 3 psi Brake Pipe rise during the release because of leaks or cold weather. If the crew does not successfully make the Application and Release they will run with the Brake Valve Cutout. (Figure 6)

Figure 6: Brake Valve cutout after Normalizing

Second, the DP system can be configured to run with the Brake Valve Cutout. There is a Remote Mode called BV OUT. (Figure 7) If this is selected, the Brake Valve on the remote is cut out and will stay that way until the crew performs the NEAR procedure. This practice is a bad habit carried over from the early days of Distributed Power. Crews figured out that they were able to defeat some bugs or software restrictions built in to the DP system by running with the brake valve cutout. Word got around in the crew rooms. These bugs have been fixed and software restrictions have been removed but old habits die hard.

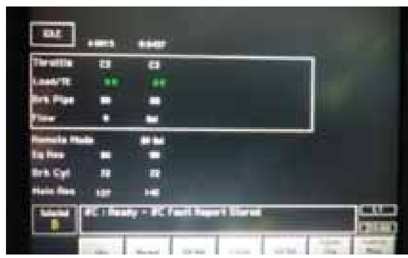


Figure 7: DP set up in BV Out mode

This scenario is typically reported as the crew is experiencing the remote dropping load everytime they get a comm loss. Crews can tell that they are running with the Brake Valve cutout because the word OUT will appear in the Flow line of the Remote unit in the DP Operating Screen. If crews or mechanical forces determine that the brake valve is still cutout the crew should repeat the NEAR procedure to recover the system.

Brake Pipe Rise

Just like making a reduction in the Brake Pipe during a Comm Loss will trigger a CLID, a rise in the Brake Pipe during a Comm Loss will also trigger a CLID. This is another safety feature of the Distributed Power system. Recall that there is a radio link and an air link in the DP system. In this scenario, the DP system detects a change in the air system. Because the system cannot confirm via the radio link that the release was actually commanded by the operator, the system makes the safe assumption that it is not a commanded release and idles down the remote using a CLID.

Once communication is restored, the crew should be able recognize CLID down by observing the same fields and messages on the Distributed Power Operating Screens as above. (Figure 2) To recover the CLID the crew should perform the NEAR procedure.

Observant crews will realize that they did not make a reduction in the brake pipe. They may report the CLID as an issue. A review of the Distributed Power logs on the remote will show a Brake Pipe Rise message. This is normal behavior of the DP system. It is noted that the Brake Pipe Rise message does not show up on the lead locomotive logs. This makes it very difficult for the crew to know why the CLID happened.

Unexpected Flow

Another condition that will result in a CLID is unexpected flow while in a communication loss. To simulate unexpected flow, artificial leaks were installed 20 cars from the lead locomotive and 20 cars from the remote locomotive. The artificial leaks have plugs with various sized orifices that can be swapped out. This flexibility allows the test team to adjust the orifice size to increase or decrease the flow.

Different iterations of this test were simulating trains with leaks entering a comm loss and trains developing leaks once the comm loss is entered. The team would induce a leak and once stabilized initiate a DP communication loss by removing power to the DP radio. Once the comm loss is established, the team would change the orifice size thus change the flow.

This test was executed using many different flows. The test was inconclusive. The test team could never successfully initiate a CLID. The test procedure should be reviewed with the Distributed Power system OEM and executed again at a later date.

One observation of note is that when the team was changing the flows (by swapping the size of the orifice in the leak) the Flow value would change to yellow. The DP Alarm log should show the message "B-Unexpected Flow". A Yellow flow value is an indication of Unexpected Flow.

Comm Loss Idle Down Timeout

We briefly mentioned above that during a communication loss the remote locomotive will continue to hold the last received request for up to 90 minutes. After 90 minutes, the remote DP system declares a major communication loss and will Comm Loss Idle Down the remote. This is an unusual condition and likely only happens when both DP radios have failed.

In any comm loss, the DP operating screen will only show the last status that the remote confirmed. Experienced crews will be able to feel in their train that something has happened to the remote. To confirm that the DP system has entered a Comm Loss Idle Down Timeout, the crew can navigate to the system log and see a message “A – Major Comm Loss”. (Figure 8) If the crew or mechanical forces are on the remote, they will see the messages “Major Comm Loss” and “Comm Loss Idle Down” in the system log.

Crews should continue pulling the train so long as they are safely following approved railroad operating rules. If stopping is required, crews should check that the DP radio circuit breakers have not opened. If the breakers on both the lead and remote locomotives are closed then Mechanical forces will be required to address the issue.

Figure 8: 90 minute Comm Loss Timeout

Figure 9: Low Brake Pipe Message

Emergency Conditions

At times a Distributed Power train will go into an undesired emergency. Crews and dispatchers have a tendency to think that the Distributed Power system has caused the emergency. This section will explore the test cases where both the Distributed Power system initiates emergencies and the Distributed Power system responds to emergencies from other sources.

A functionality of Distributed Power emergency application that is important to be aware of is that if one controlling locomotive initiates or detects an emergency, it will broadcast that emergency request to the other controlling locomotives via the radio link. The radio signal can reach the other controlling locomotives in the train before the emergency can propagate the entire length of the brake pipe. When the radio message is received, the other controlling locomotives will also initiate an emergency. This will help apply the brakes in all of the cars faster than if the emergency was propagating from one direction. This is very valuable in longs trains, especially those with multiple remotes. Sometimes this broadcast will be mistaken for Distributed Power causing the emergency.

Low Brake Pipe

The Distributed Power system will initiate an Emergency application if it detects the Brake Pipe to be less than 45 psi. Low Brake Pipe conditions can cause loss of Emergency capability. The Distributed Power system is protecting against further Brake Pipe reductions by initiating an Emergency.

When the Distributed Power Emergency is initiated, a crew should look in the System Log so that they can find out why the emergency occurred. When a “B-Low BP – Train” (Figure 9) message appears on the System Log, crews should look for defects in the brake pipe. When a “B-Low BP – Operator” message appears in the System Log, crews should check the Air Brake status of the remote locomotive.

EMV Miscompare

When Distributed Power initiates an emergency it will energize the Emergency Mag Valve (EMV). The Distributed Power system is continuously monitoring the EMV. If the monitored state does not match the commanded state DP will declare an EMV Miscompare and request emergency from all linked locomotives.

Time constraints did not allow the team to execute any of these test cases. The team decided that this condition could be tested with two locomotives linked to each other at a service track or in a yard. The train was not needed. To maximize the time with the test train the EMV Miscompare tests were not executed.

TLEM

Trainline emergencies are the most confusing Undesired Emergency application to investigate on the Distributed Power system. The source is usually a brake pipe separation in the train although the crew often thinks the Distributed Power system caused the emergency. The messages can be misleading but there is enough information in the messages to help the crew determine where to look for the brake pipe separation.

The test team made use of the artificial leaks to simulate a brake pipe separation. As mentioned above, the two artificial leaks were installed; one 20 cars from the lead and one 20 cars from the remote (Figure 3). This allowed the team to simulate brake pipe separations in different parts of the train.

When the train goes into emergency, the engineer’s screen displays a message DISTRIBUTED POWER EMERGENCY. Crews tend to go to the DP System log to see what kinds of messages are displayed. If the brake pipe separation has occurred near the front of the train, the crew may not see a message in the System Log. If the brake pipe separation has occurred near the rear of the train, the crew will see the message “A-Emergency From Remote ####”. This message makes the crew think there is an issue with the remote locomotive. Crews must look at other logs before jumping to this conclusion.

If a trainline emergency has occurred, the Distributed Power Alarm Log will give the crew a clue as to where the brake pipe separation may be. When the artificial leak installed 20 cars from the lead was opened, the Alarm Log showed the message “A-Brake Pipe Emergency” (Message 5 in Figure 10). When the artificial leak

Figure 10: Active and Inactive Brake Pipe Emergency messages

Figure 11: Emergencies initiated from cab

installed 20 cars from the remote was opened, the Alarm Log showed the message "B-Brake Pipe Emergency" (Message 8 in Figure 10). The Distributed Power system is able to display which locomotive detected the brake pipe separation first.

If the "A-Brake Pipe Emergency" message is active (highlighted in red as lines 1-3 in Figure 10), then crews should be looking for brake pipe separations in and around the cars closer to the lead locomotive. If the "B-Brake Pipe Emergency" message is active, then crews should be looking for brake pipe separations in and around the cars closer to the rear locomotive. Once the brake pipe separation is found and repaired the crew should be able to recover the emergency and continue as a Distributed Power train.

Crew Initiated

The Distributed Power system can detect that an emergency has been initiated from the controls in the cab of the lead or remote locomotive. If the engineer moves the handle to Emergency on the lead locomotive, the DP system will detect that and give an "A-Operator Emergency" in the system log. Crews should be able to follow the approved railroad operating rules to recover the emergency. This is Message 3 in Figure 11.

If the emergency has been initiated from the controls in the remote locomotive the system log will give two messages: "A-Emerg From Remote ####" and "B-Crew Emergency" (Message 1 & 2 in Figure 11). Crews will likely have to investigate why the handles on the remote have been moved and possibly reconfigure the air brakes on the remote before they can recover the emergency. They should always keep safety in mind when boarding the remote locomotive and beware of trespassers.

Throttle Lockout

When investigating Undesired Emergency applications crews or managers will board the remote locomotive and view the System logs on the Distributed Power system. They will see a message that says "Throttle Lockout" and think that there is a problem with the Distributed Power system that is causing the Throttle Lockout condition. This is actually a normal DP function that crews and managers should be aware of.

The Distributed Power system is continuously comparing the radio link commands to the air link responses. When the remote locomotive receives a radio command to release the brakes or exits from Setout mode, it checks for a Brake Pipe rise on the air link. If the remote locomotive fails to detect the expected BP pressure rise then, as a safety measure, it will inhibit throttle control and display the "Throttle Lockout" message. Crews and manager should understand that this means there is likely a Brake Pipe separation and not an issue with the DP. Crews will have to walk the train to find the separation. There is no need to relink or cycle breakers or conventionalize the train when this message is active.

Unlinking Conditions

At times crews will report that "my DP remote has unlinked itself". Those familiar with the Distributed Power system know that it is not normal for DP to unlink itself as a result of a Communication Loss or Emergency application. It is easy to dismiss these reports as inaccurate. The reality is that there are some system failures that will result in an unlink.

Distributed Power computer resets will result in an emergency application and cause DP to unlink. Examples of things can cause DP computer resets are a failure in the DP computer power supply, loss of power to the DP computer or even electro-magnetic interference (EMI). During this test, computer resets were simulated by opening the DP2 breaker to remove power to the Distributed Power computer.

Loss of power to the DP computer is an interesting example. Breakers could be tripping or loose connections could cause the power loss. Crews could unwittingly cause the power loss and unlink. Imagine this scenario. A failed air hose has resulted in a Brake Pipe Emergency. The "Distributed Power Emergency" message that is displayed by the computer screen has the crew thinking that the DP system is the source of the emergency. Since this failed air hose has not been repaired, they cannot recover the emergency. As a last ditch effort, the crew cycles the DP & EAB circuit breakers. This loss of power to the DP computer also causes DP to unlink. Now, in the crew's mind, the DP system went into emergency and then unlinked itself. How frustrating this must be for the crew.

Secondly, loss of serial communication to the DP computer will result in an unlink. This happens when there is a defect in a cable between the DP computer and the locomotive control system or when there is a defect on the serial cards on the DP system or locomotive control system. During this test, loss of serial communication to the DP computer was simulated by disconnecting the serial cable from the DP system to the IFC at the DP system.

The test team did explore these failures during our testing in South Morrill, NE. There are differences in behaviors between the system behaviors when these failures happen at the lead versus the remote.

Figure 12: Computer Resets on the Lead

Computer Resets on the Lead

Computer Resets on the Lead locomotive are relatively easy to detect. The train goes into emergency and the crew screen says DISTRIBUTED POWER COMMS LOSS EMERGENCY (Figure 12). When this happens the DP system will need to be relinked at the lead only. When this message is displayed, crews should make sure that the DP circuit breaker is closed. If it is open, they should close the breaker and relink. If it is closed and the message does not clear then mechanical forces will need to investigate the failure in the DP system.

Computer Resets on the Remote

Computer resets on the remote are a little more difficult to recognize. The remote locomotive loses its link and goes into Conventional Mode. On the lead locomotive, the yellow Comm Loss indicator is illuminated on the Distributed Power Operation screen and the Distributed Power Emergency message is displayed on the crew screen. There are no messages in the DP system log but the DP Alarm log shows “A-Brake Pipe Emergency” and “A-PC”.

When crews see the “A-Brake Pipe Emergency” message they should make sure that there is not a train line emergency. If there is also an illuminated COMM icon and they do not find an issue in the train then they should go to the remote and make sure the remote is still linked. If the crew finds that the remote has been conventionalized they should ensure the DP breaker is closed and relink the remote. Note that in this scenario, the DP session will have to be ended on the lead unit and relinked to successfully start a new Distributed Power session.

Loss of Serial Communication on the Lead

When the Distributed Power computer loses its serial communication to the locomotive control system on the lead locomotive, the DP system will unlink itself and the train goes into Penalty. Crews can recognize this event because they will get a DISTRIBUTED POWER PENALTY message on the crew screen. If the DP Penalty occurs the crew should navigate to the DP System Log and look for the “A-DP-ILC Comm Timeout” message. Additionally, the DP Alarm Log shows the following messages: “A-PC”, “B-Penalty”, “B-PC”. (Figure 13)

If the crew gets the “A-DP-ILC Comm Timeout” they can cycle the DP breaker to see if the serial connection can be reestablished and clear the penalty. If they cannot get the penalty to clear then they will likely have to switch lead locomotives to continue DP operations or conventionalize the train. Mechanical forces will need to

Figure 13: Loss of serial communication on lead

Figure 14: Loss of serial communication on the Remote

troubleshoot why the serial connection was lost.

Loss of Serial Communication on the Remote

When the Distributed Power computer loses its serial communication to the locomotive control system, the DP system on the remote locomotive will revert to Conventional Mode. On the lead locomotive, the Load/TE line on the Distributed Power Operation screen will show dashes. (Figure 14) We noted that during testing the train did not go into Penalty if the remote locomotive has a loss of serial communication.

Crews should look at the system log. If they see a "B-DP-ILC Communication Timeout" message then they should expect that the remote has some issue with the serial communication between the DP system and the locomotive control system. They can get on the remote and cycle the DP breaker to see if they can get the serial connection reestablished. If they cannot successfully relink, they will need to link to another locomotive in the remote consist or conventionalize the train. Mechanical forces will need to troubleshoot why the serial connection was lost.

Recommendation for Improvement

Clarify Messages

Emergency applications while operating in Distributed Power can be very misleading. Some Electronic Airbrake systems will display a crew message "Distributed Power Emergency" (Figure 15) when an emergency application occurs. This message is displayed even when the DP system and remote locomotive is not the source of the emergency. Other Electronic Airbrake systems display the crew message "Trainline Emergency" in these same scenarios.

This message should be standardized to always read "Trainline Emergency". (Figure 16) More often than not a brake pipe separation or dynamiters are the cause of the emergency application. The "Distributed Power Emergency" message causes these events to be improperly reported and sends crews and mechanical forces down the wrong path for troubleshoot-

Figure 15: Emergency while in DP

Figure 16: Emergency while conventional

ing. A simple "Trainline Emergency" message along with the messages in the DP alarm log described above should be sufficient information for crews and mechanical forces to diagnose the problem.

Another confusing message in the DP system log is "Emergency from Remote XXXX". When a DP system detects an Emergency application, as a safety precaution, an emergency request is broadcast to the other locomotives on the train via the radio link. The theory is that the DP system can sense an emergency and request an application via radio faster than the emergency application can propagate down the brake pipe on a long train. This will result in a faster emergency application from two directions.

This behavior is desired but the message is causing confusion where crews are interpreting the message as the remote locomotive being the source of the emergency. This message should be suppressed from view of the crews. This message can still be recorded in the DP log files so that engineering personnel can investigate events. Again, a simple "Trainline Emergency" message along with the messages in the DP alarm log described above should be sufficient information for crews and mechanical forces to diagnose the problem.

Thirdly, there are some events that happen while in communication loss that will cause the remote to idle down. These events/alarms are not sent to the lead log files. An example of this is Unexpected Flow on the remote during a communication loss. This information may be helpful in diagnosing the cause of the idle down. This alarm is only visible on the remote log. If this alarm were sent up to the lead log after communication has been restored the crew would then be prompted to check for leaks in the train after multiple occurrence of this alarm. Without this information, the crew may think that the remote is idling down for no reason and delay recognition of the issue.

Eliminate Communication Loss – Expensive Option

The first reaction to this paper may be to begin the effort to eliminate all radio communication loss. This is a very expensive option. DP radio repeaters can be placed at various locations of undesired radio communication loss. There is a cost to the equipment and maintenance. A study must be performed to determine if the cost of the repeater system reduces enough delays to make it a wise investment.

It may even be impossible in some locations. Heavily treed areas and flat surfaces (cliffs & buildings) prove to be very difficult areas to overcome radio communication losses. Areas with heavy railroad traffic have a risk that more than one DP train will be operating on the same channel. The DP system is designed so that a locomotive will not perform the action requested by another train but radio message collisions may be unavoidable.

Engineering studies would need to be performed to determine if other communication technology would prove to be a better option than the current 450 MHz. If an alternate technology is deemed better, then a railroad would need to manage the cutover to this alternate technology with compatibility of the legacy technology in mind so as not to disrupt the operation of the railroad and interoperability with other North American railroads. UP's 3,500 locomotives need to be interoperable with 17,000 locomotives across the railroad industry.

Do Not Dismiss Crew Reports

One of the worse things that could be done is to completely discount the crew reports. Railroad managers should listen to the crews. These men and women see this equipment every day. The mangers must understand the system so that they can ask the appropriate questions to determine if training is required or further investigation.

One case study illustrates this perfectly. Crews were reporting that DP systems were unlinking and causing trains to go into emergency. For a time this was dismissed as improper reporting until mechanical forces saw this behavior first hand. After further investigation, it was noticed that when the HVAC system was powered on the DP system would unlink. Electromagnetic Interference (EMI) from power spikes during HVAC startup were causing the DP computer to reset and thereby unlinking the DP system. A modification program was initiated to eliminate the EMI. Reports of unlinking have since decreased.

Improved and Remote DP Logs

For engineering personnel to fully investigate and determine the cause of an event, along with locomotive fault logs and event recorder logs, the DP logs must be taken from both the lead and the remote locomotives. Systems are in place for fault logs and event recorder logs to be obtained remotely. Systems should be implemented to obtain DP logs remotely.

If alarm, event and system logs are passed from the remote to the lead locomotives via low priority radio messages then evaluations of reports may prove to be easier. Logs from both the remote and lead locomotives would be required. It is observed that remotely obtaining DP logs would effectively make this recommendation unnecessary.

Communication loss summaries should be improved. Currently, only communication losses greater than 59 seconds are recorded in the summary entries of the DP log. Crew reports of intermittent communication losses cannot be verified via DP logs. DP log summaries should count each occurrence of a communication loss and log the time in seconds that the DP system is in communication loss. Statistics such as mean and median communication loss time may also be interesting to engineering personnel.

Training crews, mechanical forces and dispatchers

One key take away from this paper is that DP communication losses are going to happen. Where safe to do so, crews should power through the communication loss area per approved Railroad Operating Rules. Always follow your current railroad operating rules.

More experienced crews will learn what areas are consistently impacted by environmentally caused communication losses. Usually, crews can tell you during a job briefing in a crew room that the Distributed Power system will experience a communication loss between mile post X and mile post Y. They have probably already figured out the best way to configure the power on their train using Asynchronous Mode to safely power through the communication loss area and minimize their use of air to handle their train. Remember that air applications during a communication loss can be a cause of communication loss idle down event. Operating managers can verify crew power configurations and develop other configurations on simulators.

The most powerful thing that can be done is to educate the railroad personnel. Create training simulations where crews must operate in areas with communication losses. Inserting situations where the crews must deal with communication losses and idle downs in the simulations will prepare them to handle it when running trains. Providing job aides will give crews a document that can be referenced when they are unsure how to handle a certain situation.

The job aide can provide a list of common Distributed Power crew messages and give instructions on what actions should be taken when a crew gets a message from the Distributed Power system. Consider who the crews call when they need help with the Distributed Power system. The job aides should also be created for dispatchers and mechanical help desk personnel. Ensuring that all groups are working with the same instructions and guides will minimize the chances that Distributed Power communication losses will cause train delays on the railroad.

Works Cited

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Product Validation and Certification

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Introduction

The performance of electronic equipment (EE) on a locomotive is integral to mission reliability. In some cases even minor deterioration of performance can result in failure to pull the load.

Therefore, it is critical the EE be designed and validated to published industry standards. Standards set expectations for consistency in performance and reliability of EE.

In addition to developing and testing to published standards, certification from an approved body is an extra step to let railroads know the EE has been verified by an independent party.

Phenomenon

"Erratic loading"
"Unexpected engine RPM changes"
"Transition at unexpected speeds"
"Speedometer fluctuations"
"Radio Interference"

Sound familiar? The above are some of the intermittent issues reported by crews that are hard to isolate when the unit is back at the shop. The list of strange unexplainable phenomenon is endless!

Over time locomotive on-board and remote diagnostic systems have evolved to help isolate these phenomenon (in some cases using predictive diagnostics). However, even these advanced systems have trouble getting to the root cause of these issues.

Although some of the sporadic failures are inherent to locomotive design due to the continued reliance on moving mechanical parts such as relays and contactors, more is due to the environmental impact on the EE.

The Operating Environment and Impact on the Electronic Equipment

Typically the EE will be subjected to the following:

Temperature and Humidity

North American locomotives operate in a variety of climates that can also be found worldwide. On the high end, warm to tropical; on the low end, temperate to sub-arctic. Throw humidity in the mix and the variation in conditions are vast.

Some simple examples of the impact of temperature on the EE include the CPU failing to start in cold weather and, on the other end of the temperature range, overheating CPUs causing intermittent performance issues. Other issues include component tolerances drifting and integrity issues of connectors due to expansion and contraction. Humidity can also cause components to lose their isolation capability, causing significant reliability issues and numerous intermittent performance concerns.

Vibration and Shock

Locomotives often operate on old, uneven track and the alignment of the prime mover with alternators, compressors and auxiliary components causes mechanical oscillations that may lead to excessive vibration. In addition, during standard yard operations such as coupling, the EE is subjected to harsh shocks as well.

The above may lead to connectors becoming loose over time (intermittent issues), PCB solder joints being compromised and insulation deterioration on electrical harnesses. Mounted components may also loosen over time.

Electrical Noise and Radio Interference

EE can be affected by electrical noise being conducted or induced into the device. EE can also generate electrical noise that may impact other EE or sensors on the locomotive. Ensuring that EE is immune to incoming noise and doesn't generate excessive noise of its own can be difficult. Things like grounding strategies, voltage conversion methodologies, shielding and switching frequencies all affect noise emissions and susceptibility.

Electrical noise may cause deterioration on the performance of analog and digital I/O and may cause a loss of communication between onboard systems.

High Energy Electrical Surges

This occurs when a device or cable experiences significant current transitions from low to high current (or vice versa) in short amount of time. Locomotives are equipped with many devices that have these operating traits, such as motors, generators/alternators, power supplies, relays etc. As an example, this may occur during major motor or alternator transition. This rapid change in current causes a fast changing magnetic field that can magnetically couple with cables. This will cause a voltage transient that will propagate down the cables wherever loads are connected.

Power supplies are among the common components likely to be disrupted by electrical surges, compromising the entire system. Other effects of high energy surges are microprocessors rebooting, component failure and degradation of insulation – the latter is a also safety concern.

Detection or Prevention

Provided there is a clear expectation of how the EE is to function, there are two basic methods of ensuring the EE will function as intended in the locomotive environment.

- Detection – Apply the EE to a test group of locomotives
- Prevention – Laboratory simulation of the possible conditions prior to application

Detection

Here we are talking about taking the designed and production ready EE and applying on a group of locomotives for a period of time. After application, the process is quite simple – monitor, detect and resolve all observed issues.

Benefits:

- Quick- little delay in release of the product and can be quickly dispatched for trials.
- It's real – the test conditions are the intended operating environment

Challenges:

- Trial period – not all conditions may happen within the trial period (seasonal variation)
- Problems may be intermittent and difficult to observe and resolve
- Lack of consistency in conditions
- Can be disruptive to locomotive operations.

Clearly, this approach more directly benefits the EE suppliers.

Prevention

With this method, as part of a design validation process, the EE is subjected to extreme operating conditions in a lab. The conditions are generated to published specifications for purposes of repeatability.

Benefits:

- Consistent test conditions allow repeatability
- No interference with railroad operations
- Pressure is on the suppliers of EE

Challenges:

- Could be costly and time consuming
- Longer development cycles

With the prevention method, the greater advantage is to the railroads. The EE will have already been subjected and tested to locomotive type conditions prior to application on the locomotives.

Functional Design Standards

There have been several standards and/or guidelines established for EE equipment globally.

Association of American Railroads (AAR)

This standard is widely used in North America and is specifically for railway equipment. There are clear guidelines available for most EE.

Section M (Locomotive and locomotive interchange equipment) is the most relevant to EE. In terms of functional design, the guidelines do a great job of explaining how the EE is supposed to work. For example, in the case of Automatic Engine Start Stop (AESS) equipment, guideline S-5502 explains all the operating requirements such as shutdown and restart requirements.

There are also standards describing Alerter (Vigilance) operation specifying the timing of audible and visual alerts.

From the above, it's clear the see the AAR guidelines have detailed functional design guidelines, which are very helpful to software engineers.

Hardware and system engineers will also benefit from the detailing of what kind of I/O and interface requirements may need to be included.

However, hardware engineers need a better understanding of the operating conditions the hardware will need to withstand. They must look at other guidelines for this information.

Environmental Design Standards – IEC 60571

Years ago, our engineering team looked for a standard that not only covered the conditions we were looking to design to, but also a standard that has been recognized and adopted by railroads globally.

IEC 60571

This recognized standard (also interchangeable with EN50155) has been adopted by many countries. The International Electrotechnical Commission (IEC) is globally known and has members from the United States and Canada.

This standard specifically applies to rolling stock equipment with both design and validation guidelines. The expectations for performance are clear and, because the validation process is also outlined in detail, there is an increased chance of repeatability and consistency with test results.

Compliance vs. Certification

Compliance is in general terms a self-declaration – it is a supplier making the statement that their EE meets the technical requirements outlined by the standard. Suppliers may offer test reports to substantiate their claim, but otherwise it is a just a statement not validated by an independent body.

Certification requires a third party to oversee the tests and verify the results. This third party must be authorized by the certifying body to perform or witness the tests.

If tests are conducted at an approved test laboratory, the lab will issue a test report that is recognized by the certifying body. Although there are advantages to doing this, it can be a costly and lengthy exercise. If repeated tests are required this can delay the process and add cost to product release. However, the owners of the EE do not have to concern themselves with the cost of the test equipment, maintenance or calibration.

Alternatively, tests can be performed at the supplier's facility or factory provided a witness approved by the certifying body validates the test process and the equipment used. This can be a convenience for the supplier if they have the equipment. It also saves time and cost of travelling to a lab – this can add up if the product does not pass the tests and repeated trips are required.

Some other considerations of testing at the supplier's facility include maintenance and calibration of the equipment – the witness may request to see equipment calibration reports in compliance with NIMS.

Environmental Tests of IEC 60571

The standard covers the following tests:

- Visual Inspection
- Performance
- Temperature
    - o Cold start
    - o Dry heat
    - o Damp heat
    - o Cyclic
- Supply over voltage
    - o Surges
    - o Electrostatic discharge (ESD)
    - o Transient burst susceptibility
- Radio frequency interference and susceptibility

- Insulation
- Vibration, shock and bump

Descriptions of the tests and the author's experiences with the certification process are covered below.

Visual Inspection

This test is integral to end-of-line product tests. The inspection includes but is not limited to:

- Component checklist
- Examination of PCB(s)
- Mounting of components
- Restraint of harnesses
- Torqueing of fastening components
- Cleanliness – no loose wires or debris
- Visual mechanical integrity

Many of the environmental tests covered in this document require a visual verification of the EE before and after each test. For that reason, elements of this visual inspection are used repeatedly during certification.

Our experience; we already had these inspection processes as part of our quality processes and the auditor had little trouble verifying the setup.

Performance Test

This is the end-of-line functional test and ensures the product performs to its specification.

Typically this test covers system I/O, the power supply functionality and communication buses.

Our experience: again, we had little difficulty certifying this requirement as the systems we manufacture are all subjected to automated end-of-line testing. This is the preferred method as it adds repeatability and removes human error.

Temperature Tests

Cold Start Test (Tx Class)

The purpose of this test is verify the system start up at cold temperature and is performed in the sequence below:

- Cool EE (unpowered) in the temperature chamber to -40C (-40F)
- Maintain at this temperature for a minimum of 2 hours
- Power up EE and execute and verify functionality while the EE is still in chamber
- Bring EE up to room temperature and repeat functional test

Our experience: this seldom presents a problem for most EE. However, it is a great test to weed out possible termination issues with connectors, solder joints and etc.

Dry Heat Test (Tx Class)

As the name implies, the purpose of this test is to evaluate the performance of the EE in extreme dry heat conditions. The test sequence is as follows:

- Place product in chamber (powered)
- Ramp at specified rate (1C per 5 minutes) up to 70C (158 F)
- Hold at steady temperature for 6 hours
- Execute a functional test while product is still in chamber
- Bring product down to room temperature and repeat functional test

Our experience

- Can highlight potential ventilation / cooling issues
- Requires monitoring of surface temperature of electronic components
- Product orientation, mounting and proximity to other components can impact test results
- Most forced air chambers provide air circulation, thus improving cooling of EE under test; recommend testing beyond required 70C (158 F)

Damp Heat Test (Tx Class)

In this test the EE is exposed to the highest moisture, with the isolation test performed at the end.

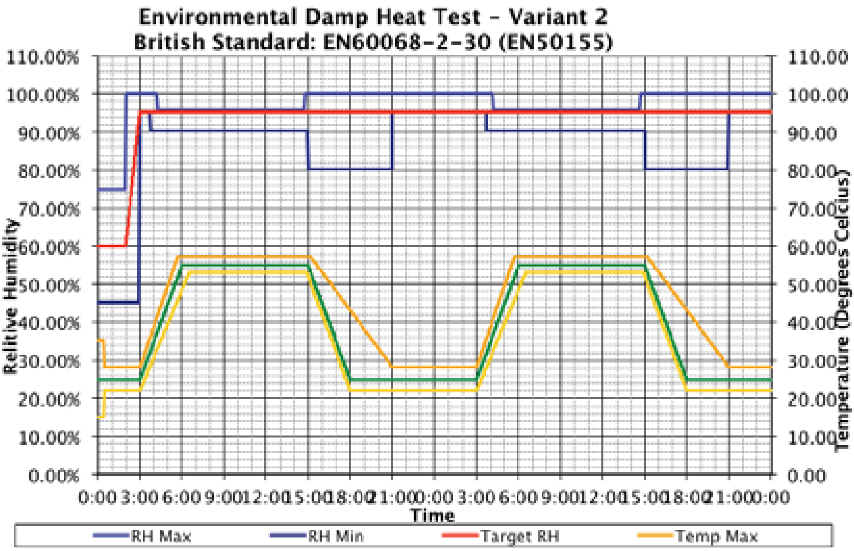
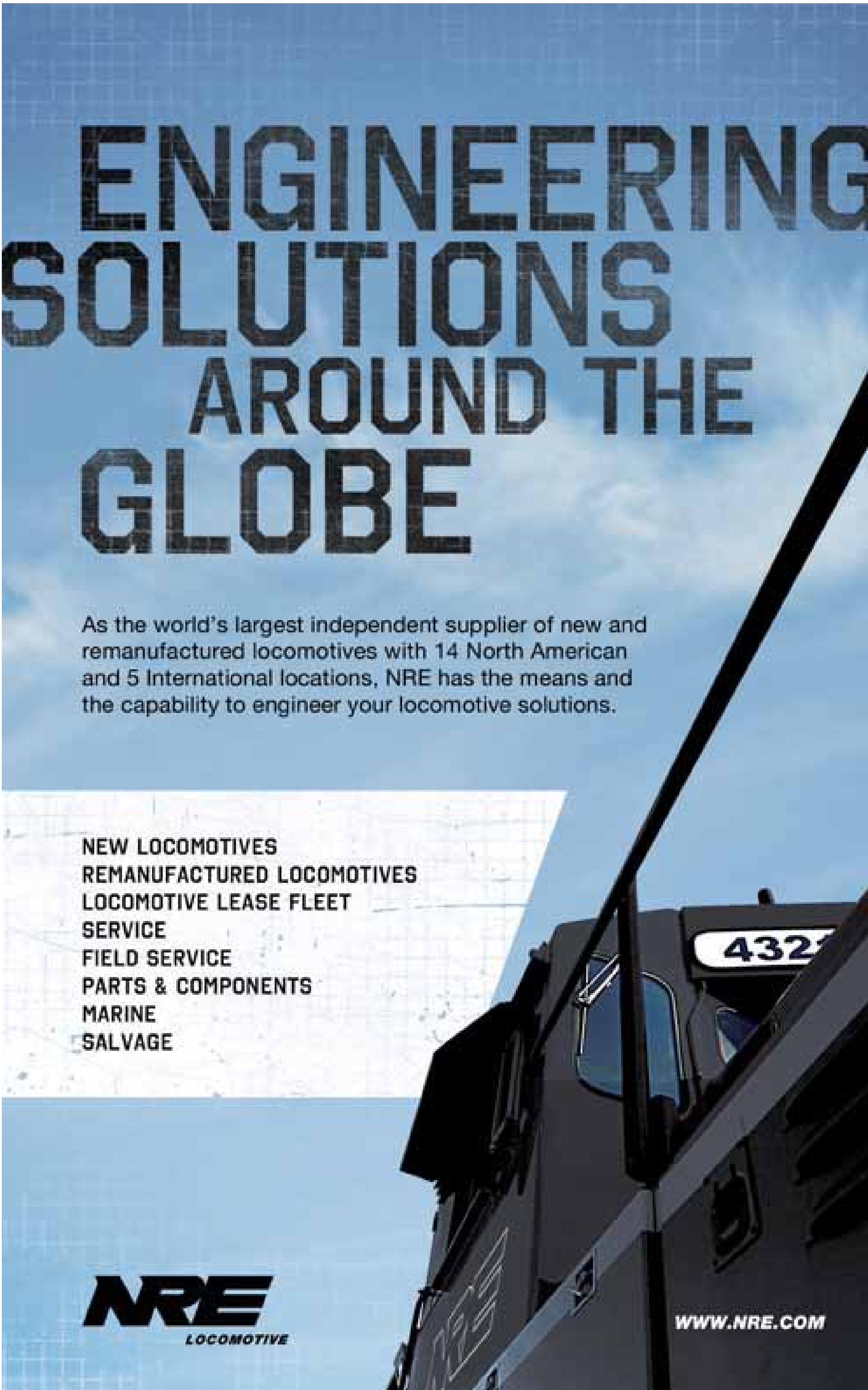


Figure 1: Temperature and humidity vs. time

Figure 2: Equipment inside temperature chamber during damp heat test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Our experience: as seen in the figure 2, the EE essentially becomes soaked in water. At one point there was 2 inches of water at the bottom of the chamber.

Our equipment passed but this can be a very difficult test to pass. If improperly sourced components are used, several issues may occur – corrosion, oxidization, insulation breakdown, electronic failures and connector failures, just to name a few.

This test was performed at the factory with the witness (auditor) verifying the test procedure and the results.

Vibration & Shock

This test involves subjecting the EE to vibration as outlined per IEC61373. The EE is mounted to a plate and subjected to vibration in three directions.

There tests can be lumped into three categories: Functional Random Vibration, Long Life Random Vibration and Shock/Bump.

Our experience: these tests were conducted and passed at a laboratory approved by the certifying body. This test weeds out issues with respect to component mounting, PCB design and cable insulation deterioration.

It can also highlight potential issues with mechanical construction of the EE, such as door hinges and latches.

High Voltage

The next series of tests involve various conditions where the EE may be subjected to high voltage conditions

Supply Over Voltage

Most EE applied to diesel electric locomotives source their power

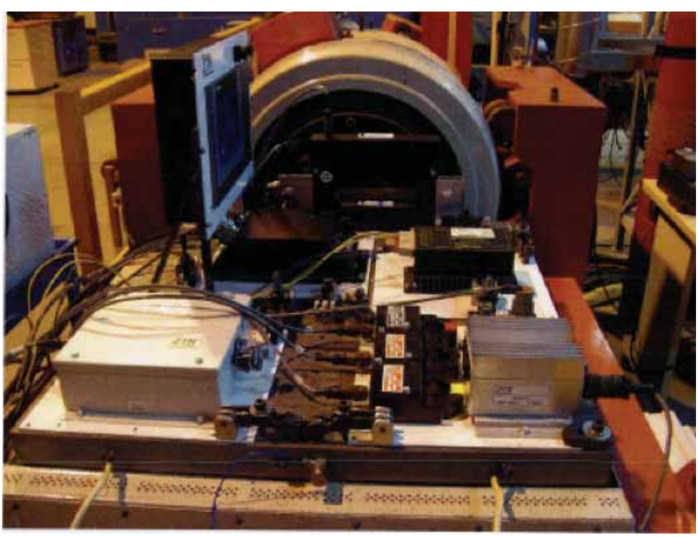

Figure 3: EE mounted for vibration test

from the battery circuit. The battery voltage is typically 64VDC and, when charging, 74VDC. The charge voltage is sourced from the auxiliary generator and may see overvoltage conditions –this is especially prevalent on older locomotives with early voltage regulator designs.

The laboratory test for this condition is as follows:

- Stepping up the source voltage in 5 steps (within one minute) to 1.4 x Un (74VDC).
- Voltage held at 1.4xUn at a minimum of 1 second.
- Functional test performed after voltage brought back to Un

Our experience: If the power supply is sized correctly for the application this test should not present a problem. This test was performed at the factory with the auditor verifying the test procedure and the results.

Surges

This test injects high energy into the EE at the power supply connections. The test sequence is described below.

- Use af Coupling/Decoupling network to select the desired Surge path and decouple the power supply.
- The surge waveform defined by IEC60060-1 (refer to figure below).
- Surge applied between 74P & GND (at +/- 2Kv)
- Surge applied between 74N & GND (at +/- 2Kv)
- Surge applied between 74P & 74N (at +/- 1Kv)
- 5 Reps with 1 Minute between each Rep

Our experience: If the EE fails this test, the problems can be difficult to find and even more difficult to resolve. Many potential intermittent issues described may be caused by the conditions of this test – so the good news is if the EE passes this test then most (if not all) intermittent issues may be weeded out!

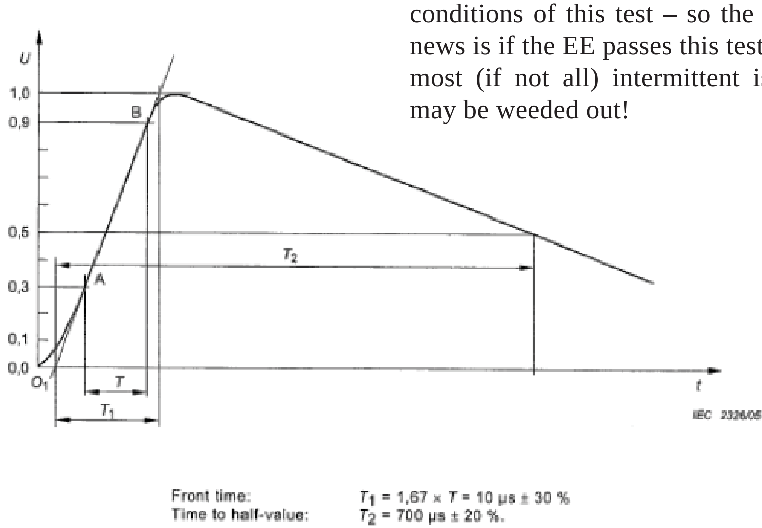

Figure 4: Typical high energy waveform

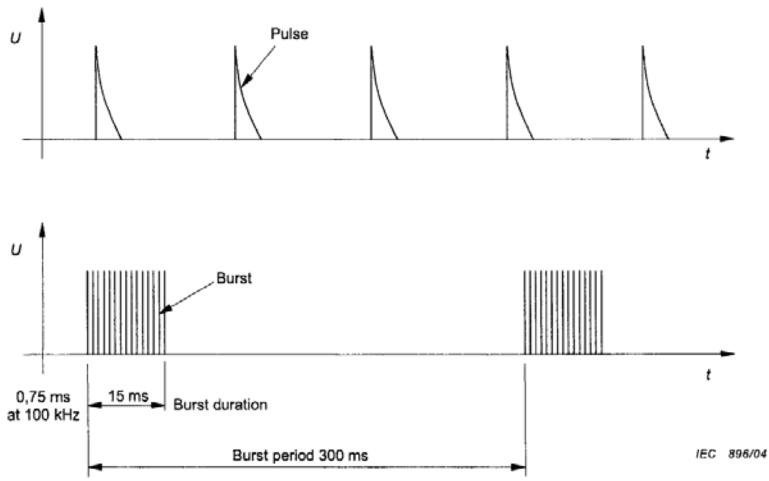

Figure 5: Fast transient waveform

Fast Transient Bursts

This tests the EE's immunity to noise. This is also known as an electrical fast transient (EFT) test. The equipment is subjected to magnetically inducted transients for a minimum of 1 minute.

The EE must remain functional during and after the test. Our equipment was subjected to +/- 2kV (waveforms shown below).

Our experience: we performed the EFT tests in house with verification from the external auditor. As with the surge test, if difficulties are encountered the root cause can be difficult to diagnose and repeatability is a challenge.

Radio Interference

The next series of tests examine the impact of the radio frequencies (RF) on the EE, as well as the amount of radio noise produced by the EE.

Radio Interference tests generally consist of the following:

- Radiated emissions
  - o How much radio noise the EE is producing in a wide frequency spectrum (100 kHz to 20 GHz). The noise must not exceed certain thresholds
- Radiated susceptibility
  - o RF noise is applied to the system.
  - o The EE is placed on a rotating table in order to place each surface under a wide frequency spectrum

- Conducted emissions
  - How much noise is EE producing through its wires; each port (i.e wire group) has to be tested individually
- Conducted susceptibility
  - How radio noise induced directly into the shield of cable (or a wire) will affect the EE

Figure 6: EE on a rotating table

Figure 7: EE during Conducted Emissions Test

Our experience: these tests can destroy the testing budget and project schedule. Cabling, shielding, grounding issues, switching electronic noise, signal distortions, communications losses to name a few possible problems.

Our EE did well during these tests (about 2 days) but we saw other companies sharing some of their horror stories. In one case a supplier explained how they repeatedly failed the test and returned with redesigns, only to fail again. This process went on for months before they succeeded.

Closing Statements

Having the suppliers of electronic equipment design and test to recognized standards provides several benefits to the railroads:

First, no more "guinea pig" scenarios—the equipment being applied has already been tested against harsh real-world locomotive conditions recreated in a laboratory.

It also establishes a level of expectation with respect to reliability. Because of this, the railroad can expect minimal disruption to operations.

In the long run suppliers also benefit from this process. In addition to improved reliability, this reduces post-commissioning costs as there should be less EE failures and issues to deal with. And having clearly defined goals and test processes drive consistency during the product design and validation process.

With respect to certification, it is a lengthy and sometimes costly process for suppliers. But having the product certified to the standard adds confidence that the product will be reliable, thereby benefitting both the supplier and the railroad in the long run.

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Sensors and Transducers Installation Tips

Eugen Grecu, VIA Rail Canada Inc.

This paper will cover installation tips based on VIA Rail's experience with sensors and transducers within the re-manufacturing program of its fleet of F40 locomotives.

A few practical examples of transducers installation on locomotives will be presented, pointing to the better or best practices in this area.

From systems' standpoint, one rail locomotive can be viewed as a complex system made up of functionally related subsystems that together form a complex whole, serving a certain purpose, which provides reliable and safe tractive and braking power to a train.

All systems on the locomotive are equipped with sensors or transducers in their feedback loops. The system's performance depends on their stable and reliable operation. When transducers fail, the system goes out of control and it can even shut the locomotive down, thus creating delays or even train cancellations.

Locomotive Control Systems Overview

As illustrated in Figure 1, the locomotives are equipped with a number of systems, each one playing an important role.

Listed on the next page are the most important systems on the locomotive and the sensors/transducers they use.

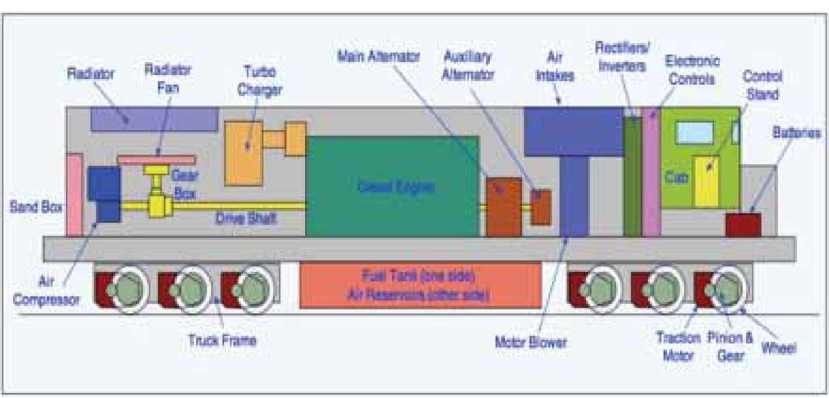

Figure 1 – Locomotive systems

Traction System

- Engine: pressure transducers and sensors (oil, water, crank case), temperature transducers, speed sensors.
- Motors and Alternators: current, voltage, bearing temperature transducers

Air Brake System

- Air compressor and reservoirs: pressure transducers and sensors
- Air dryer: air humidity transducer

Head End Power

- Engine: pressure transducers and sensors (oil, water, crank case), temperature transducers, speed sensors.
- Alternators: current, voltage, and bearing temperature transducers.

Auxiliary power

- Excitation, battery charger, alternators, and motors: current and voltage transducers.

Sensors and the Railroad Environment

The reliability of a system is dependent on the reliability of each component, hence the importance of having reliable feedback. The sensors and transducers as well as their installation must therefore be:

- Robust: designed for the type of application, considering the environment, such as temperature of operation, vibration, humidity, risk of chemical contamination with water, oil and fuel.
- Properly located on the equipment to minimize the risk of malfunction, or failure.
- Be attached properly to the control system by using the appropriate wire, connectors, and method of application.

The locomotive is the railway equipment that best represents the railroad environment. Its systems are subject to large variations in temperature, shock and vibration, and chemical contaminants such as water, oil, and fuel.

Temperature

The sensors and transducers may be required to operate in real environmental temperatures ranging from -40°F (-40°C) to +140°F (+60°C) or more.

Figure 2 – Hot environment

The effects of operating close to the highest range of these temperatures are numerous: electronics break-down, IC chips burnout, power supplies overload, clocks drifting, communications failures, accelerated aging of plastic materials and of electronic substrates.

Figure 3 – Cold environment

When operating at the lower range of these temperatures, the water lines, air pipes, and valves can freeze up, the plastic materials can become brittle and break in pieces, water condensation can form in cold areas, electrical insulating systems can break down.

Vibration

Depending on where on the locomotive the sensors or transducers are installed, they can be required to operate reliably at peak mechanical shocks up to 20G.

Vibration can lead to loose screws and ties, chattering of relay contacts, break-down of the physical packaging of electronic components, break-down of wires and component pins, chaffing of wires, intermittent electronic circuits, insulation wear by rubbing and chaffing, contacts break-down, accelerated aging of the mechanical components, etc.

Chemical contamination (oils, fuel, soot, water)

The infiltration of contaminants can lead to progressive or catastrophic electrical insulation break-down, short circuits, corrosion of electrical contacts, break-down of rubber seals and plastic materials, etc.

For reliable operation, both the sensors and their connectors must have a minimum water ingress protection of IP-67.

The sensors and transducers must be made of materials that are stable in the presence of water, oils, heat and cold.

EMI/RFI

The sensors or transducers may operate at low signal levels, which can be influenced by electromagnetic interference either radiated or conducted coming from the locomotive radios, the switching power supplies, or other on-board equipment.

Use shielded cables and the appropriate grounding scheme in order to reduce the electromagnetic and radio frequency interferences.

Location

Placing a sensor or transducer in an optimal location at the design/integration phase can prevent the operation of a control system with erroneous data, and of course it can eliminate later corrective actions.

For instance, an ambient temperature transducer must be applied in a place where there is no additional heat source, such as direct sunlight, cab heating, etc.

Methods of installation and wiring

The installation is important for a transducer to operate reliably.

The environmental influences must be taken into consideration when determining the optimal location and method of application. For instance, an oil pressure transducer can be applied away from the engine, at the end of a long conduit. By installing it this way, the transducer's sensitive electronics are protected from the higher vibrations and temperatures produced by the engine. The same transducer applied for water temperature is better installed directly onto the engine's water piping in order to avoid the water freezing in cold climates. It becomes obvious that such a transducer must be hardened for operation in harsh environments, where high vibrations and large temperature variations are encountered.

The transducer's orientation can be important as well. In the case of a water pressure transducer installed on the engine's cooling water piping, its orientation can influence the sediment buildup inside its inlet opening. As the water carries contaminants that are unfiltered, these can clog the transducer's inlet port. If the transducer is applied vertically, the inlet pointing down, the contaminants have a chance to drop by gravity and not accumulate into the transducer's port. If the transducer is applied horizontally or vertically with the inlet pointing up, the debris can accumulate and obstruct at some point the transducer's inlet, thus initiating a failure.

The wiring of sensors and transducers must provide a robust connection to the control system. The connectors must be rated for a minimum IP-67 water ingress, the cable wires must be railway or transit grade, moisture and chemical resistant, and flame retardant, no thinner than AWG18.

Sensors/Transducers – Practical Examples of Installation on Locomotives

Ambient Temperature Transducer
Related topics: Location, Temperature

The ambient temperature transducer used in this example is providing feedback to the automatic stop and start system (AESS).

The original installation location was decided on the assumption that the underframe of a locomotive reflects reasonably well the environmental temperatures since it is hidden from direct sunlight, and in the step ladder area there is sufficient air movement to prevent the creation of warm air pockets. At the top of this area, the transducer is also protected from rocks and ice.

With the original installation (Figure 4), the ambient temperature reported in operation by the control system was consistently 3 to 9°C (5 to 16°F) above normal. This situation could lead to engine freeze-ups at ambient temperatures hovering just below the freezing point.

Figure 4 – Ambient temperature transducer, original location


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Taking a thermal image under the frame with a FLIR camera revealed all heat sources that affect the ambient temperature transducer's readings.

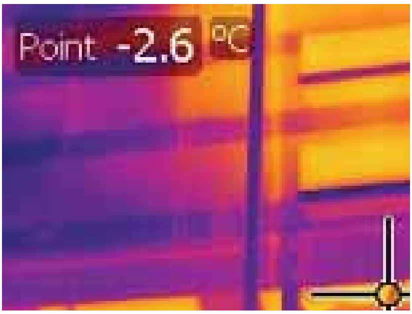

Figure 5 – Under frame temperatures

Figure 5 shows the under frame temperature distribution in a cold winter day. There is a difference of 43.2°F (75.2°C) between the coldest and the warmest point. Three sources of heat have been identified: the cabin's floor, the air ducts, and the step ladder's light bulb.

One appropriate cold spot was identified, which is not influenced by any of the heat sources identified above, and the ambient temperature transducer was relocated.

Water Pressure Transducers

Related topics: Selection, Methods of installation.

The installation of water pressure transducers at the main engine's water pump is used as an example.

The original design considerations for the installation of pressure transducers at the input and the two outlet conduits (Left and Right) were as follows:

- Freeze prevention: apply directly onto the engine
- Vibration: transducers were applied with flexible hose mounts to protect them from the effects of the engine's vibrations
- Connections: to minimize connection points, and in order to prevent intermittent contacts due to vibration and potential contamination, transducers with pigtail cable were selected
- Sufficient cable slack was allowed, in order to allow the transducer's removal without damaging the cable

Figure 6 – Water pressure transducers, flex mount

Figure 7 – Water pressure transducers, slack cable

The issues with this design started showing up after about one year of operation.

- Transducer's inlet is plugging with debris in the water (salts, ferrous oxides, etc.). It was reasoned that this is the result of combined causes: the water's turbulence, the pumping effect inside the flexible hose due to vibration, and the transducer's installation in a horizontal plane. The intermediate flexible hose translates the engine vibrations into lower frequency, high amplitude swings of the pressure transducer. Being installed horizontally, as opposed to vertically, the debris can accumulate easier inside the transducer's water inlet.
- Cable twisted and broken where it exits the transducer (Figure 8). Although sufficient slack was allowed by the original installer, during maintenance the transducers were removed or reapplied without first untying the wires.
- Cable chafing. Due to vibration, the transducer cable can rub against neighboring components/hoses, or conduits (Figure 9).
- Cable folded with multiple kinks. Wrong accommodation of slack cable
- Cable crushed by tie-raps. Wrong application of cable ties
- PVC cable jacket aged prematurely due to the high temperatures radiated by the engine (around 20°F). The plastic material dries out, it hardens and cracks. PVC proves not to be appropriate material for the environment.
- Transducer's wires (24AWG) breaking or snatching out of fast-on connectors. Identified mismatch between the 24AWG wire thickness and the 1/4in fast-on connector. On the other hand, the thin 24AWG wire breaks easily when handled, or due to vibrations. It was determined that this wire is not appropriate for the engine room environment.
- ¼" fast-on connectors:
  - o Too high insertion/pullout force for the thin wire
  - o Loose crimp: made for min. 22AWG wire

Figure 8 – Water pressure transducers, cable twisted

Figure 9 – Cable chaffing

Considering the above findings, the water pressure transducer's installation has been revised:

Vibration:

- Selected transducers rated for vibration levels that allow their direct application onto the engine's block.

Contamination with debris:

- Eliminated the flexible hoses.
- Considered the use of transducers equipped with a flat membrane interface that by design doesn't allow accumulation of debris.
- Positioned the water input pressure transducer to vertical position in order to reduce or eliminate the possibility of debris accumulation. Added pressure snubbers to limit the peak transient pressures.

Cable strain relief:

- As a temporary solution, the pressure transducers' cable strain relief was improved by applying heat-shrink tubing (Figure 10). When transducers are equipped with pigtail cable, they must also have proper strain relief means (flexible cable boots).

Connections:

- Selected transducers equipped with connectors rated for vibration and having an IP-67 rating for water ingress
- Used connecting shielded cable with thicker wire gauge: AWG #18. Used cable rated for transportation.
- Selected appropriate connector at the junction box.

Cable routing:

- Improved cable routing and tying by minimizing the applied stress (Figure 11).

Figure 10 – Cable strain relief improvement

Figure 11 – Cable tying improvements

The solutions shown in figures 9 and 10 are improvements on an existing design. New designs can be better adapted.

Oil and Water Temperature Transducers
<u>Related topics: Methods of installation, Reliability</u>

The oil and water temperature transducers are applied directly on the respective conduits. Intermittent operation can cause the control system to shut down the engine for abnormal operation. Intermittent electronics or loose contacts can be the source of these failures. Wiring errors, similar to the water pressure transducers presented above are common.

To ensure a high reliability of the temperature control system, use redundant transducers. Suppliers make available twin temperature transducers, equipped with two distinct elements.

Conclusions

Below is a summary of important considerations at the selection and application of transducers on locomotives:

Selection

Select sensors and transducers that have been designed and tested in compliance with railways standards for temperature, shock and vibration, and electromagnetic interference.

When sensors or transducers used in other industries are considered for a railway application, they must be carefully selected and validated, to ensure their compliance with all railway environmental specifications.

Choose sensors and transducers equipped with reliable, industry proven connectors with a minimum water ingress rating of IP-67

Location

Identify optimal location and transducers' orientation in order to minimize the environmental negative influences.

Use redundancy when possible for critical functions; e.g. engine oil and water temperatures.

Wiring

Use transportation grade cables and wires no thinner than AWG18-20.

Use shielded cable and ensure proper grounding schemes and connections where the EMI/RFI reduction is required.

Do not use cables with low temperature PVC insulation.

Cable routing:

Do not run cable along hot conduits.

Use as many as possible dedicated cable supports.

Report on the Committee on Diesel Material Control

Tuesday, September 23, 2014 at 8:45 A.M.

Chairman

Michael Hartung
Supt-Loco. Material and Systems
Norfolk Southern Corp
Roanoke, VA

Vice Chairman

Fred Miller
VP-Sales
Chromium Corporation
Cleveland, OH

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B. Marty	Marketing Director	Metro East Industries	E. St. Louis, IL

Note: 1st VP Bob Harvilla and Regional Executive Ron Sulewski actively participate on this committee.

PERSONAL HISTORY

Michael Hartung

Michael Hartung is on the Mechanical Department Staff with Norfolk Southern Corporation. In his current position, Superintendent of Locomotive Material and Systems, he is responsible for all Mechanical Department inventory. In his former position, Senior General Foreman – Distribution Center, he was heavily involved with the implementation of two Distribution Centers within the Mechanical Department. He has worked for NS for eight years in three locomotive shops since being hired as a Management Trainee. This is his second year on the Diesel Material Control Committee and his first as Committee Chairman. Michael is a graduate of Old Dominion University with a BS degree in Mechanical Engineering and minor in Engineering Management. He resides in Roanoke, VA with his wife Lindsay, and his sons, Brenden and Landon. He enjoys coaching his sons' baseball team and golfing.

The Diesel Material Control Committee would like to express their sincere appreciation to CSX Transportation for hosting our meeting on January 17, 2014 at their headquarters in Jacksonville, Florida. The committee also had the opportunity to attend the dinner meeting of the Southern Southwestern Rwy Club on the evening of January 17th.

The committee would also like to express their gratitude to the Norfolk Southern for hosting a committee meeting in Roanoke, VA, on April 9, 2014. The committee had the opportunity to tour the NS Distribution Center. The committee also met in Altoona, PA on June 19 and 20, 2014.

Examining Lifecycle Costs
Part One - Defining the Inputs

Prepared by:
Eric Armstrong, Miller Ingenuity
Mike Hartung, Norfolk Southern

Visions of the Project

The purpose of this paper is to take an in-depth look at the various cost drivers in the life cycle of a product for railroads. The mission is to not only look at evaluating prices and transportation, but also at all of the variables from cradle to grave that make up the true cost of products and services. As we looked at the topic, it quickly became clear that all of these variables could not be studied in depth with just one paper. As a result, this discussion will develop the inputs that will be studied by the committee in more detail in the coming years. As these topics are explored, each one may supply its own answers and become topics for other papers in the future.

One of the largest areas to look at is the initial design, tooling, and manufacturing of a product. While most of us have little influence on this aspect of the product life, it cannot be ignored in this process of understanding. Most products are designed for a specific fit and function within a system and need specific design parameters to function. Sometimes, these limits may restrict the opportunity for future innovation, as the functionality of the parts within the system cannot be compromised. Typically, the original equipment manufacturers that design the equipment bear the burden of the success and/or failure of the equipment. Solving the inherent problems with the product on a large install base of locomotives is costly for all involved and must be the primary focus for resolution. Fortunately, new technologies often bring solutions to the challenges, but often times it is not feasible to integrate these technologies on the older install base.

The production costs for a product demonstrate a range from the raw materials, labor, packaging, selling, general and administrative. Inventory costs, storage, handling, logistics all drive the cost basis for the vendor but drive on-time delivery and shorter lead times for the railroads. As we all approach a model of intelligent sustainability, the costs for design and manufacturing on a cradle to grave product will again weigh on the end user.

The procurement and contract management process are much more complex today, than in the past, because of the ability to measure more soft or intangible costs. Better data management gives us the ability to understand the hard costs in locomotives out of service for repairs as well as the impact of unscheduled out of service failures. Analyses of these drivers help everyone in the purchasing process. Better lean process management has given manufacturers a clear path to continuous improvement, as well as sustainable pricing in the presence of inflationary pressures.

The effects of lead-time are now becoming clear on both the manufacturing and procurement side of the equation. Inventory costs, planning for seasonality and fleet variability, and the effect of standard transportation costs versus expedited services need to be measured by the railroads and vendors.

The damaging effects of out of process costs in quality of the transaction from late delivery, over short damaged, poor invoice quality, warranty process issues and of course product quality are all measureable costs in the lifecycle of a product. Areas of interest to the committee in upcoming years include:

- Failure costs
  - o Unscheduled OOS vs. replacement at PM
  - o Online set outs
  - o Consequential damage
- Warranties
  - o Cost of failure
  - o Cost of recovery
- Late Deliveries
  - o Holding locomotives
  - o Material expedite costs
  - o In creased inventory costs

The benefits of these programs also play a role in the analysis. Reduction of unplanned failures, prevention of catastrophic failures account for significant savings in lost time and more time moving customer freight.

The committee will be looking more closely at these product life cycle inputs:

- Life cycle
  - o Maintenance requirements/frequency/cycles
  - o Fuel savings or emissions benefits?
  - o Failure vs. wear out
- Remanufacture of product
  - o How many times can an item be repaired?
  - o Cost to repair item.
  - o Life of product after repair vs. new.
  - o Core pool costs – purchasing, maintaining, upgrading
  - o In source versus outsource of repair
- Sustainability costs
  - o Packaging waste
  - o Recycling, reuse, repurpose or disposal of product

The intent of this paper was to lay the foundation for informative industry standards. As we continue to examine the topics mentioned, the following opportunities for life cycle cost examination will be studied more closely.

- Design and manufacturing
- Lead times
- Late deliveries/transportation
- Quality
  - o Cost of failure
  - o Warranty
- Life cycle of product
  - o Cores
  - o Reclaim-ability performance
- Remanufacturing
- Packaging
- Intelligent sustainability

Advantages, Disadvantages and Opportunities of Kits in the Supply Chain

Prepared by:
Eric Armstrong, Miller Ingenuity

kit: *noun: kit; plural noun: kits*
a set of parts or equipment needed for a specific purpose.

In one of our committee papers last year, Material Solutions for Implementing PTC, we discussed various challenges facing the supply departments on implementation of PTC. Within that paper, we discovered that material kits used to support PTC are causing a great deal of difficulty. With that in mind, we have decided to discuss all types of kits in more detail this year.

For the purpose of this discussion, we are going to break the stakeholders in to 3 basic groups.

I. End User - The person or department that applies the parts in a kit.
II. Internal Supplier - The people or operation that supports the end user directly, possibly maintains a warehouse at or near the end user facility.
III. External Supplier - The vendor community that manufactures or distributes the kits or the components used in the kits.

Scoping

In taking a look at the various ways kits are used in locomotive material management, we can see a number of scenarios unfolding. The most common kits are for rebuilding locomotive components. As an example, there are a number of different kits that are used to rebuild a traction motor combo. They can be as simple as the parts for the motor itself or as complex as all the parts needed to assemble the complete combo. The next most commonplace kits used on a regular basis are for high frequency tasks that maintain a standard bill of material. Often, the internal supplier will put all material needed for a periodic maintenance on a pallet or in a designated location. This ensures the materials can easily be accessed by the end user. Finally, we see kits for the large projects that are more strategic and are part of overhaul programs. The planning process is the key differentiator for the implementation of these scenarios.

The types of kits also vary not just by their implementation, but also by the makeup of the components in the kit. For example small kits of a tactical nature, 4 or 5 items all used in a single process, commonly used in rebuild applications I. e. gasket kits, combo kits, water pump rebuild kits, etc. Kits used on a tactical basis but a larger number of components. I. e. periodic maintenance kits, brush/brush holder kits, injector kits, etc. Finally large kits used for strategic projects. Many parts, high dollar, generally work that is scheduled and planned. I. e. Truck kits, PTC kits, engine rebuild kits, motor stator rewind kits, engine emissions kit etc.

There are different ways to procure kits and get them assembled by the various stakeholders.

I. External Suppliers - Kit material they manufacture and ship to the internal suppliers or directly to the end-users. They also will frequently bring in materials from various vendors and make kits with a combination of material they manufacture and/or distribute to others.
II. Internal Suppliers - Keep all the material on hand in warehouse and supply materials to the shop floor in the form of a kit. At times, internal suppliers also assemble various "sub" kits and bring them together at end user site for installation.

Advantages End User

The primary purpose and advantage of kitting is that all the parts needed for a job or process is in one place. This reduces the chance for errors. (I.e. Mismatching parts that may not go together such as injectors on an emission compliant engine.) Kitting also assures the appropriate materials are utilized on the job or project. Often times, the vendor will give a discounted price for a complete kit as opposed to selling the parts individually. Reduced transportation costs can be expected because the shipping of all of the parts is combined.

Advantages Internal Supplier

The internal supplier enjoys benefits in using kits supplier by external suppliers. Less “touch” of product makes value stream leaner. This minimizes the number of part numbers and transactions including material handling from the warehouse to the shop. Kitting by the external supply chain also eliminates the need for kitting on location saving time and space. By eliminating the need for multiple suppliers, kitting gives the internal suppliers the chance for a ”one-stop shop”, reducing transactional costs. Consequences of changes in the bill of material are also transferred to the external supplier.

Advantages External Supplier

There are several opportunities that make kits appealing to vendors. The most obvious is when purchase orders for kits are awarded; all of the material for the entire bill of material goes to the single vendor. As a result, vendors can increase their sales opportunities by offering parts that may not fall well within the core competency of the company. Similar to the internal supplier and end user in the reduction in part numbers and transactions that make a process leaner. Depending on the nature of the kits, vendors can often reduce packaging cost relative to supplying parts separately.

Disadvantages End User

There are several disadvantages that the end user faces with kits. The end user’s constantly changing needs frequently outdates the bill of materials requiring manual intervention within the supply base. The required change creates additional handling and delays. A manufacturer delay for a single component in a kit can cause late delivery of entire kits and hold projects for complete kit. Many repair facilities perform running repair and new installs within the same building. At a time when material shortages occur for running

repair, users are tempted to remove items from kits before using the kit for designated project. Obsolete material requires scrapping and/or purchase of new kits which adds costs and delay to schedules.

Disadvantages Internal Supplier

For the internal supplier, preparing materials for use on the shop floor or transacting business using vendor kits can present some interesting challenges. One of the most common is the end user not using all of the material delivered in a kit. Sadly some of this new material ends up discarded, but the challenge of "reintegrating" this material into inventory is difficult. The item has already been paid for once (as either a Capital purchase or Expense purchase) and placing back into inventory creates additional accounting work. This item may have never been ordered or brought into inventory as a single part number. As a result, the excess is beyond the capability of most inventory control systems to easily adjust. The other possibility often means the item is stored in a "special" place for use at a later time complicating inventory matters even further with undervaluing inventory. Many of the items in a kit are individually inventoried for other demand (i.e. Running Repair). Having these same components in a kit creates inventory redundancy.

Another disadvantage of kits occurs when vendors include non-value added items. An example of this might be including a paper gasket in a kit as a "standard" when a rubber gasket is required for the application. Another example of non-valued added items occurs when the external supplier provides both types of gasket as a "standard". This could be the result of different customer's preferences but marketing the identical kit to both customers. These leftover components then become additional inventory. If the vendor does not manufacture all of the items in the kit, then it is likely the end user is paying additional markups.

One issue common to all railroads is core material return for unit exchange and "repair and return" items. When an external supplier includes a reconditioned part in a kit, it makes tracking and integrating the core material back to the external supplier difficult. This issue is further compounded if the original material being replaced on the equipment is not an "acceptable core" for what was provided in a kit. Tracking this material can become a costly nightmare for the Internal Supplier resulting in higher material cost and wasted labor.

Disadvantages External Supplier

External Suppliers also face many challenges with kitting. For the vendor, kitting can be similar to "putting all your eggs in one basket". If the vendor is awarded the purchasing contract for a kit, they supply all material. In contrast, if the vendor loses the bid for the purchasing contract for the kit, they've lost all the business. This is despite the fact that they may, in fact, be the lowest bidder if the materials were awarded individually. There is clearly a calculated risk that the external supplier is taking.

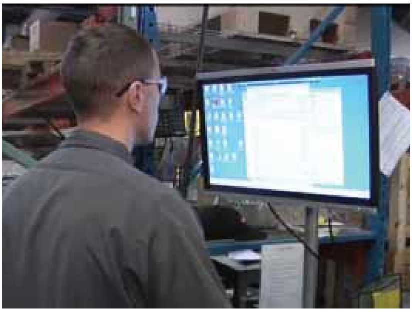
Another disadvantage can be the

end user's inconsistency in return of core material. If there are not enough cores coming back for rebuild, there will be a delay in producing a complete kit for the end user. This adds unnecessary delay or even stopping final production.

A few other disadvantages to note, the expectation is that the external supplier absorbs the cost of kitting and keeping up with bill of material changes. Each end user has slightly different needs creating many bill of materials for similar parts offsetting some of the intended part number reductions. Part numbers of kits do not align with OEM part numbers for any specific individual part. Vendors with multiple kits for the same core product may have difficulty identifying a customer's need. Finally, the inability to deliver a kit as the result of an individual item can cause late delivery of entire kit and prevent project/production completion.

Opportunities

Standardization of the end user work process, to reduce number of bill of material variables, and best practices can greatly improve the kitting process for all stakeholders. Limiting interim bill of material changes will reduce rework when kits are inventoried and then need changes. Plan for kits to only include items that are replaced 100% to avoid having material left over from the kits. Improve pricing position by limiting items where supplier brings no value add or provide at end user cost. Pick-to-light kitting systems can improve accuracy and reduce training demands.



Conclusion

While the committee agrees that kits clearly work well in some situations, there are clearly some drawbacks to kitting material. Instances where they work well are when the bill of material calls for a limited number of items that does not change often. There also is a good opportunity for kitting if the scope of work calls for 100% usage of the bill of materials. A standardized process can help to minimize the fluctuation in the demand and makeup of kits. The drawbacks to kits include situations where the end user may determine not to use some parts contained within the kit. Scenarios that cause constant change to the bill of materials also make it difficult to kit the material. Ultimately, the decision to kit, or not to kit, is up to each owner in the process. The situation must be analyzed carefully to see if the advantages outweigh the disadvantages and what makes good business sense at the end of the day.

Report on the Committee on Diesel Mechanical Maintenance

Tuesday, September 23, 2014 at 10:30 a.m.

Chairman

Tom Kennedy

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

Vice Chairman

Tim Standish

Quality Manager
Electro Motive Diesel
LaGrange, IL

Commitee Members

D. Berry	Senior Sales Manager	MTU	St. George, UT
J. Bink	National Sales Manager	JMA Rwy Supply	Carol Stream, IL
S. Bumra	Asst. Supt.	Amtrak	Chicago, IL
D. Cannon	PTC Project Manager	BNSF Rwy	Fort Worth, TX
T. Casper	VP-Sales & Marketing	Hadady Corp	South Holland, IL
S. Cronin	Fleet Engine-Diesel	Amtrak	Chicago, IL
M. Duve	Mech. Engineer-Loco. Design	Norfolk Southern Corp	Atlanta, GA
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 *(Past Pres)*	Sole Member	Northwestern Consulting	Boise, ID
A. Reid	CMO Locomotives	Iowa Interstate RR	Cedar Rapids, IA
C. Shepherd	CMO	Arkansas & Missouri RR	Springdale, AR
J. Sherbrook	VP & GM	Sherpower	Trussville, AL
B. Singleton	VP-Sales	Transpar Corp	Niskayuna, NY
T. Stewart	Engine Engineering Mgr	Peaker Services, Inc	Brighton, MI
G. Sumpter	Sales Rep	Casey & Associates	Ponte Vedra, FL
G. Wilson	Superintendent of Cars	Iowa Interstate RR	Cedar Rapids, IA
R. Wullschleger	CMO	New York & Atlantic Rwy	Glendale, NY

PERSONAL HISTORY

Tom Kennedy

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

Tom and his wife of 32 years, Joan, live in Omaha Nebraska. Their three sons (Zack, Mike, and Joe) also live in Omaha. Tom and Joan enjoy outdoor activities such as bicycle riding, BBQ’s, and playing with their German Shepherd, Nikki.

The Diesel Mechanical Maintenance Committee would like to thank Electro Motive Diesels, Inc for hosting their meeting on April 8, 2014 in Countryside, Illinois. Special thanks to Timothy Standish for arranging the meeting and hospitality. Also a special thanks to Amtrak and to Sarabpreet Bumra for allowing us to tour their Chicago facility.

Also the committee's sincere gratitude goes to both Amtrak and the Union Pacific for supporting us on a couple of teleconference calls during the season

Avoiding Logic Traps in Problem Solving

Prepared by:
Ian Bradbury, Peaker Services, Inc.

Introduction

The paper starts by considering some of the pitfalls that may befall us when trying to solve problems. A common theme is how the inferences we draw about the potential causes of the problem(s) at hand are related to how we observe. Many intuitive approaches to observation have built in to them the likelihood that we may draw erroneous conclusions or miss important patterns. Based upon this, some guidelines for the study of problems aimed at avoiding such pitfalls in practice are proposed. Levels of solution to a problem, their economics and sustainability are also considered. This leads to examination of solving problems at a higher level, for which some of these same principles will be seen to apply.

Some pitfalls in problem solving

Study of only the defectives

In Deming (1982) the story of defective nuclear reactor tubes is told:

The vice president of a huge concern told me that he has a strict schedule of inspection of final product. To my question about how they use the data came the answer: "The data are in the computer. The computer provides a record and description of every defect found. Our engineers never stop till they find the cause of every defect."

Deming discusses many of the difficulties that arise when attention is focused exclusively on defects. However, this is an approach commonly taken; we have a problem with defects, hence we should scrutinize with extreme care each and every defective item we can get our hands on. It is certainly commonplace for manufacturers to request that all defective product be returned perhaps as a part of the warranty agreement so that they might learn how to improve. It is also common for manufacturers and providers of service alike to carefully analyze customer complaints with the intent of taking actions that will improve customer satisfaction. It is typical after accidents, particularly serious ones, to perform a careful investigation, so measures can be put in place to prevent or reduce the likelihood of such accidents in the future. Such an approach seems intuitively reasonable.

To consider some possible pitfalls in such an approach we would like to offer two illustrations.

The first example of analyzing failures comes from Tveite (1990). A manufacturer of fuel injectors had been having a problem with mild leakage. When the fuel injector should have been closed, small amounts of fuel were seeping past the fuel injector's sealing surface into the engine's inlet manifold. This often shows up first as a lack of smoothness of the engine at idle or reduced ease of starting.

Under the warranty agreement, fuel injectors that were replaced at car dealerships for being leaky were returned to the manufacturer for problem solving analysis. Tear down of the fuel injectors and careful examination under the microscope revealed a relationship like that depicted in Figure 1 - Analysis of Warranty Returns.

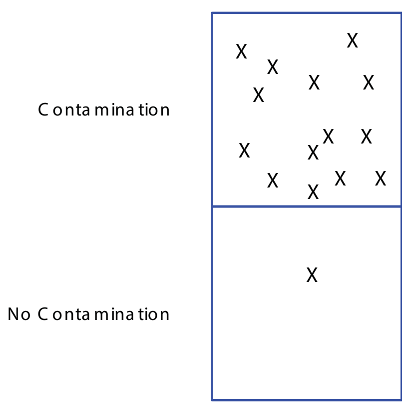


Figure 1 - Analysis of Warranty Returns

Most of the problem fuel injectors were found to contain contamination of various kinds. Contamination is a logical cause for leaks since material that becomes stuck in the seal area can provide a potential leak path. A number of actions had thus been initiated to reduce the level of contamination. Additional actions that were being considered included redesign of the injector and fuel line filters, additional washing, flushing and inspection operations in the manufacturing process, increased air filtration etc.

People working on the problem were asked whether they had examined any fuel injectors that were not leaky. They had not, but decided to do so. Figure 2 - Analysis Including Non-Failures was the result of the combined analysis.

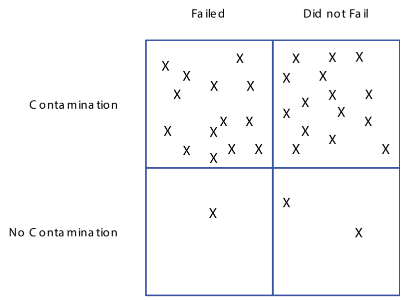


Figure 2 - Analysis Including Non-Failures

It thus became apparent that the contamination that they had been observing was present, independent of the occurrence of leakage. If "non-defective" injectors had not been examined, substantial time and capital could have been expended on reduction of the presence of contamination of the type observed without benefit to the problem at hand.

Further analysis uncovered the cause of the problem as manufacturing variability in the sealing surfaces. In-process inspection was instituted first to contain the problem. Machining process improvements to reduce variability, which resulted in significant improvement, followed this. Ultimately, the injector sealing surfaces were redesigned to be more robust to manufacturing variability. This allowed for elimination of in-process inspection and resulted in even better sealing performance at a lower production cost.

The second example is an examination of the Challenger disaster. On the evening of January 27, 1986, there were 2 conference calls between NASA and Morton Thiokol (MTI) (designers and suppliers of the shuttle's solid rocket boosters (SRB's)) to discuss 13 charts produced by MTI. One chart provided was titled "Blow By History" and is included as Figure 3 - Blow By History. Some O-ring temperature history was provided as a separate chart, and is included as Figure 4 – History of O-ring Temperatures.

BLOW BY HISTORY
SRM-15 WORST BLOW-BY
o 2 CASE JOINTS (80°), (110°) ARC
o MUCH WORSE VISUALLY THAN SRM-22

SRM 22 BLOW-BY
o 2 CASE JOINTS (30-40°)

SRM-13A, 15, 16A, 18, 23A 24A
o NOZZLE BLOW-BY

Figure 3 - Blow By History

HISTORY OF O-RING TEMPERATURES
(DEGREES - F)

MOTOR	MBT	AMB	O-RING	WIND
DM-4	68	36	47	10 MPH
DM-2	76	45	52	10 MPH
QM-3	72.5	40	48	10 MPH
QM-4	76	48	51	10 MPH
SRM-15	52	64	53	10 MPH
SRM-22	77	78	75	10 MPH
SRM-25	55	26	29 27	10 MPH 25 MPH

Figure 4 – History of O-ring Temperatures

SRB engineers from MTI argued against the scheduled morning launch on January 28 due to the low expected temperature. The engineers said that they did not have enough data to know whether the O-rings would seal properly below 53°F and recommended "O-ring temperature must be ≥53°F at launch". They had expressed similar concerns previously. Discussion focused on 2 prior launches in which blow-by had been documented; SRM-15 at 55°F and SRM-22 at 75°F. The argument by Morton Thiokol's engineers was judged by NASA managers as being too weak to delay a launch. At the point in time that they were making this decision, Challenger's launch had already been rescheduled 5 times for a variety of weather and technical problems. During one of the conference calls, NASA SRB project manager George Hardy told Thiokol: "I am appalled. I am appalled by your recommendation." Lawrence Mulloy said: "My God, Thiokol, when do you want me to launch – next April?" (Berkes (2012)). MTI's management had originally supported the position of their engineers, but reversed their position in the face of opposition by NASA management, recommending that the launch proceed as scheduled.

Tragically, the launch went forward the following morning. A (significant) blow by event occurred less than a second after ignition, which resealed from combustion by-products. This then failed as a result of wind shear with the subsequent break up of the shuttle, external tank and solid rocket boosters. Everyone on the shuttle lost his or her lives.

Immediately following the disaster, the executive director and a lawyer at NASA constructed the plot shown in Figure 5 - Simulated Reasoning of Pre-Launch Debate to represent the reasoning employed in the prior day's debate.

This graph appears in the Rogers Commission report, but is misleading as to the nature of the debate since no

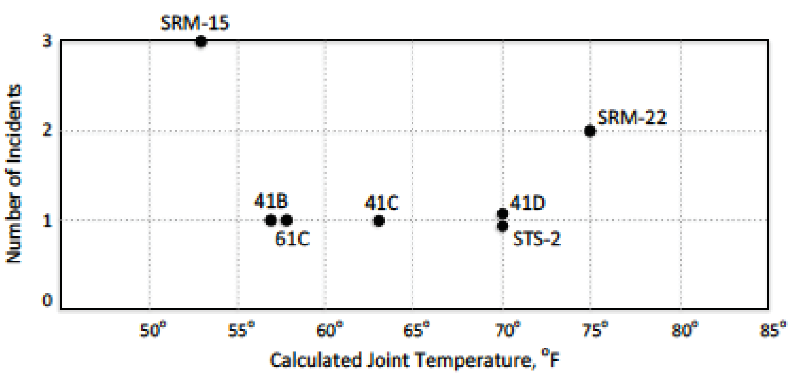


Figure 5 - Simulated Reasoning of Pre-Launch Debate

such graph was used, discussion focused only on SRM-15 and SRM-22, and the discussion didn't strongly distinguish the relative event severity.

From this plot of O-ring incidents, it is not particularly apparent that a relationship between temperature and number of incidents exists, at least over the range of temperatures observed. In examination of this graph with various groups of engineers and managers, lively discussion has occurred with people arguing opposite relationships, according to whether SRM-15 or SRM-22 is discarded as an 'outlier'. When these groups are then asked what their choice would have been if they had been responsible for deciding whether or not to launch Challenger on January 28, 1986, when it was projected to be between 26°F-29°F at Cape Canaveral, debate has typically continued along similar lines.

As mentioned above, the relative severity of damage wasn't adequately considered in the pre-launch discussions. Tufte (1997), in his extensive examination, creates a damage index to score the incidents on a ratio scale. Modifying the simulated reasoning graph to incorporate this rescaling results in Figure 6 - Pre-Launch Debate; Severity Adjusted. Had this graph been used in the debate, one might expect that the MTI engineer's recommendations would have been more strongly considered. However, in light of the strong pressure to launch, it is likely that they still would not have carried the day.

Missing from this display are data from launches where no O-ring damage had been noted. Incorporating this data results in Figure 7 – Severity Adjusted, including no damage.

Most groups, when asked whether their decision would be the same after viewing the data this way, respond that they would have decided to not launch. The concern that damage to O-rings is worsened by decreasing temperature is far more compelling from this view. Expanding the scale to the expected launch temperature range, as shown in Figure 8 - Including Projected Launch Temperature clearly shows that the predicted launch conditions are way outside the range of conditions for which data were available.

The full data displayed this way supports the engineering theory that failure risk increases with decreasing temperature. The O-rings are made from Viton rubber, which has reduced resiliency as temperature is decreased. The reduced ability of the O-rings to seal (quickly) as temperature decreases reduces their ability to accommodate joint distortion. Prediction of what would occur at 26°F-29°F depended solely upon the reliability of this engineering theory, as no SRB data existed for those conditions. Examination of all relevant data, rather than restricting analysis to cases involving defects alone can present a very different picture!

The Challenger example was presented this way to illustrate how significantly one's perspective can change with a different view of the data. It is important to note that some of the data necessary to perform this analysis had been requested by MTI engineers of NASA on more than one occasion, but not made available. Lack of access to

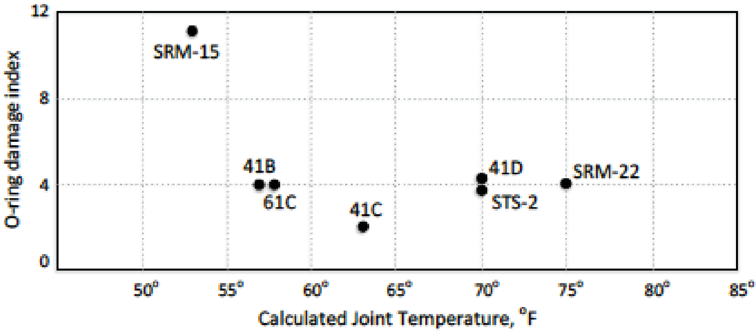


Figure 6 - Pre-Launch Debate; Severity Adjusted

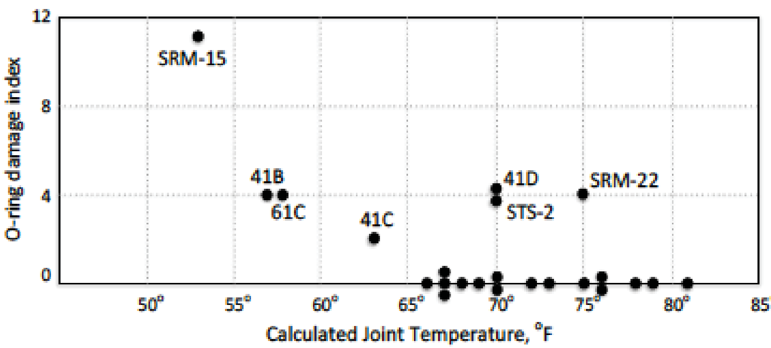


Figure 7 – Severity Adjusted, including no damage

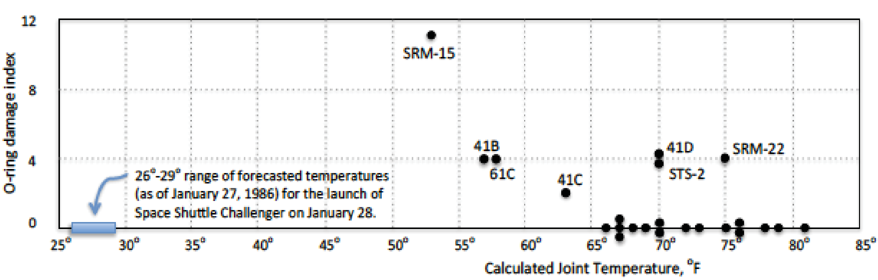


Figure 8 - Including Projected Launch Temperature

all of the information that should have been available, and a decision making environment where there was intense pressure from NASA to proceed with the launch, made it next to impossible for the MTI engineers to make their case. Additionally, the SRB O-ring seals were classified as a criticality one component, so the discussion should have been aimed at demonstrating safety, not demonstrating lack of safety (per NASA policy).

The two examples above seek to illustrate a principle of problem solving. If one only considers the "problem" category of results from a system, one may either erroneously infer presence of a causal relationship (as in the fuel injector case) or miss an important causal relationship (as in the Challenger case). To avoid these pitfalls,

- It is advisable to consider all events or outcomes whether problem or non-problem for distinguishing features. This might be more simply stated as "don't just study the defects."
- Display data with available resolution as it relates to the outcome/effect being considered
- Understand that prediction of what will occur under conditions where no test/use data exists relies predominantly on relevant theory
- Take care that the implicit values for the decision making environment are consistent with the kind of decisions being made since decisions tend to be rational to the (psychological/management) environment in which they are made

The same process that delivered the defects delivered outcomes or results that were not defective. Study of the defects alone presumes that the defects are necessarily produced by a special cause (see below for further detail). Such a presumption is frequently invalid.

Studying successes

In Search of Excellence (Peters & Waterman, 1982) was one of the most widely read business texts in the 1980's. It sold over 3 million copies in the first four years and was the most widely held library book in the United States from 1989-2006. Peters and Waterman started with a list of 62 companies based upon interview of McKinsey partners (where they worked at the time) and other "smart people" judged to be "cool", "doing cool stuff" or "where there's great stuff going on" in the opinion of the interviewees. They then pruned this list down to 43 by application of quantitative criteria. It may be worth noting that GE did not make the pruning from 62 to 43. From the 43 companies, Peters and Waterman developed the following 8 themes:

1. A bias for action, active decision making - 'getting on with it'. Facilitate quick decision making & problem solving tends to avoid bureaucratic control
2. Close to the customer - learning from the people served by the business.
3. Autonomy and entrepreneurship - fostering innovation and nurturing 'champions'.
4. Productivity through people- treating rank and file employees as a source of quality.

5. Hands-on, value-driven - management philosophy that guides everyday practice - management showing its commitment.
6. Stick to the knitting - stay with the business that you know.
7. Simple form, lean staff - some of the best companies have minimal HQ staff.
8. Simultaneous loose-tight properties—autonomy in shop-floor activities plus centralized values.

The evident conclusion one is supposed to draw – these are the things you should do if you want your company to be excellent.

If we look at the companies Peters and Waterman considered excellent 10 years later, some went on to continued success (Wal-Mart, in particular). However, many had encountered hard times or adopted practices Peters and Waterman wouldn't have considered excellent (ex. excessive diversification, mass lay-offs):

- IBM – long considered one of the best managed US firms; steady erosion of market share in mainframe and PC businesses. 2 corporate wide reorganizations
- Digital Equipment – reeling from a massive sales slump that it was unable to recover from
- Wang Labs & National Semiconductor – same story
- Revlon – long heralded as a flagship cosmetics firm in a fiercely competitive industry; went private in 1984 and dismantled assets for sale
- Westinghouse – a leader in EPS over the 80's; sold off many of its original electrical power generation and distribution businesses
- Eastman-Kodak – greatly reduced profitability forced the business to continually restructure

Peters and Waterman fell into the same trap considered above where we studied only the (fuel injector) failures. They studied only the successes, "excellent" companies. If they had studied companies considered to not be excellent and seen the same themes present, it wouldn't have been possible to conclude that the themes are sufficient for success.

A further potential logic trap is to assume that current success (or failure) is due (only) to what can currently be observed. Many causes of the current performance of a company lie in the actions taken in the past and aren't directly observable in the present.

Finally, even if a sound connection can be drawn between currently observable characteristics and current performance, will the same be true for the future or for another company? Just assuming it will be so presents more potential traps.

To avoid these pitfalls:

- As with the earlier cases, don't just study the successes, study the failures too
- Consider possible causes not presently visible since they happened in the past or somewhere other than where you are looking
- Try to understand context – what else needs to be present or absent for the cause to work – the why, or theory, behind the cause.

Failure to take variation into account

The existence of variation renders interpretation of observations more difficult. On the other hand, study of variation provides a means to guard against common forms of faulty logic.

In a manufacturing plant, castings are produced by pouring molten metal through a system of gates into a mold. The amount and distribution of porosity present in the castings are often a focus of concern.

The following describes a previously traditional practice in the plant. Whenever “too much” porosity began to appear in the castings, the gating system was changed, although no clear definition of what constituted “too much” porosity existed. When changes were made to the gating system, an apparent decrease in the level of porosity would lead to the conclusion that the problem had been solved. There are theoretical reasons to believe that gating structure can have an important effect on porosity. However, the practice had not been to use ongoing data to see the effects of gating changes or other changes on the output. No objective data on porosity were regularly collected and analyzed.

Suppose there were a consistent method used to determine when castings contain “too much” porosity . Suppose roughly the same number of castings were produced over a series of time periods and the proportion of castings produced with “too much” porosity showed the pattern of variation illustrated in Figure 9. Times when gating system changes were made are marked on the horizontal time scale.

Taking the variation shown in Figure 9 into account, it is difficult to conclude that past gating system changes have produced any sustained effect on the occurrence of “too much” porosity.[1] The stable variation in Figure 9 indicates that the problem of porosity is chronic and is produced by a collection of factors that are always acting on the results. (We have not shown statistical limits on the graphs shown in figures 9, 10 or 11. Our purpose for these figures is to characterize the behavior of streams of results that exhibit different kinds of variation. In a practical situation, the judgment of whether variation is stable or not is made on the basis of a control chart with statistical limits.) In a case such as this, the way to produce sustained improvement is to conduct a series of planned studies and experiments to understand the factors that affect porosity and to conduct tests of changes that could lower the level of porosity in production output. The structure of the gating system would be one of several possible causes of porosity that would be under study.

A different kind of circumstance in the case of casting porosity is illustrated in Figure 10. The last point in the series may indicate that a change has occurred in the conditions of production. Placing statistical control limits on the chart confirms that this point is a signal of the action of a special

1. We note here that the location of porosity may have more to do with how “too much porosity” is defined than the actual amount.

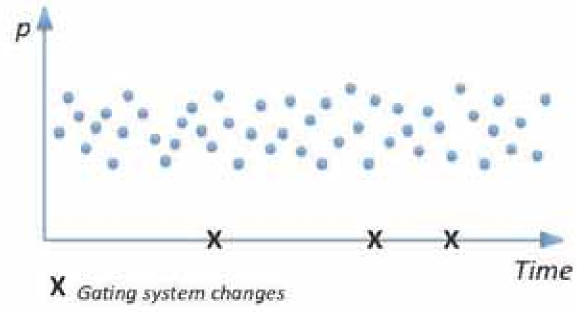


Figure 9

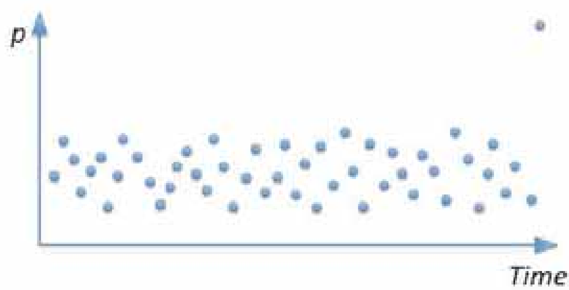


Figure 10

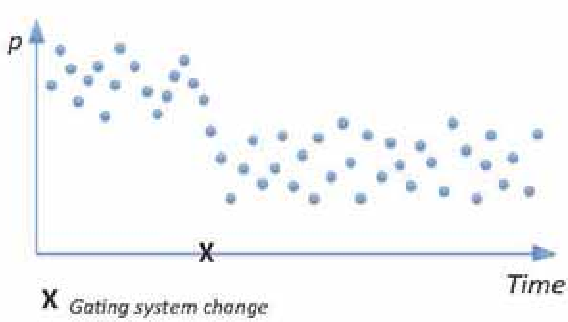


Figure 11

cause. If the same gating system in use when these results were produced had been in use for the previous time periods reflected on the chart, it is again difficult to imagine that gating system structure could be the sole cause of the worsening of results reflected in the last point.

In a case such as that shown in Figure 10, the appropriate action is not to make changes in factors that have been acting in the same way throughout the time when variation showed stability, but rather to try to identify changes in materials and conditions that may have coincided with the change in results. The thinking appropriate to the accumulated history shown in Figure 10 is that there is a special cause acting to produce the wild point and that identification of that cause should be pursued as a course of action, rather than to "tinker" with normal operating conditions to seek improvement.

Figure 11 shows a circumstance in which a change in the gating system reasonably could be believed to have an effect on the generation of porosity, given that other conditions remained roughly the same over the time period depicted. The proportion of castings with "too much" porosity produced after the gating system change shows a sustained reduction in level from what is seen to have been occurring prior to the change.

Study of variation with a methodology that enables us to link results to their causes in a logical way can help to guard against faulty logic in problem solving. The theory and methods of statistical control originated by Walter Shewhart provide a means to study variation for the purpose of improving problem solving. When results show stable variation over time (Figure 9), actions to adjust process factors in reaction to a single up or down fluctuation in results are likely to accomplish nothing but an increase in variation in the future. (This kind of behavior is described by Deming (1994) as "tampering.") When a single result provides evidence (via a point outside statistical control limits) of the existence of a special cause (Figure 10), the appropriate action is to search for unusual conditions that may have existed during the time when the result was produced. When a change is followed by a sustained alteration in the series of results that follows the change, in comparison to those produced prior to the change (Figure 11), one has some confirmation that the causes addressed in the change were acting as believed. In all of these situations, maintaining a record of variation in results provides a means to consider possible causes from a more solid logical basis than would be possible otherwise.

A further suggestion for the improvement of problem solving is:

- Determine important measures of performance of a process or system and maintain a running graphical record of variation in those measures. A simple run chart represents an improvement over no record or a record in tabular form.

Adopting this practice will provide some insurance against inappropriate theories about cause and effect.

Implicit causal assumptions in problem solving

In attempting to solve problems we have the opportunity to make one of two mistakes in our interpretation of the variation we observe and the actions we take as a consequence (Deming, 1982):

Mistake 1: Approach a problem as if it is due to a special cause, when in fact the cause belongs to the system (common causes), and

Mistake 2: Approach a problem as if it is due to the system (common causes) when in fact the cause is special.

When we look at a problem, mistake or defect (failure) and inquire what was wrong, special or different about the conditions that gave rise to it, we are implicitly making the assumption that the cause of failure is special. A consequence of this approach to thinking about cause of failure is that, even though one will achieve a perfect record regarding making mistake 2, one will maximize the frequency with which mistake 1 is made.

The following paragraph from Deming (1982) discusses the need for rules as regards these two types of mistake:

Shewhart (about 1925) recognized the fact that good management consists of making one mistake now and then, and the other one now and then. What was needed, he saw, were rules that can be put into practice by which to try to achieve minimum net economic loss from both mistakes. To this end, he contrived the 3-sigma control limits. They provide, under a wide range of unknowable circumstances, future and past, a rational and economic guide to minimum economic loss from both mistakes.

To illustrate this, let us consider the series of data shown in Figure 12 - Shewhart Control Chart.

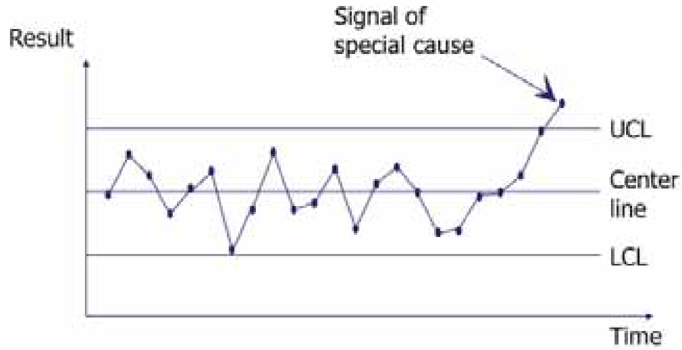


Figure 12 - Shewhart Control Chart

In this figure, the upper and lower 3-sigma control limits are shown. These provide a means of classifying the variation as being due to common or special causes of variation. The 3-sigma limits are based upon the variation inherent in the data and have no necessary relationship to performance requirements (such as specifications). In this example, the last data point falls outside the 3-sigma control limits, therefore indicating that it "makes sense" to ask what was special or different about the conditions that gave rise to that measurement (and that it doesn't make sense to seek explanation for causes of the other individual fluctuations in results). It's no guarantee of a fruitful inquiry, but experience has shown that it provides a good balance between the two types of unfruitful inquiry (mistakes 1 & 2). Some, such as Wheeler (1994), have suggested that Shewhart control limits would have been better described as learning limits as they have directly to do with learning for improvement towards a better state of control of variation.

Suppose that for the data shown in Figure 12 - Shewhart Control Chart, there are limits beyond which the part will almost certainly fail – the upper and lower failure limits, UFL and LFL. In Figure 13, the failure limits are such that the special cause identified above also falls outside the failure limits. In this case, if the inquiry into the cause of failure uses the typical logic of asking "what went wrong?", the implicit assumption of the cause being special is probably (luckily) correct. The odds of a fruitful inquiry are therefore pretty good.

However, the situation could well be as depicted in Figure 14. Pursuing an inquiry into the cause of failure on the implicit assumption that the cause is special is, at best, unlikely to be fruitful and a waste of resources. At worst, variation in outcomes will be made worse and at higher cost.

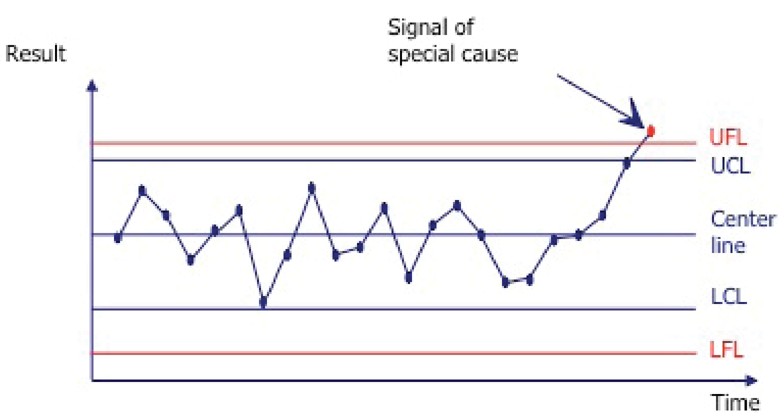


Figure 13

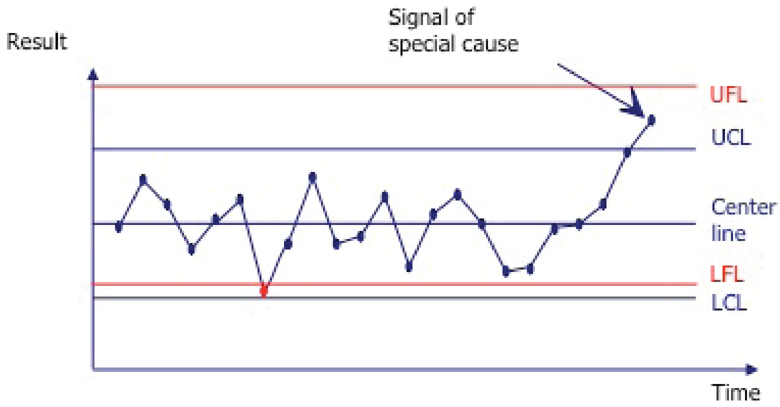


Figure 14

for talking about the dynamic structures, which may repeatedly be seen in our actions. Figure 15 - Shifting the Burden System Archetype is one of these archetypes.

In the shifting the burden archetype two solutions are displayed to a given problem. The upper loop, B1, represents the 'quick fix' approach to solving the problem, which may be thought of as taking the kind of action that makes the symptom go away. At a personal level, an example of this would be taking a pain killer to address the problem (symptom) of pain. The lower loop, B2, represents taking action on the fundamental cause of the problem we are observing. This contains a delay since the diagnosis of the fundamental cause of a problem required for a fundamental solution is typically more difficult than just treating the symptom. The loop on the right, R1, represents a disturbing aspect of this archetype that just taking the quick fix approach often

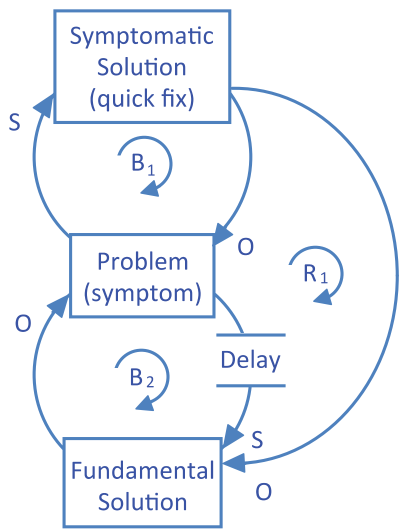


Figure 15 - Shifting the Burden System Archetype

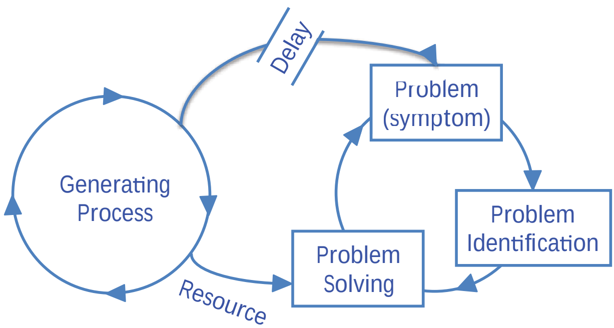


Figure 16

turn to drinking as a method to quickly relieve the stress. As the person drinks more, their physical health declines, resulting in an even worse disparity between their capability and workload. The resultant worsening of stress drives them to drink even more heavily, and the person is caught in a vicious addictive cycle.

This cycle of addiction is paralleled in business. We pull people away from working on the development of future products to solve the problems with the products of today. In doing so, we compromise the development of future products, increasing the likelihood of the future products having problems. Since we saw that pulling people away from future programs in the past resulted in problems being solved, it is addictively tempting to react to the present problems in the same manner. This is shown in the applied version of the system archetype, Figure 16, as resources being drawn away from working on the generating process to work on solving problems downstream.

Principles which one may derive from the shifting the burden archetype are:

- Discipline is required to ensure that there is continued investment in working on the fundamental solution - this may require one to experience some short-term symptomatic discomfort and cost.
- The approach taken in the symptomatic solution of a problem should be such that one learns about the deeper fundamental causes. Action on the fundamental causes will eventually reduce the level of problems generated and thus the need for symptomatic solutions.

In the case of problem solving, this means:

- Resources should be invested in improvement of the generating processes at a level that will reduce the need for solving similar problems in the future.
- Problem solving efforts should go deep enough into the understanding of causes that they generate knowl-

edge useful for improvement of the generating processes.

Some companies that appreciate this last point spend time following the introduction of a new product tracing back the deeper systemic causes of the problems experienced. This may be viewed as a feedback system for the product planning and development processes, workload assignment method and so on. This is a desirable step forward for a company trying to learn for improvement at a system level. However, a caution must be sounded about such efforts. The caution has its logical basis in the thinking explored in the first section study of only the defectives. The same inferential traps that applied to only looking at the defectives for solution of a particular problem also apply to system improvement. For example, the product planning and development processes that delivered the 'problems' observed during introduction of a new product were the same processes that delivered 'non-problems.' To avoid the types of faulty conclusions described in the first section:

- It is advisable to examine all events or outcomes whether problem or non-problem in thinking about their deeper systemic causes.

Conclusions

The main point of this paper is that many logical traps for problem solving exist when studying only the failures, or only the successes. This is so whether one is trying to solve a problem, analyze company performance or learn for system improvement. Mistakes can also be made in misclassifying the nature of variation in results behind the problems we seek to solve. The Shewhart control chart is a powerful method for minimizing the net economic loss of such errors.

Acknowledgments

This paper is derived heavily from the previously published Bradbury and Ranney (1988).

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AFM Calibration Absolutes for All Air Brake Systems

Prepared by:
Dave Cannon, BNSF Railway

- ✓ Apply proper blue signal protection, properly secure locomotive.
- ✓ Brake pipe leakage test performed first (2psi or less leakage per minute)
- ✓ Use an AAR S-5598 (.2188) orifice only.
- ✓ Brake pipe set to 90psi after angle cock opened.
- ✓ Calibration checked only when main reservoir is at 130psi ascending.

Details ensuring the five Calibration Absolutes have been successfully applied:

Note: If locomotive is in consist when air flow is tested, all main reservoir and brake pipe air connections must be isolated on the locomotive being tested prior to performing the AFM test.

1. Apply proper blue signal protection; secure (set and center) the locomotive ensuring the independent brake and handbrake are applied to prevent movement of locomotive during this test. Communicate with those around you as this test requires opening the brake pipe angle cock which will produce noise and venting of air under pressure. Use "CAUTION" when opening and closing of valves that may be under pressure! Avert your body and face.
2. Perform brake pipe leakage test. Leakage must pass within 2psi per minute before AFM can be calibrated.

Use only AAR S-5598 (.2188) Orifice

3. Place the automatic brake valve in continuous service and let brake pipe reduce towards zero. Typically BP will stop reducing around 10psi. Apply the AAR S-5598 orifice to the front brake pipe trainline hose then slowly open the brake pipe angle cock (Apply to rear hose if necessary).

4. After returning to the cab, place the automatic brake valve to the release position allowing equalizing reservoir and brake pipe to charge to 90psi.
   • If brake pipe pressure falls below 90psi, it will be necessary to adjust the equalizing reservoir feed valve until a steady state of 90psi exists in the brake pipe. Typically adjusting the ER feed valve between 91psi and 93psi will produce a steady state 90psi brake pipe after the orifice has been applied. Allow brake pipe to stabilize before proceeding.

5. Calibration can now be measured only when the following conditions are met:

- Main Reservoir pressure must be at 130psi ascending (After the air compressor begins pumping). If main reservoir pressure will not maintain, it will be necessary to throttle the engine up until the main reservoir pressure cycles as intended (130psi – 140psi).

- Brake Pipe pressure must be at 90psi (steady state)

- Required flow reading: 60 +/- 3 CFM.

- If calibration is necessary, attempt to adjust as close to 60 CFM as possible.

Restoring the system after calibration has been performed

1. Before removing the orifice, place the automatic brake valve in continuous service allowing brake pipe reduce to zero. Once brake pipe pressure reduces, it will be safe to close the brake pipe angle cock and remove the orifice.

2. If it was necessary to adjust equalizing reservoir to compensate for inadequate brake pipe pressure during testing, it will be necessary to adjust equalizing reservoir pressure back to 90psi.

3. Reposition brake valves to meet single unit or consist requirements.

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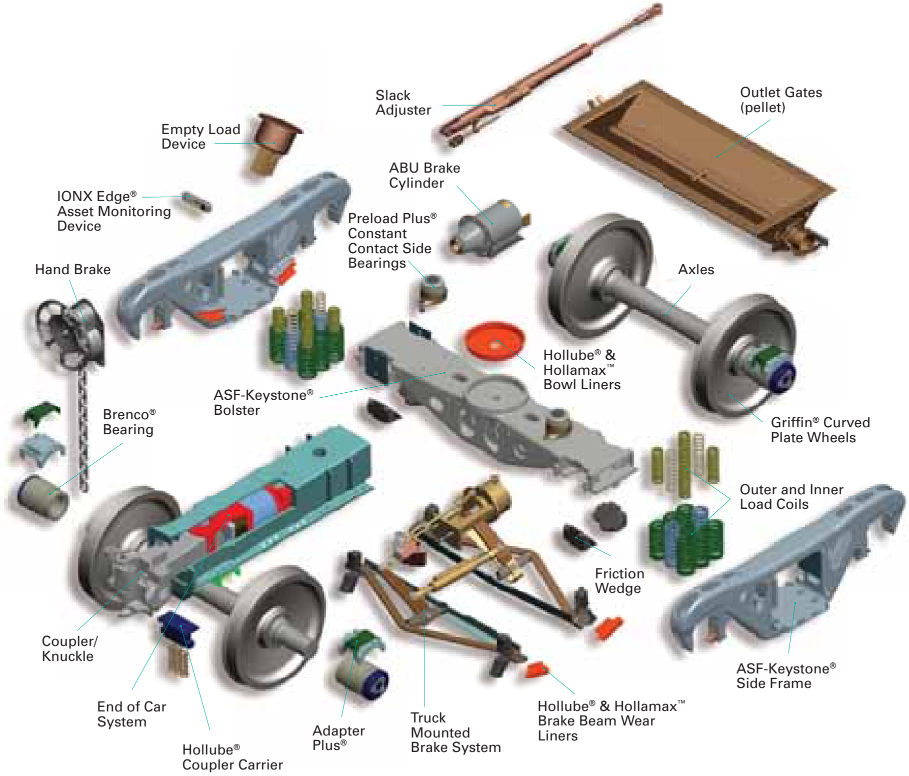

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Locomotive Hand Brake Maintenance, Best Practices

Prepared by:
Greg Wilson, Iowa Interstate Railroad

One of the simpler components to maintain on a locomotive is the hand brake system. By design the hand brake systems are relatively bullet proof. Although changes influenced by the industry over recent years have added additional operational enhancing features to the system, they still remain simplistic in nature.

49 CFR PART 232.105 (b&c)

(b) All locomotives ordered on or after August 1st, 2002, or placed in service for the first time on or after April 1, 2004, shall be equipped with a hand or parking brake that is:
(1) Capable of application or activation by hand;
(2) Capable of release by hand; and
(3) Capable of holding the unit on a three (3) percent grade.

(c) On locomotives so equipped, the hand or parking brake as well as its parts and connections shall be inspected and necessary repairs made, as often as service requires but no less frequently than every 368 days. The date of the last inspection shall be either entered on Form FRA F 6180-49A or suitably stenciled or tagged on the locomotive.

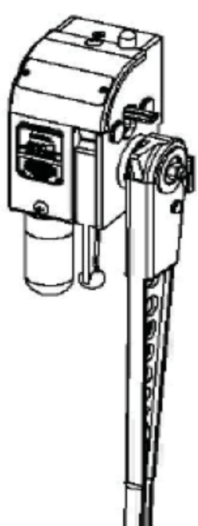
Handbrake Identification

Pictorial Overview of the frequently used locomotive handbrake used in North America freight locomotives today.

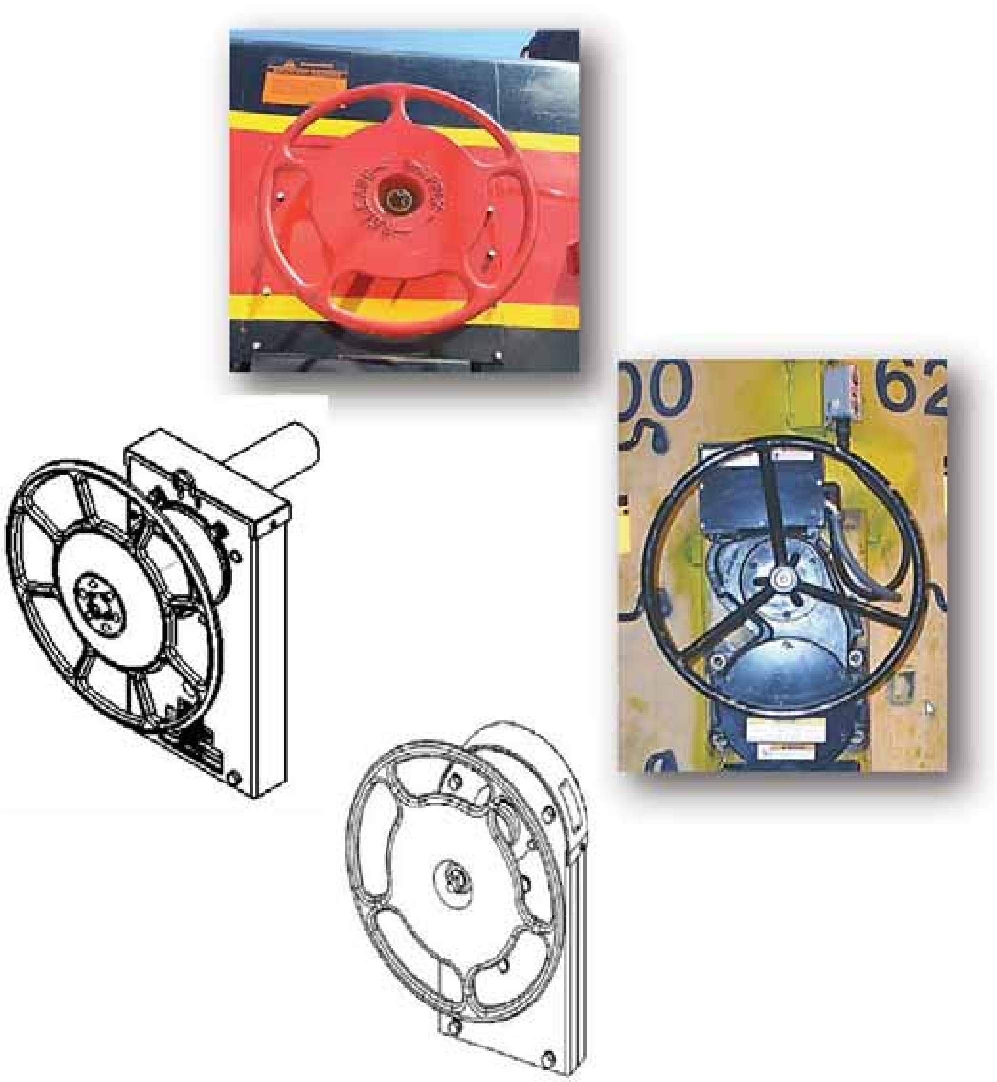
For maintenance purposes proper identification is essential. Regardless of the handbrake exterior design, many different configurations are available for each model from the manufacturer.

WHEN REPLACING PARKING BRAKES ENSURE YOU ARE USING THE PROPER BRAKE FOR YOUR APPLICATION.

*Manual and Electric, **Lever Style**, Parking Brakes*



*Manual and Electric, **Wheel Style**, Parking Brakes*



Lever Style parking Brakes

Manual lever style parking brake maintenance and inspection

1.1 Visually inspect hand brake assembly for defects.

1.2 Ensure the hand brake applies and releases properly

1.3 Check to see if paw pin is loose or bent. Replace if required.

1.4 Release the hand brake. The Pawl Pin should be in the lowermost position.

1.5 Check to see if there is sufficient spring pressure holding the Pawl Pin in the lowermost position. IF NOT REMOVE THE HAND BRAKE FROM SERVICE.

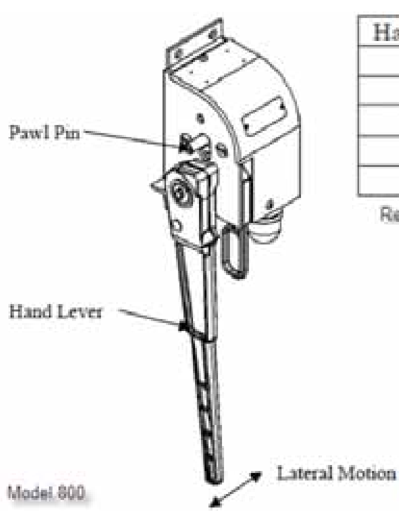
1.6 Pump the Hand Lever a few times. The paw pin should be in the uppermost position.

1.7 Check to see if there is sufficient spring pressure holding the Pawl Pin in the uppermost position. IF NOT REMOVE THE HAND BRAKE FROM SERVICE.

1.8 Ensure that all shafts and bolts are tight. *Model 800 inspect that all shafts are “staked” in place.

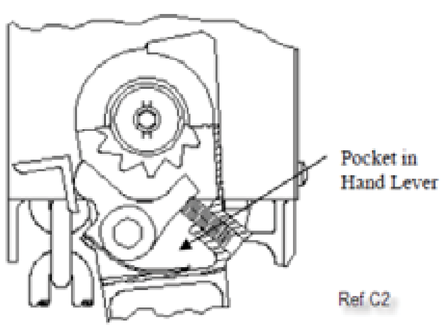
1.9 Inspect Hand Lever for excessive lateral motion. If lateral motion is greater than that listed, REMOVE THE HAND BRAKE FROM SERVICE. Ref C1

1.10 Inspect and remove any excessive foreign matter in the pocket in the Hand Lever which could cause the Hand Lever Pawl to malfunction. *Model 800. Ref C2



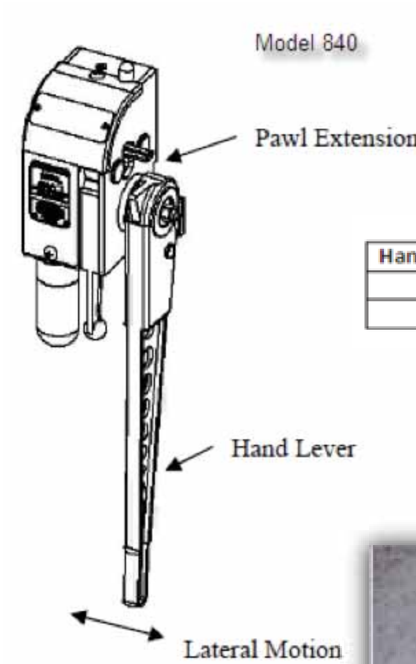
Hand Lever Length	Max. Lateral Motion
16”	1 3/16”
18”	1 5/16”
20”	1 ½”
22”	1 5/8”
24”	1 ¾”

Ref. C1



Ref C2

Manual lever style parking brake maintenance and inspection, continued



Hand Lever Length	Max Lateral Motion
12"	7/8"
18"	1 5/16"

EXAMPLE OF HOW TO MEASURE LATERAL MOTION

Lubrication

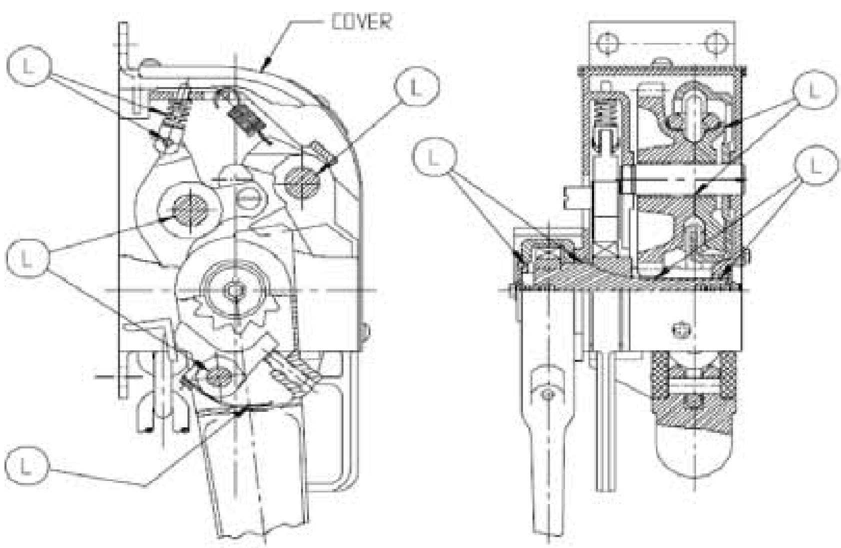
Model 800 and 840 Lubrication recommendations.

For all manual hand-brakes, the manufacturer recommendations are:

In order to preserve the efficiency of the Hand Brakes they should be periodically cleaned and lubricated. Use any good grade of lubricating oil or spray lubricant. The hand brake should be lubricated at least once a year.

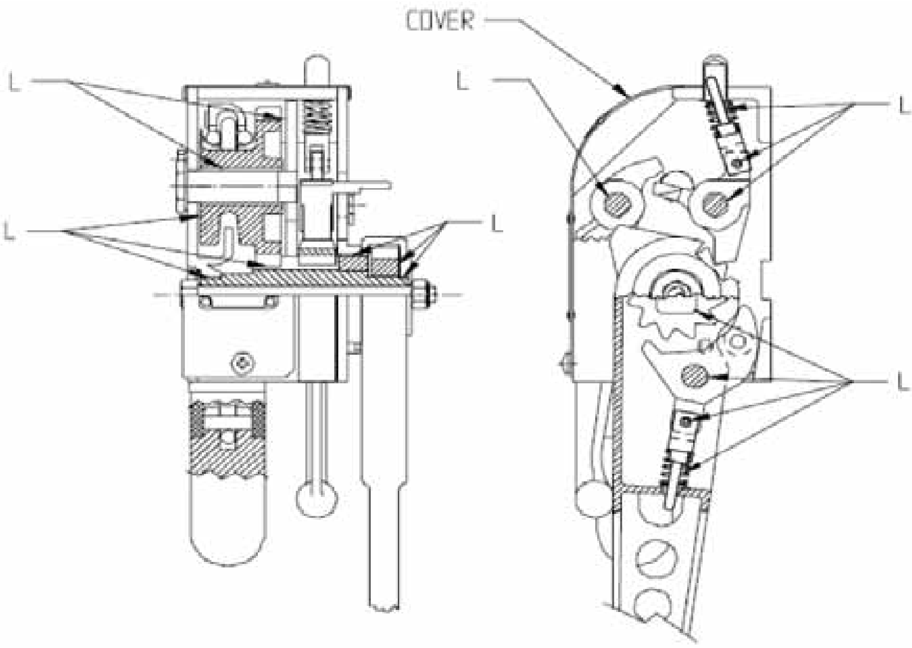
Model 800 Hand Brake; lubrication points.

1. Remove the Cover.
2. Lubricate all points as shown below.



Model 840 Hand Brake; lubrication points

1. Remove the Cover.
2. Lubricate all points as shown below.



Electric lever style parking brake maintenance and inspection.

At every locomotive maintenance interval as recommended by the manufacturer:

2.1 The parking brake should be checked for normal operation, both manual and automatic modes.

2.2 Mounting bolts should be checked and tightened if necessary.

2.3 Check the parking brake chain for excessive wear. (Reference shop standards.) Excessive chain wear will cause binding of the parking brake. Catastrophic chain failure can lead to injury or locomotive rollaway.

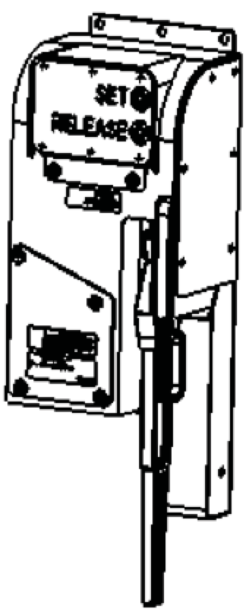
2.4 At the annual locomotive maintenance interval:

2.5 Do not remove the brake's front cover at annual inspection and test; the gear train does not require lubrication on an annual basis.

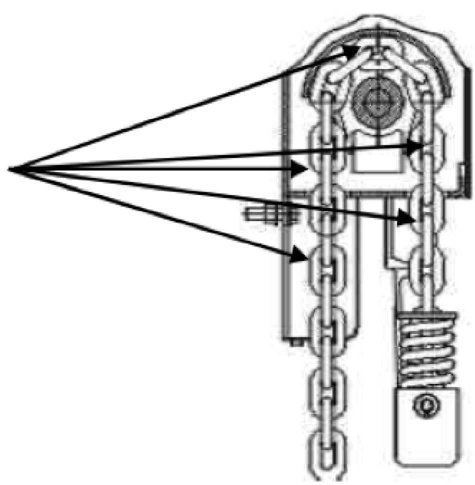
2.6 Grease the portion of the chain that makes contact with the take up sprocket as the chain passes back and forth through the brake. Use high quality NLGI #2 grease.

2.7 The manufacturer recommends lubricating the gear train as infrequently as possible.

393 Series



Section of chain lubricated during annual maintenance.



Manual wheel style maintenance and inspection.

Model 210 Inspection

3.1 Visually inspect hand brake assembly for defects.

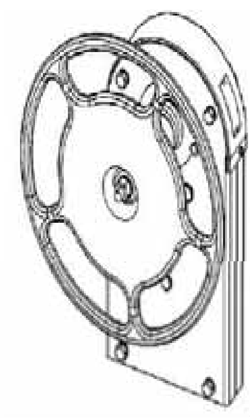
3.2 Ensure the hand brake FULLY applies and FULLY releases properly.

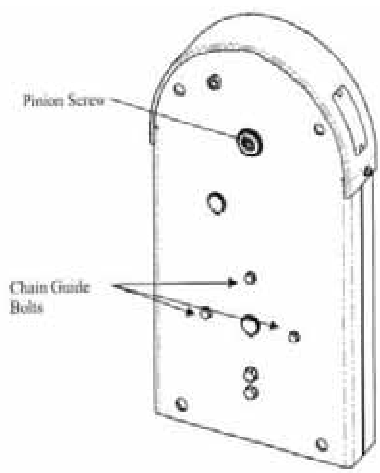
3.3 Inspect hand wheel drive shaft bearing wear. Drive shaft bearing wear can be measured using 3/32 inch hex wrench. If a ½ inch length of the wrench can be inserted between drive shaft bearing and the drive shaft. Wear in excess of 3/32 inch requires removal of hand brake.

3.4 Ensure that all bolts are tight.

3.5 If possible inspect the chain guide mounting bolts without removing the hand brake. If any Chin Guide bolt is missing or broken, remove the hand brake.

3.6 If possible inspect the rear Pinion Screw without removing the handbrake. If Pinion Screw is loose, broken or missing, remove the hand brake.





Manual wheel style hand brake continued.

Model 850 hand brake

4.1 Visually inspect hand brake assembly for defects.

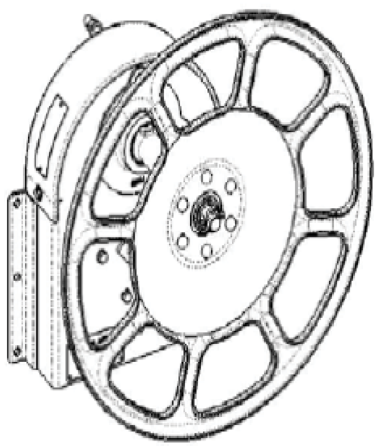
4.2 Ensure the hand brake FULLY applies and FULLY releases properly.

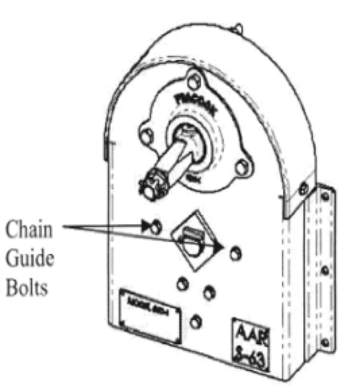
4.3 Inspect hand wheel drive shaft bearing wear. Drive shaft bearing wear can be measured using 3/32 inch hex wrench. If a ½ inch length of the wrench can be inserted between drive shaft bearing and the drive shaft. Wear in excess of 3/32 inch requires removal of hand brake.

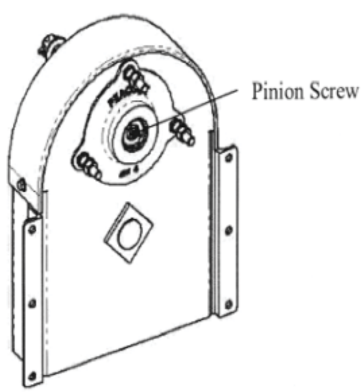
4.4 Inspect that all bolts are tight.

4.5 If possible inspect the chain guide mounting bolts without removing the hand brake. If any Chin Guide bolt is missing or broken, remove the hand brake.

4.6 If possible inspect the rear Pinion Screw without removing the handbrake. If Pinion Screw is loose, broken or missing, remove the hand brake.







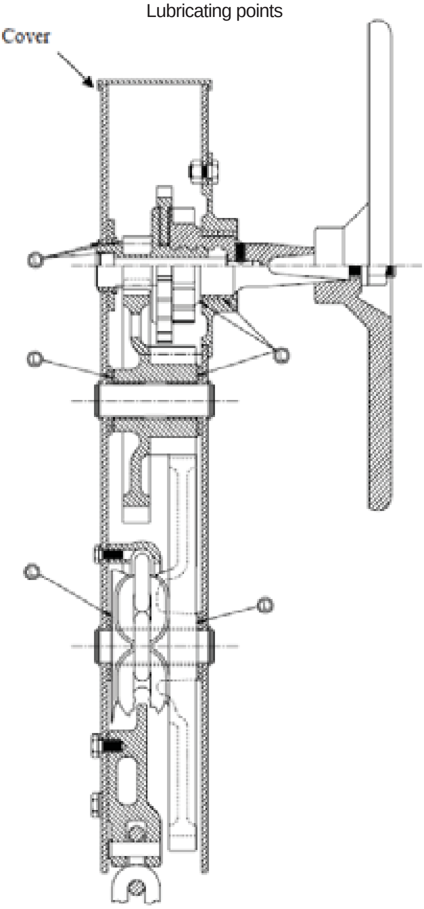
Manual wheel style hand brake lubrication.

5.1 To maintain operational efficiency of hand brakes it is recommended the brakes be periodically cleaned and lubricated. Use any good grade of lubricating oil or spray lubricant. The handbrake should be lubricated on during annual inspection.

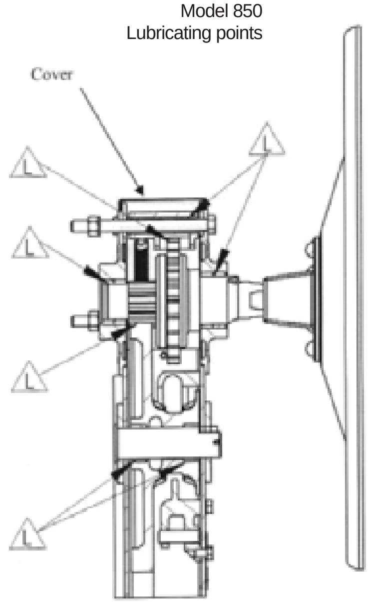
5.2 Remove the Cover.

5.3 Lubricate all points as shown below.

Model 210
Lubricating points



Model 850
Lubricating points



Electric wheel style maintenance and inspection.

6.1 During scheduled locomotive maintenance, the parking brake should be checked for normal operation.
6.2 Using the automatic controls, SET and RELEASE the parking brake three times. Brake operation should be consistent with appropriate LED's shown. The wheel should remain stationary during both set and release cycles.
6.3 Using the manual wheel, SET and RELEASE the parking brake three times. The amount of force required to set the brake should feel consistent from one application to the next. The amount of force required to release the brake should be much less than the force required for setting the brake. Any unusual slipping or pulling should be noted and reported.
6.4 During scheduled locomotive maintenance, all mounting bolts should be checked and tightened if necessary.
6.5 During scheduled locomotive maintenance, **the parking brake chain should be checked for excessive wear.** (Reference shop standards). <u>**Excessive wear will cause binding of the parking brake. Catastrophic chain failure can lead to injury or locomotive rollaway.**</u>

Annual Inspection
7.1 During annual inspection repeats checks 6.1 thru 6.5.
7.2 Apply lubrication to the portion of the chain which makes contact with the chain sprocket during operation of the brake. This will help minimize chain wear.
7.3 The manufacturer recommends the use of Loctite® Super Lube Grease with PTFE.
7.4 Operate the brake several times to assure lubrication is evenly dispersed.
7.5 Remove any access lubrication.

Annual handbrake system checks and maintenance for any locomotive parking brake.

1) Inspect pulleys, levers, and other rigging components for proper range of motion and ease of movement. Any bound, stuck or bent item should be repaired. A**ll pulleys should <u>rotate freely about their center pins</u>. Missing or damaged pulleys should be replaced.**

2) Check chain routing to assure chain is not rubbing against the through holes in the carbody or the chain intake hole underneath the parking brake. **<u>CHAIN WILL WEAR</u>**.

3) Record brake inspection per FRA requirements, **<u>49 CFR 232.205 (c).</u>**

Locomotive Washing Considerations

Users should follow the AAR's recommendations presented in Circular Letters C-9822 and C10762 when using high pressure washer to clean locomotives. Circular C-10762 specifically points to high pressure washes and/ or the use of chemical sprays as the root cause for certain hand brake failures.

References:
Safeset™ Locomotive Parking Brake, Operation and Maintenance Manual; Bulletin: OMM393 Series Revision D; Graham-White Mfg.

Electromotive M.I. 1577, Rev. A

Technical Service Bulletin, TSB-0081 Revision Level 10/9/09, Graham-White Mfg.

Ellcon National, Instruction 128; Revision 6-14-06

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Andrew Reid, CMO, Iowa Interstate Railroad

Mark Michel, Engineering Department, Ellcon National

Locomotive Cab Securement

Presented by:
Tom Kennedy, Union Pacific Railroad

With the increased focus on national security, locomotive Cab Securement has taken on a greater importance to protect against unauthorized locomotive operation. Protection of the crews from intrusion while operating, such as in a siding waiting on a signal, is also included in the Cab Securement umbrella. Additionally, with the increased integration of electronic equipment such as control computers, crew displays, Positive Train Control (PTC) equipment, etc. asset protection against theft and vandalism has become of paramount importance.

What is Cab Securement?

Simply put Cab Securement is securing the front and rear doors and ensuring that the window locks are fully functional, for both during crew operation and when the locomotive is unattended.

Is there an FRA Requirement?

FRA Emergency Order No. 28, Notice 1 was released August 02, 2013 that established additional requirements for attendance and securement of certain freight trains and vehicles on mainline track or mainline siding outside of a yard or terminal. This Emergency Order supplements FRA's Securement regulations of 49 CFR 232.103(n). The emergency order was released after the FRA re-examined its regulations governing securement after the July 06, 2013 derailment in Lac-Megantic, Quebec, Canada and upon review of its inspection records of securement defects that showed a significant non-compliance, approximately 4,950 recorded defects, across the railroads. There are detailed requirements in this FRA emergency order too numerous to attempt to summarize in this paper so it is left to the railroads to review the order and to develop their plan of compliance. As a final note, this FRA Emergency Order establishes significant penalties, potentially both civil and criminal, for noncompliance.

Is there an AAR Standard?

AAR standard S-5520, Locomotive Cab Securement, was adopted in 2012 and revised May 2014. In addition to basic security requirements, central to this standard is the adoption of a standard lock and key set for the cab front door to ensure that interchanged locomotives can be unlocked and secured when on foreign railroads. In the interest in avoiding duplication herein please refer to S-5520 for identification of the lock and key requirements.

This standard also requires that all locomotives in interchange service must be equipped to this standard no later than March 01, 2017.

How is the Cab Secured?

Different model locomotives have different provisions for door securement but all follow a similar strategy. The rear cab door on road units is typically secured with a slide bolt from the cab interior such as that shown in Picture # 1. Some models may incorporate an internal latching mechanism in the door latch as shown in Picture #2. Some models may have front door latches not equipped with an internal latching mechanism as shown in Picture #3. Regardless of whether or not the door latch incorporates an internal latching mechanism a deadbolt latch must be incorporated to ensure proper door securement.

Picture 1

Picture 2

Picture 3

Models with front vestibule doors typically have latch assemblies incorporating a locking mechanism into the latch or have a separate slide bar latch that the crew can latch to provide for crew security. Typical latch assemblies for front vestibule doors are shown in Pictures 4, 5, and 6.

Picture 4

Picture 5

Picture 6

The front cab door typically incorporates a standard latch that may or may not incorporate an internal latching and locking mechanism, depending on customer requirements. The cab securement program provides for the application of an external latch that the crew can secure when leaving the locomotive unattended. Railroads have taken different approaches to securing the front door but as per AAR standard S-5520 discussed above, a standard key and lock have been specified to ensure that secured cabs of foreign railroads can be unlocked during interchange. Two approaches for external cab securement are shown in Pictures 7 and 8.

Picture 7

Picture 8

Key features of the approach shown in Picture 7are: 1) the slide bar when extended blocks the front of the door from opening, 2) the key remains in the lock until locked to serve as a reminder to place the latch in a locked or unlocked state, and 3) the slide bar is installed at an upward angle to prevent door blockage in the event that the latch was not secured in the unlocked position upon crew entry into the cab. Picture 8 shows the door secured by welding locking tangs onto the nose frame and front cab door.

Whatever approach is chosen be careful with the installation to prevent creating a problem such as a snag or pinch point hazard. Additionally, for crew egress safety or access for emergency responders, the front door latch must be in the unlocked position before locomotive dispatch.

The last element of cab securement is ensuring that the cab windows are equipped with a latching device in the interior of the cab to prevent them from being opened from the exterior of the cab. Picture 9 shows a typical cab sliding window latch in the center of the window.

Picture 9

Cab Securement Equipment Maintenance?

Periodic maintenance is critical to maintaining optimum performance of the cab securement provisions. The periodic maintenance consists of an inspection for proper function and the application of a good quality lubricant with a water dispersant, anti-corrosion preventative, and good penetrating and clinging properties. The recommended inspection and lubrication interval is at least every six months or more often as indicated by railroad experience. For the lubricant there are numerous products commercially available on the market meeting the above requirements, such as those designed for firearm cleaning, maintenance, and preservation. The selection of the appropriate product is left to the railroad. As a final note do not over lubricate and cleanup overspray or over application to minimize dirt and dust collection which can lead to premature failure.

Summary

Cab Securement is an FRA mandate with AAR requirements that helps prevent unauthorized locomotive operation or movement and assist in asset protection and help reduce vandalism and theft. Please refer to the previously referenced FRA and AAR documents for the specific requirements.

The Drooping Brake Head – A Perennial Problem

Presented by:
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Written & Illustrated by:
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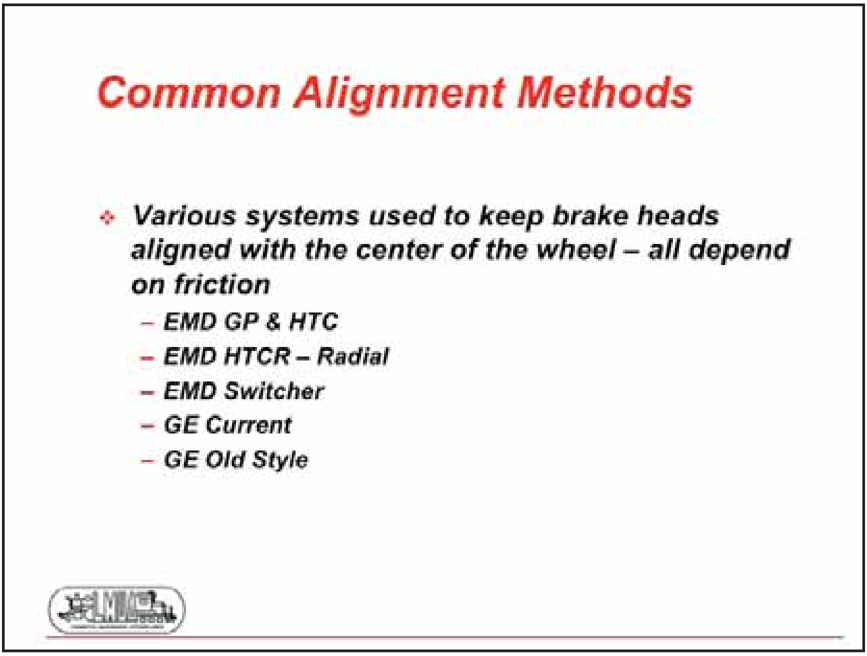
Figure 1

The drooping brake head is a common problem every inspector has witnessed at one time or another when inspecting locomotive brake rigging. In Figure 1, the drooping brake head condition can result in uneven and excessive brake shoe wear. If not repaired, this condition can potentially damage the brake head and possibly damage the locomotive wheel. I plan to cover the various methods (listed below) currently being used to insure the brake head alignment with the center of the wheel, advantages and disadvantages with different methods, and what can be done to accomplish the repair when the problem occurs.



First, all locomotive brake rigging is designed to keep the brake head aligned to the center of the wheel. This alignment is accomplished when the brakes are applied and should remain when the brakes are released. Over the last several decades, a wide variety of systems have been used to accomplish this. The systems currently used by EMD and GE have evolved into relatively simple and cost effective systems. The list above illustrates the systems which are seen on most current locomotives. As mentioned, all system varieties rely on friction to hold the brake head in alignment. Component wear and damage affects the ability of these systems to maintain this alignment.

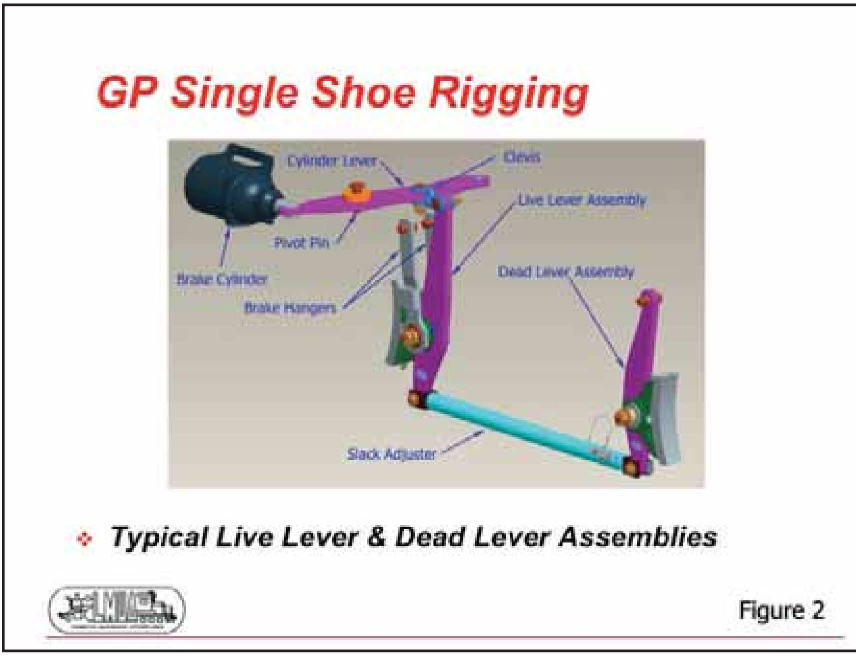


Figure 2

Live and dead lever assemblies will be addressed frequently in this paper. Figure 2 illustrates typical GP single shoe brake rigging and the basic parts of the brake rigging system. The cylinder braking force is transmitted through the cylinder lever to the live lever assembly which is hung from the frame by the brake hangers. The force is transmitted through the slack adjuster to the dead lever assembly. The dead lever is hung directly on the frame.

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cover a lot of ground.

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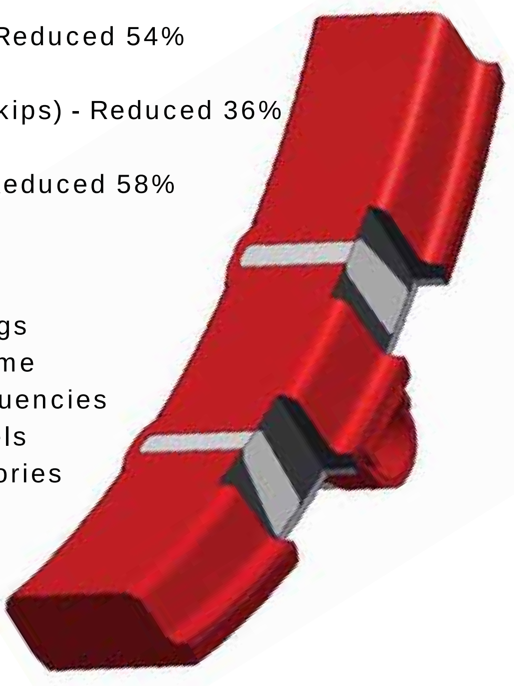

BENEFITS:

- Reduces Wheel Set Turnings
- Reduces Out of Service Time
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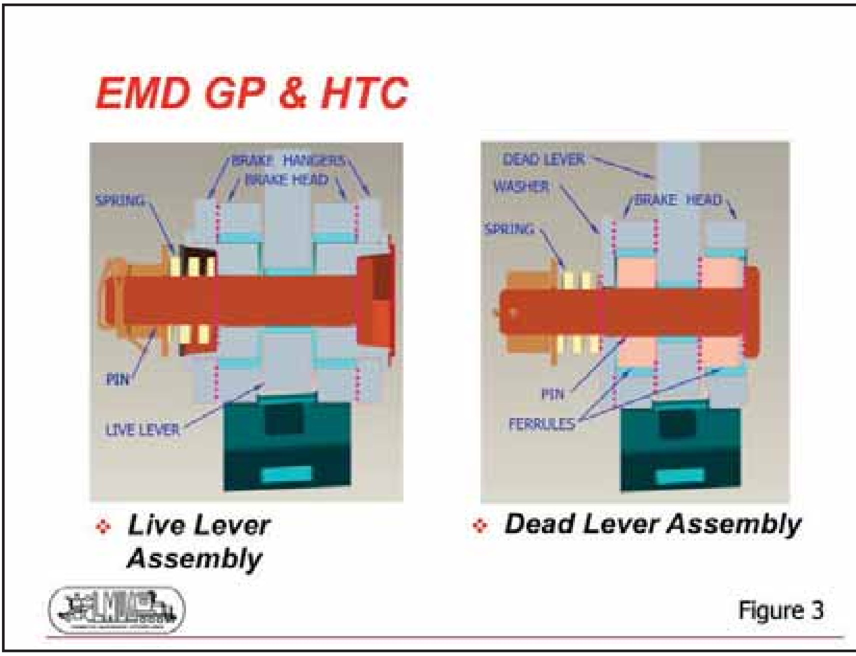
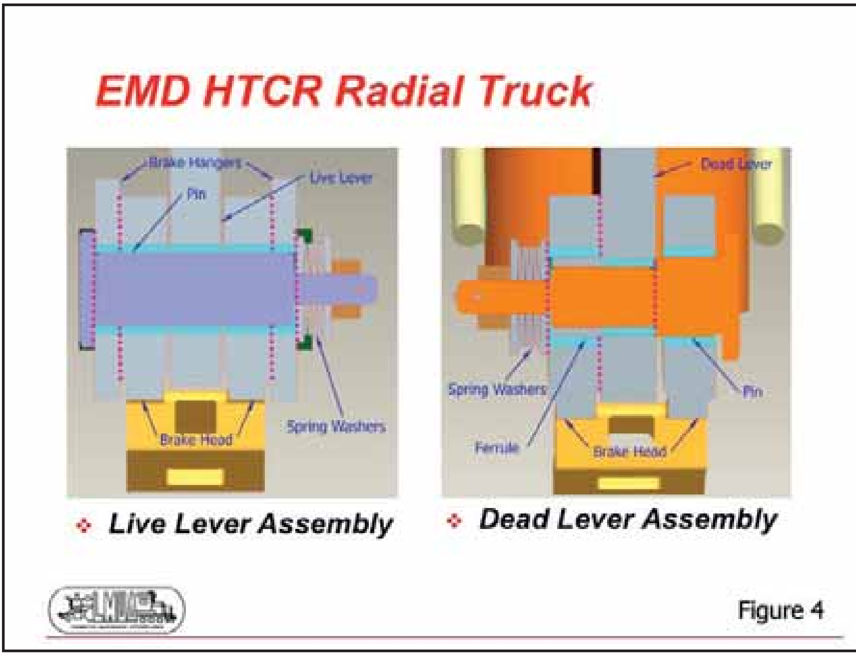


Figure 3 illustrates the alignment system currently used on EMD GP and SD HTC brake rigging (both clasp and single shoe arrangements). In this system, a spring load is applied through the pin which applies friction to keep the brake head aligned. This system is assembled with the spring set to a specific height. This allows for a predictable friction force which carries a significant advantage when trying to maintain proper brake shoe alignment.

The live lever assembly includes two brake hangers which are held against the outer surface of the brake head by spring force applied through the pin. The brake lever is allowed to move freely. The red dotted areas illustrate where the friction force acts to maintain alignment. This friction force is quite high, at approximately 1200 lbf.

In reference to the dead lever assembly, the friction force is applied though the inner ferrule, against the lever, and then against the brake head. The friction force keeping the brake head aligned is identical to the force on the live lever.



On the more recent EMD radial trucks, a somewhat similar system is used as shown on Figure 4. This arrangement uses spring washers (Belleville springs) to apply the friction load. The spring washers are again assembled to a specific height giving a predictable friction force. It is believed the spring washers were used to avoid a clearance issue caused by the greater height of the previous coil spring arrangement. Similar to the GP/HTC arrangements, on the radial truck, friction on the live lever assembly is applied though the brake hangers against the brake head. The lever is free to move. On the dead lever assembly, a stepped feature on the pin applies force against the lever which is held against the inside of the brake head. Therefore, the brake head is held in alignment with the lever.

While this arrangement solves the clearance problem, there have been some additional reported challenges. First, the spring washers must be assembled in the correct orientation to yield the desired and designed friction load (see Figure 5 for correct orientation).

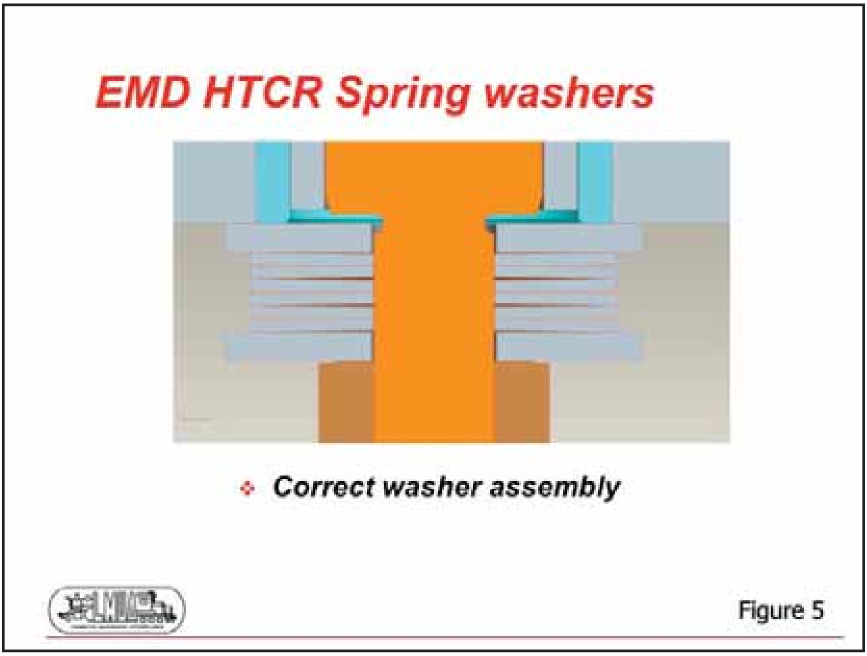


Figure 5

Second, there have been reports of pin failures due to the small diameter of the threaded shank on the pin. Finally, the relatively small bearing area of the spring washer can wear into the mating parts reducing the available friction force. For locomotive applications where clearance is not an issue, some major railroads have specified a change and are using the "old style", and obviously preferred, coil spring loaded pin. These arrangements are available, but the user must be sure that there is sufficient clearance on the particular application for the approximately .75" greater length of the coil spring arrangement. The modified arrangement is similar to the GP/HTC pin arrangement.

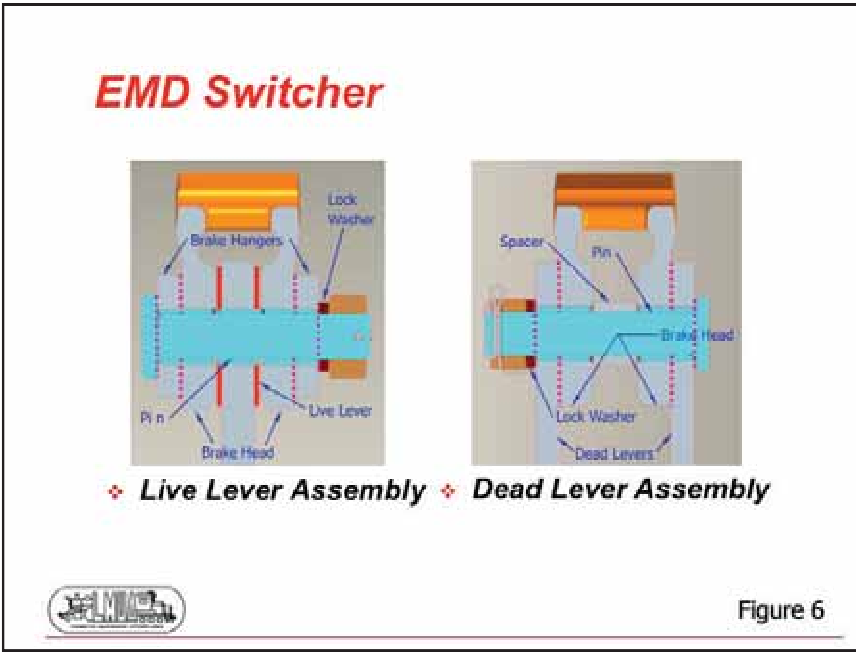
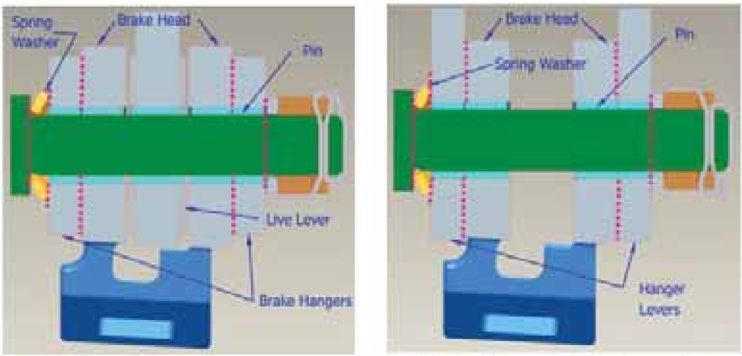


Figure 6

There are two styles of trucks when referencing EMD switcher style trucks, both rigid-AAR and flexible (or flexicoil). A simpler system is used with these styles of locomotive truck as shown in Figure 6. This system does not use a spring. Alternatively, it applies the friction force through a lock washer tightened until the cotter pin can be applied. On the live lever assembly, the brake hangers are held against the brake head and the lever is free to move. On the dead lever assembly, the hanger levers are held against the brake head and a spacer is added to prevent deformation of the brake head. While this system is simple, there are potential pitfalls and challenges to be concerned with. First, the friction force is not predictable since it depends on manual tightening of the nut. Secondly, over tightening can result in brake head deformation and binding of the brake rigging.

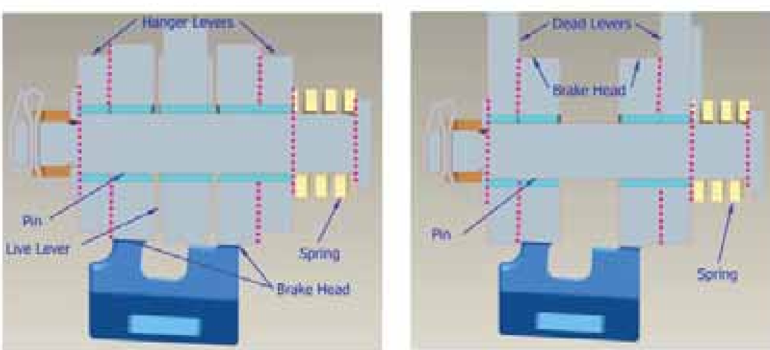
GE Old



- Live Lever Assembly
- Dead Lever Assembly

Figure 7

GE Current



- Live Lever Assembly
- Dead Lever Assembly

Figure 8

Figures 7 and 8 reference GE locomotives. For many years, GE used an arrangement similar to the EMD switcher as illustrated on Figure 7. The major difference was that GE used a single large spring washer in addition to the lock washer. This arrangement has the same disadvantages as the EMD switcher arrangement. In addition the hardened spring washer could wear into the softer material of the mating parts. Recognizing this as a problem, more recent GE locomotives have used a spring loaded pin arrangement as shown on Figure 8. On the live lever assembly, the brake hangers clamp against the brake head leaving the lever free. On the dead lever assembly, the hanger levers clamp against the brake head holding it in alignment. In most cases, the new spring arrangement can be used to replace the older spring washer arrangement. There may be certain trucks where interference occurs. So, checking for interference issues must be accomplished prior to attempting the conversion.

So, what can you do if your brake head is drooping?

EMD GP/HTC/Radial

- Disassemble the brake rigging and check for wear. Replace worn parts (i.e. pins, bushings, springs, washers, ferrules, spacers, etc.).

EMD Switcher

- Tighten the nut, insuring not to over tighten and distort the brake head.

GE Old Style

- Tighten the nut, insuring not to over tighten causing distortion of the brake head.
- If this doesn't work, disassemble, check components for wear and replace worn parts as necessary (i.e. pins, bushings, washers, etc.).
- Assuming no clearance issues, replace the current pin assembly with the spring arrangement.

GE Current Style

- Tighten the nut slightly to move the cotter to the next slot in the nut.
- If unsuccessful, disassemble, check components for wear and replace worn parts as necessary.

Conclusion

After reviewing the positives and negatives of the various current systems, the coil spring loaded pin system of the EMD GP/HTC and the GE Current system appear to be the most effective. Both systems have an easily determined preload on the pin which is applied by setting the spring height. Additionally, the larger pin threads reduce the risk of pin failure and the larger bearing surfaces make the pins more resistant to wear effects.

Constitution and By-Laws Locomotion Maintenance Officers Association

Revised September 22, 2003

Article I – Title:

The name of this Association shall be the Locomotive Maintenance Officers Association (LMOA).

Article II – Purpose of the Association

The purpose of the Association, a non-profit organization, shall be to improve the interests of its members through education, to supply locomotive maintenance information to their employers, to exchange knowledge and information with members of the Association, to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad industry.

Article III – Membership

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

Section 2- Associate Membership shall be composed of persons currently or formerly employed by a manufacturer of equipment or devices used in connection with the maintenance and repair of motive power, subject to approval of the General Executive Committee.

Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at Annual Meeting, and shall have the privilege of voting or holding elective office.

Section 3- Life membership shall be conferred on all past Presidents. Life membership may also be conferred on others for meritorious service to the Association, subject to the approval by the General Executive Committee.

Section 4- Membership dues for individual railroad and associate membership shall be set by the General Executive Committee and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end on September 30. Members whose dues are not paid on or before the opening date of the annual convention shall not be permitted to attend the annual meeting, shall not be eligible to vote and/or shall not be entitled to receive a copy of the published Pre-Convention Report or the Annual Proceedings of the annual meeting. Failure to comply will result in loss of membership at the end of the current year. Life members will not be required to pay dues, but be entitled to receive a copy of the

Pre-Convention Report and Annual Proceedings.

Article IV- Officers

Section 1- Elective Officers of the Association shall be President, First Vice President, Second Vice President, and Third Vice President. Each officer will hold office for one year or until successors are elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, he may continue to serve as an executive officer and be allowed to elevate through the ranks as naturally as occurs, to include the office of President.

Section 2- There shall be one Regional executive officer assigned to oversee each technical committee. Regional Executives shall be appointed from the membership by the General Executive Committee for an indefinite term, with preference given to those having served as a Technical Committee Chairperson. A Regional executive who leaves active service may continue to serve as such, and shall be eligible for nomination and election to higher office.

Section 3- There shall be a General Executive Committee composed of the President, Vice Presidents, Regional Executives, Technical Committee Chairpersons, and all Past Presidents remaining active in the association.

Section 4- There shall be a Secretary- Treasurer, appointed by, and holding office at the pleasure of the General Executive Committee, who will contract for his or her services with appropriate compensation.

Section 5- All elective officers and Regional Executives must be LMOA members in good standing. (See Article III, Section 4.)

Article V- Officer, Nomination, and Election of

Section 1- Elective officers shall be chosen from the active membership. A Nominating Committee, composed of current elective officers and the active Past Presidents, shall submit the slate of candidates for each elective office at the annual convention.

Section 2- Election of Officers shall be determined by a voice vote, or if challenged, it shall require show of hands.

Section 3- Vacancies in any elective office may be filled by presidential appointment, subject to approval of the General Executive Committee.

Section 4- The immediate Past President shall serve as Chairman of the Nominating Committee. In his absence, this duty shall fall to the current President.

Article VI- Officers- Duties of

Section 1- The president shall exercise general direction and approve expenditures of all affairs of the Association

Section 2- The First Vice President, shall in the absence of the President, assume the duties of the President. He shall additionally be responsible for preparing and submitting the program for the Annual Meeting.

The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers to underwrite the cost of the **Annual Proceedings.**

The third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly distributed, monitoring membership levels and reporting same at the General Executive Committee.

The Vice Presidents shall perform such other duties as are assigned them by the President.

Section 3-The Secretary-Treasurer shall:

A. Keep all the records of the Association.

B. Be responsible for the finances and accounting thereof under the direction of the General Executive Committee.

C. Perform the duties of the Nominating Committee, and General Executive Committee without vote.

D. Furnishing security bond in amount of $5000 of behalf of his/her assistants directly handling Association funds. Association will beat the expense of such bond.

Section 4-The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.

B. Monitor material to be presented by the technical committees to ensure reports are accurate and pertinent to the goals of the Association.

C. Attend and represent LMOA at meetings of their assigned technical committees.

D. Promote Association activities and monitor membership levels within their assigned areas of responsibility.

E. Promote and solicit support for LMOA by helping to obtain advertisers.

Section 5-Duties of General Executive Committee:

A. Assist and advise the President in long-range Association planning.

B. Contract for the services and compensation of a Secretary-Treasurer.

C. Serve as the Auditing and Finance Committee.

D. Determine the number and name of the Technical Committees.

E. Exercise general supervision over all Association activities.

F. Monitor technical papers for material considered unworthy or inaccurate for publication.

G. Approve topics for the Annual Proceedings and Annual Meeting program.

H. Approve the schedule for the Annual program.

I. Handle all matters of Association business not specifically herein assigned.

Section 6-The General Executive Committee is entrusted to handle all public relations decisions within LMOA and coordinated associations with confidentiality.

Article VII-Technical Committees

The technical committees will consist of:

Section 1-A chairperson, appointed by the President and approved by the General Executive Committee.

Section 2- A vice Chairperson, selected by the chairperson and approved by the President.

Section 3-Committee members as follows:

A. Representatives of operating railroads and regional transit authorities submitted by their Senior Mechanical and Materials Officers and approved by the President of LMOA.

B. Representatives of locomotive builders designing and manufacturing locomotives in North America.

C. The Fuel and Lube Committee will include members from major oil companies or their subsidiaries as approved by the General Executive Committee.

D. At the direction of the General Executive Committee, non-railroad personnel may be allowed to participate in committee activities.

Section 4-All individuals who are on technical committees must be LMOA members in good standing (See Article III, Section 4).

Section 5-Subjects for technical papers will be selected and approved by the General Executive Committee.

Article VIII-Proceedings

Section 1-The Locomotive Maintenance Officers Association encourages the free interchange of ideas and discussion by all its attendees for mutual benefits to the railroad industry. It is understood that the expression of opinion, or statements by attendees in the meetings, and the recording of papers containing the same, shall not be considered as representatives or statements ratified by the association.

Section 2-Those present at any meeting called on not less than thirty days advance written notice shall constitute a quorum

Article IX-Rules of Order

The proceeding and business transactions of this Association shall be governed by Robert Rules of Order, except as otherwise herein provided.

Article X-Amendments

The Constitution and By-Laws may be amended by a two-thirds vote of the active members present at the Annual Meeting.