LMOA

Locomotive Maintenance Officers Association

Proceedings of the 74th Annual Meeting

SEPTEMBER 22-25, 2012

Chicago, Illinois

2012 Advertisers Index

Amglo Kemlite 189
Amsted Rail Group 69
Bach Simpson . . . . 181 & 185
Clark Filter 55
Electro Motive Diesels (EMD) 79
Graham White 89
Hotstart 93
Industrial Specialty Chemicals, Inc 121
LPI Lift Systems 225
Magnus, LLC 19
Miba Bearings , U.S. 7
Morgan AM&T 147
Mosebach Manufacturing 45
MPL Technology . . . . .49 & 171
Peaker Services . . . . .Outside Back Cover
Penn Locomotive Gear . . . . .Inside Back Cover
Power Rail Distribution 27
Rail Products Intl 61
Railroad Friction Products 15
Safety Kleen Systems Inc 135
Simmons Machine Tool 217
Snyder Equipment Inc . . . . Inside Front Cover
Tame, Inc 105
Transportation Equipment Supply 209
Trico Corp 127
Wabtec Global Services 39
ZTR Control Systems . . . . 97, 159, 201 and 203

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Simmons Machine Tool

Snyder Equipment, Inc.

Tame, Inc.

Transportation Equipment Supply

Trico Corp.

Wabtec Global Services

ZTR Control Systems

2012 TOC and Index

List of LMOA Advertisers 2

LMOA MVP Recipients 4

State of the Union Address 20

Acceptance Speech 24

Diesel Material Control Committee 28-46

Diesel Mechanical Maintenance Committee 47-116

Fuel, Lubricants and Environmental Committee 117-145

New Technologies Committee 146-187

Diesel Electrical Maintenance Committee 188-212

Shop Safety, Processes and Equipment Committee 213-232

LMOA By-Laws 233-236

2011 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 2011.

NAME	COMMITTEE
Keith Mellin	Diesel Electrical Maintenance
Derald Sweatt	New Technologies
Tim Standish	Diesel Mechanical Maintenance
Joe Hiznay	Fuel, Lubricants and Environmental
Paul Foster	Diesel Material Control

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

LMOA EXECUTIVE COMMITTEE

The executive officers of the Locomotive Maintenance Officers Association wish to express their sincere gratitude and appreciation to the Burlington Northern Santa Fe Railway for hosting and supporting the annual LMOA joint technical committee meeting in Overland Park, Kansas on May 8 and 9, 2012.

Special thanks go to Bill Smith, Bryan Asher, Ron Douglas, Jeffrey Garrels and Bennie Fortner who gave tours of the Overland Park Training Center to LMOA committee members and for hosting the luncheon on Monday, May 8th.

Special recognition is given to Brad Queen, BNSF and 1st VP of LMOA and our President, Ron Bartels, Via Rail, for making all the necessary arrangements that resulted in a productive and successful joint committee meeting.

The executive officers of the Locomotive Maintenance Officers Association wish to express their sincere gratitude and appreciation to Dwight Beebe, Temple Engineering, and chairman of the Fuel, Lubricants and Environmental Committee for sponsoring the luncheon meeting of the executive committee of LMOA in Minneapolis, Minnesota immediately following the conclusion of the September 2011 rail show.

Thanks Dwight for your continued support of the organization.

PAST PRESIDENTS

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

1982	N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
1983	F.D. BRUNER (Deceased), Asst. Chief Mechanical Officer, R&D, Union Pacific RR
1984	R.R.HOLMES, Retired Director Chemical Labs & Environment, 600 Brookestone Meadows Place, Omaha, NE 68022
1985	D.M.WALKER, Retired, Asst. Shop Manager, Norfolk Southern Corp, 793 Windsor St, Atlanta, GA 30315
1986	D.H.PROPP, Retired, Burlington Northern RR, 10501 W. 153rd St, Overland Park, KS 66221
1987	D.L.WARD (Deceased), Coordinated-Quality Safety & Tech Trng, Burlington Northern RR
1988	D.G. GOEHRING, Retired, Supt. Locomotive Maintenance, National RR Passenger Corp, 1408 Monroe, Lewisburg, PA 17837
1989	W.A.BROWN, Retired, I&M Rail Link, 9047 NE 109th St. Kansas City, MO 64157
1990	P.F.HOERATH, Retired, Sr. Mech. Engr. Shop, Conrail 1534 Frankstown Rd, Hollidaysburg, PA 16648
1991	D.D.HUDGENS, Retired, Sr Mgr R&D, Union Pacific, 16711 Pine St., Omaha, NE 68130
1992	K.A.KELLER, Retired, Supt. Locomotive Maint, Reading RR, 241 E. Chestnut, Cleona, PA 17042
1993	W.R.DOYLE, Project Manager, Sound Transit, Seattle, WA 98104
1994	M.A.COLES, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
1995	C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
1996	G.J.BRUNO, Retired, Supt.-Mechanical, Amtrak 14142 S.E. 154th Pl, Renton, WA
1997	D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
1998	H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
1999	JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak 1130 Walnut Ave, Osawatomie, KS 66067
2000	RON LODOWSKI, Production Mgr, CSX Transportation, Selkirk, NY 12158
2001	LOU CALA, Retired, Duncansville, PA 16635
2002	BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
2003	BRIAN HATHAWAY, Consultant, Port Orange, FL 32129
2004	BILL LECHNER, Retired, Sr Genl Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp, Altoona, PA 16601
2005	TAD VOLKMANN, Director-Mech. Engrg., Union Pacific RR, Omaha, NE 68179
2006	BRUCE KEHE, CMO, CSS&SB, Michigan City, IN 46360
2007	LES WHITE, Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
2008	MIKE SCARINGE, Director-Locomotives, Amtrak, Beech Grove, IN 46109
2009	DENNIS NOTT, Northwestern Consulting, Boise, ID 83703
2010	BOB REYNOLDS, Sales Manager, Amglo Kemlite Laboratories, Calgary, Alberta T24 2V8
2011	JACK KUHNS, V.P. Sales, Graham White, Salem, VA 24153

Our Officers

President

MR. RON BARTELS

Sr. Manager - Equipment Reliability and Electrical Engineering

Via Rail-Canada

Montreal, Quebec

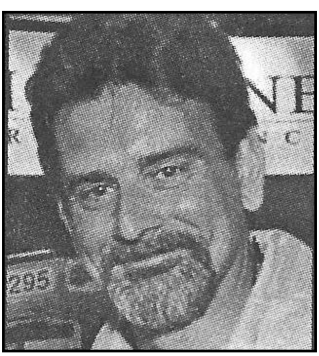
1st Vice President

R. BRAD QUEEN

Manager of Locomotive Utilization

BNSF Railway

Fort Worth, TX



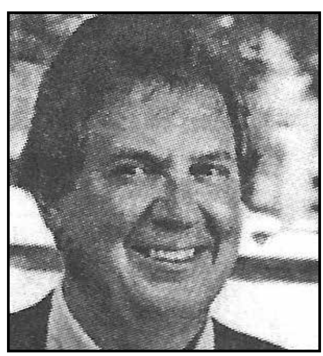
2nd Vice President

DAVE RUTKOWSKI

Chief Mechanical Officer

Providence & Worcester RR

Worcester, MA



3rd Vice President

MR. BOB HARVILLA

Asst. VP - Regional Sales

Power Rail Distribution

Duryea, PA

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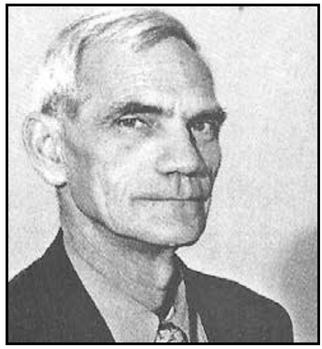
MR. WEYLIN R. DOYLE
Project Manager
Sound Transit
Seattle, WA 98104



MR. BRIAN HATHAWAY
Consultant
Port Orange, FL 32129

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

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

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Chairman of Nominating Committee

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V.P. Sales

Graham White Manufacturing

Salem, VA 24153

MR. BOB REYNOLDS

Sales Manager

Amglo Kemlite Laboratories

Calgary, Alberta T2Y 2V8

MR. ROBERT RUNYON

Retired

Norfolk Southern Corp.

Engineering Consultant

Roanoke, VA 24042

MR. MIKE SCARINGE

Director -Locomotives

Amtrak

Beech Grove, IN 46107

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

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

Our Regional Executives

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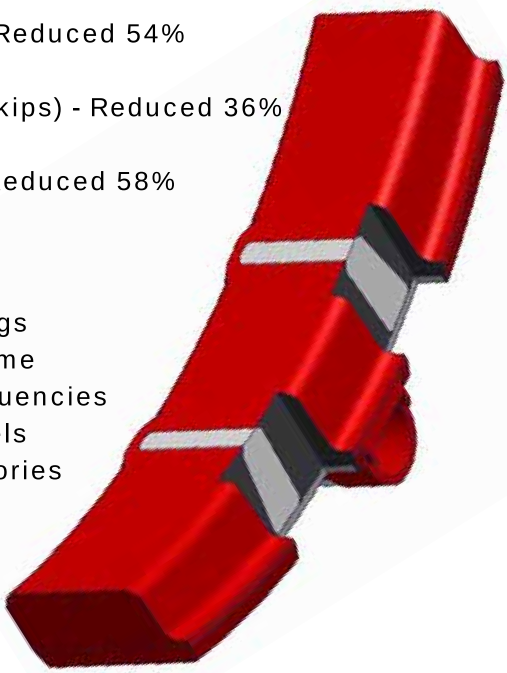

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Executive Officers at the 2011 Minneapolis Convention -left to right -Newly Elected 3rd VP Bob Harvilla, Power Rail Distribution, Past President Bob Runyon, Consultant, Past President Tad Volkmann, Union Pacific, Newly Elected President, Ron Bartels, Via Rail-Canada, Newly Elected 2nd VP Dave Rutkowski, Providence & Worcester RR, Outgoing President, Jack Kuhns, Graham White, Past President Bruce Kehe, Gary Railway, Past President Mike Scaringe, Amtrak and Newly Elected 1st VP Brad Queen, BNSF Rwy

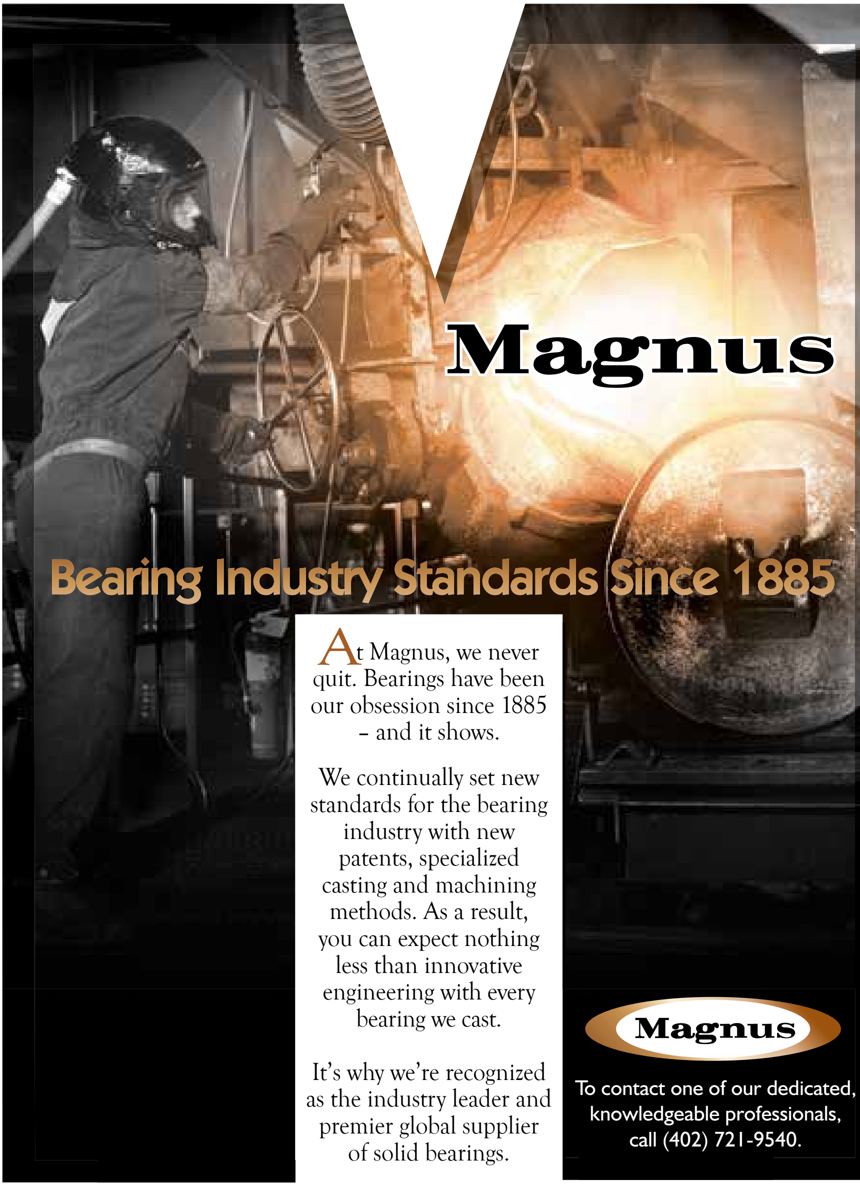
Past President Bob Runyon, Consultant, helping Newly Elected 2nd VP Dave Rutkowski, Providence & Worcester, put on his LMOA Blazer as Newly Elected President Ron Bartels, Via Rail-Canada looks on

Newly Elected President Ron Bartels, Via Rail-Canada, helps Newly Elected 3rd VP Bob Harvilla, Power Rail, put on his LMOA Blazer

Outgoing President Jack Kuhns, Graham White, (right) presents gavel to Newly Elected President Ron Bartels, Via Rail-Canada, which was witnessed by Past President Bruce Kehe, Gary Railway (center)

Past Presidents (left to right) Mike Scaringe, Amtrak, Jack Kuhns, Graham White and Bruce Kehe (Gary Railway) pictured with their LMOA Past Presidents Pins

Past President Tad Volkmann, Union Pacific (left), presents LMOA Watch to Outgoing President Jack Kuhns, Graham White. Newly Elected 1st VP Brad Queen, BNSF, attended the ceremony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2011 State of the Union Address

Monday, September 19, 2011–Minneapolis MN

President Jack Kuhns

Let's start with industry challenges we have faced this year- Weather extremes have played a big role this year. Heavy 2010/11 winter snowfalls helped set the stage for rain induced flooding in the western and northern plains, record high temperatures this summer across the nation resulting in wide-ranging drought, tornadoes in the south and so far this year one hurricane that hobbled the northeast causing major flooding and record rainfalls creating transportation problems for commercial operations and commuters alike.

These events while localized were no less an extreme burden on our industry overall for service interruptions, equipment damage and maintenance related problems. In spite of all these events and certainly some are on-going and may leave lasting effects, many have experienced a strong uptick in our related businesses. While car loadings trends have flattened somewhat in recent weeks, overall service demands are still at very high levels while we continue to rush headlong into what is widely considered to be the fall peak season.

The subject of what makes railroads excellent investments can be, and is often, debated but I believe it is our historical ability to deal with such aforementioned adversity that sets us apart.

However, when it comes to discussion about how our industry is perceived as an economic bellwether; it is a short conversation, this is simply fact. Most will say it is because our industry is historically flexible and more resilient to the rapid rise and fall of the economy than others due to the wide range of products serviced bridging the entire economic pyramid. From the base to the top, from basic foodstuffs, grains, corn and wheat to all manners of finished goods and of course the backbone of worldwide energy production, coal. Analyst's observations generally concur that this is largely due to tightly controlled and planned spending managed by forward thinking, well developed and mature organizations. As an industry we do not tend to re-invent the wheel even though we are always looking towards technological breakthroughs that will allow for game-changing advances.

Federal regulations on equipment requirements and operations also have negative impacts that must be overcome or absorbed into our respective business models while still providing the return the investors expect. Based on this simple and selective overview, you might guess I am suggesting the RR's are hauling the nation's economic recovery. We have a strong history of doing just that and I doubt we intend to let these latest issues become excuses, I would suggest you not stand in our way! As an industry let us all help haul the nation forward through cooperation and communication. On another note, let us not be confused, our competition is ourselves. We as an industry are blessed with a distinct advantage over highway hauling of goods and services, our fuel efficiency cannot be matched, however, our competitor's flexibility and timely service are the benchmarks we must embrace. We can learn best practices from one another; apply them to our products and services, then we can put some real distance between us and them. Our goal should be to make the decision as to which form of transportation services are used, a simple one, Rail! Some obvious specifics are: Application and maintenance of PTC equipment will require additional training and process incorporation to become manageable. Several roads are well on their way to meeting the deadlines for installation and implementation. However, it could be a case of we don't know yet what we don't know! Perseverance, Training and Cooperation will be the order of the day here. Fleet size analysis-This is certainly not a new challenge, it is probably one of the oldest but certainly one of the most complex questions debated among operators. Replace with new, upgrade existing models or run to failure…. Our slow down of 2009 idled much of our industry's fleets. We learned some valuable lessons regarding storage dos and don'ts. Please reference the on-going LMOA papers dedicated to this topic, using collective knowledge that was gathered and vetted, followed with "Best Practices" recommendations.

Also influencing fleet decisions will be emissions opportunities that will continue to present themselves. Making the best choice from available solutions will be the result of thorough study as to the true life cycle costs as well as allowing for commercial and tactical advantages based on these choices. Ongoing issues related to the 30/60 rule persist, the need for advanced training at the same time as basic training presents a real challenge. Finding and then keeping good employees is an ongoing challenge. Managing the upturn in business presents hiring and planning concerns, is this here to stay? Do I increase my workforce or production capacity to handle business spike levels or do I "make due" and plan conservatively for a medium? Will I be able to satisfy my customers with these choices and still remain loyal to my workforce? Should I make a bold investment into a new product or process during these difficult to judge cycle phases of business? Industry Opportunities- Identify what is important to you and then focus on it! All of us have opportunities to improve-There are ways to reduce dwell time, throughput speed and train speed by making investments in human resources or by embracing new shop scheduling technology or time saving products. At our joint meeting held in Omaha in May and hosted by UP, John Estes offered some insight and challenges to our group. He suggested those producing products to design for efficiency, maintainability and most of all, system compatibility. I feel this is now the era of communication, open communication, more important now than ever before. I was once told (not that many years ago it seems) that I should find another line of work. Face to Face communication is a thing of the past, with all the information available on the internet, who needs someone talking in front of you much more slowly than you can read…fast forward to present day I maintain that the opposite is what has become the truth! With the pace of business we all operate at now, we have to rely on others to sort through TMI, we MUST be able to trust others and take their word for what they have gleaned through their research and can then digest it for you. Trust does not come easily. Only those with a proven track record of honesty will be afforded this level of trust.

Of course we all have the opportunity to research every possible option, but do we have the ability? The time? Rest assured, what has been a constant of communication and a cornerstone of our industry has been the LMOA. In its 73th year, it has been described as an elite think tank or study group…. or a collection of industry geeks! The basis for meeting "qualifications" for membership has always been the same- self-starting professionals who have found that they need an additional creative outlet to satisfy their souls. They all contain some level of a passion for learning, sharing and creating. They desire to influence policies, industry practices and likewise their own careers. They find an outlet for these energies through the LMOA. They can be compared to the athlete who sticks around after the game to practice his free throws or heads to the weight room after practice or goes to the driving range after a match to refine his shots. Professionals…in their own right are always looking to improve their knowledge and performance. The guys you want on your team….As an afterthought, if you can't be described in this manner, history shows you will not belong to the LMOA long. It is what you contribute, not take away….peer pressure is that strong! The LMOA has certainly evolved. We have achieved an effective mix of railroad employees and support suppliers….and our membership roll is growing, however, we are always looking for additional committee members. It is desirable to be on a winning team! Suppliers have equal status and I would offer that their contributions in the last few years have helped LMOA be more effective and pure. The fact is that even as a third generation LMOA'er I would not have been able to fill the role as LMOA President as a supplier if suppliers (before me) had not demonstrated their worth to the organization. We are held to a higher standard as I have counseled in the past; this is a linear reference back to that trust factor. Membership is not for direct commercial gain. As a supplier, and supported by the companies I have had the pleasure of working for, I have been able to justify my expenses associated with membership by bringing home a much clearer understanding of what the industry needs in the form of products and services. I have learned the details of systems and components that I would not have been otherwise exposed to. For the companies that have supported me I have returned knowledge that helped effectively use resources directly towards reducing product development time and cost. This knowledge has then benefitted the industry with cost effective products and services. You might have guessed by now that I am just a touch biased…..Proud is actually a better description of what I feel of the LMOA!

We have had some retirements this year and we will miss them and their contributions. Ron Lodowski Bill Kirdeikis, Dennis McAndrew, Chuck Kunkel and Glenn Bowen. For those of you in the position to approve, please consider allowing participation in the LMOA, especially if you feel as I do that the LMOA is something special and a worthwhile venue for personal and professional growth and learning! I thank you all for your time today and I have been honored to serve you all as President this year!

Acceptance speech

Tuesday, September 20, 2011–Minneapolis MN

Ron Bartels, Via Rail-Canada

Good morning, Ladies and Gentlemen, members of the Executive Committee, and fellow members of the LMOA.

It really is an honour to accept the position of President of the LMOA for the years 2011-2012. It is an honour because this organization that started 73 years ago has survived and thrived mainly due to the dedication of its members. These members, and many of us are members in the room, spend a lot of their personal time making this organization work, on top of their regular work hours. While making it work, the railway members bring back home tools that they can use to benefit:

Number 1: (always number 1) the safety of railway industry personnel and the general public

Number 2: the reliability of the railway industry's locomotives

Number 3: the cost of maintaining locomotives

Number 4: the productivity of those same locomotives

And last but not least, number 5: the environment.

Take a look at the list of presentations at this conference and you'll see that each one of them addresses at least one, if not more, of these five benefits.

As Jack Kuhns spoke of yesterday, the members from the supply industry equally benefit. They bring home a better understanding of which products and services the railways need and when, and how they will benefit the railway industry. This valuable information helps the suppliers offer the right products and services at the right time, which then comes back full circle to help the railways realize some or all of those five benefits.

When I was offered the position of 3rd Vice President that I knew would eventually lead to being President of the LMOA, I asked myself if I was the right person for the position. My exact words were (and this is a direct quote from my email) "… if the executive board will accept a 3rd VP from a Canadian passenger railroad with no operations in the US, then I will gladly accept". As you can see, the board agreed to the idea. My thinking was that I work for VIA Rail, a Canadian passenger railroad with 74 diesel-electric locomotives and where a normal train might have 300 trailing tons. This is nothing at all like a class 1 freight railroad. Larger class 1 freight railroads can easily have 74 units out of service at any given time and a freight train pulling over 15,000 tons is commonplace.

I realized, though, that the fact that the company where I work is not the same as everyone else's is not a disadvantage. I don't necessarily represent your company but one person isn't what makes this organization strong. It's all the members from mixed backgrounds: freight railroads, passenger railroads, big railroads, small railroads, suppliers of materials and services. So, I accepted the position and I will do my best to build on Jack's and previous Past Presidents' excellent work.

My LMOA "career" actually started in 1998 . I had been working at VIA for less than a year and I was talking with Les White, no doubt about something related to locomotives. Les, who unfortunately is not at this conference, said something to the effect of "Ron, you should join the LMOA." At the time, all I knew about the LMOA was, back in the late 1980's when we were still both working at CN, Les would struggle to find time to finish writing papers for LMOA and it looked like it was a lot of work. Somehow, Les convinced me it was worth it and in 1999, I gave my first presentation for the electrical committee.

Two things I want to add about joining the LMOA. 1. I was right. It is a lot of work. It can easily take up a few weeks per year, depending if you are presenting and on your role in the organization. Being chairman of the Electrical committee was particularly demanding and I'm sure that the chairs of the six committees can relate to that. And 2. Yes, it definitely was worth it. When someone asks me why they should join the LMOA the first thing I tell them is that you will build relationships with a group of people that deal with the same kind of problems as you. These are people you can call when you're scratching your head about something and, more often than not, someone on your committee, or possibly another committee, will be able to help you out in one way or another. You will also find yourself helping those same people somewhere along the way. These relationships are what make me keep come back, year after year. If you're not a member of LMOA and you're not convinced of the benefits, I say "Try it, you'll see what I mean."

I also encourage you to visit the indoor and outdoor exhibits. You'll meet people that you may end up working with in the future and I guarantee you'll leave knowing more than when you got here. You'll also be supporting some of the people and companies who help make these meetings possible. The worst thing that will happen is that you may wear out your shoes.

This year, like every other year, brings some new challenges to the LMOA. Union Pacific has asked for support from the LMOA to drive the industry to build reliability into locomotives "right out of the box", instead of having to incrementally add it in the field throughout their life cycle. UP also asked LMOA to develop software design standards. Both of these opportunities will be addressed at the meeting of the LMOA Executive Committee this afternoon.

Our Shop Equipment committee has a new expanded focus. It is now called the Shop Safety, Processes, and Equipment committee. To join the committee or for any other information, I urge you to speak to Bill Peterman, chairman of the committee, after their presentations which will start in a few minutes.

Next year, we again have a new location for the annual meeting September 23-25. It will include indoor exhibits and will be back in Chicago but not at the Hilton. The days are over when it was always in the same place every year. Mark it in your calendar and stay tuned for more details. The 2013 convention will be in Indianapolis.

I'm here today but I didn't get here by myself. First and foremost I have to thank my wonderful wife, Karen, and my incredible daughters, Kaitlin and Hannah, who are the most important people in my life in everything that I do. They may not help write presentations or organize meetings but I wouldn't be who I am today without them. I also want to thank VIA Rail and Bob Becker, who has been my director for the whole time that I have worked there. They have been very supportive of my LMOA activities, even when the meeting was in Las Vegas. I want to give a special thank you to all of the committee members and the Executive Committee of LMOA for your continued support, and Ron Pondel our Secretary-Treasurer. Ron, you're amazing, we couldn't do it without you and please don't stop working your magic.

Thank you all for your attention and enjoy the rest of the presentations and the convention.

Report on the Committee on Diesel Material Control

Monday, September 24, 2012 at 9:00 A.M.

Chairman

Fred Miller

VP Sales-North America

RELCO Locomotives, Inc.

Vice Chairman

Vacant

Commitee Members

D. Behrens	Managing Director	Alstom Transport	Shreveport, LA
D. Bird	Purchasing Manager	KCS Railway	Los Angeles, CA
R. Delevan	Mgr-Transp. Products	Morgan AMT/National	Dallas, PA
E. Fonville	Supt. Loco. Material	Norfolk Southern	Atlanta, GA
P. Foster	President	Power Rail Dist. Inc.	Duryea, GA
J. Fronckoski	Senior Procuerment Manager	CSX Transportation	Jacksonville, FL
M. Gast	Senior Materials Manager	CSX Transportation	Waycross, GA
M. Kadar	Manager Merch. Engineering	Union Pacific	Omaha, NE
T. Meyers	Purchasing	BNSF Railway	Fort Worth, TX
P. Pinson	Purchasing Manager	Rail America	Jacksonville, FL
M. Zerafa	Purchasing Manager	National Rwy Equipment	Dixmoor, IL

Note: Michael Hartung will be replacing Eric Fonville as Norfolk Southern representative on the committee.

PERSONAL HISTORY

Fred Miller

Fred Miller began his railroad career at Teledyne Metal Finishers in 1969. He continued his career with Chromium Corporation and Durox Company. His current responsibilities at RELCO include sales of all RELCO products for the Canadian RR's, Mexico and the Midwest and Eastern RR's. Fred works out of his office in Medina, Ohio. Fred and his wife, Marsha, combined their families 12 years ago and have 7 children. Their 8 grandchildren with one more on the way keeps them very busy.

The Diesel Material Control Committee would like to express their sincere appreciation to the CSX for hosting their meeting in Jacksonville, Florida on January 19, 2012. Special thanks to Jim Fronckoski for making all the arrangements. The committee also toured the CSX shops in Waycross, Georgia which was arranged by Mark Gast and Bill James for which we owe a debt of gratitude.

The committee would also like to thank the BNSF and Brad Queen for hosting the annual joint technical committee meeting in Overland Park, Kansas on May 8 and 9, 2012.

Tracking Cores

Prepared by:
Mike Kadar, Union Pacific

Repairable Material Programs

There are costs that can be incurred as a result of poor care management.

- Settlement payments to UTEX vendors for not retuning repairable cores
- Increased expenditures and long lead times when purchasing new rather than requalified, repaired or remanufactured material
- Large core pool investments to accommodate long cycle times
- Late orders when cores are not provided in a timely manner

These factors can add up to millions of dollars in additional material costs.

In order to have an understanding of this issue, it is important to know certain terms and their meanings.

Repairable/Core Material
Definitions

- **Repairable/Rotable** Failed/removed material that can be repaired and reused
- **Core** Bad order material item returned to the vendor for possible repair
- **Core Pool** Spare bad order cores owned by vendor or customer
- **UTEX/UX** Vendor repairs spare cores to provide immediate shipping upon customer order - Customer then owes vendor a core within a defined period
- **Repair and Return** Customer returns spare cores for repair - Only repaired by the vendor upon receipt
- **Fallout** Loss of a core when unrepairable and scrapped
- **Requalified** Test, repair only if not to spec - Returned without repair if no defect
- **Repaired** Test, isolate failure(s) and fix only those failures
- **Remanufactured** To "like new" with complete disassembly and reassembly, all parts requalified or replaced with new
- **Rebuilt, Reconditioned, Refurbished, Etc...** ALL to customer or OEM spec

Repairable Items
Examples

Core Collection and Return
Past Current State at UP

- Does not reflect the importance and value of the railroad's repairable material program and cores
  - Currently valued at more than $100M annually (over buying all new)
  - Remaining opportunity valued at up to $25M

Core Management

New Current State at UP

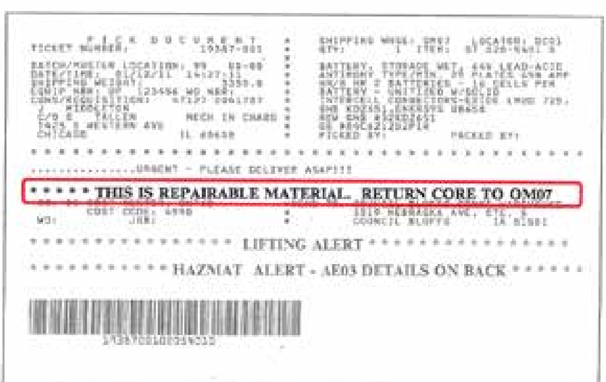
1. **Supply/Storeroom delivers repairable items with bar coded pick ticket bagged & attached to good order part**

2. **Craft uses part, completes RETURNS form on bag, swaps pick ticket from good part to bad, moves part to shop collection area**

Core Management

New Current State at UP

- **Bar Coded Pick Ticket with REPAIRABLE Message**



P I C K D O C U M E N T

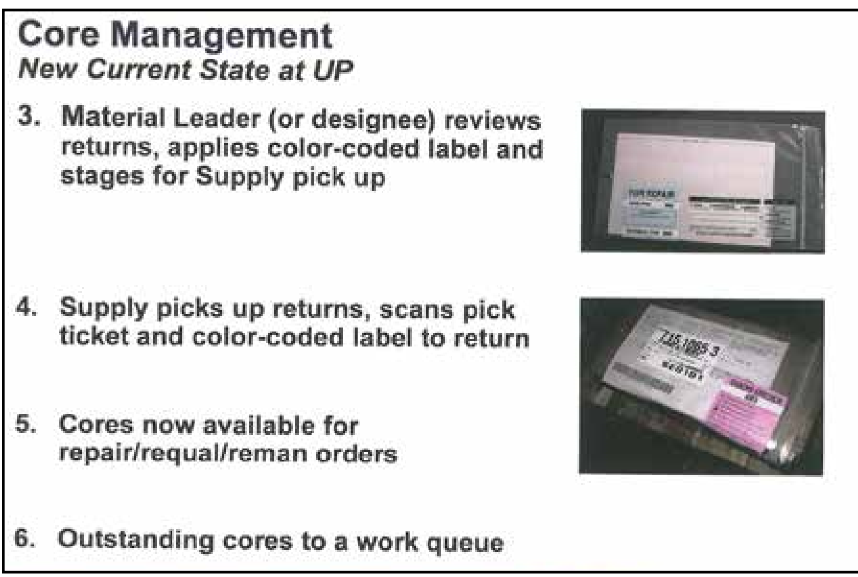
URGENT - PLEASE DELIVER ASAP!!!

* * * * * THIS IS REPAIRABLE MATERIAL. RETURN CORE TO OM07

* * * * * * * * * * * * * * * * LIFTING ALERT * * * * * * * * * * * * * * * *

* * * * * * * * * * * * HAZMAT ALERT - AE03 DETAILS ON BACK * * * * * *

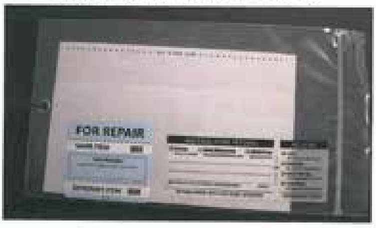

Core Management
New Current State at UP
RETURNS Form Completed By Craft
Color Coded Label
Attached By Material Leader
RETURNS
GOOD ORDER
BAD ORDER
DEFECTIVE
NO CORE
LOST
MISSING
NEW INSTALL
SCRAPPED
Water Leaks
LH
RETURN PART(S) WITH PICK TICKET ATTACHED
RETURN PICK TICKET
FOR REPAIR
SAME ITEM
Item Number
DIFFERENT ITEM


Core Management
New Current State at UP
3. Material Leader (or designee) reviews returns, applies color-coded label and stages for Supply pick up
4. Supply picks up returns, scans pick ticket and color-coded label to return
5. Cores now available for repair/requal/reman orders
6. Outstanding cores to a work queue

Return Material Tagging

Color-Coded Labeling

Color-Coded Label Attached by Material Leader

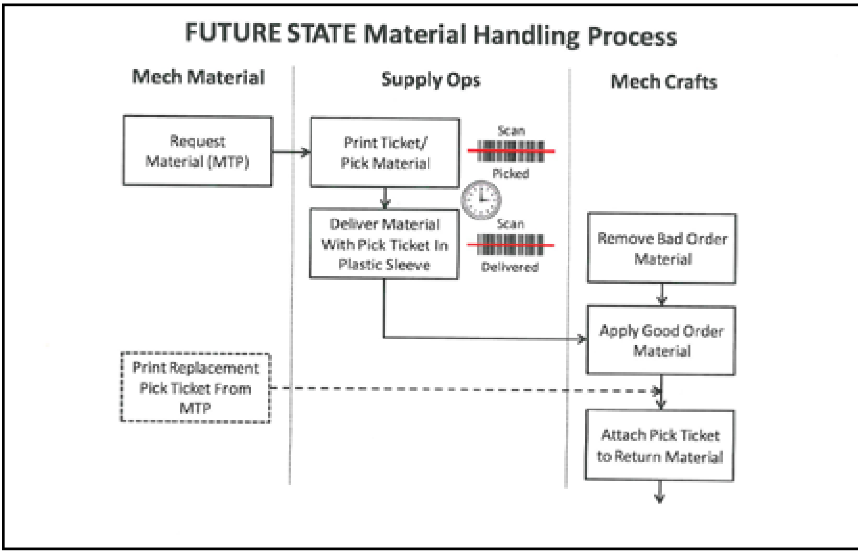


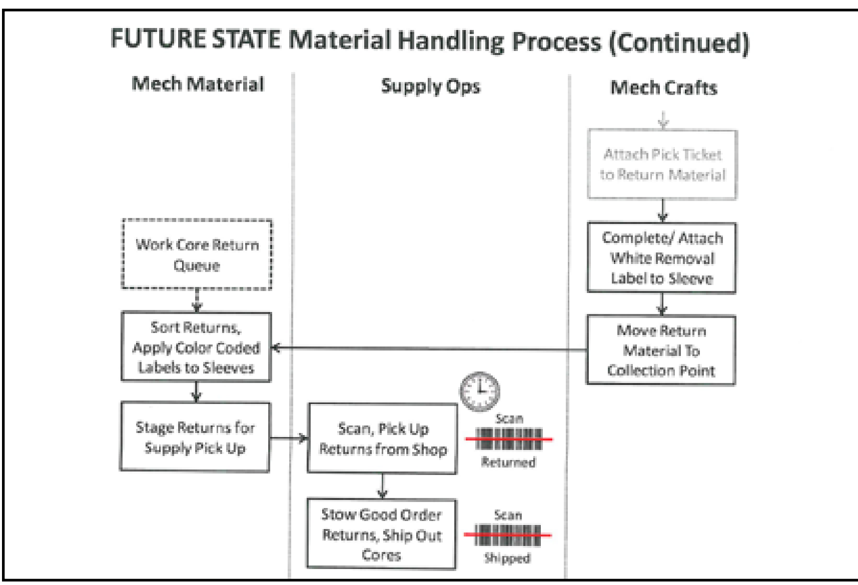
Processed Return (GOOD ORDER) at the Warehouse

- ALL Color-Coded Labels:

Outstanding Core Queue

New Web Application For Real Time Tracking


FUTURE STATE Material Handling Process
Mech Material
Supply Ops
Mech Crafts
Request Material (MTP)
Print Ticket/ Pick Material
Scan
Picked
Deliver Material With Pick Ticket In Plastic Sleeve
Scan
Delivered
Remove Bad Order Material
Apply Good Order Material
Print Replacement Pick Ticket From MTP
Attach Pick Ticket to Return Material


FUTURE STATE Material Handling Process (Continued)
Mech Material
Supply Ops
Mech Crafts
Attach Pick Ticket to Return Material
Work Core Return Queue
Complete/ Attach White Removal Label to Sleeve
Sort Returns, Apply Color Coded Labels to Sleeves
Move Return Material To Collection Point
Stage Returns for Supply Pick Up
Scan, Pick Up Returns from Shop
Scan
Returned
Stow Good Order Returns, Ship Out Cores
Scan
Shipped

Repairable Materials Programs

To-Do List for September (aka June)

- Identify current state and best practices on other railroads
- Quantify value of core program-opportunity on other roads
- Expand process scope to vendors
- Tie cores to RMA (Return Material Authorization)
- Perform failure analysis
- Discuss possibility of vendor run UP warehouses and the SMT tool for managing core

Bar Coding: An Update on Tier Emission Compliance

Prepared by:
Ron Delevan / Morgan AM&T

Almost fifty years ago, bar coding was a process into which the AAR was deeply involved. The promise of combining computer power and data collection was at a point indicating magnificent potential in freight car data collection and reporting. Unfortunately, the technologies fell short of fulfillment.

In current times, the power of computers, cell phones and various data collection methods have inundated us with the ability to collect and report mind boggling, mountainous amounts of data. Beyond that is our ability to store, sort, categorize and view that data in millions of forms and for as many reasons. So much data can be obtained that it becomes a daunting task to decide which data points one should use.

We are each affected, personally, by data collection every minute of our lives. From our experience at the retail store, driving, credit card use, cell phones, watching television, and such, much of our life is touched by; you guessed it, BAR CODES. In some manner, we introduce more order by BAR CODES.

Pic 1. Our Earth

Pic 2. Common Bar Code

Pic 3. Lazar Bar Coding

The AAR has turned its attention to the value of BAR Coding in the tracing and reporting of components on freight cars. In July of 2012, the AAR released, "AAR COMPONENT IDENTIFICATION (CID) BAR CODE STANDARD" which carries the AAR Standard "S-920". The Standard defines the Bar Code as:

BAR CODE

A pattern of information-encoding symbols (symbology) that is machine-readable in real time.

- 1D linear bar code symbology is a single row of dark bars and light spaces, variable in width and height.
- 2D (two dimensional) stacked symbology uses multiple rows of variable-width bars and spaces.
- 2D matrix symbology encodes information in a two-dimensional pattern of data cells.
- "Code" or "payload" refers to the actual data that the bar code contains, whereas "symbol" or "image" refers to the arrangement of the bars and spaces or data cells.

Figure 1. Bar Code Definition by AAR Standard "S-920"

Much of this Standard revolves around being able to identify components such as wheels, axels, bearings and the supplier. The Standard lays out various required data points and a method to have the vendor / railroads bar code approved. Of course, the serious nature of wheels, axles and bearings do not need to be outlined here and those issues are understood by anyone in the Railroad Industry. More importantly, BAR CODING under the AAR rules provides the ability to track down rail equipment that may have components with a suspected defect.

On the subject of Locomotives, the AAR is working on various standards to assure BAR CODING for components is standardized and viable for all of the Industry to value and use. Our look into BAR CODING for Locomotive Emission Compliance will touch on expected AAR requirements and will cover alternate method and thoughts for consideration.

The Bar Code must be approved by the AAR and is subject to this Standard under 3.0 "BAR CODE LABEL APPROVAL PROCESS" as shown in Figure 2.

3.0 **BAR CODE LABEL APPROVAL PROCESS**

3.1 Each material supplier generating or applying an AAR-required bar code must have the bar code approved by the AAR before use. This approval process is made available to ensure that the subsequent customer (the downstream user) has a central point for conflict resolution. However, it is recommended that the supplier also works directly with each customer to ensure satisfactory performance.

3.2 The current process through which AAR CID bar codes are approved is as follows:

3.2.1 The supplier required to apply the bar code must provide a sample bar code design/layout

Figure 2. AAR BAR CODE Label Approval PROCESS as out lined on AAR Standard "S-920"

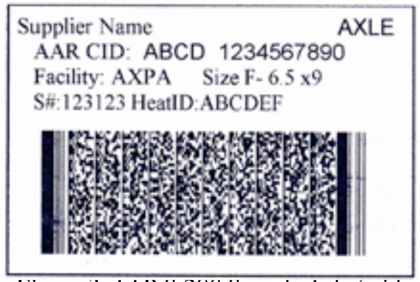


Figure 3. AAR S-290 Sample Axle (with CID) Bar Code

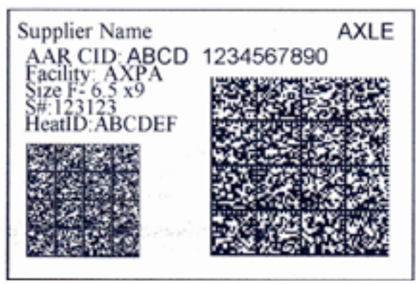


Figure 4. AAR S-290 Sample Axle (with CID) Bar Code

Tier Level Compliance and Bar Coding:

AAR presented sample Axle Bar Codes (Figures 3 and 4) can be easily modified to include other pertinent data necessary to comply with Tier Level label requirements under EPA guidelines.

Tier Level Emissions are relative to a number of things including the standard they were originally built and updates or upgrades as required meeting a specific level. The Tier Level is of course the responsibility of the owner or operator and in such the degree of compliance could be different from Locomotive to Locomotive. Many locomotives are used across various railroad properties through interchange and usage agreements. It is conceivable that a particular locomotive may suffer an emissions sensitive component while being used on another property. The owner of the failed locomotive would justifiably be concerned that the level of Tier compliance would be safe guarded and protected and that the repair location would be able to identify the level of compliance and the correct replacement part to be used.

Compliance with the regulations covering emissions looms large in our future. In such, non-compliance can become more burden and more costly. In order to protect the integrity of the locomotives compliance level, we must make certain specific use of components and guard their integrity (for example):

1. Turbo Chargers
2. Fuel Injectors
3. After Coolers
4. Control Devices including Software
5. Piston, Heads, (Power Assemblies)
6. Etc

Compliance Under Title 40 of EPA Regulations

Certain requirements are made under Title 40 Protection of the Environment include the following:

Title 40: Protection of Environment

PART 1033—CONTROL OF EMISSIONS FROM LOCOMOTIVES
Subpart B—Emission Standards and Related Requirements

§ 1033.135 Labeling

(D) A prominent unconditional statement of compliance with U.S. Environmental Protection Agency regulations which apply to locomotives, as applicable:

(1) "This locomotive conforms to U.S. EPA regulations applicable to Tier 0+ switch locomotives."
(2) "This locomotive conforms to U.S. EPA regulations applicable to Tier 0+ line-haul locomotives."
(3) "This locomotive conforms to U.S. EPA regulations applicable to Tier 1+ locomotives."
(4) "This locomotive conforms to U.S. EPA regulations applicable to Tier 2+ locomotives."
(5) "This locomotive conforms to U.S. EPA regulations applicable to Tier 3 switch locomotives."
(6) "This locomotive conforms to U.S. EPA regulations applicable to Tier 3 line-haul locomotives."
(7) "This locomotive conforms to U.S. EPA regulations applicable to Tier 4 switch locomotives."
(8) "This locomotive conforms to U.S. EPA regulations applicable to Tier 4 line-haul locomotives."

(E) The useful life of the locomotive.
(F) The standards/FELS to which the locomotive was certified.

Title 40 specifically requires that the Locomotive is labeled and includes the wording found under Section D, Lines 1 through 8, "This locomotive conforms to U.S. EPA regulations applicable to…"

.

In such, a bar coding scheme, as currently in consideration by the AAR for emissions should include the possible marking or coding of components as previously listed.

Tier compliant components carry a certification based upon the manufacturer or rebuilder meeting specified requirements and subsequent certification of the engine and thus the locomotive. OEM part number designations may not be adequate to prove continued compliance through the components' life cycle. Providing BAR CODING options would allow most components to carry their separate and individual compliance history.

The code goes on to be specific about the life integrity of labels on locomotives and engines:

On The Locomotive:

(2) The locomotive label must meet all of the following criteria:

(i) The label must be permanent and legible and affixed to the locomotive in a position in which it will remain readily visible. Attach it to a locomotive chassis part necessary for normal operation and not normally requiring replacement during the service life of the locomotive. You may not attach this label to the engine or to any equipment that is easily detached from the locomotive. Attach the label so that it cannot be removed without destroying or defacing the label. For Tier 0 and Tier 1 locomotives, the label may be made up of more than one piece, as long as all pieces are permanently attached to the locomotive.

On The Diesel Engine:

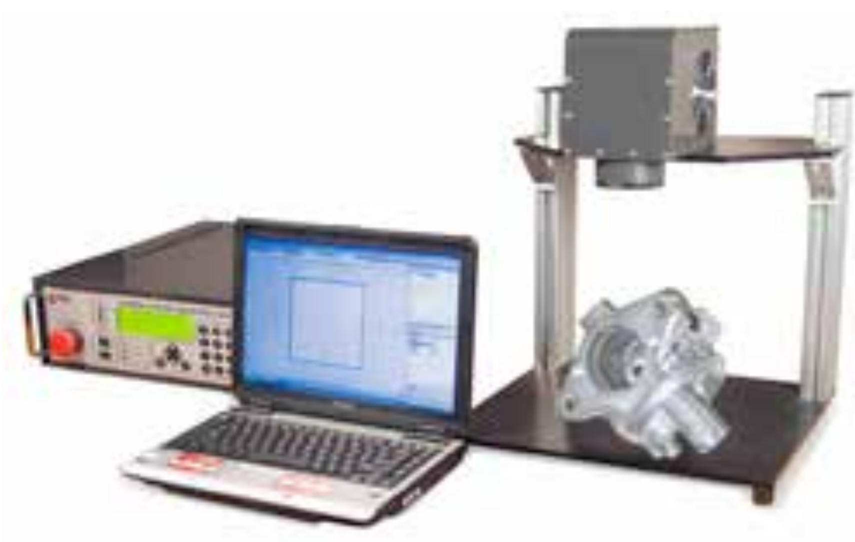
(2) The engine label must meet all of the following criteria:

(i) The label must be durable throughout the useful life of the engine, be legible and affixed to the engine in a position in which it will be readily visible after installation of the engine in the locomotive. Attach it to an engine part necessary for normal operation and not normally requiring replacement during the useful life of the locomotive. You may not attach this label to any equipment that is easily detached from the engine. Attach the label so it cannot be removed without destroying or defacing the label. The label may be made up of more than one piece, as long as all pieces are permanently attached to the same engine part.

Laser bar coding would qualify as a non-destructible method of labeling! The Bar Code label could carry all information necessary to comply with such regulations.

Laser Bar Coding:

CO2 and YAG lasers appear to have the most power and the largest material applications. The small size capability of laser allows for large amounts of information to be stored directly on the part or item to be marked. Most powerful attribute of laser etched bar coding is its ability to survive all types of environments.



Pic. 4 CO2 Laser desk top units

Pic. 5 CO2 Laser in Operation

Both desk top and remote laser systems are available.

For BAR CODING of large items, steel plates can be printed and attached to the engine block and the locomotive frame as indicated by "Title 40: Protection of Environment". The steel plate can be removed and updated or replaced at each overhaul. The steel plate or badge would fulfill the requirement and could carry a complete history of the engine or components.

Smaller components can be appropriately marked with information using the same laser systems.

Pic. 6, 7, 8 Laser etching

Conclusion and Options:

Although there are many methods to mark, follow and inventory components, locomotives and systems, few can carry data necessary under Title 40 to provide enviromental sustainable survival. Laser etching of components, tags and lables can fullfil the intent of Title 40. There are other means of tagging including RFID and engraving that have merit. However, RFID alone lacks the readable verbage direction. Serious consideration of using Laser etched BAR Coding coupled with inventory and component tracking might be in order.

Report on the Committee on Diesel Mechanical Maintenance

September 24, 2012 at 10:30 A.M.

Chairman

Ian Bradbury
President & CEO
Peaker Services, Inc.
Brighton, MI

Vice Chairman

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

Commitee Members

R. Aranda	General Foreman-Locos.	Belt Rwy of Chicago	Bedford Park, IL
D. Berry	Senior Sales Manager	MTU	St. George, UT
S. Bumra	Asst. Supt.	Amtrak	Chicago, IL
D. Cannon	Mgr-Mech. System Loco.	BNSF Rwy	Fort Worth, TX
T. Casper	VP-Sales & Marketing	Hadady Corp	South Holland, IL
M. Daoust	CMO	Tshiuetin Rail Transp	Clarke City, Quebec
B. Edwards	Mech. Foreman	Montana Rail Link	Livingston, MT
T. Frederick	Director-Mech Systems	CSX Transportation	Jacksonville, FL
D. Freestone	Mgr-Loco. Opns	Alaska RR	Anchorage, Alaska
J. Hedrick	Principal Engineer	Southwest Research Institute	San Antonio, TX
J. Kuhns	VP Sales	Graham White	Salem, VA (Past President)
D. Nott	President	Northwestern Consulting, LLC	Boise, ID (Past President)
D. Rutkowski	CMO	Providence & Worcester RR	Worcester, MA
C. Shepherd	CMO	Arkansas & Missouri RR	Springdale, AR
J. Sherbrook	VP & GM	LocoDocs, Inc	Mazon, IL
B. Singleton	VP-Sales	Transpar Corp	Niskayuna, NY
T. Standish	Quality Manager	Electro Motive Diesels	LaGrange, IL
T. Stewart	Engine Engineering Manager	Peaker Services Inc.	Brighton, MI
G. Sumpter	SE Regional CMO	Rail America	Jacksonville, FL
K. Wollschlager	Reliability Technician	Trico-Predict	Pewaukee, WI
R. Wullschleger	CMO	New York & Atlantic Rwy,	Glendale, NY

Note: Sean Cronin, Amtrak, will be joining the committee at the convention.

PERSONAL HISTORY

Ian Bradbury

Ian was born in Sheffield, England and obtained a B.Sc. in Mathematics from UEA and a Ph.D. in Statistics from the University of Birmingham, England before coming to the U.S. He spent 4 years teaching statistics at UT Dallas and Oakland University, Michigan, and 7 years leading GM Powertrain's engine design quality effort before joining Peaker Services (PSI) as President in 1997. Ian acted as trustee for the first leveraged ESOP transaction in 2000 and PSI is now a 100% employee owned company. PSI's historical core for over 40 years has been service and upgrade of EMD engines and controls in locomotive, marine and power generation. Since joining PSI, Ian had led the effort to diversify the company into controls for other diesel, natural and bio-gas engines, steam and gas turbines. He obtained an MBA from the University of Michigan in 2003. Ian is a member of ASME and serves on the W. Edwards Deming Institute advisory board.

Ian and his wife of 21 years, Kathy, are both keen mountain bikers and craft beer consumers. Kathy teaches yoga and 'enhance fitness' as well as smoking a mean brisket. They have two sons - James (20) and George (18). James plans to pursue architecture and structural engineering, George, illustration and graphic design.

The Diesel Mechanical Maintenance Committee would like to express their sincere appreciation to Amtrak and a big thank you to Sarabpreet Bumra for sponsoring a committee conference call in December 2011. They also sponsored conference calls for our meeting in Springdale, Arkansas and the committee meeting held during the joint technical conference in Overland Park, Kansas.

The committee would also like to sincerely thank the Arkansas & Missouri Railroad for hosting and supporting our meeting in March 2012 in Springdale, Arkansas. Special thanks to Casey Shepherd for arranging a tour of their brand new shop and a train ride.

We would also like to thank the BNSF and Brad Queen for hosting the annual joint technical committee meeting which was held at the BNSF Training Center in Overland Park, Kansas on May 8 and 9, 2012.

Failure Modes and Effects Analysis

Prepared by:
Tom Kennedy, Union Pacific Railroad

Failure Modes and Effects Analysis (FMEA) is one of the most powerful and proactive analytical tools available for safety, performance, and reliability enhancement during product development and in the investigation and correction of failures. Other powerful and proactive tools such as Fault Tree Analysis (FTA), Finite Element Analysis (FEA), and Sneak Circuit Analysis (SCA) were previously discussed in the author's 2011 LMOA Design for Reliability Paper.

FMEA Background:

There is abundant material available for the understanding and application of FMEA's. Two helpful introductory sources of information are SAE publication J1739 and MIL-STD-1629. The military standard adds criticality of failure modes and therefore renames FMEA, FMECA (Failure Modes Effects Criticality Analysis). Both sources aim for the same objective, to improve product performance, through identification and elimination of potential failure modes, minimization of their frequency, and/or improving their detectability. The purpose of this paper is to present the basic concepts involved in performing FMEA's and champion their application to locomotives for improved safety and reliability performance. For detailed training in the detail process, a recommended first course of action is to familiarize oneself with either the SAE or Military publication referenced above. Commercial resources are also available for training and mentoring. If you want to expand beyond Excel for data management there are numerous software platforms available dedicated to FMEA performance with some integrated with other Design for Reliability (DFR) activities. Choose the training and software that works best for your company.

Why FMEA:

It is not a matter of whether a failure will occur, but when it will occur. Since failures are inevitable, we need to ensure that we fully understand our design and manufacturing processes and how their performance potentially impacts the customer. Failures create unreliability ($Q = 1 - R$) which directly affects the bottom line of the producer (OEM) and consumer (railroad) with missed revenue opportunities, delivery penalties, increased repair costs, additional material stocking, increased shop space, etc. Also, governmental mandates frequently increase product hardware and software content, often degrading reliability performance. With the additional content, the reliability of the added content and the existing content must be addressed with a target to achieve a net zero loss in reliability and preferably an increase. Properly designed and executed FMEA's help mature a product earlier in the development cycle, reducing the quantity of failures in system and field test and ultimately customer application. An industry accepted premise is that the cost for corrective action increases at a factor of 10 for every layer of indenture, as shown below

Component	***$1***
Module	***$10***
Assembly	***$100***
Subsystem	***$1,000***
System	***$10,000***
Locomotive	***$100,000***

The take away point here is: FMEA's, do them early and do them often!

FMEA Planning

A well-structured Reliability Program Plan will specify the performance of FMEA's (three unique types) starting as early as possible. One mistake often made is waiting for hardware to actually be designed or "bread boarded" or mocked up. System level FMEA's should be initiated during the concept stage of development (System FMEA's). Once a design is underway, the FMEA transitions to a Design FMEA, which digs further into the technical design elements and parts selection and integration. As the design progresses and manufacturing plans are being developed another set of FMEA's called Process FMEA's are initiated. Each one of these FMEA's builds upon the previous FMEA's. The FMEA's are living documents and are to be updated as changes in design or processes occur and additional data becomes available through such activities as Finite Element Analysis (FEA), tests, demonstrations, etc. The results of the FMEA's should be included in project design reviews, as discussed in the author's 2011 LMOA Design for Reliability paper. One note on FMEA planning – cascade the requirement to conduct FMEA's to your first tier supplier's with data review and approval requirements.

FMEA Basics

An FMEA is a cross-functional activity using a "bottoms up" type of analysis that assesses design or process risk by calculating a Risk Priority Number (RPN). RPN is the product of the ratings for failure severity, probability, and detectability.

RPN = Severity x Occurrence x Detectability

RPN is used to prioritize attention and action on failure modes. Comparatively higher RPN values result from failure modes that have relatively more severe consequences, are relatively more likely to occur or are relatively more difficult to detect when they do occur. Actions to address/mitigate a failure mode with high RPN therefore can be classified as ones that reduce failure severity, probability or detectability, or some combination. Realistically, not every failure mode can be addressed, so a method for determining which failure modes require mitigating action needs to be defined. A common practice is that any failure mode where the severity represents potential cause of injury or death or catastrophic equipment or process loss must be mitigated, regardless of RPN value. Some organizations follow a practice of requiring mitigation of all failure modes with an RPN above some (arbitrary) limit. As an alternative to this approach, the author recommends use of Pareto analysis to identify which failure modes to focus upon. This method is more refined than an arbitrary limit and helps focus resources on the biggest paybacks. This approach is also more robust to shifts in scoring practice over the longer term, provided scoring methods are consistent for the RPN's being compared at a given point in time. Additionally, different FMEA practitioners may use different scales for ranking the severity, occurrence, and detectability of failure modes. The most common is to use a scale from one to ten, which we will discuss later. Different scales are acceptable provided you are consistent across your FMEA initiative and do not mix processes for RPN's which you are comparing. An example FMEA sheet is shown below with discussion of the entries to follow.

Subject:	
Vehicle (S):	
Other Areas Involved:	
Affected Suppliers/Plants:	
Participants:	

FMEA Date:	
Engr Release Date:	
Design Responsibility:	
Facilitated By:	

Line No.	Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Class	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Design Controls	DET	RPN	Recommended Action (s)
4	Lamination provide space for coils	inadequate space	short or grounds	8		Damage insulation during installation if too tight	2	Check every slot	1	16	
5	Stator frame bebars :provide mounting for nose link and support bearing housing	Cracks in weld,excessive deflection	Structual motor damage, rough ride	10		Insufficient weld size,lack of understanding of environmental conditions	4	Based on simularity of current design	2	80	FEA analysis/field testing Note CP and Alaska

FMEA Definitions – Header

The header identifies the FMEA subject matter, systems, the application vehicle, participants, date performed, etc.

FMEA Definitions – Item/Function

This column identifies the hardware element or process element under study. This element should be concise and descriptive.

FMEA Definitions – Potential Failure Mode

This column identifies potential failure modes of the hardware element or process element under study and is based on previous product performance, test data, industry and/or military data books. For example the failure modes of a valve spring could be: broken coil, "K" value to high, "K" value to low or wrong material. For an electrical example the failure modes of a capacitor could be: shorted, open, capacitance too high, capacitance to low, or "noisy".

FMEA Definitions – Potential Effects of Failure

Enter into this column the potential effects of the failure upon the assembly, subsystem, system, etc. This data can be obtained from previous product experience, testing, computer simulation, engineering analysis, industry and/or government data books. Be as descriptive as possible.

FMEA Definitions – Severity

This column identifies the severity of the potential failure modes based on a qualitative rating using guidelines such as the following table.

There are many sources available to rank the severity but most will align with the above sample. Whatever criteria you use be consistent across all FMEA's. It is important to have clear guidelines that are consistently understood between people performing FMEA's. Lack of such introduces variability into the RPN's that reduces ability to depend on their value for effective prioritization. This applies equally to rating probability and detectability. Clarity of guidelines can be evaluated by testing consistency of classification for common examples between raters.

FMEA Definitions – Class

This column is a yes or no entry and ties the FMEA element to whether or not it is related to a product or process key characteristic. This column is optional.

Severity Rating	Description	Definition
10	Hazardous w/o warning	Death or Loss of Locomotive
9	Hazardous with warning	Severe Injury or Major Equip Damage
8	Very High	Locomotive is Inoperable
7	High	Major Customer Dissatisfaction
6	Moderate	Degraded Locomotive Operation
5	Low	Moderate Performance Loss
4	Very Low	Minor Performance Loss
3	Minor	Nuisance Failures
2	Very Minor	Minor Effect, not Noticeable to User
1	None	No Effect to Performance or User

FMEA Definitions – Potential Causes / Failure Mechanisms

In this column identify the potential causes and failure mechanisms that can cause the failure mode under study. This data can also be obtained from previous product experience, testing, computer simulation, engineering analysis, industry and/or government data books. Be as descriptive as possible.

FMEA Definitions – Occurrence

This column identifies the occurrence or the frequency of the potential failure modes based on a qualitative rating using guidelines such as the following table.

There are many sources available to rank the severity but most will align with the above sample. Whatever criteria you use, be consistent across all FMEA's.

FMEA Definitions – Current Design Controls

This column is used to identify the current design or process controls in place to detect a potential failure mode and reduce its frequency and/or increase the detectability.

Occurrence Rating	Description	Failure Rate
10	Inevitable	5%
9	Very High	3%
8	Repeated Failures	1.5%
7	High	0.5%
6	Routinely Occurring	0.3%
5	Occasional Failures	0.15%
4	Moderate Failures	0.05%
3	Few Failures	0.04%
2	Low	0.03%
1	Unlikely	0.005%

FMEA Definitions – Detectability

This column identifies the detectability of the potential failure mode.

Detectability Rating	Description
10	Absolute Uncertainty
9	Very Remote
8	Remote
7	Very Low
6	Low
5	Moderate
4	Moderately High
3	High
2	Very High
1	Almost Certain

There are many sources available to rank detectability but most will align with the above sample. Whatever criteria you use, be consistent across all FMEA's

FMEA Definitions – RPN

This column identifies the RPN calculation; see previous RPN discussion.

FMEA Definitions – Recommended Actions

In this column list the recommended actions to be taken to reduce the RPN level to an acceptable level. Design and process changes are used to reduce the occurrence or frequency of failure and improve the detectability of the potential failure. Design and process changes and controls cannot reduce the severity of failure. The only method to eliminate the severity is to eliminate the component or process element in its entirety without replacing it.

In Conclusion

Today's products are complex and highly integrated. Their development requires that safety and reliability be a central element of the design and manufacturing processes – and FMEA's are an excellent proactive tool to help achieve this. To achieve these objectives, the OEM's must enhance their knowledge and expertise with FMEA's and rigorously apply them.

The railroads must actively support the FMEA processes by requiring and insisting that FMEA's will be used on all new product and process designs and also be applied during problem solving and modification development. This requires the railroads to enhance their own engineering knowledge and expertise in the FMEA process and also actively participate in OEM FMEA's.

Main Generators - AR Type Traction Alternators - Best Practices - II Removal, Installation and Alignment

Prepared by:
Richard Aranda and James Sherbrook

Introduction

Last year the topic of main generators was introduced. Identification and general maintenance were overviewed in Main Generators – Best Practices Part One. In a continuation of last year's paper – main generator removal, installation and alignment will be addressed.

As review, the term "main generator" is generically used throughout the locomotive industry to refer to a locomotive's generator or alternator. A generator is a direct current (DC) device. An alternator is an alternating current (AC) device. The main generator or traction alternator consists of two, three phase, alternating current generators utilizing a single spherical bearing. The spiders of the two machines are bolted together; the coupling disc of the companion alternator is bolted to the coupling of the engine. The outboard end of the alternator rotor is supported by a bearing (ITS/MI 3317-1).

Removal

After one has verified that a generator has failed and a replacement has been ordered, a repair site location must be chosen. Work can be performed outside where the locomotive may have failed (on-site at a field location) or at a locomotive repair back shop.

When preparing to remove a failed generator from an EMD or GE locomotive, drain the cooling and lubricating oil systems. Disconnect all piping connections from the carbody to the engine. Disconnect air ducts to the air box from the end housing. Remove the inertial filter housing. Remove the rear traction motor blower ducting. Disconnect all wiring between the generator and any wiring connecting ancillary systems to the carbody. Disconnect and extract carbody hood or roof hatch section, if so equipped. Disconnect drive couplings. Unbolt and remove dowels from the failed generator and remove generator (LOCODOCS).

On EMD locomotives, the locomotive frame supports the generator. On earlier GE locomotives, the generator set is supported entirely by the engine. On later Dash 9 and Evolution Series locomotives, the alternator is supported by the frame as GE does not use the frame feet at the alternator. There is an anti-torsion support in-between the mounting pads (NS). The generator armature is bolted to the engine crankshaft. The generator frame is bolted to the engine frame at four mounting pads. Alignment is maintained with shims between the mounting pads and the main frame and dowels in the two upper mounting pads (GEI-81985E).

The GE power plant may be removed from the locomotive with or without the generator attached. Lift the power plant at provided lifting eye locations only. Generator lifting eye locations are designed to support the weight of the generator only. Do not use lifting slings on the generator when lifting the engine generator set combination. Doing such may result in damage (GEI-81985E).

If removing the complete GE power plant, remove the engine hold down bolts. Back out the horizontal jacking bolts multiple turns. Grind out any tack welds and remove wedges from each pad at the generator end of the engine. On later Dash 9 and Evolution Series locomotives, it is necessary to support the engine frame at the alternator end of the frame prior to attempting to remove the alternator (NS). It should be noted that if reinstalling the same engine, alignment time may be saved by turning the jacking bolts on one side of the engine in snug against the frame while backing off only those on the other side to allow removal clearance. Do not align on top of the jacking bolts. Only remove the wedges toward the free end of the engine. During reinstallation, the engine can be placed against these established reference points. Only minor adjustments will be required to properly align (GEI-81985E).

In older GE locomotives, caution should be taken when uncoupling GE 5GT586 generators from engines or moving them alone. 1/8” thick fiber or paper shims must be inserted between the armature and the two bottom excitation field poles to support the armature when it is not coupled to the engine. The shims should be removed after the generator is coupled to the engine. 5GT598 generators were redesigned and shims are not required for this model (GEI-81985E).

When removing a GE generator with the engine still within the locomotive, perform the steps as noted above. Remove the left bank camshaft gear cover. Through this opening, remove the 12 bolts connecting the generator armature to the engine crankshaft. Attach lifting cables to the generator lifting lugs. Remove the generator mounting bolts. Work the generator evenly off its dowels in the upper two pads. Use 1-3/8”-12 jack bolts in these pads or a pry bar. Collect generator shims and return them to their original locations once the generator is free (GEI-81985E).

Installation

After removing the failed generator, clean and prepare the mounting bases, clean out mounting bolt and clean coupling surfaces. Weld up old dowel holes in the locomotive deck. New dowel holes will be drilled later, after the alignment of the replacement generator has been completed. Prior to accepting a remanufactured replacement generator from a vendor and installing it into a locomotive, check the following (BRC, LOCODOCS):

1. Were shims installed under the armature to prevent the armature from moving during shipment?

2. Were all bolt and dowel holes cleaned, repaired or renewed?
3. Verify that the part number plate information is the correct replacement.
4. Verify that the air box is the correct application for the existing auxiliary generator.
5. Open the inspection cover and check the brushes and the collector ring. One railroad has found it better to have generators shipped in without brushes or with brushes removed from the brush holders to prevent breakage during transport and alignment (NS).
6. Verify that the lifting pad holes are debris free and covered.
7. Test the generator electrically. A megohmmeter test with 1000V should result in a two megohm reading or above. A megohmmeter is a satisfactory replacement for a high potential test. Dirt and moisture accumulation is sufficient to cause leakage; if a high potential is applied, insulation breakdown may be caused. This condition may be aggravated by sudden temperature changes, such as those resulting from equipment that has been stored outside in the cold and then brought into a warm building (MI 3304). Moisture must be eliminated in units that have been shut down for an extended period of time. A megohm reading of less than one megohm should be viewed with suspicion. Before applying a high potential, the cause of low megohmmeter readings should be determined and corrected. This may be accomplished by separating complicated circuits into individual circuits and isolating specific equipment and testing separately (MI 6800).

The time to find a problem with the replacement generator is before it is installed, not after it has been aligned and during the final testing process.

In EMD locomotives, lift the replacement generator into place onto the mounting platform. Reference *EMD Generator Alignment* below to start the alignment process.

In GE locomotives (excluding EVOLUTION series locomotives), if the complete power plant was removed, power plant reinstallation is the reverse of the removal, as previously outlined. If the generator was assembled to the engine and aligned prior to installation in the locomotive, all measurements must be rechecked to assure against misalignment during handling (GEI-81985E).

When mounting a GE generator to an engine (excluding EVOLUTION series locomotives), clean coupling flanges on both the generator and engine crankshaft. Remove any nicks or burrs with a file. Pre-align generator and crankshaft coupling bolt holes. Lift the generator and carefully move it up to the engine. Align dowels to the two upper mounting pads. Insert all bolts in the mounting pads and tighten. Insert all coupling bolts and tighten. Reinstall previously removed generator aligning shims. Reinstall shims in their original positions. (It should be noted that if this particular engine and generator have not been assembled together before, start with an equal thickness of shims on all

four mounting pads. If 3/32" shims have been tack welded to the lower generator pads and are undamaged, do not remove these shims). Tighten generator mounting bolts evenly and torque to appropriate torque values. Tighten armature flange coupling bolts evenly and torque to appropriate *GE Torque Values*. (Reference LMOA paper "Basic Torque Wrench Practices" published 2012 by Tim Standish for additional information.) Use Threadtex or equivalent for all torque fasteners above 600 ft-lbs. Apply lockwire to bolt heads as required. Reinstall the left bank camshaft gear cover (GEI-81985E).

Alignment

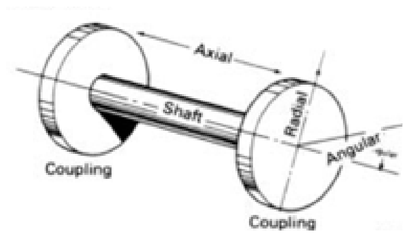
In mechanical systems, precise alignment reduces stresses in couplings and shafts thereby minimizing vibration, bending of shafts and unequal bearing loads. Proper alignment extends the life of the engine and rotating equipment components. The alignments through the couplings must be precise enough to make the engine and generator revolve true and be free from vibration (MI 1753). Alignment procedures differ between EMD and GE locomotives.

Although alignment in a rotating system is usually focused on coupling surfaces, the actual concern is the alignment of the shafts. It is more convenient in EMD locomotives to affix dial indicators to coupling surfaces or on the edge of a flywheel than to position them on the machine shaft. This is particularly true when dealing with generators where the main shaft is physically inaccessible. Flywheel edge variation measurement is related to the orientation of the shaft center with respect to a reference point: the other shaft centerline or a fixed surface such as the generator housing or locomotive deck. In this application, a dial indicator reading on the edge of a flywheel is a valid means of determining shaft rotation alignment (MI 1753).

Proper power plant operation requires that the generator armature or rotor shaft and the generator frame or stator housing must be aligned to the engine crankshaft. Since the generator has only one roller bearing, radial and angular alignment is determined at the engine end of the generator utilizing two dial indicators mounted on support rods. Positioning and mounting of the indicators will vary between EMD generator models (MI 1753).

The dial indicator is the most commonly used tool for rotational alignment work. Dial indicators are designed to be as versatile as possible so their actual application may require adaptation. Supports and adapters can be obtained or fabricated to suit individual use requirements and preferences. Dial indicator scales are calibrated to read in thousandths of an inch. Some scales read from zero up to a number such as 100. Some have plus and minus values on both sides of zero for ease of recording measurements. The maximum indicator reading refers to the highest reading attained while performing the measurement. The total indicator reading (TIR) is the total change in indicator reading disregarding the indicator reference (MI 1753).

Before one can align a generator, one must understand alignment terminology. To begin, there are three categories of misalignment: parallel, angular and radial (performed simultaneously) and axial.



MI 1753

Parallel misalignment is the difference between the centerlines of the driven equipment and the driving equipment. Excessive motion results from parallel or angular misalignment. This excessive motion leads to friction, heat and vibration (BRC).

Angular misalignment is the angle of intersection between the centerlines of the driven equipment and the driving equipment. Moving one end of the driven shaft so that it is parallel to the driving shaft makes corrections for angular misalignment. If the angular dimension is within proper limits but the radial is not, then move the shaft in a direction perpendicular to its rotating axis. Move the shaft a distance equal to the highest positive dial indicator readings toward the opposite side of the coupling. The proper distance and direction of the movement is determined by the recorded indicator readings (MI 1753).

Radial is measured outward from the center of the shaft in a plane perpendicular to the main axis of the shaft. Radial misalignment is the difference in position of the rotating axis of one shaft from a reference point. When two shafts are coupled together, the reference point is the center of rotation of one of the shafts (MI 1753).

In most alignment situations it is advantageous to correct angular and radial misalignment simultaneously. If radial alignment is satisfactory but angular is in need of correction, the shaft end being aligned is properly located but the remote end of the shaft must be repositioned (MI 1753).

Generators require special consideration because of the critical positioning of the rotor relative to the stator axially and radially. Axial positioning is important to avoid rotor thrust loads on end bearings. Radial positioning, also know as air gap equalization, is necessary for proper interaction of rotor and stator fields or armature and the main poles during its electrical phase of the operation. (MI 1753).

Axial is measured back and forth along the rotating axis of the shaft. Axial misalignment means that the position of the whole shaft must be shifted in the direction of its length. Axial dimension is usually used in reference to shaft thrust on the end bearing. The shaft, being offset, causes an axial load on the bearing (MI 1753).

The alignment of an EMD generator to an EMD engine can be divided into three operations: thrust, angular and radial or air gap setting (MI 1753 and MI 1765).

Thrust means adjusting the axial position of the armature or rotor to the generator frame. All crankshaft thrust at the generator end of the engine is removed by prying the crankshaft toward the generator. Removing an oil pan hand hole cover and prying between a crankshaft web and a crankcase "A" frame accomplish this. It should be noted that it may be necessary to rotate the flywheel slightly with a turning bar to pry the crankshaft toward the generator in some 16 and 20 cylinder engines (MI 1753).

Locate the "X" dimension that is stamped on the generator. Refer to *EMD Generator Alignment Table*. This measurement was determined during final generator assembly with the armature positioned so that all endplay is taken up in the direction of the engine coupling. Move the generator frame either towards or away from the engine until a measurement is obtained which is the total of the "X" dimension plus the bearing thrust dimension as detailed in *EMD Generator Alignment Table* (MI 1753).

Angular means to correct the angularity of generator to engine coupling. Angular and radial corrections are performed simultaneously (MI 1753).

Radial means to balance and set the air gap between the generator armature and field poles (MI 1753). Close tolerance air gap measurements can only be taken by removing the paint from the stator and rotor. The following locations should be prepared as follows:

1. Paint should be removed from the inside diameter of the stator laminations in a strip four inches wide by six inches in length, the depth running from both ends of the stator assembly inward and on the radial line. Measure 36 degrees on either side of the stator diameter vertical centerline and top and bottom. This will provide eight stator measurement points. See Air Gap Measurement Points for additional information (MI 1765).
2. Remove the paint from the outside diameter of one pole in a strip three inches wide by six inches in length and symmetrically about the radial centerline of the pole. This will provide two rotor measurement points (MI 1765).
3. Number the scraped poles and the stator frame, placing numbers visibly on the slip ring side of the generator so that pole location, with respect to the stator, in always know (MI 1765).
4. Obtain the air gap between the rotor and stator by placing a feeler gauge between the rotor and stator where the paint has been removed. The feeler gauges must extend to a minimum four-inch depth from the outer edge of the pole end piece. The measurements should be recorded at both ends of the poles. (MI 1765).
5. Clearance for A, B, C and D of Air Gap Measurement Points should be held within 0.010" of each other. The total variation between any four readings should not exceed 0.010". The difference in air gap at either end of the pole piece cannot exceed 0.005" (MI 1765).

6. The shaft should be rotated so that the pole marked number one will stop at points A, B, C and D where readings are recorded. Make necessary adjustments by shifting the stator frame. Install or remove shims under the generator mounting feet to raise or lower it (MI 1765).
7. After final tightening of the generator hold down bolts, recheck all readings. If tolerances are satisfied, dowel the generator to the mounting base. Reference *EMD Generator Shaft Alignment and Air Gap Equalization* for additional information (MI 1765).
8. Install brushes in the brush holders and seat (NS).

Couplings

Couplings are used to connect shafts to shafts, shafts to machines and machines to machines. Coupling faces may be rigidly bolted together or use rubber bushings between them. Coupling face and bushing design variations allow couplings some freedom of movement in radial and angular alignment. Although couplings can withstand nominal misalignment, the shafts must be aligned as accurately as possible to reduce stress. All flexible couplings that connect engines to generators are of similar designs with minor differences in construction to provide specialized application or control of interchangeability between models (MI 1753).

Types of driveshaft couplings:

Bushing type coupling with steel insert – used on EMD and GE locomotives – this style coupling was designed to compensate for angular and limited axial misalignment. If parallel misalignment exists, it will be present on two remote ends of the driveshaft arrangement. Parallel misalignment will be revealed as angular misalignment. Angular and parallel misalignments are interdependent and make this coupling arrangement simple to align. Maintenance requirements – visually inspect (BRC).

Bushing type coupling without steel insert – used on some GE Dash 7 locomotives – this style coupling was designed to compensate for parallel, angular and axial misalignment but cannot support the weight of the driveshaft. This coupling design is difficult to align because parallel and angular misalignment act independently. Maintenance requirements – visually inspect (BRC).

Generator/Alternator couplings:

Flywheel or coupling disc design – used on EMD locomotives – allow for parallel or angular misalignment while limiting axial misalignment. Maximum misalignment allowed is nominal preventing disc fatigue. Maintenance requirements – none (BRC).

Rigid type coupling design – used on GE locomotives – allows the alternator and diesel engine to be connected and aligned as an assembly prior to installing the assembly in a locomotive. The rigid coupling allows for parallel or angular misalignment. It limits axial misalignment. The permissible misalignment is very limited preventing engine crankshaft fatigue. Any misalignment deflection is focused on the rear crankshaft throw. An advantage to this GE design is that it allows the engine and alternator to be assembled on the shop floor and then placed in the locomotive. With EMD's design, the engine must be mounted in the locomotive. The generator is then installed in the locomotive and aligned to the engine. Maintenance requirements – none (BRC).

The generator armature is essentially the flywheel for the engine and is joined to the engine crankshaft by means of a flexible coupling comprised of a generator coupling disc and an engine-coupling disc. Each disc is attached at its center to its respective part by mounting bolts. The discs are mechanically fastened to each other at their outer edges. The engine coupling disc rim is marked by degrees around its circumference. Holes are provided for rotating the crankshaft (MI 1753).

Prior to performing alignment checks, bolt both coupling halves together and torque to proper values (MI 1753 and GEK-76564A). Reference LMOA paper "Basic Torque Wrench Practices" published 2012 by Tim Standish for additional information.

The use of two rigidly mounted dial indicators attached to one coupling is the recommend method for measuring the surfaces of the other coupling. The plunger of one indicator is placed in parallel to the shaft, button resting on the coupling face, as close to the edge as possible, beyond the coupling bolts. This indicator will read angular misalignment. The plunger of the second dial indicator is mounted against the edge of the coupling vertical to the shaft. This indicator will measure the radial misalignment (MI 1753).

1. Depress dial indicator plungers about half of their total travel after they are positioned. This will allow the indicators to measure the widest range of plus and minus values (MI 1753).
2. After the indicators are applied, rotate the shaft until the indicators are in the top perpendicular position. At this position, set each indicator to zero. This establishes a reference point from which misalignment can be measured (MI 1753).
3. Angular and radial measurements should be taken at zero, 90, 180 and 270 degree positions. Record the initial measurements and measurements after each adjustment. Add a line with a description of the alignment corrective action and record angular and radial measurement. Recorded measurements will provide a permanent record. It may be helpful to draw a circle and label the top zero, sides and bottom to the graphically reference indicator reading positions to the coupling faces of the generator armature shaft (MI 1753). See EMD Generator Alignment Report for an example.
4. Rotate the armature shaft to obtain indicator measurements at each 90 degree position and record readings. If a reading of zero maintains through a full shaft rotation, the shaft would be in perfect angular alignment. In most cases, one

should have some variation, plus or minus values, with every alignment operation. If the indicator pointer moves in the direction of increasing numbers, the reading should be recorded as a plus value. If moved in the decreasing number direction, the reading is recorded as a minus value. Reference *EMD Dial Indicator Alignment Tolerances* (MI 1753).

5. After indicators have traveled a full 360 degrees around the coupling, both indicators should read zero as they return to their starting point. If they do not, an error has been made, discard readings and investigate the source of the error (MI 1753).

Potential sources of error:

- Indicator mounts may have shifted during the alignment check and changed the indicator reference.
- Coupled equipment may have shifted during alignment check.
- Plunger movements may have exceeded the range of the indicator.
- The indicator may be out of calibration or faulty

After the reason for error has been found and corrected, take a new set of indicator readings (MI 1753).

EMD GENERATOR TO ENGINE INSTALLATION AND ALIGNMENT

When installing a replacement generator:

1. Once the replacement generator has been maneuvered into place, remove armature shims.
2. If the previous generator was mounted in place with shims under the mounting feet, reuse the original shims as a starting point in the alignment process. Additional shims may have to be added or shims may have to be removed (MI 1753).
3. Lift the housing to set the air gap. Once it is equalized around the circumference, tighten all coupling bolts evenly (MI 1753). Connect the ring gear to the flywheel. Torque coupling bolts to 295 ft-lb. (Reference LMOA paper “Basic Torque Wrench Practices” published 2012 by Tim Standish for additional information.) Measure the final gap between coupling disc to ensure uniformity. The final gap should measure no less than 0.0015” (MI 1753).
4. Remove generator thrust (MI 1753).
5. Remove any guard prior to mounting dial indicators (MI 1753).
6. Mount indicators on mounting brackets at coupling to crankshaft mounting bolts. The first bracket is affixed with tapped indicator mounting hole in alignment with the engine barring hole nearest the top dead center degree marking on the coupling rim. The second bracket is positioned 180 degrees from the first bracket. Reading from dial indi-

cators on generator frames must be taken from clean areas on machined surfaces. Such surfaces must be free from varnish or paint (MI 1753).

7. Depress the indicator plungers halfway as the indicators are positioned. This will allow the indicators to measure the widest range of plus and minus values (MI 1753).
8. Rotate the engine flywheel with a turning bar or engine jack until the indicator rods are in the top center position (MI 1753).
9. Set both dial indicators to zero. This establishes a reference setting to measure misalignment against (MI 1753).
10. Check dial indicator installation. A light tap on the indicators and support rods will verify all are firmly mounted and qualify the zero setting. This will also reveal any loose motion in the linkage (MI 1753).
11. Keep a written record of indicator readings. Draw a circle and label each 90 degree position. Top dead center is designated as the zero reference throughout the alignment procedure. Draw a line table to record indicator measurements at each reading position during the alignment process and for each corrective step. See *Generator Alignment Report* for an example (MI 1753).
12. With the indicator, turn the flywheel 180 degrees in a clockwise direction, when facing the bearing end. Then rotate the flywheel 270 degrees counterclockwise. The counterclockwise rotation may be necessary to prevent the dial indicators from striking alternator terminal boards, if so equipped. Record measurements every 90 degrees (MI 1753). It should be noted that one experienced in aligning EMD generators does not find it necessary to crank to the bottom side of the flywheel. Simply add 90 degrees to the 90 degree and 270 degree readings. These two readings should equal the bottom indicator reading (BRC).
13. Dial indicators should register zero when they return to their initial starting point. If they do not, investigate for cause of error, correct and take readings again (MI 1753).
14. Perform adjustments, as required, to correct alignment. Add shims under generator to adjust vertical plane alignment. Adjust misalignment of the horizontal plane by shifting the generator from one side to the other with pry bar or hydraulic jacking system. Remember, any movement of the generator frame will affect the coupling and air gaps. Readings from both indicators must be taken after each corrective step (MI 1753).
15. When indicator readings are within alignment tolerances (plus or minus 0.010” if measured on coupling surface and plus or minus 0.020” if measured on the stator housing), install and tighten generator hold down bolts. Recheck all alignment readings including bearing thrust. If all are within tolerance, the generator can be considered aligned. Torque mounting bolts – reference *EMD Bolt and Torque Data* (MI 1753). (Reference LMOA paper “Basic Torque Wrench Practices” published 2012 by Tim Standish for additional information.)
16. Drill new dowel holes and dowel

the generator to the mounting base. Reinstall removed guards.

17. Install brushes in brush holders and seat (NS).

GE GENERATOR TO ENGINE ALIGNMENT – MEASURE CRANKSHAFT WEB DEFLECTION

In GE power plants (excluding EVOLUTION series locomotives), engine to generator alignment must be checked whenever the power plant has been installed in a locomotive, when main bearings have been renewed or whenever any signs of distress have been observed associated with this alignment. Engine generator alignment is determined by measuring the web deflection of the crankshaft at the rear connecting rod throw. Reference throw number eight on 16 cylinder engines. Reference throw number six on 12 cylinder engines and throw number four on eight cylinder engines. Before one begins, make sure that the jacking screws are out of the way. Do not measure the deflection with the generator on top of the jacking screws. Measure deflection and make corrections as follows (GEI-81985E):

1. Loosen all compression release plugs and rotate the crankshaft until the rear crank pin is approximately 45 degrees from top center. Place the crankshaft deflection gauge, part number 147X1227, or pivoted dial indicator, between these webs utilizing the punch marks, which are found about 3/16" from the edge of the web. If utilizing general purpose dial indicators, make sure they are capable of measuring 0.0005" deflection. Mount the gauge parallel to the axis of the crankshaft. Make sure it is located exactly opposite of the centerline of the crank pin (GEI-81985E). Use dial indicator #41D797425P1 or equivalent, graduated to measure 0.0001" when installing GE alternators (GEK-76464B).
2. Set the indicator to zero. Make sure the indicator does not move with respect to the crankshaft while checking deflection. Remove all strain from the barring over hub at the crankshaft free end. The recorded readings may not be accurate and damage may result if the strain is not removed (GEI-81985E).
3. Rotate the crankshaft in both directions recording measurements at 45, 135, 225 and 315 degree positions. (Reference *GE Crankshaft Positions When Measuring Web Deflection* for additional information.) Do not hit the deflection gauge with the connecting rod by rotating the crankshaft too far (GEI-81985E).
4. Return the crankshaft to its original position and recheck the dial indicator. If it has not returned to zero, investigate and repeat Steps 2, 3 and 4 (GEI-81985E).
5. The indicator measurements must not exceed the total deflection given in *GE Deflection Data* for all four measuring points. If deflection exceeds this value, make corrections by adjusting shims under the bolting pads of the main generator. The shim thickness needed will be found to be twelve times the value read on

the dial indicator (GEI-81985E).

6. Finally, make sure all web deflection readings are recorded and that all generator armature and frame to engine mounting bolts have the appropriate *GE Torque Values* applied evenly (GEI-81985E). Reference LMOA paper "Basic Torque Wrench Practices" published 2012 by Tim Standish for additional information.

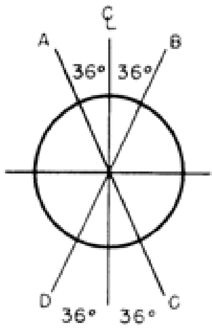
Conclusion

A locomotive is a power plant on wheels. Rotating equipment must be properly installed, aligned and maintained to provide long service life. There are numerous steps to perform proper removal, installation and alignment. Installation and alignment methods vary between generator models and locomotive manufacture. If the main generator is not properly maintained, the locomotive will not move.

EMD Generator Alignment Table – Sources MI 1753 and MI 1765

Main Generator	"X" Dimension Measure From	Stamped "X" Dimension Location	Bearing Thrust Dimension in Inches
AR5, AR6, AR10, AR11, AR15 & AR16	Bearing housing bolt head at one o'clock position to the outer face surface of the collector ring assembly (Applies to generator equipped with large bearing)	End housing	1/8 + 0 – 1/32
AR10-D14	Machined face of bearing housing to the outer face surface of the collector ring assembly (Applies to generator equipped with small bearing)	End housing	1/8 + 0 – 1/32
A5A, A7, A11, A15 and A20	Bearing cover face to the bearing outer race	Bearing housing mounting flange	1/16 + 0 – 1/64"
AB20 and A33	Bearing cover face to the bearing outer race	Bearing housing mounting flange	1/8 + or – 1/32"
D32-D14	Top right face surface of the outer bearing cover to the outer end surface of the collector ring assembly	End housing	1/16 + 3/64 – 1/64
D32P, D32S and D32T	Top right face surface of the outer bearing cover to the end surface of the armature shaft	Top of the horizontal spoke of the end housing	1/16 + 3/64 – 1/64
D25C, D25P, D25R and D25S	Bearing cover face or chisel marks to the outside end face of the bearing retainer	End housing under one of the commutator covers	1/16 + 0 – 1/64

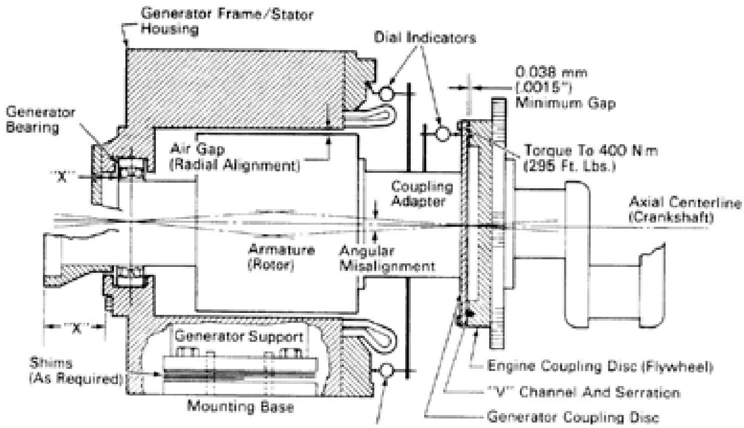
Air Gap Measurement Points – MI 1765



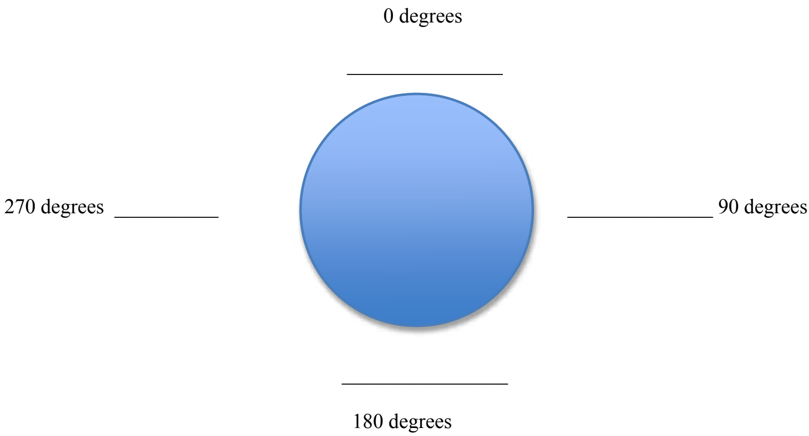
EMD Bolt and Torque Data – Source MI 1753

Main Generator	Mounting Bolt Size	Torque
D25	1-1/14” – 7	800 foot pounds (ft-lbs)
AR type, A20 and D32	1-1/2” – 6	1500 ft-lb
Coupling disc (6)	1-1/2” – 12	1800 ft-lb
Coupling disc (12)	1-1/4” – 12	1350 ft-lb
Engine to generator coupling bolt nuts	_” – 16	295 ft-lb

EMD Generator Shaft Alignment and Air Gap Equalization – MI 1765

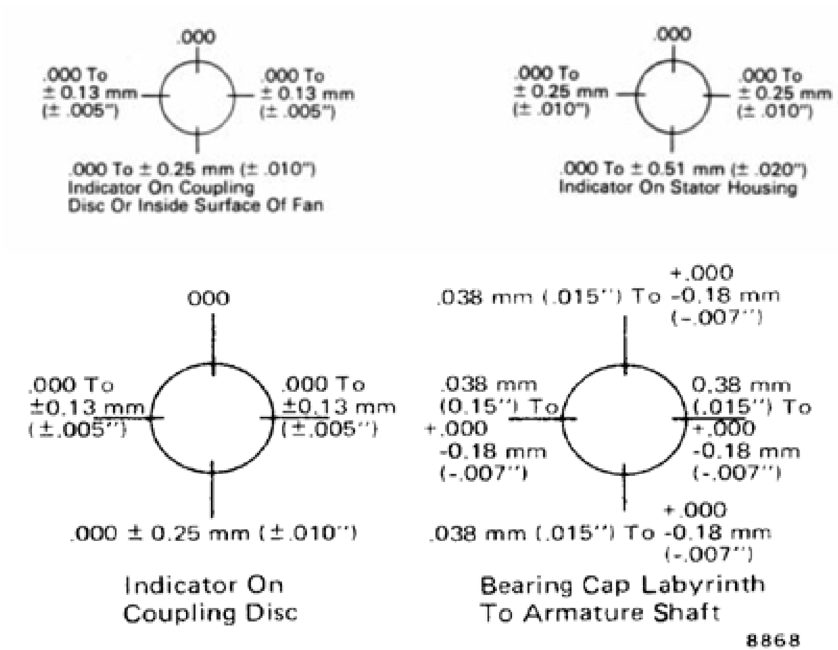


EMD Generator Alignment Report

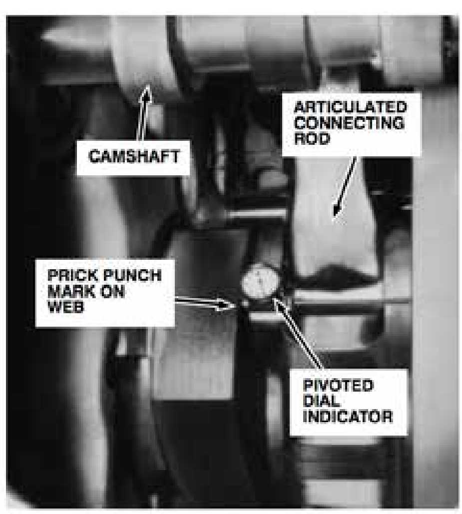


Alignment Corrective Step	Measurement Description	Top or Zero	Right Side or 90 degrees	Bottom or 180 degrees	Left Side or 270 degrees
	Coupling				
	Generator				
	Coupling				
	Generator				
	Coupling				
	Generator				

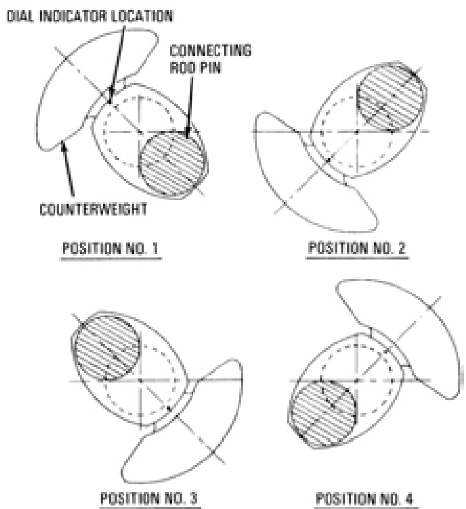
EMD Dial Indicator Alignment Tolerances – MI 1753 and MI 1765



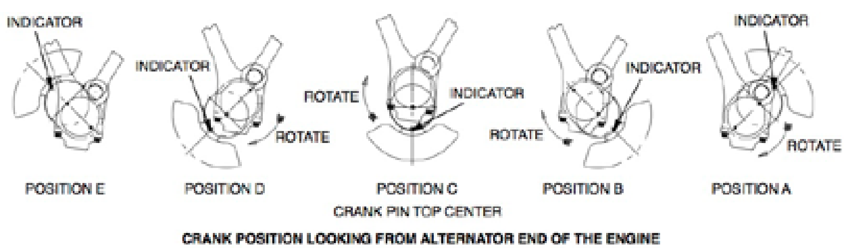
GE Engine Generator Alignment Measured by Crankshaft Web Deflection



GE Crankshaft Positions When Measuring Web Deflection - Generators - GEI-81985E



GE Crankshaft Positions When Measuring Web Deflection – Alternators – GEK-76464B



GE Deflection Data – GEI-81985E

Crankshaft Web Deflection #8 (16 cylinder engine), #8 (12 cylinder engine and #4 (8 cylinder engine Crank Pin	Inches
Total Deflection, Good Alignment, NEW EQUIPMENT	0.0000 to 0.0005
Total Deflection, Realignment, USED EQUIPMENT – MAXIMUM ALLOWED	0.002
Jack Bolt to Frame Clearance – Each Side of Engine – Engine Cold	0.010
Jack Bolt to Frame Clearance – Readjust after Engine is at Maximum Operating Temperature	0.000

GE Torque Values – GEI-81985E

Generator Mounting Bolt Description	ft-lb
Generator Frame to Engine Frame	625 – 675 ft-lb
7FDL Engine – Crankshaft to Generator Armature – Bolts without washers and with lockwire – Method #1	975 – 1025 ft-lb
7FDL Engine – Crankshaft to Generator Armature – Bolts and Hardened Washers, without lockwire – Method #2	1040 – 1160 ft-lb
Notation: One may convert from Method #1 to Method #2, eliminating the use of lockwire by adding harden washers, part #41A230195P1 and torque to Method #2 specifications	

Resources

BELT RAILWAY OF CHICAGO (BRC), THE, Interview/BNSF Generator Training Class: Richard Aranda: February 1, 2012.

EMD M.I. 1753, Alignment of Locomotive Rotating Equipment, Revision F, (June 1983): 1 - 5, 10 – 12, 13 and 18.

EMD M.I. 1765, Alignment of Rotating Equipment, Revision C, (July 1979): 10, 12, 13 and 15.

EMD M.I. 3304, D15 and D25 Main Generators, Revision B, (November 1980): 25.

EMD M.I. 3317-1, Scheduled Maintenance and Overhaul Instructions AR and TA-Type Traction Alternators, Revision F, (October 2001): 5.

EMD M.I. 6800, High Potential Tests for Locomotives in Service, (February 1959): 2 and 3.

GE GEI-81985E, MI-99104E, Power Plant Removal, Installation and Generator Alignment, (August 1980: 1, 2, 4 and 6 – 10.

GE GEK-76464B, MI-99106-004B, Engine and Alternator Removal and Installation, and Alternator Alignment, (May 2001): 7, 8.

GE GEK-76564A, MI-H9106-006A, Alternator Removal, Installation and Alignment for 7HDL Engines, (February 2000: 4.

ITS Locomotive Training Series, Switcher Electrical, Third Edition, (October 1998): 1-2.

LOCODOCS, INC., Interview: James Sherbrook: February 3, 2012.

NORFOLK SOUTHERN RAILWAY (NS), Interview: Jeff Cutright: June 6, 2012.

Finding an EPA Certified Emissions Kit for Locomotive Engine Overhaul

Prepared by:
Ted E. Stewart, P.E., Peaker Services, Inc.

Researched and Compiled by:
John Hedrick, Senior Principal Engineer, Medium Speed Diesel Engines,
Dept of Emissions Research & Development, Southwest Research Institute and
Ian Bradbury, President & CEO, Peaker Services, inc

Abstract

Locomotive Emission Standards and Targets are changing as a result of continued efforts to improve air quality for the benefit of public health. For purchasers of a new locomotive, the manufacturer is required to comply with the currently applicable standard. For remanufactured engines, existing owners may need to apply a certified emissions kit to comply with remanufactured engine emissions standards. In such a case, how might the owner find out what the certified remanufacture kit options are? This paper provides an introduction to the EPA's Office of Transportation and Air Quality, (OTAQ), Document Index System, (DIS) as a means of answering this question. It describes the steps involved in using the Website along with some helpful notes and tips. Some summary information from OTAQ is presented as of the middle of 2012. This may be out of date by the time of publication, but the search method we describe will allow for an updated search at any future point in time.

Locomotive Emission Standards and Targets

Locomotive Emission Standards and Targets have changed, and will continue to change as the EPA regulates tougher locomotive emission standards in their effort to clean the environment. Figure 1: Locomotive Emissions Targets provides a quick snapshot of how these regulations have changed from the initial implementation of 40 CFR Part 92 regulations that took effect on January 1, 2000 to where the emission standards will be in three short years.

The majority of operating locomotives in the US are required to comply with the current emissions regulations (40CFR Part 1033), which became effective January 1, 2010. An exemption is provided for railroads that qualify as a small business. For reference, the following EPA definitions are provided.

A small railroad is one that is **classified by the Small Business Administration as a small business**,. A small "Line-Haul" railroad has fewer than

1500 employees and a small "Switch" railroad has fewer than 500 employees[1].

For railroads owned by "parent companies", the number of employees used to determine the small business status is the combined number of employees of the railroad and the parent company. (**"it doesn't matter what the "parent" company does in their business, if a railroad doesn't fit the definition of 'small' they would have to comply with the regulations[2]"…**).

In short, if your (parent) company would not qualify for an SBA loan, your company is required to comply with the regulations.

So, if you have determined that you have to comply, how do you find out which certified emissions kits are available?

Introduction to EPA's OTAQ DIS

EPA's Office of Transportation and Air Quality (OTAQ) Document Index System (DIS) website can be found at the following address and offers an opportunity to query a wide range of industries, (Air, Marine, Locomotive and Trucks). In addition, it offers a historical overview of all EPA certified emissions reduction kits.

http://iaspub.epa.gov/otaqpub/pubsearch.jsp

The opening page is presented in Figure 2: DIS Opening Page with the red arrows providing the instructions for finding Certificates of Conformity for locomotive models certified in 2012.

Filtering by certificates of conformity provides only emissions kit certificate results (eliminating entries such as EPA informational notices). Filtering by Locomotives narrows the search to locomotive emissions certificates. Emissions kits have to have a certificate for the year of application, so filtering by 2012 as "model year" further narrows the search to kits currently certified for use in 2012. The "manufacturer" is the emissions certificate holder, so selecting "All" doesn't limit the search to a particular certificate holder. "Vehicle Model" is where you would enter a particular locomotive model, if you want to so limit your search. Using the search criteria displayed in Figure 2: DIS Opening Page would therefore return the first 20 entries for 2012 locomotive emissions certificates of conformity

The following examples are provided to illustrate search results and highlight some potential pitfalls.

1. A search for an EMD SD60 locomotive emissions kit certified for model year 2012 (the entry screen completed as in Figure 2: DIS Opening Page, but with "SD60" entered in the "Vehicle Model" field), returns the results shown in Figure 3: EMD SD60 options

This lists the following two kits:

a. EMD engine family CEMDK-0710TMA, and
b. National Railway Equipment, Co. engine family CNREK-0710MUI

One might conclude from this that these are the only EPA certified kits available to apply to an SD60 in 2012.

1 From the Exclusion and Exemption Provisions, Technical Highlights, EPA420-F-99-037, the EPA definition of a "Small Railroad"
2 Direct excerpt from 2/2/2007 correspondence with EPA

However, if one performs a search without filtering by vehicle model = SD60, certificates are shown for both Advanced Global Engineering (AGE) and CSXT. In these cases, the vehicle model was entered as GP/SD60. To make sure you capture all possible entry variations, the authors recommend not filtering by vehicle model.

2. A search for a GE ES44 locomotive model certified in 2012 (the entry screen completed as in Figure 2: DIS Opening Page, but with "ES44" entered in the "Vehicle Model" field), would show the following five options, as illustrated in Figure 4: GE ES44 options:
   a. GETS Business Operations engine family CGETG0958EFB
   b. GETS Business Operations engine family CGETG0958EFD
   c. GETS Business Operations engine family CGETG0958EFT
   d. GETS Business Operations engine family CGETG0958EFX
   e. GETS Business Operations Engine family CGETG0958EFB

Additional Notes and Search Tips

In addition to emissions kits, a search by "All" manufacturers yields other results that may be of interest. If an emissions critical component is to be used from a manufacturer other than the certificate holder, a component certificate of conformity is required. An example of this is Delphi Diesel Aftermarket's component certification of GE injector nozzles. Delphi used the following abbreviation in their applications; 6GETK0668EFA/FB/FD/FF/PC. None of these engine families will show up if a search is conducted for the individual dash-9 models.

Listings are also included for new engines and locomotives.

The EPA Database also provides the names of suppliers of emission control devices, such as the Automatic Engine Start Stop (AESS) systems, (GE Transportation, Invensys Rail, Motive-Power Inc. and ZTR Control Systems). Application of a certified AESS system became a compliance requirement with 40CFR Part 1033.

For the sake of legibility, two columns of data have been deleted from the search results displayed in the figures. The first of these is Size/Link and the second Related Documents. All search results for Size/Link had a link to a PDF of the EPA certificate for the manufacturer. The certificates provide some additional information not provided in the summary listings displayed in earlier figures.

For instance, the certificate in Figure 5: Certificate for CGETK0668EFA is provided through DIS for the associated kit. This indicates original locomotive model years for which the kit is applicable (1996 to 1998) and components included in the rebuild kit. Some certificates include additional information on what has to be done at the time of installation in the text of the bottom box. It should be noted that the information available is not always consistent from one filing to another and is minimally informative. The information should be adequate for identifying currently available solutions.

Finally, the information is only periodically updated on DIS, so manufacturers may have been issued a certificate of compliance for some time prior to appearance in search results.

Summary Information Available for 2012 certificates as of summer 2012

The following information was compiled from the DIS system in summer 2012. It is an effort to provide an overview of available solutions as of that point in time. The data was taken from DIS and put into an Excel spreadsheet, which is available by contacting any of the authors of this paper. No guarantees are provided as to the accuracy of the information contained since many assumptions were needed to classify results where information from DIS is incomplete.

Figure 6 through Figure 9 are pivot tables obtained by entering different filter criteria in the cells with a funnel icon next to them. This provides an overview of the number of kits available for different engine applications from different kit manufacturers. In the process of producing these tables, it was noted that AESS systems only have entries for a single year, presumably the year in which the certificate was originally issued. This is something else to consider when limiting your search criteria on DIS. The data retrieved were from January 1, 2010 onwards to filter out certificates from the prior emissions standard. To find AESS systems certified prior to this date requires a broader search to be performed.

Whereas this provides a view of how many kits are available for a given application, it doesn't describe the differing nature of the kits available. Figure 10 is a classification of 2012 kits that provides some of these distinctions, with a lot of guesses having been made in the absence of definitive information. The kits identified by the yellow cells are all believed to be variations of power assembly changes for reduced PM, improved after-cooling and timing changes for reduced NOx. In all of these cases, the changes to the appearance and operation of the engines are externally minor. The red cells involve the use of after-treatment (Diesel Oxidation Catalysts or Diesel Particulate Filters) for the reduction of PM. The salmon and light green cells involve repowering the locomotive with either multiple generator sets or a newer design of engine. The bright blue cell involves conversion of the engine from mechanical to electronic fuel injection. In all of these latter cases, the changes from application of the emissions kit are more externally apparent and may involve changes in the operation or maintenance requirements for the locomotive.

Conclusions

The EPA OTAQ DIS website is a useful resource for discovering available sources of emissions kits for your locomotive application. The website is self-explanatory and easy to navigate, however, some care is required in how search criteria are entered to ensure that you find all entries of interest. The information is of a terse summary nature, so it is necessary to contact the kit manufacturer to obtain significant information about the nature of the emissions kit. The authors have tried to provide overall summary information that is a helpful at the time of publication.

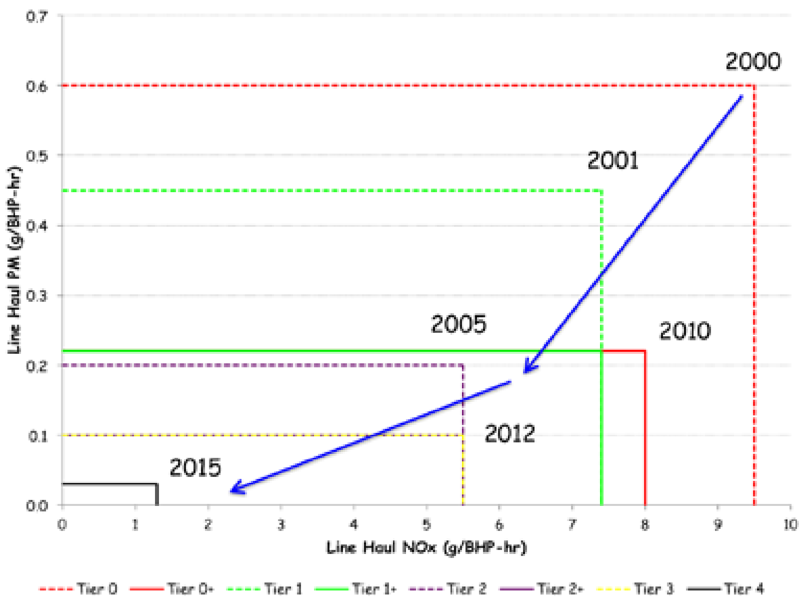


Figure 1: Locomotive Emissions Targets

Figure 2: DIS Opening Page

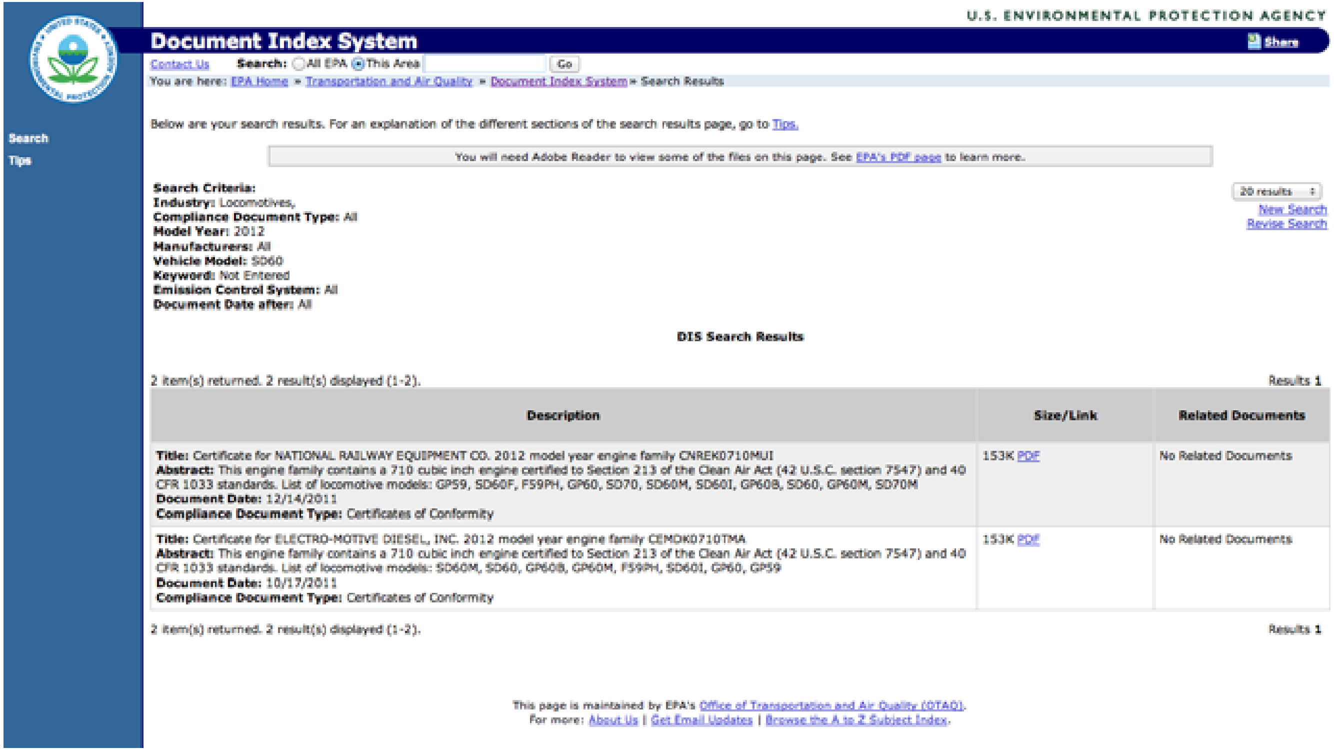


Figure 3: EMD SD60 options

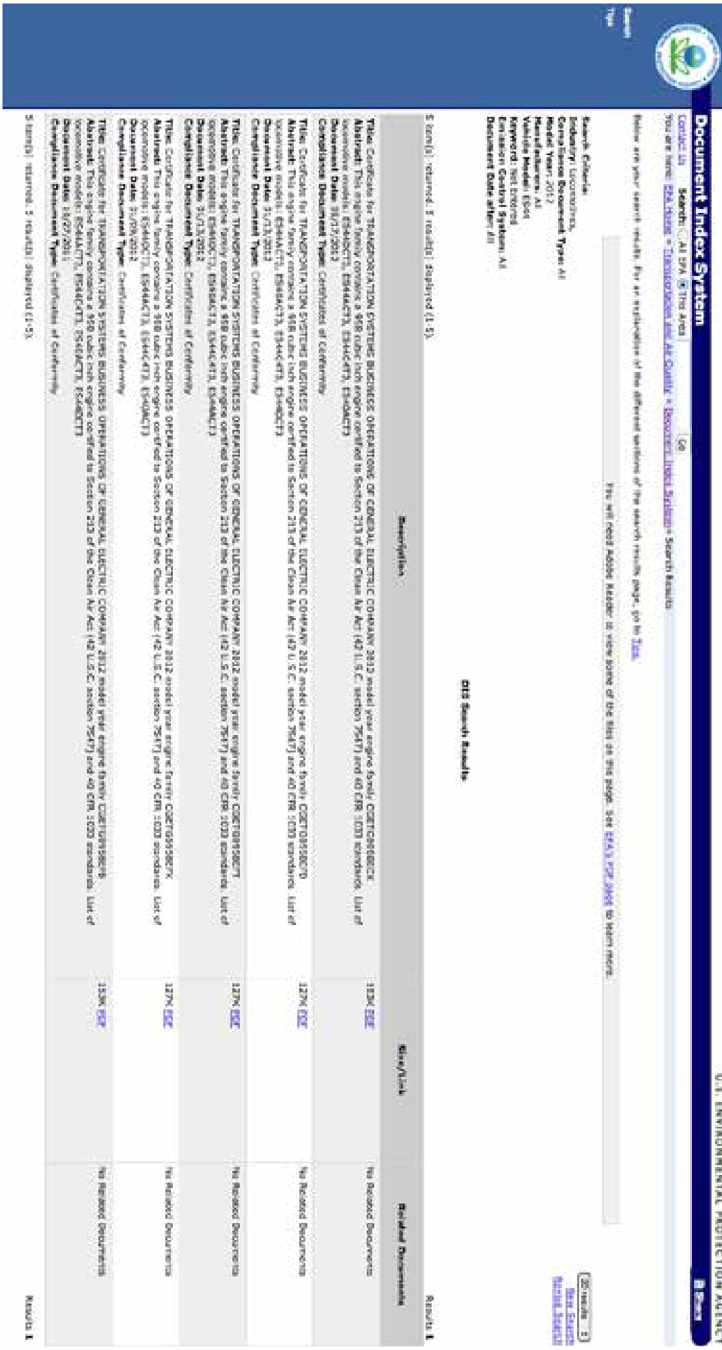
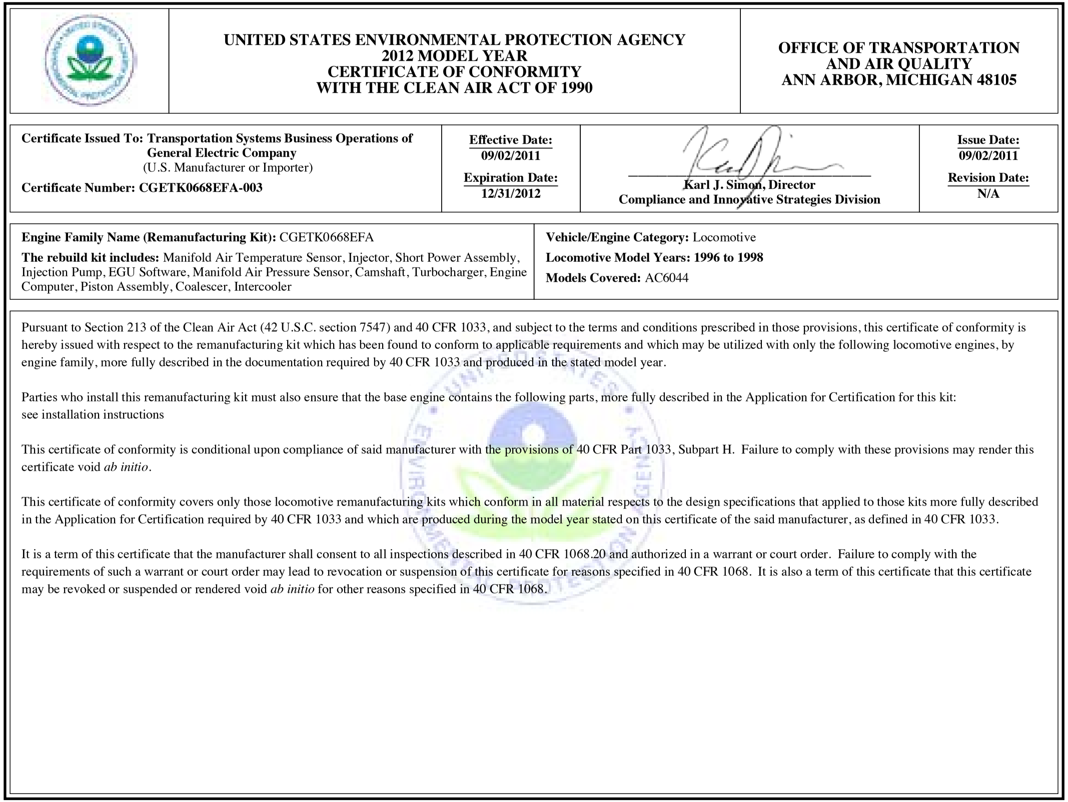


Figure 4: GE ES44 options



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
2012 MODEL YEAR
CERTIFICATE OF CONFORMITY
WITH THE CLEAN AIR ACT OF 1990

OFFICE OF TRANSPORTATION
AND AIR QUALITY
ANN ARBOR, MICHIGAN 48105

Certificate Issued To: Transportation Systems Business Operations of General Electric Company
(U.S. Manufacturer or Importer)
Certificate Number: CGETK0668EFA-003

Effective Date: 09/02/2011
Expiration Date: 12/31/2012

Karl J. Simon, Director
Compliance and Innovative Strategies Division

Issue Date: 09/02/2011
Revision Date: N/A

Engine Family Name (Remanufacturing Kit): CGETK0668EFA
The rebuild kit includes: Manifold Air Temperature Sensor, Injector, Short Power Assembly, Injection Pump, EGU Software, Manifold Air Pressure Sensor, Camshaft, Turbocharger, Engine Computer, Piston Assembly, Coalescer, Intercooler

Vehicle/Engine Category: Locomotive
Locomotive Model Years: 1996 to 1998
Models Covered: AC6044

Pursuant to Section 213 of the Clean Air Act (42 U.S.C. section 7547) and 40 CFR 1033, and subject to the terms and conditions prescribed in those provisions, this certificate of conformity is hereby issued with respect to the remanufacturing kit which has been found to conform to applicable requirements and which may be utilized with only the following locomotive engines, by engine family, more fully described in the documentation required by 40 CFR 1033 and produced in the stated model year.

Parties who install this remanufacturing kit must also ensure that the base engine contains the following parts, more fully described in the Application for Certification for this kit:
see installation instructions

This certificate of conformity is conditional upon compliance of said manufacturer with the provisions of 40 CFR Part 1033, Subpart H. Failure to comply with these provisions may render this certificate void *ab initio*.

This certificate of conformity covers only those locomotive remanufacturing kits which conform in all material respects to the design specifications that applied to those kits more fully described in the Application for Certification required by 40 CFR 1033 and which are produced during the model year stated on this certificate of the said manufacturer, as defined in 40 CFR 1033.

It is a term of this certificate that the manufacturer shall consent to all inspections described in 40 CFR 1068.20 and authorized in a warrant or court order. Failure to comply with the requirements of such a warrant or court order may lead to revocation or suspension of this certificate for reasons specified in 40 CFR 1068. It is also a term of this certificate that this certificate may be revoked or suspended or rendered void *ab initio* for other reasons specified in 40 CFR 1068.

Figure 5: Certificate for CGETK0668EFA

Class	EMD Retrofit Kit
Model Year	2012

Kit Count	Column Labels							
Kit Manufacturer	645E	645E3-2S	645E3B	645E3B/C F3B	645F3B	710G3A	710G3B	710G3C
Advanced Global Environmental	3					1	1	1
CSX Transportation Inc.	2	1	3			1		
Electro-Motive Diesel Inc.	1		1	1	1	1	2	4
HK Engine Components LLC			1					
National Railway Equipment Co.	1			1		1		
Oceanair Environmental LLC	2		1					
Peaker Services Inc.			1					
Total	**9**	**1**	**7**	**2**	**1**	**4**	**3**	**5**

Figure 6

Class	GE Retrofit Kit
Model Year	2012

Kit Count	Column Labels				
Kit Manufacturer	Dash 8	Dash 8 & 9	Dash 9	GEVO	HDL
Advanced Global Environmental	1		4		
GE Transportation Systems Busin	2	2		1	1
Total	**3**	**2**	**4**	**1**	**1**

Figure 7

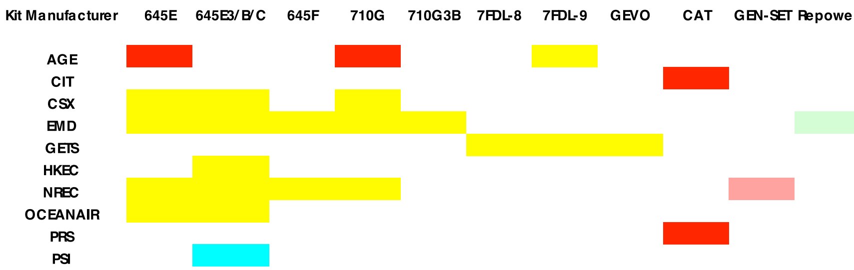
Class	Caterpillar
Model Year	2012

Kit Count	Column Labels
Kit Manufacturer	4.88 liter engine
CIT	2
Progress Rail Services	1
Total	**3**

Figure 8

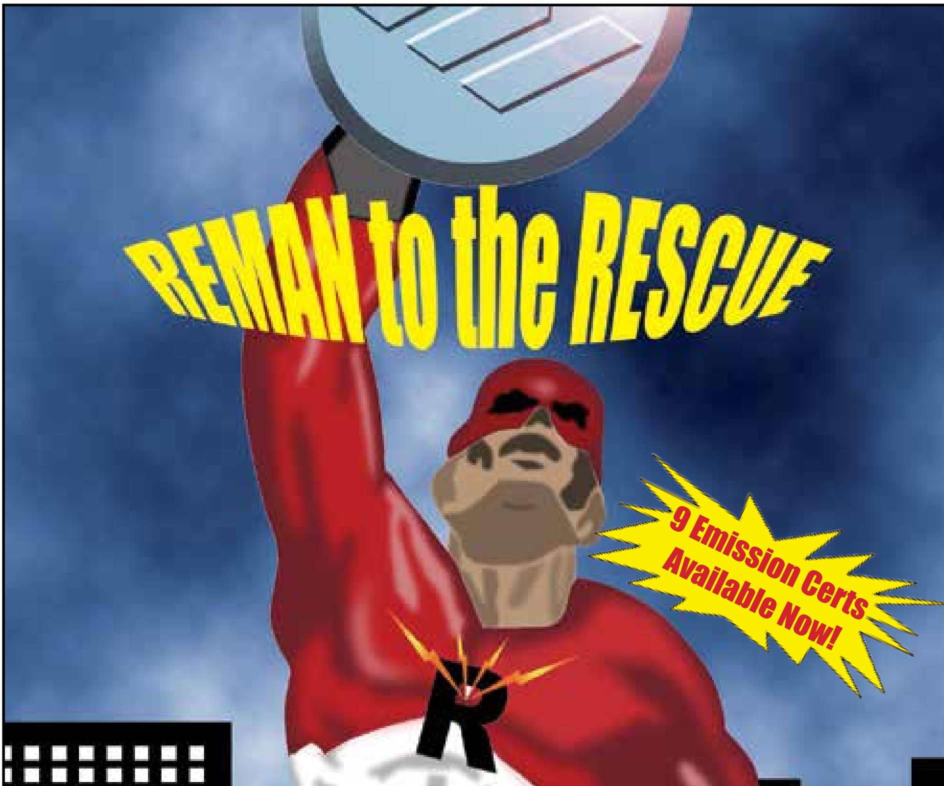
Class	AESS	
Kit Count	Column Labels	
Kit Manufacturer	2010	2011
GE Transportation		1
Invensys Rail		1
MotivePower Inc.	1	1
ZTR Control Systems	1	
Total	**2**	**3**

Figure 9



AGE	ADVANCED GLOBAL ENVIRONMENTAL
CIT	CIT RAIL
CSX	CSX TRANSPORATION
EMD	ELECTRO-MOTIVE DIESEL
GETS	GENERAL ELECTRIC TRANSPORATION SYSTEMS
HKEC	HATCH & KIRK ENGINE COMPONENTS
NREC	NATIONAL RAILWAY EQUIPMENT
OCEANAIR	OCEANAIR ENVIRONMENTAL
PRS	PROGRESS RAIL SERVICES
PSI	PEAKER SERVICES, INC.

Figure 10


REMAN to the RESCUE
9 Emission Certs Available Now!

Locomotive Idle Minimization

Prepared by:
David M Rutkowski, Providence and Worcester Railroad
William Edwards, Montana Rail Link

Introduction

The purpose of this paper is to discuss the pros and cons that have not been documented with the concept of locomotive idle minimization apparatus. We will discuss two options for idle minimization: Auxiliary Power Units (APU's) both diesel and shore-powered and Automatic Engine Start Stop (AESS) systems. We have found numerous challenges, particularly with installation of the APU units and gearing up for the work required throughout the year to maintain the units. We will briefly discuss high points pertaining to operation, modification, and utilization of the units. The AESS systems have a few issues, which we will discuss. We will discuss issues with the APU's in greater depth.

Why do locomotives idle?

Locomotives idle for a wide variety of reasons. These include track issues due to logistics, capacity and state of repair. Weather and equipment issues, train and crew scheduling and maintenance of essential needs also can create situations that force a locomotive to sit idling. In some applications, locomotives have been observed to idle for 90% of their possible duty cycle.

Why do we care that locomotives idle?

Since it has been the historical norm for many railroads to idle locomotives while not working, why change? While the locomotive is idling, it is burning fuel at a rate of 4-6 gallons per hour. Reduction of this idling time can produce a significant reduction in operating fuel cost and emissions. Noise and main engine run hours are reduced when the main engine is shut down. Also, maintenance and safety issues related to oil loading of air-boxes and stacks are reduced. However, some costs can go up as a result of idle minimization. The anti-idling systems introduce new maintenance requirements of their own, and some existing systems have significantly increased duty cycles, such as for locomotive starter motors. The Providence and Worcester Railroad has applied 17 APU's, 13 fuel operated heaters and 9 AESS systems. The benefits of this program are illustrated in Figure 1 – Figure 3. Figure 1 and Figure 2 show the estimated PM and NOx reductions and Figure 3 the estimated fuel savings as a result of this project – all of a significant magnitude! Montana Rail Link has applied and uses 50 APU systems on a variety of EMD locomotive models ranging from SW1200 switchers to SD40-2's and currently have 16 SD70 ACe's equipped with AESS in our fleet. Much like the Providence and Worcester Railroad, lower emissions and fuel savings were very attractive benefits associated with the purchase of these systems. Another added benefit for MRL is the ability to strategically stage power at outlying locations in anticipation of increasing traffic levels without having to ship units from a central location. These systems give the user the ability to shut a locomotive down in extreme winter weather for days at a time saving fuel, lowering emissions and in some situations just being a good neighbor. In short, no matter what reasoning is for purchasing an APU system the benefits are significant; and in some cases these systems have the ability to pay for themselves is a year's time. Over the past few years, MRL has tracked performance on 34 APU's; and last fall reached a milestone of a million dollars in savings.

Idle minimization systems

These fall into two categories – Auxiliary Power Units (APU's) and Automatic Engine Stop Start systems (AESS). An APU is a device that provides energy for functions other than propulsion. An AESS is a system that keeps a locomotive ready without wasting fuel.

Effective January 1st 2010, a railroad applying a locomotive emissions kit must include an AESS system meeting the standards described in 40 CFR part 1033. The following section is an abstract of federal emissions regulations as they relate to APU's. These and other requirements in 40 CFR part 1033 need to be borne in mind if applying an APU as part of a 1033 certified emissions kit.

40 CFR 1033.510 - AUXILIARY POWER UNITS.

§ 1033.510

Auxiliary power units:

If your locomotive is equipped with an auxiliary power unit (APU) that operates during an idle shutdown mode, you must account for the APU's emissions rates as specified in this section, unless the APU is part of an AESS system that was certified separately from the rest of the locomotive. This section does not apply for auxiliary engines that only provide hotel power.

a. Adjust the locomotive main engine's idle emission rate (g/hr) as specified in §1033.530. Add the APU emission rate (g/hr) that you determine under paragraph (b) of this section. Use the locomotive main engine's idle power as specified in § 1033.530.
b. Determine the representative emission rate for the APU using one of the following methods.

1. **Installed APU tested separately.** If you separately measure emission rates (g/hr) for each pollutant from the APU installed in the locomotive, you may use the measured emissions rates (g/hr) as the locomotive's idle emissions rates when the locomotive is shutdown and the APU is operating. For all testing other than in-use testing, apply appropri-

ate deterioration factors to the measured emission rates. You may ask to carryover APU emission data for a previous test, or use data for the same APU installed on locomotives in another engine family.

2. **Uninstalled APU tested separately.** If you separately measure emission rates (g/hr) over an appropriate duty-cycle for each pollutant from the APU when it is not installed in the locomotive, you may use the measured emissions rates (g/hr) as the locomotive's idle emissions rates when the locomotive is shutdown and the APU is operating. For the purpose of this paragraph (b)(2), an appropriate duty-cycle is one that approximates the APU engine's cycle-weighted power when operating in the locomotive. Apply appropriate deterioration factors to the measured emission rates. You may ask to carryover APU emission data for a previous test, or use data for the same APU installed on locomotives in another engine family.

3. **APU engine certification data.** If the engine used for the APU has been certified to EPA emission standards you may calculate the APU's emissions based upon existing EPA-certification information about the APU's engine. In this case, calculate the APU's emissions as follows:
   - For each pollutant determine the brake-specific standard/FEL to which the APU engine was originally EPA-certified.
   - Determine the APU engine's cycle-weighted power when operating in the locomotive.
   - Multiply each of the APU's applicable brake-specific standards/FELs by the APU engine's cycle-weighted power. The results are the APU's emissions rates (in g/hr).
   - Use these emissions rates as the locomotive's idle emissions rates when the locomotive is shutdown and the APU is running. Do not apply a deterioration factor to these values.

4. **Other.** You may ask us to approve an al ternative means to account for APU emissions. [73 FR 37197, June 30, 2008, as amended at 73 FR 59190, Oct. 8, 2008]

AESS systems

AESS systems have numerous advantages:

- They are relatively easy to integrate with existing locomotive systems, typically requiring a relatively small amount of space.
- The operation of the AESS system is automatic, monitoring parameters such as length of time idling, main air reservoir pressure, battery voltage, ambient and engine coolant temperature to determine when the main engine can be shut down and when it needs to be restarted. Typical logic is shown in Figure 4 for GE's AESS system
- The study results shown in Figure 5 illustrate that EMD's EM2000 AESS system was effective in automatically shutting down the engine

41% of the total potential idling time, and that the above and other permissives weren't met to shut down the engine 37% of the total potential idling time.
- It is possible to use AESS systems in combination with other idle reduction measures.
- Generally, provided the ambient temperature is above 35F, AESS systems are quite effective for idle reduction.

Disadvantages of AESS systems include:
- Operators can override shutdown if they decide it is "necessary". In the EMD study results shown in Figure 5, this was 16% of the time that the unit could possibly have been shut down
- Ambient temperatures below 25F will typically prevent shutdown
- Unattended restarting of the main engine increases the risk of damage. For instance, a failure to restart could result in freeze damage
- For EMD engines, significantly higher duty cycle for starter motors (reducing starter motor and ring gear life)

Diesel APU's

Diesel APU systems have numerous advantages:
- APU can cycle on and off automatically
- APU can provide battery charging so the main engine doesn't need to restart to maintain battery condition
- APU can heat main engine coolant and oil so the main engine doesn't need to restart to maintain temperature
- APU can run a small air compressor
- With all these capabilities, and adequate maintenance of other locomotive systems, a diesel APU can completely prevent unnecessary main engine restarts in the winter

Diesel APU systems also have a number of disadvantages:
- They have a large footprint, which can present a placement issue
- They require additional fuel and electrical connections
- They can still be noisy, though at a higher sound frequency than the main engine. This is effectively mitigated if the APU is mounted inside the carbody.

APU Design and Maintenance Considerations

Out of the box design

It is important to plan ahead and choose a practical, user-friendly location to mount your APU. Keep in mind you will need access to check and add fluids, make repairs when needed and the time will arise when it is necessary to remove the unit for one reason or another. Work with your vendor so you can both decide the best placement for your APU with these points in mind. Some manufacturers advertise that their product can be installed on walkways, and this in fact can be done. If this is an installation location that interests you, it may be beneficial to build an enclosure around the APU to combat the elements. Installation support has been difficult to obtain for some APU designs.

Documentation support

One APU manufacturer took over a year to provide updated documentation for APU design revisions. It is recommended that a purchaser confirm that current documentation is available at the time of purchase.

Design incompatibility

The auto shutdown system offered with earlier models of APU is now obsolete and cannot be retrofitted or interchanged with the newer system. It is advisable to investigate this if updating an existing system.

Vibration

Ensure your APU is installed in a location and manner that will minimize vibration to the unit. There have been reports of electrical issues, loose bolts and loose connections as a result of too much vibration. Most diesel driven models come equipped with rubber mounts and hardware. It's important to inspect rubber mounts routinely as they do get brittle and break out. Field experience has been that the vibration dampeners need to be replaced often.

Oil make up tank design

One APU design has a solid steel oil makeup tank with oil level mark on the exterior. There is no way of knowing how much oil is in the tank as designed. It was therefore necessary for the user to fabricate their own dipstick using the existing oil fill cap.

Grounding Issues

Ensure that the APU is isolated from the locomotive. Locomotives alone are not grounded; they are equipped with a ground relay circuit. What is a Ground Relay? It is an electrical relay provided in diesel electric traction systems that protects against damage from "Earth Grounds". If a ground is detected in the locomotive's electrical system the relay will shutdown the electrical drive. Also called an "Earth Fault Relay", a ground relay is similar to Ground Fault Interrupter (GFI) which can be found in the majority of homes. Some APU models are equipped with a "Ground Switch" that is picked up when the APU is started and remains picked up as long as the APU is running. If the "Ground Switch" fails you may see a Low Voltage Ground in the locomotive electrical system when the APU is shut down. Note: The Ground Relay Circuit protects against High Voltage Grounds where most grounding issues caused by an APU are of the Low Voltage variety.

Control box issues

Some control boxes house an LCD display that shows run time, date, etc. When this display fails, stored data is lost and irretrievable. Without the data history, tracking APU performance and its relation to fuel savings is compromised. Failures have also been experienced due to inadequate wire crimps inside the control box. Weak crimps can cause electrical shorts, which have resulted in burnt AC boards. The wiring harness that runs from the door of the control box where the LCD and control buttons are located is susceptible to abrasion from vibration and from opening and closing the door. The door latches on the control box door fail and need to be replaced often. In some instances, restarting APU's after they have failed to start clears fault history. This compromises proper maintenance and reliability of the APU. Control issues can be extremely difficult to troubleshoot on some designs.

Engine over-speed faults

APU magnetic pickup (speed) sensors should be inspected and cleaned of debris on a regular basis. Failure to do so can result in APU over-speed faults.

Dead Batteries

There have been numerous reports associated with APU batteries not maintaining an operational charge. Check battery voltage routinely and more so during the winter months. Some APU models are equipped with an alarm system that gives a warning when the APU has failed. If this failure is not addressed or the alarm is not disabled in a timely manner the alarm system will drain the APU battery and can also drain the locomotive batteries. MRL's experience has been that the APU batteries have a much shorter life than expected. This appears to be independent of the model of battery used, and is therefore likely a design or environment issue. In addition to this, some models of locomotive battery charger systems have proven to be unreliable.

Circulation Pump failures

Currently, there is no indication that the circulation pump is working properly. You may think things are great. All the lights that indicate systems are "go" are illuminated but low and behold, the circulation pump has failed and the next thing you know the locomotive has dumped its engine cooling water if it is equipped with a coolant dump valve or worse you have just experienced freeze damage to your locomotive cooling system and engine. Make sure your locomotive is equipped with a coolant dump valve and the operation of the dump valve is checked during routine maintenance.

Fluid temperature sensor failures

Some fluid temperature sensors are potted on top of the threaded brass housing where the wires feed into the sensor. Excessive heat causes this connection to weaken, resulting in an unstable connection. Wires have broken free of the sensor, which in turn triggers sensor faults.

Corrosion in coolant system

Rust and stop leak will coagulate in Low Pressure Air Compressor Heads, which can prevent adequate flow of heated water through the cooling system. Ensure that the coolant system is completely flushed and contains a corrosion inhibitor that meets or exceeds OEM specifications. There are companies that manufacture a tool that is designed to flush gunk from the cooling ports inside air compressor heads.

Cold Cabs

Not all APU models are available with the option to heat locomotive cabs. CFR 49 229.119 Cab, Floors and Passageways (d) requires that: *The cab shall be provided with the proper ventilation and with a heating arrangement that maintains a temperature of at least 50 degrees Fahrenheit 6 inches above the center of each cab seat*. Cold cab temperatures can cause cab computer displays to become flakey; this problem typically goes away once the cab warms back up. There is also the potential for toilet failures from freezing. This is easily remedied by use of RV antifreeze. If you choose an APU model that does not offer the option of cab heat, you may want to consider designing a heat exchanger or installing 110V heat. AESS will heat cabs when the prime mover is running. In colder temperatures it's wise to leave sidewall heaters on low or medium.

Research your heating options

Whether you choose an electrically driven or diesel driven APU system you will be faced with choosing from a number of models and options. System options can range from engine coolant heating and circulation to engine coolant and lube oil heating and circulation, locomotive battery charging, locomotive cab heating/cooling and there are even options for satellite monitoring.

Freezing brake valves

Air lines under the cab have frozen in some circumstances, resulting in Positive Train Control (PTC) Advanced Civil Speed Enforcement System (ACSES) failures. A solution for this is currently in the development stage.

Biofuel issues

If you are going to use Bio Diesel, ensure your system has a retrofit to prevent coagulation of your fuel.

Intake filters plugging

The engine air filters for the APU can plug if not maintained according to factory recommendations. It has been found that using a quality aftermarket lifetime air filter can help with this issue. These filters are more costly when initially purchased but there is a potential for overall savings. If one of these types of filters is used, it's important to know that most manufacturers require the use of a special cleaner and it can take time to get the filters desirably clean. An alternative solution is to plumb the air intake to the APU directly outside to eliminate premature filter failure. The inside of the carbody is not a very clean environment.

Sharing lube oil possible zinc contamination

Ensure that the lube oil samples are taken from the APU and Prime Mover separately. It is not recommended to share Prime Mover oil and APU oil in the same system for fear of Zinc contamination. MRL is currently in the process of switching from conventional engine oil to synthetic oil in all their APU's. Tests performed during the winter of 2011-2012 indicate it should be possible to go a year between APU oil changes. Air, oil and fuel filters will still have to be changed on a more frequent schedule.

Other miscellaneous comments

Following warranty work, "Run Tested" units have been received missing major components. For example, a unit installed upon return was started and immediately shut down on low oil pressure. Upon teardown of the oil pump, it was discovered that the drive gear was missing. It is suggested that vendor qualification and testing prior to installation be considered.

Subcomponent parts for APU's can be difficult to find.

One noteworthy topic centers on the engine featured on the APUs. For instance, one generator-powered APU features a Kubota engine. This is beneficial because there are many Kubota dealers throughout the country. A diesel driven APU uses a Yanmar engine, which is used in a variety of John Deere equipment, making parts easily obtainable. This information may be useful after the warranty has run out and you are looking to repair or repower your APU.

Conclusions

We have identified many issues in this paper, which naturally may lead one to question whether it is worthwhile to install an idle minimization system on your locomotive. A number of the issues raised can be addressed through design revisions to the idle reduction systems and their installation. This will still leave a number of additional service and maintenance tasks that you didn't have before. Is it worth it? The benefits if done well can be significant:

- Fuel Savings: At outlying points, P&W saw 40% fuel savings using APU's last winter. At these points, both Diesel and 110Volt Shore Power versions were used.
- Lube oil savings: P&W has seen 3% savings in main engine lubricating oil consumption during winter operation
- Emissions Improvement: Potential for significant PM and NOx reductions (see Figure 1 and Figure 2).

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M J Bradley & Associates

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Power Drives

Kim Hotstart

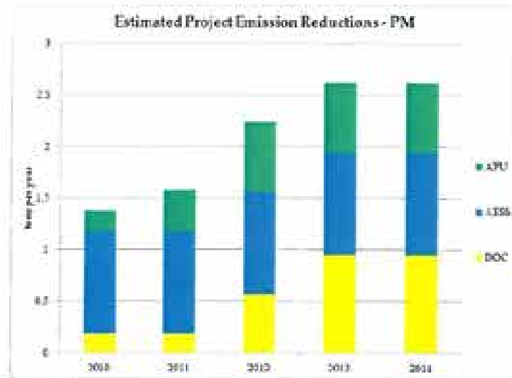

Figure 1

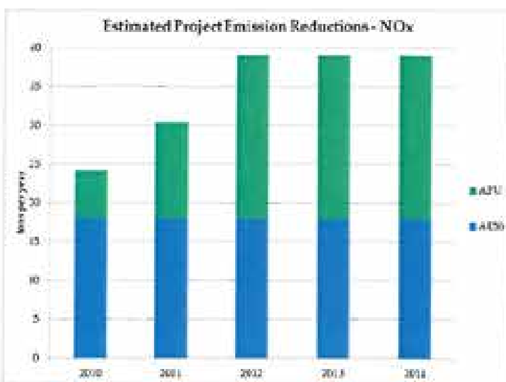

Figure 2

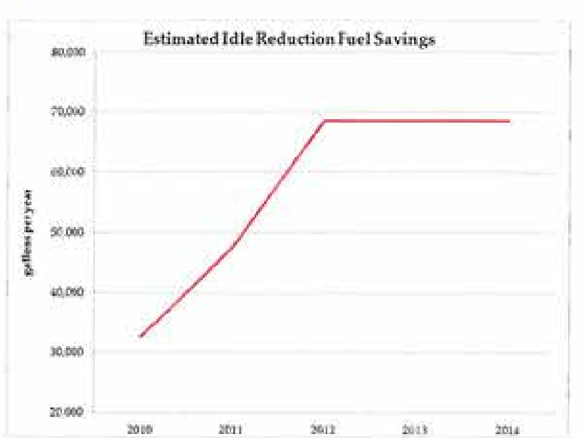

Figure 3

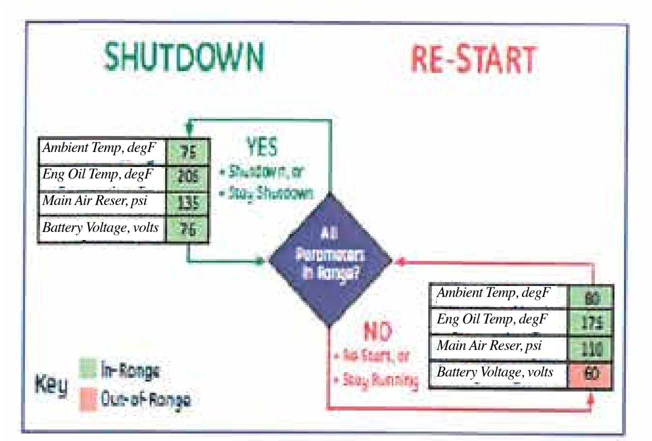

Figure 4

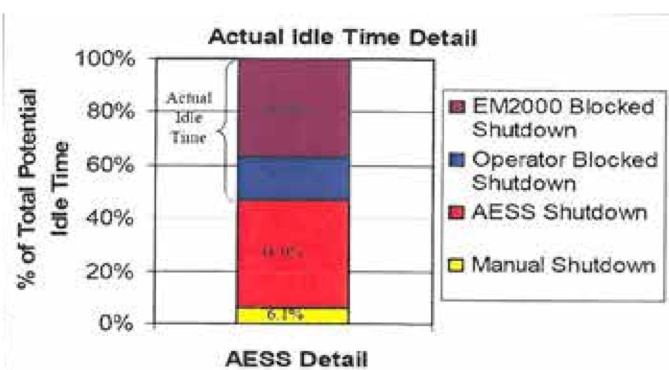

Figure 5

Manual Torque Wrench Basics

Prepared by:
Tim Standish, Electro-Motive Diesel, Inc.
Presented at September 2011 Convention in Minneapolis, MN

There are many maintenance practices to help keep your locomotive fleet running, but one topic that is often overlooked is proper manual torque wrench usage. It seems like a simple enough topic, but there are many items that need to be considered to properly torque fasteners. This is not about how to design a bolted joint or select the proper hardware, but how to properly apply fasteners to achieve the proper clamp load as designed by the engineer. Improper bolt torque can result in failures due to over tightening such as bolt failure and thread stripping or under tightening causing a loose joint or component wear; which in either case can lead to expensive repairs and unscheduled locomotive shopping. This paper will take you through safety, basic torque concepts, types of hand torque wrenches, proper usage, and torque verification.

First and foremost is safety. The following should be included in normal safety talks if not done so already. There are a number of ways in which injuries can be prevented by just being aware of tool basics, pinch points and surroundings. Improper socket and adapter choices can result in tool failures that can cause injuries to hands or arms, so make sure that the torque values do not exceed the tool ratings. This often occurs when using reducing adapters when the proper size drive sockets are not found or when the outside diameters of sockets are ground down to fit certain clearances. Make sure tools are kept clean as an oily handle can lead to hand slippage. Make sure sockets are fully engaged on the bolt head or nut and the wrench is pulled parallel to the surface being tightened or the wrench can slip off causing an imbalance to the assembler. If using large wrenches with higher torques, make sure a proper foot stance is used just in case the wrench slips and you will be able to catch yourself. Often workers end up putting all their weight onto the wrench with feet together and if the wrench slips the assembler will fall to the ground or hit some other object. As in all general safety practices, work areas need to be clear of items that are not in use. Often it takes a combination of factors to have a serious accident. For example, a wrench slipping causing an assembler falling backwards and landing on a part or some other equipment that was not put back in its proper location. There are times when torque is performed while in awkward positions or while on a platform with minimal space. In such circumstances a job safety analysis should be conducted to avoid injury and may often require special tooling to eliminate the hazard. Some of this special tooling includes torque multipliers or custom extensions. Torque multipliers comes with their own hazard of pinch points from the reaction bar, so keep hands and fingers clear of the bar when using them. Most of the above items are pretty obvious, but as workers become complacent on the job, reminders such as these can help them keep their mind on task.

To get started, some basic torque definitions will be covered. First off, what is torque? From a basic definition standpoint for our purposes, it is a force applied at a distance on a lever to rotate an object. **See figure 1.** So torque is a force (F) multiplied by the distance it is exerted (d). For example, if you take a 1 foot long lever and place a 25 lb weight at the end of it you get Torque = 1 ft x 25 lbs = 25 ft lbs. **See figure 2.** Some basic units that are normally used in torque are foot pounds (ft lbs), inch pounds (in lbs), and Newton meters (Nm). Next is why do we measure torque? When engineers design bolted joints they are primarily concerned with the amount of clamp load that is holding the joint together by applying tension to a bolt. As long as the forces trying to pull the joint apart don't exceed the amount of clamp load, then the joint will remain intact. Obviously this is a simplistic look at what goes into bolted joint design, but the main idea is that if a bolt is applied with the proper amount of load (tension), it will perform as designed. But, how do you know if the correct amount of load is applied? There are a number of ways, including bolt tensioning, nut rotation, strain gaging, and direct tension indicators/load indicating washers, but the most common is torque control. Torque control is where a fastener is tightened using a torque wrench to a specified value that translates to a specific amount of tension on a bolt as calculated by the engineer. As the bolt is turned, the rotational force is converted into an axial force down the bolt via the threads causing the bolt to elongate creating a load on the joint. **See figure 3.** It should be noted that much of the torque applied does not go into the actual elongation of the bolt but to overcome friction. **See figure 4.** In this figure, torque goes into friction at the head and the bolt threads. These values are estimated and will vary based on material and hardware used, but in this example only about 13% of the torque applied goes into bolt elongation. This will be revisited later as bolt lubrication is discussed.

Most critical fasteners on locomotives will have a torque values specified in the maintenance manual. Some have special torque tooling due to the high values, but most will require a manual torque wrench. There are a variety of manual torque wrenches available. Some of the most common include: dial, beam, adjustable click, fixed click and digital. **See figure 5.** Many of the wrenches shown can come with a variety of heads from fixed, to ratcheting, to custom extensions. Each type offers different advantages depending on where the wrench is used, the number of fasteners, quantity of the same type of fasteners, and criticality of the joint. Regardless of the wrench type, wrenches are designed for a certain range of torque and many manufacturers recommend using a range of 20% to 100% of max, and not to exceed the max rating when tightening or loosening. Note that some manufacturers warn against using a torque wrench to loosen fasteners as it may impact its accuracy. In general, it is a good practice to use calibrated wrenches for tightening only and to use other tools for removal. Typical wrench accuracy is +/- 4% where some of the new digital wrenches achieve +/- 1%. The dial and beam type offer up flexibility of using a wrench for many applications without adjusting the wrench, but require a good straight on look at the needle and scale to avoid reading error. Adjustable click type wrenches allow for flexibility but require the assembler to properly set the "micrometer" scale for each use. Follow the manufacturer's instructions for proper setting as some may require turning the adjustment handle down below the desired value first and then adjusting up to final value. The advantage of a click wrench is that a visual confirmation is not needed since a click is felt indicating the desired torque has been met, making it a good wrench for areas where scales can't be easily read. Some drawbacks are improperly setting micrometer scale or using a wrench that you thought was at a setting and not verified before using. The next wrench is the preset click. It is just that, it is set at only one value and locked in and if the value needs to be modified, it needs to be brought back to a meter and set. These are good for standard jobs where a number of the same torque value fasteners are torqued. The set value of these wrenches need to be marked somewhere on the wrench. **See figure 6.** Digital torque wrenches are becoming more common and offer direct readings of actual torque, audible alarms, and color-coded screens when values are met. Some other advantages include data collection, multiple torque settings, and bolt counting to ensure all bolts are properly done for a particular operation. There is so much more to a digital wrench that wrench suppliers should be called in to see if they are right for a particular application.

Regardless of the wrench type, there are a number of items to cover for proper usage. Some basics include proper gripping of the wrench, proper use of extensions, and proper pulling of the wrench. As noted earlier, torque is a force applied at a certain distance. Therefore it is essential that the torque wrench is only handled at the grip since that is the wrench calibration point. Handling the wrench at a shorter distance on the wrench or using 2 hands on the wrench with one placed at a shorter distance will cause false torque readings. **See figure 7.** For example, if we take the weight noted in figure 1 and move it to a distance of .5 feet, the torque value will be reduced (Torque = 0.5 ft x 25 lbs = 12.5 ft lbs). **See figure 8.** It should be noted that this example is for a weight on a straight beam; however, click wrenches may not follow this pattern due to the location of the "click" mechanisms in the wrench. Bottom line is to hold the wrench at the

proper location. If two hands are needed to turn the wrench, then use one hand over the other hand at the grip. **See figure 9.** Another common mistake is to use a "cheater bar" at the end or using an extension in front of the wrench. If length is added to a wrench, s**ee figure 10,** it has the opposite affect on torque than from handling it short. If a .5 ft extension is added to a wrench, the torque value will be increased (Torque = 1.5 ft x 25 lbs = 37.5 ft. lbs). **See figure 11.** If an extension is needed, then the wrench should be calibrated with the extension attached and noted on the wrench as such. If wrenches are not properly marked as set up, then there is a risk of someone disassembling it and using it at the shorter distance creating an under torque situation. An extension can be used and maintain proper torque value if it is used at a 90o angle to the wrench. **See figure 12.** To be sure, the wrench and extension should be checked on a torque meter. Finally, if the proper pulling technique is not used, a false reading will be achieved. The wrench needs to be pulled smoothly up to the torque value and not with a quick jerking or stop-start motion. Once the torque is achieved the force on the wrench needs to be released. Often assemblers like to pull through a click, give a little extra at the end of pull, or even double clicking a wrench. These are all bad habits that can result in inaccurate final torque values.

Besides wrench handling, there are a number of other ways in which hardware can be improperly torqued. One is running hardware down with an impact wrench that requires a specific torque value. Normally this will result in an over torqued condition even before you put a torque wrench on it. Another is not providing enough clearance for the wrench. There may be times when applying a bolt in a tight space and the wrench head or body binds on the part or some other obstruction and you will get an improper torque value or a "click" when you are only flexing the wrench against an object and not turning the bolt. Also torque patterns need to be followed as called out. Often, parts need to be applied in a couple of steps to be drawn in to properly compress a gasket and may also require a pre torque and a final torque value listed. Running nuts or bolts down to the final value bypassing the pre torque step will result in leaks, improper stresses on parts, and possible part damage. If a pattern is not noted, common sense sequence should be followed such as star or criss-cross patterns. There are also bolts that call for a torque at a lower value and then turned a certain amount of degrees, normally called nut rotation or torque angle. Nut rotation provides a more accurate means of achieving desired bolt elongation and is developed through much analysis of the joint and actual bolt length measurements. Proper pre torque and final rotation must be adhered to in order to achieve proper clamp load and can be done by marking the hardware and surface after pre torque and then turning to a desired angle. And finally, ensure proper hardware is used such as grade and locking material. Bolts and mating threads should be free of rust, nicks, burrs, or debris as that will increase thread friction resulting in a lower than desired torque.

When the engineer designs a bolted joint, there are other factors that are taken into consideration including usage of anti-seize, thread lubricant, or thread locker such as Loctite. The main point here is that if something is called out per the maintenance manuals, then that is what should be used. Any deviation from this may result in a joint failure. There are times when lubricant is called out for the bolt. If you recall, only around 13% of the torque goes into the elongation of the bolt, the rest goes into friction. A way to get more of the torque into the bolt itself and to reduce torque variation is to use a thread lubricant, which will reduce friction by around 30%. **See figure 13.** The lubricant should be used (unless otherwise noted) on all mating surfaces including the threads, bolt head, and washer faces. **See figure 14.** Grease should only be used when called out. If it used on bolts that should be applied "dry" more torque than desired will go into elongating the bolt and may lead to bolt failure, stripped threads, broken flanges, or depending on the application an improperly compressed gasket resulting in a leak.

The final subject is quality verification of torqued components. Facilities may already have a number of these items in place, but there are three main items to look at for quality: wrench calibration, torque verification, and torque training. As part of any ISO 9001 certified company, there should be an established gage calibration system per the control of monitoring and measuring equipment section. Normally a certain frequency is set for wrench calibration based on usage or manufacturer recommendations. Some facilities set up torque wrench calibration frequencies at 6 months or 1 year, however, there can be many bolts torqued between intervals and finding a wrench out of specification at the normal calibration interval would be a cause for concern for recently assembled parts. A good option is to set up torque meters to verify wrench readings in the shop areas. **See figure 15.** The meters need to have an accuracy of 0.5% for standard torque wrenches and 0.25% for digital wrenches. Assemblers can verify wrenches on a more frequent basis such as weekly or even daily for more critical fasteners. Variable wrenches should be calibrated at multiple intervals, usually 20% increments of max rating. A log sheet at the meter can track wrench readings and if the checks are being performed. The next quality topic is torque verification and can be accomplished in a number of ways. One is through witness marking the bolt head from the center of the bolt onto the washer and then onto surface of part after torquing. **See figure 16.** This is useful because you can easily tell if a job was completed through visual examination, if you audit torques with a torque wrench you can see if the fastener moved, and if you do normal inspections of components you can inspect to see if any hardware is coming loose. One point to emphasize is if there are a number of bolts to torque, the assembler should torque each one and then mark each one, not torque,

torque, torque and mark, mark, mark. By marking after each torque you will know where you started and left off. Another torque witness mark technique is to mark the bolt as above but do after the bolt has been seated and then torque to final value, sometimes called split line torque marking. The advantage in this method is that you can tell if the head moves after initial rundown. If the head does not move, it has been over torqued. The final witness marking is for bolts or nuts that go to a nut rotation. The bolt and surface are marked at a pre torque and then the rotated to the desired angle. The angle then can be checked with a template. There are special torque wrenches available that will paint mark a fastener either on top of the head or on the side of the bolt and mating surface to indicate the bolt has been torqued. This is a quicker way than manual marking, but special wrenches and sockets are needed. Torque audits can be conducted in a number of ways, but one of the most common is checking breakaway torque in the tightening direction. Breakaway torque records the peak torque value when the bolt breaks loose. This value will usually (but not always) be 15% higher than installation torque. Breakaway torque for bolts used in gasketed joints may be 65% of installation torque due to joint relaxation, therefore may not be an acceptable means of auditing. A second method is to mark the socket and part, loosen the fastener, and then tighten to realign the marks and record the torque value. A third is to check the residual torque in the tightening direction. This is done by moving past the peak torque; once the bolt starts moving the torque drops down slightly, this is the residual torque. Lastly is the breakaway torque in the loosening direction. All these values would have to be compared to known values through tables or through testing. The final quality subject is torque training, which is not only essential for new assemblers, but also a good refresher for experienced assemblers. All the above topics can be covered along with some hands on demonstrations. A torque cart can be set up with a torque meter to demonstrate proper usage of wrenches along with modifying lengths. **See figure 17**. A bolt tension gage can also be used to show the difference between using dry and greased bolts.

As you can see, there are a lot of items associated with manual torque wrenches but if the above items are understood, along with talking with wrench manufacturers, hopefully loose bolt failures will be a thing of the past. I would like to thank the Mechanical Committee for their input and feedback on this topic along with Don Reynertson from Sturtevant Richmont for information on torque wrenches and torque training.

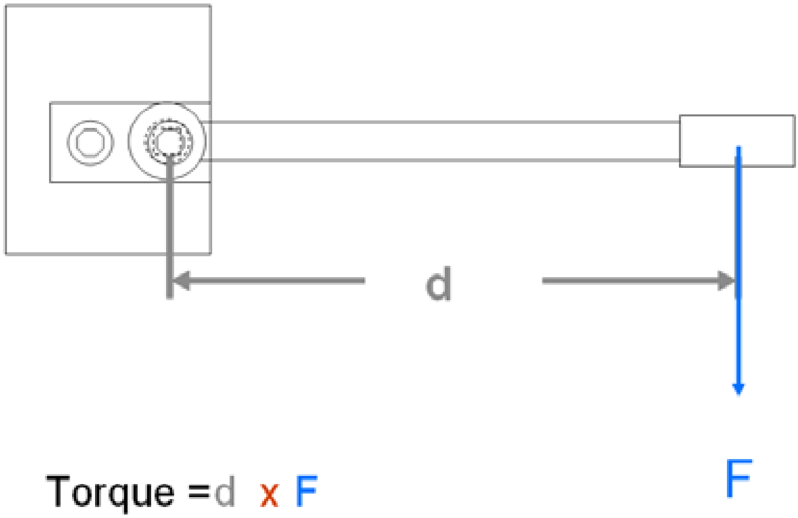

Figure 1: Torque Definition

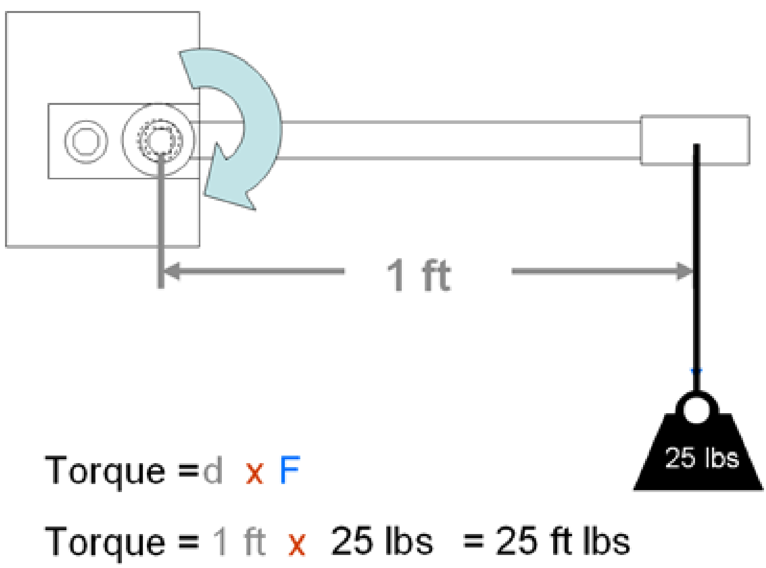

Figure 2 : Torque Example

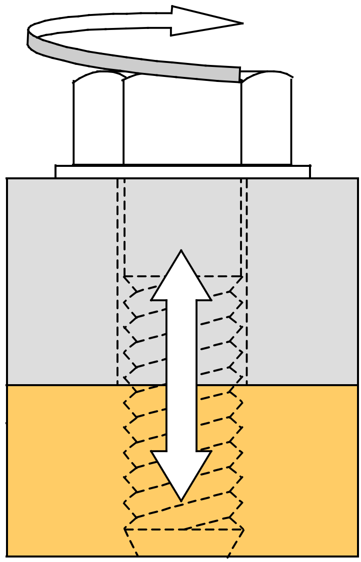

Figure 3 : Torque and Axial Tension

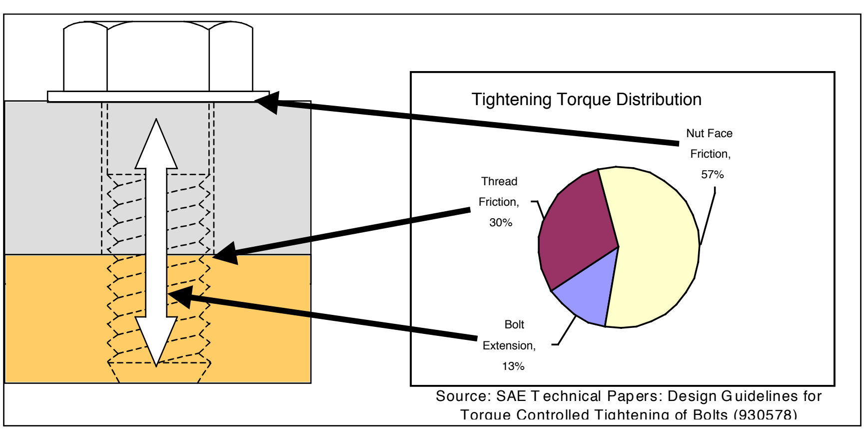

Figure 4 : Torque Distribution

Figure 5 : Types of Manual Torque Wrenches

Figure 6 : Preset Click Wrench with Torque Value

Figure 7: Improper Wrench Handling

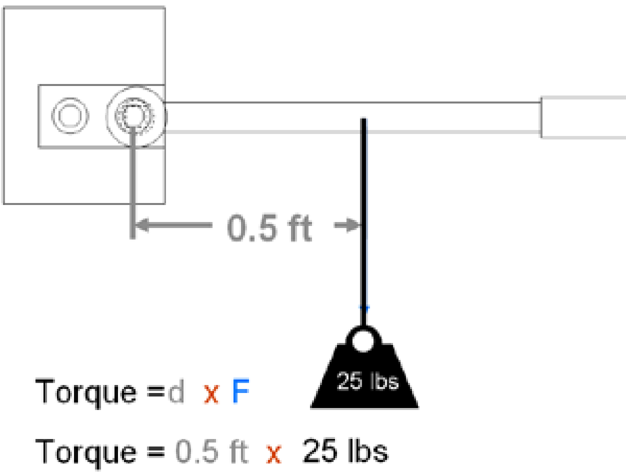

Figure 8 :Torque Example with Shorter Length

Figure 9: Proper Wrench Handling with Two Hands

Figure 10 : Adding an Extension

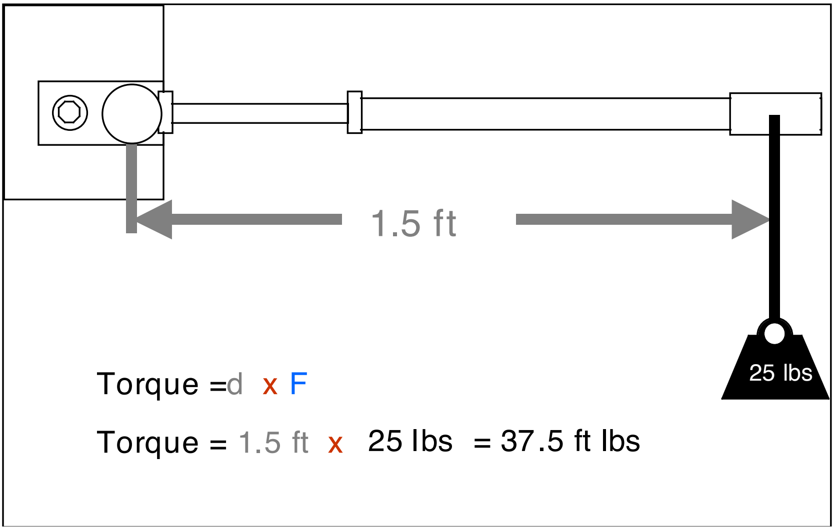

Figure 11 : Torque Example with Added Length

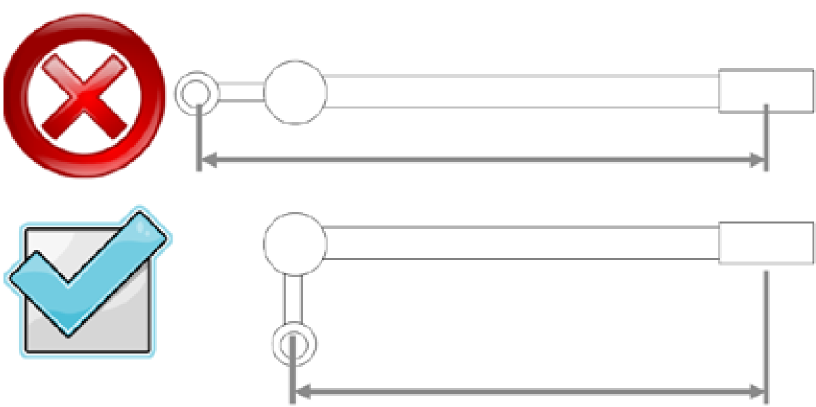

Figure 12: Use Extenstions at 90o

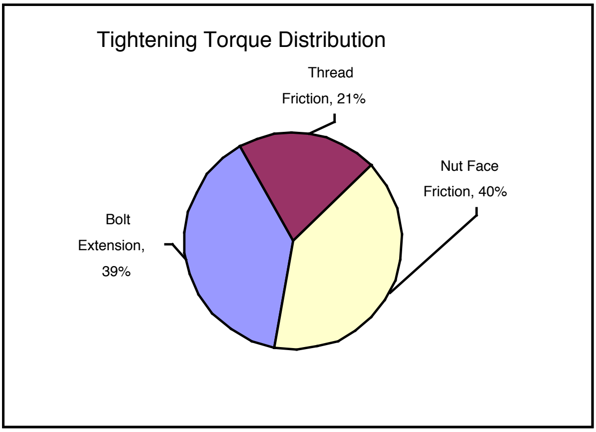

Figure 13: Thread Lubricant Usage and Friction Reduction

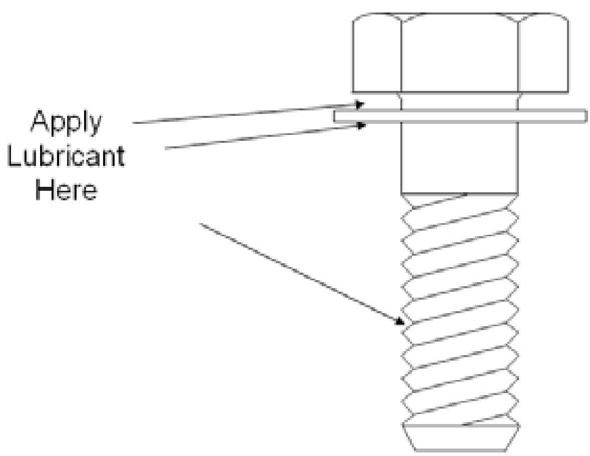

Figure 14: Lubricant Application

Figure 15: Torque Meters

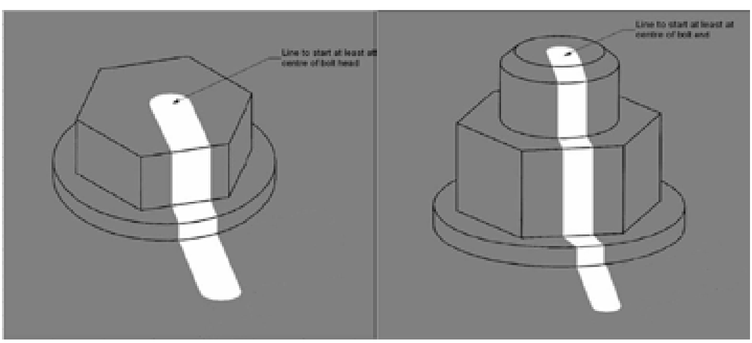

Figure 16: Witness Marking

Figure 17: Torque Training Cart

Report on the Committee on Fuel, Lubricants and Environmental

September 24, 2012 at 1:30 PM

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Dwight Beebe

Vice President

Temple Engineering

Liberty, MO

Vice Chairman

Kevin Bills

VP-RR Operations

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K. Wazney	Chemist/Testing Specialist	Canadian Pacific	Winnipeg, Manitoba
V. Wiszniewski	Researcher	Exxon Mobil Research & Engineering	Paulsboro, NY

PERSONAL HISTORY

Dwight Beebe

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

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

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

The Fuel, Lubricants and Environmental Committee would like to thank Tom Gallagher of Oronite for hosting the following conference calls for the committee

December 8, 2011 winter conference call

July 26, 2012 conference call for presentation review of paper entitled Incipient Failure Detection Tool - presenter Najeeb Kuzhiyil (GE Transportation)

August 9, 2012 conference call for presentation review of paper entitled LMOA Gen 6- Locomotive Engine Oil Definition Discussion

The committee also wishes to express their sincere appreciation to Najeeb Kuzhiyil of GE for hosting the conference call on March 12,2012 in which the committee discussed the technical papers for 2012 and for hosting the conference call on August 16, 2012 for presentation review of paper entitled LMOA FL&E: Durability Test Protocol for Alternative Fuels and Biodiesel - presenter Dennis McAndrew

The committee held a meeting in Jacksonville, Florida on January 26, 2012 which was so generously supported by the CSX and graciously hosted by Wain Strickland. Thank you, Wain

The committee wishes to take this opportunity to thank the BNSF and Brad Queen for hosting the joint technical committee meeting held on May 8 and 9, 2012 in Overland Park, KS

Diesel Engine Health Prediction with integrated Lube Oil Analysis

Prepared by:
Manoj Kumar Prabhakaran, Dennis McAndrew, Abhijith Jain, Prashant Kumar, Dariusz Oracz, Krzysztof Korycinski, Najeeb Kuzhiyil

Abstract

The performance and reliability of locomotive engines and related components are of primary importance to railroads for ensuring better utilization of their fleets. Engine lubricating oil plays a key role in keeping the engine clean, and can provide valuable insights into engine health. Components such as bearings, cylinder liners and piston rings undergo wear introducing debris into the engine oil. Increased blow-by raises soot loading that contributes to higher viscosity of the oil and increases oil degradation rate. Typical ranges for engine oil parameters can be established for a normal operating engine over a period of time by carefully analyzing historical engine oil data. This paper describes the development of an engine health monitoring and failure prediction software tool which uses engine oil analysis and engine components failure data collected over a substantial period of time. Validation of the tool demonstrated potential failures can be predicted months in advance resulting in maintenance cost savings and better locomotive availability. The analysis and prediction capabilities of this tool, Incipient Failure Tool (IFT), could apply to large engines used in railroad, industrial and marine applications.

Introduction

The primary function of lubricants is to prevent metal to metal contact between interacting surfaces. Engine oil also keeps the engine clean through detergent action and inhibits soot agglomeration in the oil via dispersant properties. However, it is impossible to avoid mixed and boundary lubrication in the diesel engine which causes wear of components such as piston rings, bearings, cylinder liners and cams. The resultant metal particles are washed away by the lubricant from the point of production. Most of the microscopic wear metal particles stay suspended in the bulk oil increasing in concentration over time. Changes in the concentration trend over time provide valuable insights into the wear rate.

Long term data for various parameters, at different ages of the failed engines compared against the data of normal working engines provides mathematical model (transfer functions) to create a candidate list of engines that are more likely to fail. This paper describes the development of a software tool utilizing engine oil analysis data and component usage histories to predict engine health and potential component failures of diesel engines. The tool has been validated using a large set of field data.

1. Methods

Most railroads have instituted regular engine oil condition monitoring to determine the quality of the engine lubricating oil and to detect coolant leaks, fuel dilution and undue component wear. Engine oil samples are typically drawn at 10 - 15 day intervals and sent to a laboratory for analysis. Analytical results are uploaded into a central database for processing, review and potential work order generation. Corrective actions may be generated based on preset limits of oil properties, wear metal parameters and recent maintenance history. The established oil condition monitoring system has inherent limitations due to the variations caused by differences in engine component and oil life, engine utilization and operating environment.

Oil is typically tested for the following physical and chemical parameters: viscosity, base number (BN), oxidation, nitration, water, fuel, soot, contaminants and wear metals. Since viscosity is directly related to oil film thickness it is the most important oil parameter in terms of lubrication. BN indicates the ability of the engine oil to neutralize acidic combustion byproducts and oil oxidation products. Soot loading, fuel and water contamination in the oil contribute to changes in viscosity and component wear. Wear metal elements in the oil provide clues to which components are wearing and the concentration changes of each element indicate the rate of wear.

In the process of developing the Incipient Failure Tool (IFT) all the parameters are compared among the normal and failed engines between their overhaul intervals. Data sets from a railroad fleet were selected for developing the tool for their consistency, integrity and frequency of sample collection.

The model uses three years of oil analysis data and engine component usage data to create the transfer functions (TF). A transfer function is a formula that describes effects of the input parameters (viscosity, wear metals, soot, component usage, etc.) on the life of the components. Statistical methods used in creating the transfer functions were ANOVA and regression. Each parameter was analyzed separately to determine any potential correlation with failures. Using these TFs, the IFT can predict potential failures for the next 6 months.

A flow diagram of the IFT is shown in Figure 1.1. Upon identifying a failure risk, units are sent for inspection.

Schematic diagram of the process is as shown in Figure 1.2. This adaptive approach provides in updating changes to the engine hardware, oil chemistry and operating conditions.

To understand relationship between engine oil parameters and component failures, the frequency of various failure mechanisms in the field were studied. An example of the results is shown in Figure 1.3. Engine component failures were correlated to engine oil analytical results. Engines with component failures showed statistically significant differences in oil analysis compared to engines without failures. This correlation provides insight into defining the work scope required during inspection. It was also observed that individual instances of component

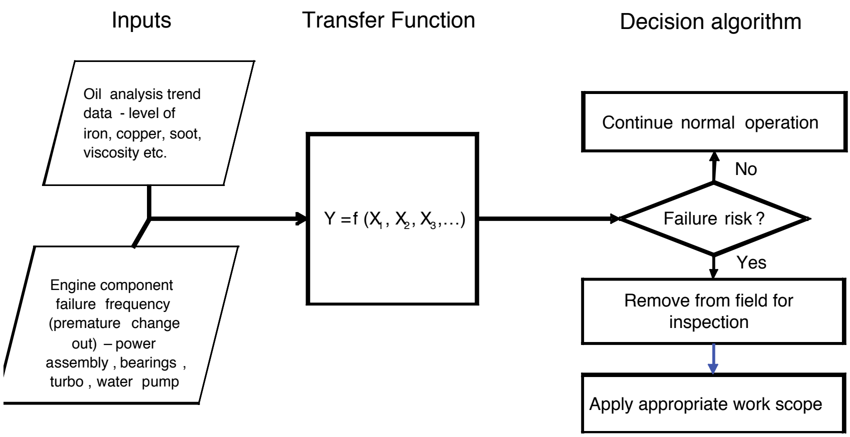

Figure 1.1 Logical flow diagram of Incipient Failure Tool.

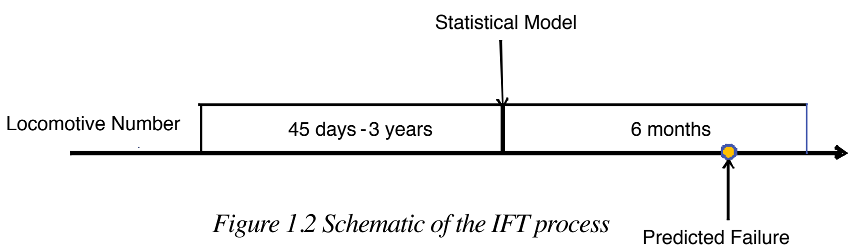

Figure 1.2 Schematic of the IFT process

usage correlated well with engine failure, and both correlations were used in development of the transfer functions. The IFT was developed to self-learn by continually updating the transfer functions using latest data while discarding data that are older than 3 years so that the tool uses only recent information.

The inputs for development of the transfer functions considered were:

- Average values for each of the oil parameters for the entire data set
- Slopes of each oil parameter
- Integrals above/below certain level of oil parameters (e.g. soot above 30 abs)
- Unscheduled usage of engine components
- Engine age

Using the IFT with the above inputs, close to a hundred parameters were identified. All combinations of these parameters were tested taking 8 of them at a time from which 13 combinations were found to be statistically significant for failure prediction. The chosen scenarios were then applied to the field data for predicting the incipient failures.

An example is shown in Table 1 for one of the 13 scenarios. The slopes, integrals, averages and component us-

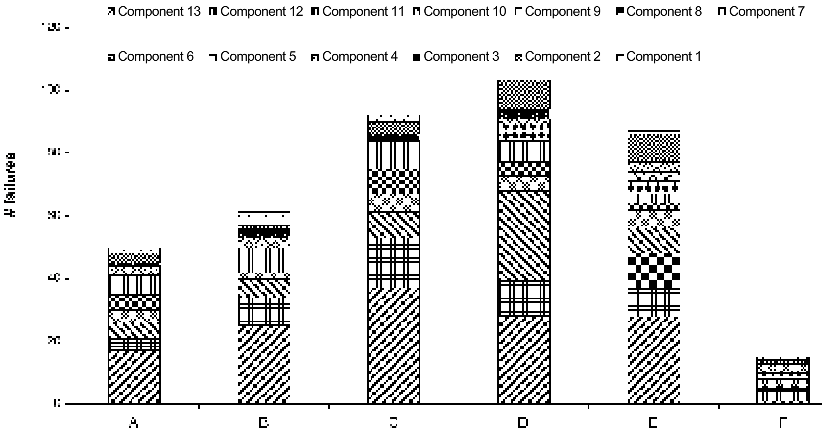

Figure 1.3 Most common causes of engine failures with their occurrences (Sample Data)

ages were used in this combination. The first negative number in the parenthesis denotes the number of cumulative days for the data set before the scenario date. The second negative number denotes the days between the last sample and the scenario date. It can be seen that slopes and integrals of the same parameters are considered to be another parameter for a different time period. Such combinations provide better correlations than the averages over a single period in time.

BORON - slope (-195,-15) increasing period 0
BORON - integral (-746,-15) over set value
LEAD - slope (-195,-15) entire period 1
LEAD - slope (-105,-15) entire period 1
LEAD - slope (-60,-15) entire period 1
100 VISCOSITY - integral (-1125,-15) over set valu
100 VISCOSITY - integral (-745,-15) over set value
100 VISCOSITY - integral (-380,-15) over set value
100 VISCOSITY - average (-60,-15)
100 VISCOSITY - integral (-745,-15) under set valu
IRON - average (-195,-15)
SOOT - integral (-1125,-15) over set value
PA - count (-1050,-15) rate
Split Gear - count (-1050,-15) rate

Table1. An example of the combinations of parameters used to determine the incipient failure

2. Data Clean Up

Due to inherent errors in sampling and data reporting, some of the data points in the large database used were not consistent with the rest of the data. It was imperative to remove these points from the database so that the TF built from the database is robust and hence capable of predicting failures. Several methods have been employed to identify incoherent data. Duplicates were deleted from the database by looking at the dates of sampling. The spikes that were beyond the possible limits of the individual parameter determined by the IFT were scrubbed. The data spikes that were significantly out of the normal trend for the individual parameter were removed. The data scrubbing process looks for inconsistent data points with respect to trends and also for shifts expected for the parameter dependencies. The concept of this data scrubbing is shown in Fig. 2.1

For example, increase in soot and oxidation values are expected, when there is a considerable increase in viscosity. If the soot and oxidation values do not increase with the viscosity then the accuracy of the viscosity value is doubtful. In addition, if 3 or more of all parameters or 2 of 4 main parameters (soot, iron, copper and lead) contain doubtful values, then entire sample data was neglected.

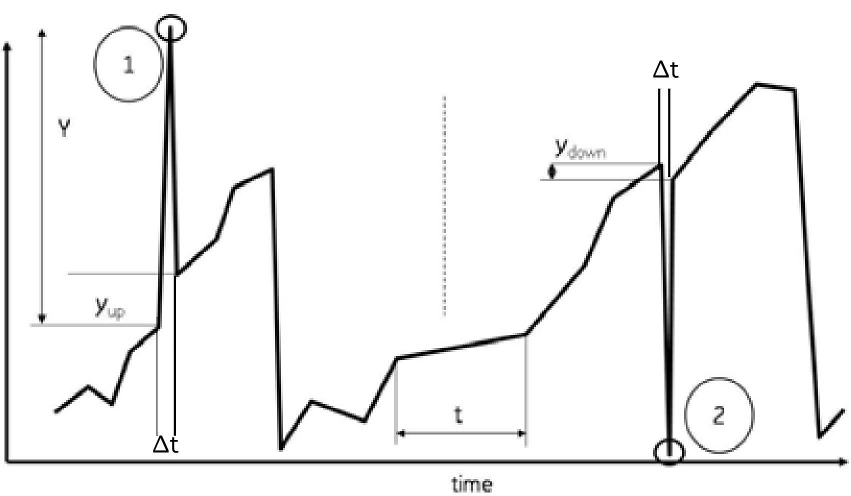

Figure 2.1 Conceptual schematic of the spike-cleansing macro. Point 1 and 2 show the outliers.

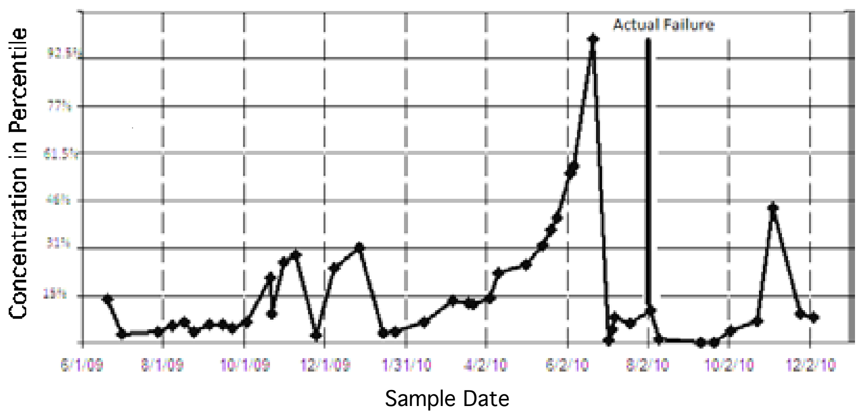

Figure 2.2. An example of rate of change of parameter leading to failure

Changes in oil properties such as viscosity provide insight into the condition of the oil but not the health of the engine components. Therefore, it was necessary to find a robust indicator that could predict the health and performance of the components. For example, it was found that lead content in the oil was an excellent indicator of bearing wear as lead is one of the primary materials used in the main bearings. Tracking the varying lead content in the oil is a good indicator of bearing wear, therefore, lead content in oil data was used as one of the inputs in developing regression models to indicate potential main bearing failures. Figure 2.2 shows an example of an actual engine failure occurred after the oil analysis showed high lead content over two months. Similarly, soot content in oil observed over time also correlated well with main bearing failures.

In the initial development of the transfer function, only the absolute values of the oil parameters were considered wherein the prediction was based on the warning and set critical limits. Failures and oil parameters depend upon locomotive utilization, engine oil chemistry and maintenance practices. The absolute value approach did not provide any scope for customizing the IFT for the fleet and changing operating conditions which in turn reduced its efficacy.

In order to mitigate the variations from fleet to fleet and the operating conditions, a percentile approach was developed. In this method, all the oil parameters and failures are converted into percentiles based on the set of data used to create the transfer functions. Hence the inputs to the model are percentiles not direct values from oil analysis, e.g. the average iron content for a

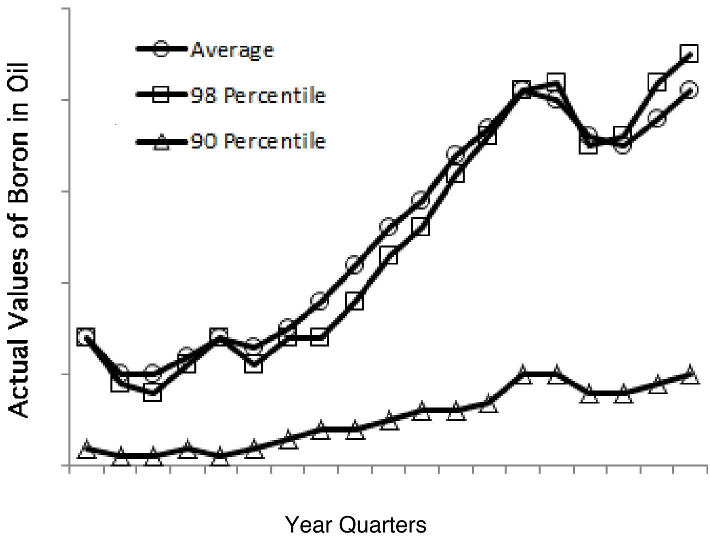

Figure 2.3. Example of the percentile approach to oil parameters

given locomotive is x ppm, the input will be y, because y% of the remaining locomotives in given data set have an average iron lower than x ppm. Only the bottom 5 percent were considered for inspection which improved the accuracy and the self-learning capability of the tool.

In figure 2.3, the levels of Boron in percentiles are shown. While the 98 percentiles are very close to the average values, the 90 percentiles are far below the averages which show the variation between the number of units with high and low boron. It is important to note that the actual values have increased significantly for the average and the 98 percentile over the years. Such an increase would cause the software to predict more failures if the absolute numbers are used to predict the failures. On the other hand, the percentile approach takes the overall change in the parameter across the entire fleet into account thereby improving the prediction capability.

Another method employed to improve the accuracy was to use the area under the curve methodology to determine the effect of parameters on failures instead of the parameters crossing the absolute limits. A continuously higher level of soot was found to correlate well with bearing failures rather than occasional excursions of soot in the engine oil. Slopes of the parameters were found to be correlating well with failures in most of the parameters.

3. Validation

In the initial phase two different validation strategies were devised. The first strategy was to predict the engine health from historical data and check if they failed in the next 6 months (in historical data). The second strategy was to predict failure at a future date and thereafter inspect the health of the engines for which failures were predicted.

	Good no engine issue within 6 months	Bad engine issue within 6 months
Passed – not sent for inspection by IFT	92.6%	2.4%
Failed – sent for inspection by IFT	3.0%	2.0%

Table 3.1. Percent error in prediction by the IFT

The transfer function was applied to a set of approximately 7700 locomotive data points. These data points were not included in the data set that was used to generate the transfer function. A basic statistical test was performed to address the accuracy of the tool. The results are shown in Table 3.1: 5.0% of the locomotives were sent for inspection of which 2.0% had actual component failures. About 3.0% were sent for inspection which did not have any issues. The tool was unable to detect any incipient failures in about 2.4% of the fleet.

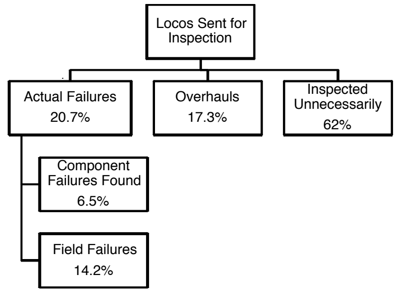

Figure 3.2. Validation of the transfer functions in two sets of data

As shown in Figure 3.2, of the inspected units, it was found that 20.7% had actually reported failures, 17.3% were overhauled, and 62% did not have any component failures in the following 6 months. This evaluation demonstrated that the tool predicted about 38% of the failures before 6 months. Among the predicted failures 6.5% were catastrophic that would save millions of dollars for operating volumes that are typical of a class-one railroad. In general approximately 5 units had to be inspected to prevent one failure (20% effectiveness) while approximately 15 units had to be inspected in order to prevent a catastrophic failure (6.5%).

4. Conclusions

The Incipient Failure Tool utilizing engine oil analysis data and component failure data has proven effective for a North American locomotive fleet. The tool was developed from analysis of historical data and validated over several data sets. The tool predicted 35-40% of failures that needed maintenance intervention by about 3-6 months in advance. This tool has the potential for early failure detection, improved locomotive utilization and substantial savings. It is developed to be self-learning and has the capability to improve its prediction in the future. Incipient Failure Tool is primarily effective in locomotive diesel engines, but can be applied to industrial and marine applications.

5. Acknowledgements

We would like to acknowledge and extend our gratitude to the following persons and committee members who have made this work possible:

- Piotr Zalewski, Lead Engineer EDC Warsaw Poland and Slawomir Wawrow, Engineer EDC Warsaw Poland for their technical support.

- LMOA FL&E Committee

Locomotive Durability Test Protocol for Alternate Fuels and Biodiesel

Suggested Field Test Protocol to Evaluate the Impact of Blended Diesel Fuel on Locomotive Durability, Reliability, Availability, Performance, and Related Items

Blend to be 80% Diesel Number 2 and 20% of a Biodiesel

Prepared by:
Dennis W. McAndrew, Dennis W. McAndrew, Inc.

Table of contents:

1. Abstract
2. Introduction
3. Federal Railroad Administration Project Proposal
4. Discussion
    4.1 Risk Assessment
    4.2 Fuel Supply
        4.2. a. Diesel
        4.2. b. Biodiesel
5. Flow Chart
6. Locomotives
    6.1 Manufacturers
    6.2 Models
    6.3 Number of Units
7. Field Test Location
8. Durability Protocol
9. FMEA Inputs
    9.1 Pre-combustion
    9.2 Combustion
    9.3 Post-combustion
10. Conclusions
11. References
12. Acknowledgements

ABSTRACT

Use of biodiesel blends and alternative fuels are becoming more widespread in the rail industry and there is currently no formal procedure for evaluating the effects of these fuels on locomotive components and systems. This paper provides a suggested locomotive durability field test protocol.

This suggested field test protocol includes the locomotive components and systems to be evaluated in pre and post testing as well as comments on the importance of each of the factors in the complete system. The complete system is comprised of the locomotive components and systems, the number and type of locomotives to be included, selection of the fuel or fuel blends to be evaluated, field test location as this affects locomotive duty cycle and the amount of power generated, and other relevant inputs. The suggested durability protocol is modeled after parts of the Locomotive Maintenance Officers Association (LMOA) crankcase oil field evaluation, GE's January 2011 SAE TC-7 subcommittee presentation of a suggested process to evaluate the

impact of the use of biodiesel fuel, and additional information.

INTRODUCTION

A locomotive field biodiesel durability/endurance protocol must be designed such that if there are positive and/or negative effects on locomotives or railroad operations, due to a major change to the fuel's chemical and physical properties, those effects can be observed, measured, and assessed. The protocol should be universally accepted by the concerned parties, i.e., Railroads, Original Equipment Manufacturers (OEMs), Diesel Fuel Suppliers, Biodiesel Supplies, Filter Manufacturers, Testing Laboratories, and other interested parties.

What should the procedure incorporate to evaluate the locomotive systems if alternative fuels are used? It should not only evaluate the component's durability, but be comprised of a multi-step complete system process that includes the following:

1. Analytical laboratory testing and evaluation of potential fuels
2. Component rig endurance testing
3. Engine performance testing
4. Stationary locomotive system performance testing
5. Multi locomotive performance and endurance testing
   a. Field performance testing
   b. Field endurance evaluation

The goal of this document is to create the foundation of an alternative fuels field test protocol, with the initial focus on B20. With careful consideration of the many input variables and concerns of the involved parties, it is believed an acceptable alternative fuel field test protocol can be developed. If accepted, this logically developed protocol could be successfully utilized, as the LMOA crankcase oil field test procedure that has been utilize by the rail industry for over thirty years.

To help achieve acceptance of the protocol, it is recommended the LMOA's Diesel Engine Lubricating Oil Field Evaluation Field Test Procedure be used as a starting template in the designing of a biodiesel durability field test protocol. After three years of debate and work, the original oil field procedure was approved by the LMOA's Fuels and Lubricants in 1976. When needed, there were only a few modifications to the procedure to accommodate/account for some unique features on different railroads. However, for the most part, the protocol was used successfully as written as the accepted oil field evaluation protocol until 1999. In 1999 the protocol was updated[1].

FEDERAL RAILROAD ADMINISTRATION PROJECT PROPOSAL:

Project proposal submission is required by June 2012. SAE – TC7 subcommittee members and invited guests developed the project proposal to help evaluate the current impact of the use of lower concentrations of biodiesel fuels (B5) on the railroads' system and the locomotives. The committee developed five areas to be investigated.

- SAE–TC7 subcommittee members and guests developed the five items in proposal

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 Future Funded Projects
4. Laboratory Testing
5. Literature Survey

- Deliverables

If the project proposal is granted, Southwest Research Institute will be the lead investigator on the 2012/2013 grant. The group will follow this 2012/2013 grant with a submission for further FRA funding for the needed long term field durability evaluation.

DISCUSSION

With the expected introduction of new locomotive designs to meet future Environmental Protection Agency (EPA) emission compliance regulations and using a railroad's standard diesel fuels, there became a need to update the crankcase engine oil field test procedure. In 1999 the Fuel, Lube and Environmental (FL&E) committee recommended that a small task group be formed to work on updating the procedure. The task force consisted of Bob Dittmeier (Afton Chemical) as the moderator, and the two OEM representatives, Dan Meyerkord (EMD), and Dennis McAndrew (GE). The update was completed that year and presented at the LMOA annual fall meeting in 2000. The updated procedure was published in the LMOA 2000 proceedings[1].

The pre and post test component evaluation recommended in the oil procedure can be considered as a useful starting point in the selection of components that should be evaluated when using an alternative fuel. By following a detailed protocol, that includes the multi complex systems, the effect of a higher concentration of biodiesel fuel on the complete locomotive system will provide information on elements to be concerned about, or elements that are not of concern, backed with data rather than speculation.

Risk Assessment: The determination of whether or not there are items of concerns, that need to be closely monitored or not, should be made only after a comprehensive risk assessment has been completed. This risk assessment evaluation could employ the Failure Mode Effect Analysis (FMEA) methodology[2].

Each organization involved with the manufacturing of the locomotives, diesel fuels, alternative fuels, filters, and the railroads must all have a part in the development of the final comprehensive field test protocol. It would be recommended that at the start of the development of the process, each organization should complete a FMEA related to their product or in the case of the railroads their infrastructure. For example, the OEMs would evaluate the locomotive's individual components and systems, the railroads their infrastructure and operational requirements, and the fuel producers would evaluate availability, production process, transportation, and storage of the fuels.

After each party has completed their FMEA, there should be a joint review to obtain a consensus on how each FMEA highlighted potential concerns, or eliminated of some concerns, be captured as input into the final acceptable field test protocol. The LMOA FL&E members, along with members of the SAE TC-7 subcommittee, could act as facilitators in bringing the multiple groups together for the final composition of the protocol. If the protocol is accepted by the committees' members, the probability of a successful accepted field test protocol would be enhanced.

Fuel Supply: Although the proposed procedure would apply to alternative fuels as they are developed and brought into commercialization the remainder of this paper will concentrate on biodiesel fuels as they are currently getting the majority of the attention and are more widely used.

The durability study must start with the selection of the raw materials or biofuel used in manufacturing the biodiesel, followed with the biodiesel blend, and the diesel fuel. During the 1970s, 1980s and 1990s there were improvements to the engine's designs; however, the basic engine design remained the same. This was also true for the diesel fuel supply, i.e., its chemical and physical properties were relatively unchanged. In the late 1990s and early 2000s, new government emission regulations required changes to both the fuel supply chemistry and locomotive systems. The greatest change to the fuel was the requirement to lower the fuel sulfur content ultimately down to 15 parts per million (ppm). The newly designed low emission compliant locomotives were designed, tested, and evaluated with the ultra-low sulfur fuels (USLD).

However, in addition to the fuel sulfur change, recent interest in the potential use of diesel fuels blended with a concentration of biodiesel fuels greater than 5% emphasized the need for additional controlled field tests. The tests' purpose would be to evaluate the impact of the addition of higher biodiesel fuel concentration to the locomotive's durability, availability, and reliability. This paper's focus is on differences in the fuels and locomotive systems as input to the development of a durability testing protocol. It will not cover fuel transportation, fuel handling logistics, storage, and cost differences.

Are the variations or differences in both the diesel fuels and biodiesel fuels such that those differences in the aromatic content, amount of unsaturated compounds, and/or other fuel properties important in the solubility or miscibility of the biodiesel fuel blended into the diesel fuel? Is the solubility or miscibility a function of the selected diesel fuel, the selected biodiesel, or a combination? Are all these different fuels completely fungible? The answer to these questions should be a major consideration in the development of the field test protocol.

An earlier 2005 LMOA paper discusses some of the potential positive and negative impacts on locomotives if biodiesel fuels were to be used[3]. Information in this 2005 LMOA paper highlights areas that need greater understanding via. a closely monitored field test. Those areas of potential concern

noted in the paper should be included in the field protocol.

A 2007 LMOA FL&E paper clearly shows the diversity of controls on fuel quality monitoring by the railroads, and the dependency of the railroads on their fuel suppliers to provide a quality fuel product[4]. This dependency must also be a factor when designing the protocol. As a minimum it would reinforce the requirement for the biodiesel suppliers to be a quality BQ 9000 producer/supplier.

Diesel Fuels: The selection of the field test location or locations would determine the specific diesel fuels being used during the testing period. At a minimum, the fuel should be ultra-low sulfur diesel fuel meeting the ASTM D-975 specification, and any additional testing requirements the railroads and OEMs might require. If there are properties not listed in the specifications, which if clearly understood would be helpful in interpreting the locomotive's performance, durability, and availability during the field test, that property should be measured. Also the understanding of the post-testing evaluations could be enhanced with this additional information of the fuel's properties.

Examples of a few of the chemical or physical properties variations are as follows: aromatic content, density, energy content, solubility, miscibility, and others properties that are of interest to the testing parties with regards to biodiesel fuels. Diesel fuels in California (CARB fuels) are not only low in sulfur, but also low in aromatic, unsaturated content, and density. Ultra-low sulfur fuel in other parts of the country can have aromatic content greater than 30% and differences in the other properties.

The following points out the importance of understanding when fuel properties vary. One OEM evaluated two fuels with differences: sulfur, aromatic content, density, and energy content in a four stroke high pressure jerk pumps engine. The effect of the differences on the locomotive engine's combustion efficiency and emission was measureable. The percent of aromatics in the fuel is one factor that determines the fuel's modulus of elasticity. With the jerk pump injectors, the fuel's modulus of elasticity affects the time it takes to compress the fuel to open the injector needle[5]. This slightly alters the injector timing and in turn emission. The importance of this measured difference in engines should be considered important in Tier 0, 1, and 2 locomotives. With the introduction of common rail systems in one OEMs Tier 3 and Tier 4 locomotives, the compression timing issue would be of a lesser concern in those units with common rail. Does biodiesel add variation to the fuel's properties such as the modulus of elasticity?

Biodiesel Fuels: There are several factors that need to be considered before the field testing actually starts with regard to the biodiesel. Some concerns of the railroads could be addressed or potentially eliminated with results from laboratory beaker tests, component tests, and stationary engine tests. Laboratory testing results could be incorporated with the selection process of the biofuel used to make the biodiesel for the locomotive field durability testing.

During the LMOA FL&E winter 2012 committee meeting in Jacksonville, FL, it was mentioned there is a research study being conducted at one of the universities in North Carolina evaluating the differences of biodiesel when the supply source varies from one biofuel to another. The research being conducted, at that university, could help in the understanding of solubility, miscibility, surface tension, water affinity, and other properties such as oxidation stability of the different sources of biofuels, i.e., are these differences a concern or not? Research conducted by the oil companies and oil additive companies would also be very informative, and a valuable source for reference.

The railroads and biofuel suppliers need to understand how the biodiesel will be delivered, stored, its quality control procedures, blending controls, and other items. There needs to be a collection system in place that collects fuel specimens from not only the fuel storage tank, but fuel and oil specimens from the locomotives. Frequent specimen collections would capture any potential deviation from the specification before it potentially creates a problem. Verification of the fuel quality in the storage tank and in the locomotive is a requirement. This is not only to verify the storage tank biodiesel fuel meets specification, is free of contamination, and its quality, but more importantly the biodiesel fuel properties and concentration in the locomotives' fuel tank.

Flow Chart: The flow chart for the durability protocol is one part of a larger protocol. The following chart is a suggested system flow that encompasses more than the determination of what components to monitor during a durability test.

Each block requires that a group decision be made for a successful evaluation. After the FMEA and risk assess-

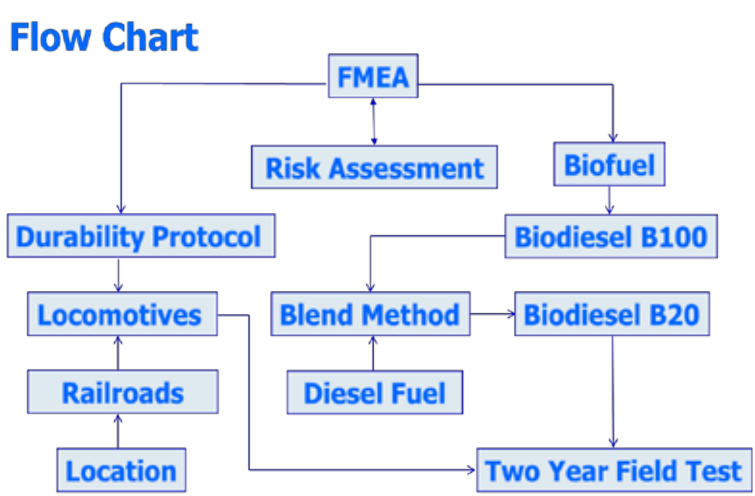

Figure 1: Protocol flow chart

ment, as discussed above, the system flow must start with the selection of what biofuel is to be used. This would be followed with the manufacturing of the biodiesel (B100), and blending method decisions. The FMEA and risk assessment should have highlighted the component and systems that need to be closely monitored during the field evaluation. Also, it would suggest what components to remove for detailed inspection and evaluation post field test.

Locomotive Selection: The establishment of new stringent EPA emission requirements, created the need for the OEMs to develop new locomotive engines, control systems, fuel systems, and other major changes. These changes were to ensure the locomotives were compliant with the new emission regulations.

This in turn created an increase in cost and complexity requirement for the field testing of the fluids used in the increased number of locomotive models. The crankcase oil field testing protocol allowed for up to 10 test locomotives and reference locomotives.

However, historically one OEM accepted the performance results from field tests where there were four test locomotives and two controlled locomotives. With the introduction of newly designed emission compliant locomotives, that OEM required that future crankcase oil field test evaluation have an inclusion of the new emission compliant locomotives in the LMOA oil testing protocol. This resulted in requiring not only six Tier 0 or 1 locomotives, but six Tier 2 test locomotives, and when available six Tier 3 locomotives. Modeling the crankcase lubricating oil field test protocol, alternative fuel testing, at a minimum, should include the following:

1. GE and EMD locomotives
2. Tier 0 or 1+, Tier 2 locomotives, and Tier 3 if available for both builders
3. Four test locomotives and two control units for each type at a minimum
4. Number of locomotives:
   a. GE: six Tier 1+, six Tier 2, and six Tier 3 if available (12 to 18 locos)
   b. EMD: six Tier 1, six Tier 2, and six Tier 3 if available (12 to 18 locos)
   c. Total number of units: 24 to 36 locomotives

The test and reference locomotives are to be new or recently rebuilt/remanufactured locomotives. It is highly recommended that all required pre measurements be obtained during the manufacturing of the engines and locomotives. This will allow for the field evaluation to proceed with locomotives with a known starting condition, and no down time on the railroad's location at the start of the test.

Field Test Location: In this author's opinion, there is no ideal single low cost, short term, one field test location for the evaluation of locomotives utilizing alternative fuels, which adequately evaluates all locomotives' performance parameters required to satisfy all the interested parties. A few of the major long term performance parameters that need to be measured includes such elements as: retention of emission compliance, maintaining or improving durability, availability, and reliability.

Therefore, the selection of the test location or tests locations, diesel fuel, biofuel, biodiesel fuel, number of units, operational requirements, sampling of fuels and oils, system controls and other items should be with compromises which are agreed to by the involved testing entities before testing commences.

One of the major decisions to be made early in the process is the determination of how the test will be conducted, and the source of the biodiesel. Also could the work effort be divided between several railroads? One railroad would test the biodiesel on GE Tier 1, another EMD Tier 1, a third GE Tier2, and so forth. Addressing testing location first, two methods of running the field test could be as follows:

- Allow the test and reference units to operate in general revenue service.
- Allow the test and reference units only to operate in a predetermined local region or corridor.

Both approaches have positive and negative attributes that need to be discussed prior to the selection of one. If general revenue services were to be selected, it would allow the locomotives to be operated in the exact environment that the railroads' fleets operate. This would expose the locomotives to all the variations that the fleets are daily exposed to in service. There would be little question as to the test not being representative of a "typical" duty cycle. However, it becomes very difficult, if not impossible to supply the biodiesel fuels at what would be many railroad fueling locations. It would also be next to impossible to ensure the test locomotives are only filled with the test fuels. It would be more likely that the test locomotives would be topped up with straight diesel, negating the test. In other words, it would be very difficult to control not only the fuel, but tracking the test and reference units.

For a more controlled and manageable field test, it would be recommended that the second method be chosen. Although the locomotives would not be exposed to all the variables in general revenue service, the ability to control several of the important test parameters would be improved. Therefore, it is recommended the locomotives only operate between city A and city B or in a controlled region that allows the locomotives to return to a home-base for fuel and general maintenance. Because of the scope of the project it would be very likely that two or more railroads would be required to complete the evaluation. One railroad could offer to evaluate GE locomotives and the other railroad EMD locomotives.

The selection of the biofuel used to produce the biodiesel should be completed after the questions brought up in the fuel section are addressed. The blending of the selected biodiesel into the railroad's diesel No. 2 fuel would be fixed by the test location. Therefore, it should be noted if the fuel is a CARB type fuel, or a fuel with higher aromatic content and higher density. To eliminate concerns that different results could be obtained if CARB or non CARB fuels were used, if possible two locations could be selected in different parts of the country using the different diesel No. 2 fuels.

Durability Evaluation: Only after selection of the biofuel, biodiesel, the blend method (splash blend vs. meter blending in pipes), test location, locomotives, and other pretest requirement can the actual durability testing start. A properly designed durability test, would by default, also collect several other important operational items, e.g., availability, reliability, performance, MWHr, meeting or exceeding all railroads expectations. Prior to this point, all logistical decisions, test city/cities or region/regions, legal agreements, contact names and contact's phone numbers, items to be monitored, midterm inspections, final inspection, and component removal should be in place.

For the durability protocol, it would be the recommendation to follow the LMOA Crankcase Oil Field Test Procedure with a few modifications. Much of the suggested testing and processes presented at the SAE TC-7 subcommittee January 2011 meeting4, for the evaluation of biodiesel, should have been completed before the field test and is discussed in the FMEA input section. Much of the SAE TC-7 subcommittee presentation was focused on items before the field evaluations were to start.

One major difference in the fuel evaluation over crankcase oil testing is that it is recommended the fuel test protocol time period be two years in duration. Two premeasured power assembles are to be removed at the one year period, with two power assembles at the completion of the second year. Additional components' removal at both the one year and two year would also be required. For details of the individual component tests, laboratory testing, and engine tests could be confidential; therefore the OEMs should be contacted to determine what components are to be evaluated and specific information that could be shared. The process flow and timing can be found in the Flow Chart discussion section.

FMEA Inputs

FMEAs, from the different involved organizations, would provide critical inputs into the development of a complete system approach to creating a controlled acceptable field evaluation. As for the durability testing protocol, the OEMs should have major input as to what components they would like to have detailed pre and post-test evaluation requirements.

Because of the complexity of the locomotives, it is believed that by dividing the locomotive into three distinct functional regions, the development of the locomotive FMEA becomes more manageable. A well-developed FMEA will aid in understanding risks to the assets due to changes to the fuel supply. One of the outputs from the FMEA would be to implement suggested controls and oversights during the field evaluation to mitigate risks of the valuable locomotive assets, while allowing the railroads to maintain on time delivery.

The three functional regions would include components or systems that are directly in contact with the fuel, or influenced by the fuel are as follows: pre-combustion, combustion, and post-combustion. A detailed examination of some of the major components in the three regions were cultivated to help assess if there are increased risk of failure to those component's and system's durability, reliability, and availability, useful life, function, or changes in performance when concentrations of B20 biodiesels are used. The risk assessment (FMEA) should have helped emphasize areas of greater or lesser concerns prior to stating the field evaluation.

Those three divisions could be improved upon with suggested additions or deletion from the OEMs. The divisions are intended to point out areas where the use of biodiesel fuels could affect the durability of the multi systems. The post-test evaluation of components, systems, emission, and performance will clarify if there are or are not components or systems that potentially require a redesign if higher concentrations of biodiesel are to be used.

Pre-combustion: By this author's classification, the pre-combustion region includes the fuel tank and all components between the fuel tank and the high pressure pump.

Fuel Tank: Locomotive fuel tanks are commonly a ferrous based alloy. Because of biodiesel fuel's different affinity for water, will there be an increase in corrosion (rust)? It might be considered low risk to have sufficient corrosion such that it would be great enough to allow through a hole that would leak fuel from the tank. However, if there were an increase in the amount of rust, that increase could potentially create other problems discussed later. At the water fuel interface, will there be an increased concentration of biological growth in the tank? The mass of organic matter from organism growth could contribute to fuel filter plugging and an increase of organic acids from the organism's byproduct of respiration. If there is an increase in water in the tank how much will reach the high pressure pumps?

Volume: Biodiesel fuels are of lower energy content by volume. With the reduction of volumetric energy, will the onboard fuel energy be sufficient to maintain the current frequency of filling, and the current fuel running maintenance locations?

Screens: Will locomotives fitted with filter screens before the low pressure suction pumps have an increased suction side restriction resulting in reduced fuel flow as a result of a potential increase in rust? This potential premature plugging would require a change to the screen maintenance. Locomotives without screens could allow a greater concentration of rust debris to be drawn to the low pressure pump, placing it at risk for failure.

Sight Gage: Fuel tanks sight glass gage seal materials were selected to be compatible with No. 2 diesel fuel. The elastomer was not necessarily selected for biodiesel, so there could be a compatibility issue with higher concentrations of biodiesel. If there is a compatibility issue, the question that could be asked is although not compatible; does the elastomer seal still function in the present of B20 as a seal until the end of its expected useful life?

Low Pressure Suction Pump: If there are increased concentrations of rust/debris in the fuel tank, will that rust/debris be carried to the pump? Would this debris contribute to an increase in pump bearing failures? A second potential issue is with the solvency of biodiesel (fatty acid methyl esters (FAME)) fuel. The suction pumps winding are in contact with the fuel. So will the solvency difference of the biodiesel to diesel affect the varnish used on the motor's windings? The end of the test will determine if these are or are not concerns.

Fuel Heater: The Tier 0, and 1 units use copper tubes in the fuel heaters. Would the introduction of higher concentration of biodiesel accelerate corrosion of the copper tubes? If corrosion rate were increased to the point of a leak hole, the engine coolant and fuel would be cross contaminated.

Pipes and Hoses: The fuel jumper hose between the power assemblies were specified to be compatible with diesel fuel. They were not selected to be used with biofuels. The field test will demonstrate if the fuel supply hoses are also capable of delivering biodiesel without failure.

Filters: With the introduction of biodiesel, will the fuel filters be able to maintain function, efficiency, and useful life? Field testing should provide the answer to this potential concern.

High Pressure Pumps: In preparation of the fuel injection event, through the injectors, requires the fuel to be pressurized. This pressurization process generates heat. With the oxygen already part of the FAME molecules, would the biodiesel oxidize at a faster rate than the diesel fuel? If so, it could create a situation where there is an increase deposition of varnish or lacquer on the high pressure pump components? This in turn could potentially alter the function of the pump?

Combustion: The combustion region encompasses the components involved with the combustion event. This starts with the high pressure pumps, intake valves, injectors, followed with cylinders, rings, and the piston crown, and ending with exhaust valves and blow by-gases.

Laboratory testing can evaluate the following six items involved in the combustion process.

1. Needle lift: Would concentration of 20% biodiesel alter the timing of the injector needle lift? Would the oxygen atom being part of the fatty acid methyl esters (FAME) molecule improve combustion negating any timing differences? If there is still a timing difference, is it significant or not to alter the durability or reliability of the combustion components?
2. Injection sprays: Due to surface tension and density differences would different fuel droplet sizes be produced? If the physical size is different would the penetration distance be altered and increase fuel impingement on the cylinder walls?
3. Ignition delay: (changed?)
4. Kinetic or premixed burn stage: (changes?)
5. Diffusive burning: (changes?)
6. Diffusive and end of burning period: (changed, extended?)

The response of the system to the above combustion events can be observed by evaluating some components, e.g., rings, ring grooves, and liners.

Ring groove deposit changes: As noted in the injection spray section, would the droplet size alter the deposition/formation of deposits in the ring grooves. If there is an increase mass of deposit in the ring groove, the function of the rings will be impaired.

Cylinder liner: There are concerns of an increased rate of varnish and/or lacquer deposit accumulation on the cylinder liner's walls. If there is in fact a deposition of varnish and/or lacquer on the liner's wall the negative asperities (valleys) will fill with that material, thereby inhibiting the ability of the negative asperities to function as an oil reservoir. If this were to occur, the liners probability of scuffing and potential failures would be increased.

Full power: One OEM's testing has shown that when B20 biodiesel fuels are used, the locomotive was able to make full power. However, with higher concentration it can become an issue in making full power. That is because of the lower volumetric energy, there may not be enough time to inject sufficient volume of fuel in a cycle to allow for the production of full horsepower. Also as the unit injects fuel late in the thermo cycle it could contribute to hotter exhaust. Those hot exhausts could contribute to exhaust valve seat durability, exhaust pipe, and turbocharger issues.

Fuel consumption differences: Biodiesel fuels volumetric energy content is less than that of a typical No.2 diesel fuel. Therefore, it would be expected to have an increase in the volume of fuel consumed with increasing concentration of the biodiesel content. Although testing has shown this to be true, the increase is not a direct ratio of the energy content differences. It could be that because of the oxygen being part of the B100 fuel's hydrocarbon, the combustion efficiency is slightly different. In other words the increase although measurable is often somewhat less than expected.

Post-combustion: The post-combustion section starts with the exhaust value opening, piston on the down stroke, piston ring relaxing, and in-cylinder temperatures and pressures lowering. This region includes not only the material being exhausted, but any material bypassing the piston rings (blow-by).

Exhaust: With biodiesel fuel's lower energy content, it would likely require an increased volume of fuel to be injected per cycle to make equivalent power compared to No.2 diesel fuel. The need to inject an increased volume of fuel longer in a cycle would require an extended time of fuel injection. This could result in late combustion, and in turn increases exhaust temperatures.

Temperature: With the use of higher concentrations of biodiesel fuel will there be an in-cylinder temperature difference? Would the temperature difference be sufficient to affect the durability or not? Because of the expected need to inject more volume of fuel later in a cycle, will that result in later in-cylinder combustion resulting in hotter exhaust?

Emissions: Performance testing of biodiesel blends in locomotives engines has shown emission controlled compounds (required for emission compliance) to be reduced, except for NO^x increase.

Turbo speed changes: If the exhaust is hotter, would that increase turbocharger speed thereby altering durability?

Blow-by gasses: With the use of higher concentration of biodiesel fuel will there be an increase of unburned fuel bypassing the ring liner interface? If so, what impact would that have on the useful life of the oil and oil additive package? Would the biodiesel (FAME) oxidize in the crankcase oil to change the rate of oil oxidation? Would a different rate of organic acid formation from oxidation result in corrosion of the lead bearings?

Laboratory selection for fuel and crankcase oil testing: Critical to have acceptable test methods data and a quality laboratory to run all required tests.

Analytical tests selection: The selected laboratory or laboratories must have the capability to run not only the standard battery of fuel and oil tests, but have the flexibility to run special test that might be required.

Base number depletion Acid number increase: Understanding the relationship is critical to determine proper analytical tests for both the acid and base numbers.

Engine condition changes: Post-test locomotive inspection to note any changes in the test locomotives compared to the reference locomotives. A few examples of components to evaluate would be; piston under crown deposits, cylinder liners deposits, emissions, filters, low and higher pressure pumps, and other changes to component's condition. The protocol would follow the crankcase oil protocol with the addition of components of interest to the OEMs and railroads.

CONCLUSION:

Successful Alternative Biodiesel Fuel Field Test Protocol, driven by a desire for a cost effective reliably alternative energy sources drives the need to:

1. Develop an industry accepted field test protocol for the evaluation of the complete system
2. Evaluate alternative fuels in revenue service
3. Have the field protocol preceded by comprehensive component tests such as:
   a. Laboratory tests of the fuel's chemical and physical properties
   b. Component tests
   c. Locomotive component tests
   d. Engine laboratory tests
   e. Locomotive stationary tests
4. Longer term locomotive field test evaluations to evaluate any long term effects

Understanding if there are negative effects on the components, engines, locomotives, or systems as a result of using alternative fuels, e.g., biodiesel fuel at a B20 concentration, would be one of the goals of the protocol.

If components are found to have been affected, with the use of concentrations of biodiesel at B20 blend, those components or systems would need to be redesigned so successful use of B20 biodiesel could be achieved.

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I would like to thank the LMOA FL&E committee members for their helpful comments on this paper and associated presentation.

Also, I would like to give special thanks and acknowledgement to the National Biodiesel Board for their sponsorship of this effort.

Report on the Committee on New Technologies

Monday, September 24, 2012 at 3:30 P.M.

Jim Christoff
Business Manager, Traction
Morgan AM&T/National
Cicero, NY

Vice Chairman
Tom Mack
VP-Sales & Business Development
Motive Power & Equipment Solutions
Greenville, SC

Commitee Members

S. Bendriss	Electrical Engineer-Propulsion	Amtrak	Wilmington, DE
D. Brabb	AVP-R&D	Sharma & Associates	Countryside, IL
D. Brooks	Product Development Mgr	ZTR Control Systems	London, Ontario
J. Clapper	Asst. Supt-Motive Power	Wheeling & Lake Erie RR	Brewster, OH
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C. Nordhues	Product Line Manager	Invensys Rail	Louisville, KY
C. Prudian	Senior Systems Engineer	Electro Motive Diesels, Inc	LaGrange, IL
T. Shah	Product Mgr-Global Eng Platforms	GE Transportation	Erie, PA
D. Sweatt	Telecommunications Project Mgr	CSX Transportation	Jacksonville, FL
T. Volkmann	Director-Mechanical Engineering	Union Pacific RR	Omaha, NE (Past President)
K. Ulbick	Sales Manager	Peaker Services, Inc	Brighton, MI
J. Whitmer	Electrical Designer	Motive Power	Boise, ID
B. Wolff	Sales Engineer-Rail	MTU	Detroit, MI
C. Wyka	Senior Reliability Specialist	CN RR	Edmonton, Alberta

Note: Tim Wymer of Norfolk Southern and Tarek Elkhatib of the Union Pacific will be joining the committee at the 2012 convention in Chicago

PERSONAL HISTORY

Jim Christoff

Business Manager, Traction Segment
Morgan AM&T / National
Cicero, NY

Jim who was raised in Western Pennsylvania now finds himself living in Cicero, NY. His 30 plus years in the carbon business have given him a broad knowledge of DC rotating equipment and an understanding of the operating conditions and environments that are present in railroad freight and passenger service.

Jim has worked for Morgan Crucible plc (parent company of Morgan AM&T/ National) for 23 years. From 1989 thru 2001 he handled the East Coast Transit, Industrial, and Consumer Business. In 2002 he started working exclusively on Transit and Traction business and in 2005 he was promoted to Business Manager of Traction in the Americas.

Jim and his wife Diane have two children and 2 grandchildren. When work is done they enjoy boating, golfing, and visiting their children.

The New Technologies Committee would like to express their sincere appreciation to David Brooks and ZTR Control for hosting the committee's meeting in November 3, 2011 in London, Ontario. The committee wishes to thank ZTR for using their facility for the meeting and for hosting the dinner on November 2nd and a lunch on November 3rd.

The Committee also wishes to thank Randy Nelson and Cummins, Inc. for hosting the committee's spring meeting on April 3, 2012 in Columbus, Indiana. Randy treated us to dinner on April 2nd and to lunch on ApriI 3rd. After the committee meeting, we toured Cummins Technology Center in Columbus before traveling to Seymour, Indiana to tour their large engine plant where we had the opportunity to view their, yet to be released, 95 liter engine.

We also wanted to express our sincere appreciation to the BNSF for hosting our annual joint technical committee meeting at Overland Park, KS on May 8th and 9th and to thank our President Ron Bartels and 1st VP Brad Queen for making all the necessary arrangements and to our Secretary·Treasurer Ron Pondel who is the glue that holds it all together.

Additionally, the New Technologies Committee had a conference call on January 16, 2012 to discuss the progress of the committee's technical papers to be presented at the September convention in Chicago.

Tractive Effort and Adhesion: A Review of Yesterday, a Look at Today, Concerns for Tomorrow

Prepared by:
Tom Mack, Vice President, Motive Power & Equipment Solutions, Inc.

Most locomotive buyers are familiar with the classic tractive effort curves supplied by the locomotive manufacturers for a locomotive. Even more common is a simple to read published chart of maximum tonnage rating for a particular locomotive model on a particular division of the railroad. These tonnage ratings are usually based on the tractive effort ratings for the given locomotive and may include its short time traction motor ratings. The tractive effort chart helps to determine how much tonnage the locomotive is actually capable of pulling, but depending on severity and length of grades on a particular section of track, the locomotive traction motor short time ratings must be taken into consideration so as not to damage or totally burn out the traction motors. Hence we immediately begin to see that in the long run, while tractive effort is certainly something that we are interested in, it is not the only aspect of the locomotive that must be taken into consideration when choosing a locomotive. A locomotive may be able to pull a certain load (tractive effort), and achieve a certain speed (horsepower), but if it does so at the cost of damage to a critical locomotive component (e.g. TM burnout), then the additional tractive effort is not worth the cost.

The age old question of "How much can that locomotive pull?" has been asked by children watching trains probably since the time locomotives first started pulling railcars! It is certainly an important question even for a railroad itself to ask. But while every railroad wants to see the use of its locomotives maximized, and although the measurement of the economics of locomotive maximization is more critical today than ever before, determining just "how much" a locomotive can pull is more difficult than meets the eye. Today's railroad must also take into account the costs associated with increasing a locomotive's pulling power, or tractive effort. Is the more powerful locomotive really "designed for reliability?"

For example, what railroad would not want to get better fuel efficiency from their locomotive? But at what cost? If a manufacturer were to offer a fuel efficiency option that cost more than the fuel savings over the life of the locomotive, the better fuel efficiency would simply not be worth the price. This differential is fairly easy to calculate. To calculate the locomotive savings or cost increase you simply use the following formula:

*(g * c * l) - O = s   g = Gallons per Year reduced, c = Cost per Gallon l = life of locomotive O = option cost s = savings*

What if a locomotive could pull more tonnage (produce better tractive effort) without increasing fuel usage simply by adding an option? Again, the answer might seem obvious that this "option" would make sense. But the same issue arises with tractive effort as does with fuel efficiency. If the cost of the added tractive effort is higher than the additional revenue generated by hauling more tonnage, the better tractive effort is simply not worth the price. But what formula do you use?

We might think that with the extra tractive effort a modern locomotive can deliver, we can very simply add additional tonnage to the trains we pull. But the additional tonnage pulled at low speed might require more horsepower at road speed, and if the locomotive does not have enough horsepower to pull the train at a required higher speed, it does not matter that we have more tractive effort at low speed. So somehow we must also add the required train speed into our equation without it starting tractive effort simply means we can start moving a train not that we can't put it on our mainline.

Finally, there is the added subject of maintenance. If our fuel efficiency increase comes simply from a design change to a piston or injector, components that are standard across both the lower efficiency and higher efficiency engine, our maintenance costs may be identical on the higher efficiency engine. But if we have to add new components that are subject to constant failure, or require a higher level of maintenance, then even if our simple fuel savings vs. option cost calculation shows the fuel efficiency option to be cost effective up front, it may actually be a poor choice in the long run due to increased maintenance costs and/or locomotive down time.

With the advent of new high power electronics, AC traction motors, and computer controlled traction control systems, the issue of tractive effort cost effectiveness is one that the LMOA New Technologies Committee felt was important to reconsider and review. But first of all we must determine how we actually calculate tractive effort, what tools and information we have at our disposal, and whether or not we need to change the way we look at tractive effort requirements. The purpose of this initial paper is simply to re-acquaint LMOA members with the basics of tractive effort and update this with a review of the latest options for and advancements in traction control (which can increase available locomotive tractive effort).

Tractive Effort Physics

Almost 50 years ago an EMD primer on locomotives stated that unless the ratio of weight on drivers to effort is at least 4:1, chances are good that the wheel will slip. Stated conversely, when "adhesion" (the ratio of tractive effort to weight on drivers) exceeds

25%, the chances are good that the wheel will slip.

This simple premise helps us to realize that tractive effort has to do with physics. When we think of the physics involved in adhesion and tractive effort, there are four major physical areas that in a perfect world we can influence when it comes to how much tractive effort we can potentially get from our locomotive.

1. **Weight** – As pointed out earlier, the weight of the locomotive directly affects the amount of tractive effort that can be applied to the rail. Hence the maximum real world tractive effort that can be applied to the rails is often expressed as adhesion percentage (or adhesion ratio) times weight. Hence, under perfect conditions, two locomotives that can maintain the same adhesion percentage, say 25%, but have different weights, will produce different amounts of tractive effort. A 200,000 pound locomotive could produce 50,000lbs of starting tractive effort, whereas the same locomotive ballasted to 240,000 pounds could produce 60,000lbs of starting tractive effort. Put another way, by simply increasing the weight of the locomotive, the 240,000 pound locomotive could pull 20% more cars than the 200,000 pound locomotive.

2. **Gear Ratio** – Though gear ratio will not change the tractive effort calculation, it will change the ability of the locomotive to pull a given amount of weight for a given time. While the actual curve does not change, the point at which the locomotive produces the given traction will, and hence, the locomotive can pull more tonnage because it can continuously move the train at a slower speed. The slower the speed, the higher the tractive effort that can be produced.

3. **Traction Motor Type** – AC or DC? The choice could also be said to be a matter of physics. Since a DC motor works in a different way than an AC motor, we can take advantage of the better control characteristics of an AC motor simply by replacing the DC motors in the locomotive truck. Using AC traction can thus give us better tractive effort. Even DC traction motors have different characteristics that will affect tractive effort. For example, an EMD D78 traction motor can handle higher current loads than an EMD D77 traction motor. It thus has a higher tractive effort rating than a D77 traction motor.

4. **Truck design** – High adhesion trucks, radial design, etc. What truck do we want to use? Usually our choice of trucks only applies to new locomotive builds, whereas the previous three are areas that can be changed during a rebuild (although switching from DC traction motors to AC traction motors has traditionally not been done because 1) it requires an upgrade of the control system to high current inverters; and 2) there has not been an availability of an AC substitute for the most common DC traction motors such as the EMD D77/D78.)

There are also some other physical ways of controlling tractive effort, such as sanding the rails, but these are more environmental controlled (e.g. during rain, on rusty rails, slick spots, etc.) and unlike the previously mentioned areas, do not require an overall physical change to the locomotive.

The need to sand the rails highlights a very important point when it comes to the physical aspects of tractive effort. Since we don't live in a perfect world, the influences of physical aspects of our locomotive and its environment will limit what we can do to actually change the locomotive to get better tractive effort. So while increased weight will theoretically get us better tractive effort, the amount of tractive effort that can be developed is actually totally independent of the locomotive's weight.

Because of this, many people get confused in regard to how tractive effort is actually calculated, and how locomotives perform. Unfortunately, the information produced by the locomotive manufacturers and rebuilders many times simply adds to the confusion. Although most manufacturers provide nice, professional looking charts and brochures, a major problem exists in regard to the standards and calculations used to produce these charts and claims of tractive effort and performance. As will be seen, if manufacturers are to "design for reliability", and CMO's and executive buyers are to receive truly useful information, we need to have standards set and sufficient information provided to truly understand what is being provided by the locomotives we buy.

So let's start with our basic piece of information, the tractive effort chart.

Tractive Effort – The Calculations

It was just mentioned that the weight of the locomotive will have a direct effect on the ultimate tractive effort our locomotive produces. While this is true, what is many times forgotten is that tractive effort as a calculation has nothing to do with locomotive weight!

Per EMD, the calculation for tractive effort is fairly simple and straightforward:

TE = (HP x Transmission Efficiency) / Speed

More specifically, EMD uses the tractive effort calculation for DC traction motor locomotive as:

TE = (HP x 308) / Speed

According to this equation Tractive Effort (TE) is calculated by taking our locomotive's horsepower (HP) and multiplying it by the constant 308. (More on where this constant comes from will be discussed later in this paper.) The result is then divided by the speed. This gives us our Tractive Effort number. If we plot these numbers across a graph, we get our "classic" tractive effort chart, an example of which is found in Figure 1. This particular chart comes from advertising information from National Railway Equipment for its 2GS14B locomotive:

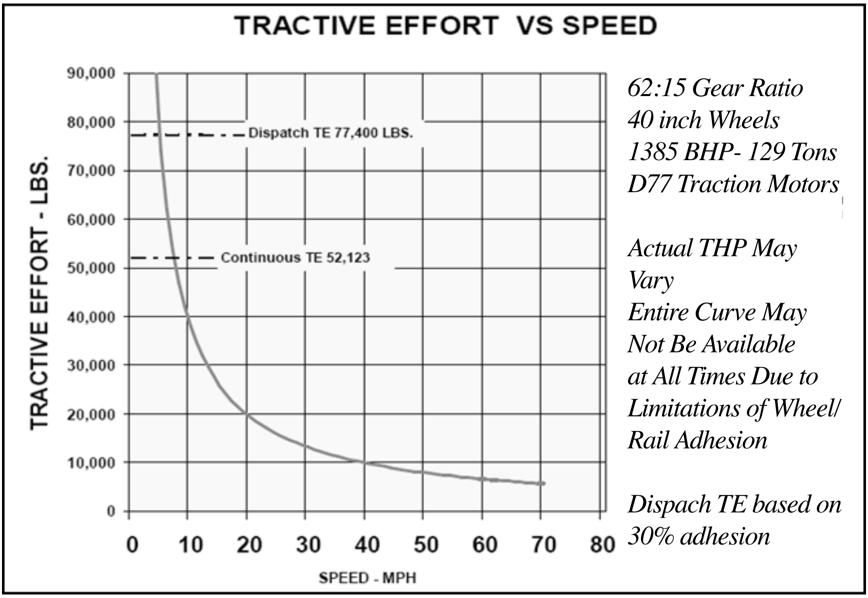

Figure 1 - NRE "Classic" Tractive Effort Chart

While the NRE tractive effort chart lists locomotive weight (129 tons) and a 30% adhesion level, note that neither adhesion nor weight are part of the EMD TE calculation. Note the disclaimer regarding actual THP (traction horsepower) and adhesion, which may be different due to wheel/rail conditions. On this chart a common component is also missing. Where did "Starting Tractive Effort" go? Is it now "Dispatch TE"? That appears to be the case, but no explanation is made of what the term "Dispatch TE" really refers to.

Thus we begin to see some issues with the current state of tractive effort charts. Each locomotive manufacturer certainly has the freedom to design and publish its own tractive effort charts. Figures 2 and 3 illustrate a more intricate tractive effort chart produced by Brookville Equipment for its Co-GenerationTM series of locomotives (Brookville's versions of the multi-genset locomotive, similar to NRE's 2GS14B locomotive whose TE chart is shown in Figure 1).

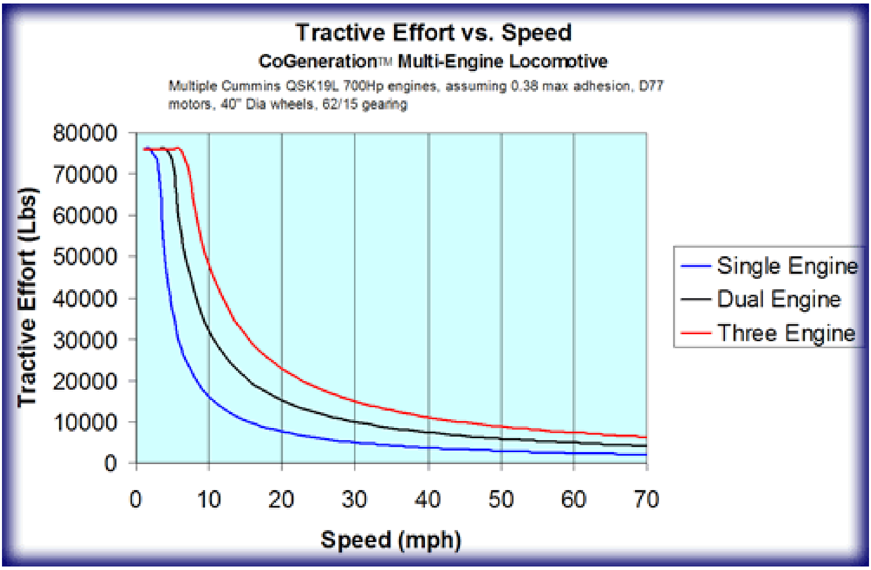

Figure 2 – Early Brookville Tractive Effort Chart for Co-GenerationTM Locomotives

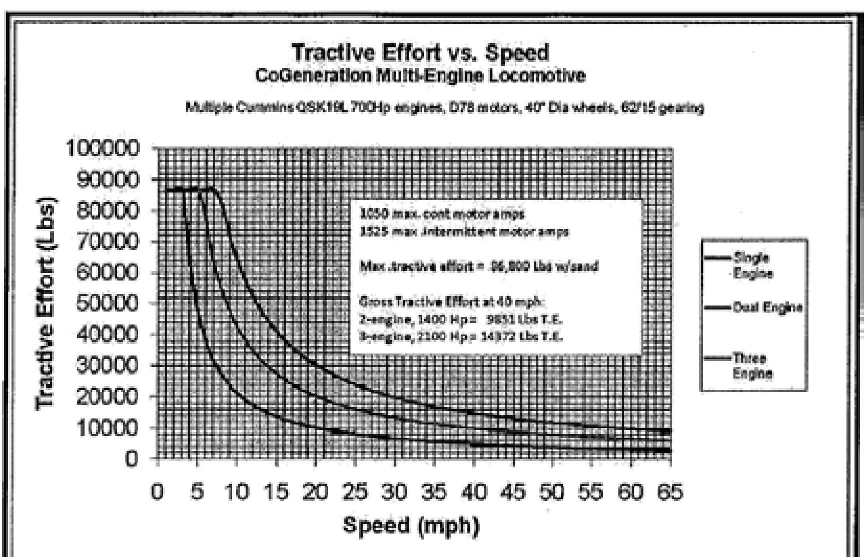

Figure 3 – Late Version of Brookville Tractive Effort Chart for Co-GenerationTM Locomotives

The chart in Figure 2 combines the tractive effort curves for three different models of locomotives. Unlike the NRE tractive effort chart in Figure 1, this chart does not list the locomotive weight and “assumes” a 0.38 (38%) maximum adhesion level. Also of note is that Brookville clearly states the type of traction motor used on the locomotive. Choice of traction motors will affect the maximum tractive effort that can be continuously sustained by a locomotive.

A later version of the Brookville TE chart (shown in Figure 3) contains additional information which is very helpful to understanding the basis for information in the chart. For example, not only is the type of traction motor listed (EMD D78), but the continuous and intermittent amperage ratings of the traction motor are listed (1050 Amps continuous and 1525 Amps intermittent). As mentioned earlier, a locomotive’s traction motors have a real and direct bearing on the maximum tractive effort we can expect our locomotive to produce. The basis for this statement goes back to two simple mathematical calculations.

First, Ohm’s law tells us that P = E x I. In other words, horsepower (HP), which can also be expressed as kilowatts (kW) or thousands of watts (P), is equal to volts (E) times amps (I). For a traction motor, the amperage (current) translates to torque, while the voltage translates to speed. So if a traction motor can handle a higher continuous amperage, the voltage to transmit the locomotive’s horsepower (or kilowatts) to the rail will be lower. And since voltage is speed, the locomotive can operate continuously at a lower speed and will thus produce a higher continuous tractive effort, just by switching to a more robust traction motor.

Second, remember our tractive effort calculation as expressed by EMD, namely TE = (HP x 308) / Speed. Ohm’s law tells us the traction motor that supports higher amperage will support lower voltage and thus lower speed. Since the tractive effort calculation uses speed as the divisor, as long as horsepower remains constant, the lower the speed, the higher the tractive effort produced. Thus a locomotive that can run continuously at a lower speed than a similar locomotive of the same horsepower will produce higher tractive effort.

Put another way, if two locomotives of the same horsepower have an identical tractive effort chart, the locomotive with higher amperage capacity traction motors (e.g. an EMD D78 vs. an EMD D77) will provide a higher sustained tractive effort simply due to the physical characteristics of the traction motor.

But back to the Brookville tractive effort chart. Note that the Brookville chart uses the term “Maximum Tractive Effort”, not “Starting Tractive Effort” as used in many older TE charts, or “Dispatch TE” as used in the NRE tractive effort chart. While we might assume that all three terms are the same, are they? We really don’t know.

Brookville has also added a new twist to the maximum tractive effort number. Notice that the chart states this is “Maximum Tractive Effort…

w/ Sand" (italics added). What would our maximum tractive effort be without sand? How does this compare to the "Dispatch TE" on the NRE chart? Is the NRE "Dispatch TE" with sand? If not, what would it be with sand?

The NRE chart states the "Dispatch TE is based on 30% adhesion". What about the Brookville locomotive? The earlier version of the Brookville chart states that the tractive effort numbers are "assuming 0.38 max adhesion". Nowhere in the later Brookville chart is a maximum adhesion percentage mentioned, only the maximum tractive effort. Since none of the charts list the weight of the locomotive, we have no basis to do calculations.

Finally, why does the Brookville TE chart in Figure 3 list "Gross Tractive Effort at 40 mph"? What is the significance of 40 mph and why is it important, especially since this speed point is not specifically pointed out in other manufacturers' tractive effort charts? So while our TE charts are certainly full of information, how do we use them to compare different locomotives?

The point here is not to denigrate any manufacturer's tractive effort chart or to suggest that they are hiding anything. The charts do provide a wealth of information. But by what standard is the information derived and presented? Without standards, we cannot make comparisons, and without comparisons, it is difficult to make informed buying decisions. Since railroad CMO's are looking for locomotives "designed for reliability", how can we be sure the locomotive we purchase is truly designed for our needs if we can't compare them to one another or truly understands their capabilities?

Tractive Effort – Weight and Adhesion

Now that we have determined that tractive effort is simply a physics equation, just where do weight and adhesion come into play?

Interestingly, not all manufacturers agree with the physics equation for tractive effort. Chattahoochee Locomotive Company (CLC) has written a white paper that goes into details concerning tractive effort, adhesion, and AC vs. DC traction locomotive performance. The paper is filled with calculations and examples to explain not only tractive effort, but locomotive performance comparisons. But this paper states:

"The equation to calculate tractive effort is: *TE = effective machine weight x adhesion coefficient*. *Note that horsepower isn't part of the calculation for tractive effort*." (italics added)

Notice that CLC states unequivocally that "horsepower isn't part of the calculation for tractive effort." They list the tractive effort equation as the simply locomotive weight times the adhesion capability of the locomotive. Why this apparent contradiction with the physics just discussed?

This is because in the real world, physics and achievable results do not always mix. Just because physics tells us something is achievable does not always mean we can achieve the calculated results. Hence the often used disclaimer in advertising, "Actual results may vary", or in the case of tractive effort charts, "Actual THP May Vary" and "Entire Curve May Not Be Available At All Times Due To Limitations of Wheel/Rail Adhesion". In essence what we are being told is that we need to look beyond the tractive effort charts to real world examples, which is in essence the direction taken by the CLC paper.

Does that mean that we do not need tractive effort charts or tractive effort information? Not at all! But what is being presented in this LMOA white paper is that there is a need for a consistency and standardization in locomotive performance and/or data reporting. For example, the CLC paper introduces three terms in regard to tractive effort:

- STE – Starting Tractive Effort
- CRTE – Continuous Running Tractive Effort
- RTE-X – maximum short term Running Tractive Effort for X number of minutes

While Starting Tractive Effort is a familiar term (although missing entirely from the NRE and Brookville tractive effort charts shown in Figures 1-3), CRTE and RTE-X are totally new terms used only by CLC, even if their meaning appears quite obvious. CLC is not alone in introducing its own set of terms, as EMD in its Locomotive Application Guide uses the term "All Weather Adhesion" to refer to the adhesion level a user can expect a locomotive to produce 99% of the time. GE uses at least six different terms applying to tractive effort (see Figure 5).

So when the "wheels hit the rails" we cannot discount that weight and adhesion level play a very real part in tractive effort. But how is this information really conveyed in our tractive effort charts and locomotive specification brochures?

Tractive Effort Calculations – The Devil in the Details

There are additional aspects of the tractive effort calculation that must be taken into account but are seldom mentioned. This has to do with the horsepower used in calculating tractive effort and the transmission efficiency constant that is used.

Back to our basic EMD DC traction motor locomotive tractive effort calculation presented at the beginning of this paper:

$$TE = (HP \times 308) / Speed$$

The first issue we must deal with is the value we use for the horsepower number in the equation. This horsepower value should not be the overall horsepower provided by the engine or engines used on our locomotive. This engine horsepower is usually referred to as "Brake Horsepower" or BHP. Since tractive effort has to do with the power we supply to the rails, the horsepower value we use in the tractive effort equation must take into account a loss of engine horsepower to run auxiliary equipment, such as fans and traction motor blowers. We usually refer to this as "Traction Horsepower" or THP, which is the defined as the engine's brake horsepower (BHP) minus its accessory load (horsepower required for auxiliaries such as fans, blowers, air compressor, auxiliary 74v systems, etc.). Thus, an EMD SD40-2

is often called a 3,000 HP locomotive, when in actuality, 3,000 is the traction horsepower rating of the locomotive. An SD40-2's 16-645E3 engine is actually producing as much as 3,280 HP according to EMD (3,280 BHP minus 280 HP for auxiliaries = 3,000 THP).

Not all tractive effort charts, however, appear to utilize THP in their equation. For example, the NRE tractive effort chart in Figure 1 clearly states "1385 BHP". But the question arises, is the NRE tractive effort chart based on BHP or THP? If it is based on BHP, then clearly the chart cannot be compared to an EMD chart which uses THP for its calculations.

Interestingly, a later tractive effort chart for a 129 ton NRE 1,400 BHP 2GS14B locomotive shows the locomotive rated at "1300 THP". BHP is not even mentioned on the chart. But while the 30% starting tractive effort of 77,400 pounds on the newer and older tractive effort charts remains the same, the "Continuous TE" rating changes from 52,123 pounds on the earlier chart (Figure 1) to 44,165 pounds on the later chart. To complicate matters, the most recent tractive effort released by NRE for the 2GS14B locomotive rates the locomotive at "1225 Traction HP" with "Continuous TE = 50,537 Lbs." Continuous speed is listed as 7.7 MPH. (The locomotive's Continuous Speed is not specifically mentioned on the earlier charts.) Hence there is clearly a need to consult the manufacturer for a copy of the latest tractive effort chart when making purchasing decisions or comparing various locomotive models.

Similar issues can be found in the Brookville charts. Since the Brookville charts both mention Cummins 700hp QSK19L engines (which are rated by Cummins at 700 HP at the flywheel without auxiliary loads), and the later chart shown in Figure 3 specifically lists the "Gross Tractive Effort at 40 mph" as "2-engine, 1400 Hp = 9851 Lbs. T.E." and "3-engine, 2100 Hp = 14372 Lbs. T.E." it would appear that Brookville uses BHP in its TE chart calculations, not THP as EMD does. So it would appear that we could compare the two engine NRE 2GS21B TE chart with the Brookville 2-engine Cogeneration Multi-Engine Locomotive, but if neither chart is based on THP, then are we really seeing the correct tractive effort numbers on any of the charts? And how do we compare these charts with a tractive effort chart we would get from EMD?

Second, to complicate things even further, the tractive effort equation requires we supply a transmission efficiency constant in order to get to the real tractive effort numbers. So just where did EMD come up with the constant "308"?

According to EMD, the transmission efficiency is through the:

- Main Generator
- Switch Gear
- Cables
- Traction Motors
- Traction Motor Axle Gears
- Inverters (on AC locomotives)

EMD clearly states in its locomotive guides that the calculated transmission efficiencies for its DC traction motor locomotives is 82%, and for its AC locomotive this number jumps

TE Constant	315	=	375	lb. Miles per Hr x	84%	Transmission Effeciency	
Tractive Effort	136,957	lbs =	4,000	THP x	315	(TE Constant) /	9.2
Adhesion	33%	=	136,957	lbs TE /	415,000	Weight on Drivers	

Figure 4 – Tractive Effort and Adhesion Calculations for EMD SD70AC Locomotive

to 84% (hence the transmission efficiency constant for an EMD SD70AC locomotive has been listed as 315, compared to 308 for a DC SD40-2). The transmission efficiency is multiplied by the constant 375, which refers to one horsepower being equal to 375 mile-pounds per hour. Since tractive effort is expressed in pounds and correlates to speed and horsepower, 375 mile-pounds per hour is the horsepower correlation that must be used when calculating tractive effort. Hence, an SD40-2 with an 82% transmission efficiency results in a horsepower transmission efficiency constant of 308 (0.82 x 375 = 308) and an SD70AC with an 84% transmission efficiency results in a horsepower transmission efficiency constant of 315 (0.84 x 375 = 315). The resulting tractive effort and adhesion calculations are shown in Figure 4.

But while EMD has published information on its transmission efficiency constants used in its tractive effort charts, what about the other manufacturers? To be fair, EMD does not show the transmission efficiency constants on its published tractive effort charts. In order to find the transmission efficiency and tractive effort calculations, one must go to other sources, such as the EMD Locomotive Application Guides that EMD has supplied to locomotive students since the 1960's, and which have gone through several revisions. But at least that information can be found. A review of multiple tractive effort charts from multiple manufacturers shows that none really supply all the necessary information to determine how tractive effort charts were calculated. Without this information it is virtually impossible to make an accurate tractive effort comparison of locomotives from different manufacturers.

Based on the currently published data, it is becoming clearer that today's generation of locomotives, along with an increasing number of manufacturers of new locomotives, require new reporting and comparison methods. There are a number of questions that must be answered. It could be argued that this information should be provided on the next generation of tractive effort charts for CMO's and locomotive buyers. Some questions and values that should be taken into consideration and even shown on charts include:

1. Who decides "transmission efficiency" as used in the tractive effort chart?

   a. What value is used?
   b. How is it determined? (e.g. efficiency of the main generator, DC choppers or AC inverters, traction motors, etc.)
2. What speed is used for TE calculation for comparison purposes?
   a. Minimum Continuous Speed (MCS) which is based on thermal constraints of the traction motor is many times used, so what traction motor is being used on the locomotive and do multiple manufacturers use the same thermal constraints?
   b. What about AC traction locomotives that don't have a Minimum Continuous Speed?
   c. What about new generation chopper equipped DC traction locomotives?
      i. How do the choppers affect transmission efficiency? Higher? Lower?
      ii. How do the choppers affect DC traction motor thermal limits?
      iii. What efficiency values are used with the new traction control electronics?

Much of this information is unpublished, and for some manufacturers may even be considered a trade secret. But as CMO's demand "design for reliability", these numbers become critical. "Design for reliability" requires we as locomotive buyers and locomotive manufacturers develop a common ground that allows true evaluation of today's generation of locomotives. Otherwise, we may end up overloading our locomotives and their traction systems, which will directly affect reliability and long-term maintenance costs.

Tractive Effort – Can Tractive Effort Really Replace Horsepower?

With the advent of DC chopper traction control, a new dimension was added to tractive effort potential of modern locomotives. At the same time, a new level of confusion was also added. Locomotives with lower horsepower were touted as having the ability to pull the same trains and do the same work as a higher horsepower locomotive. Much of this capability was attributed to the fact that locomotives equipped with solid state DC choppers could produce much higher tractive effort than their older counterparts. The argument was made that by increasing the tractive effort, a lower horsepower engine could be used, thus saving fuel and maintenance expenses. It was also said that these locomotives would be most cost efficient since the newer locomotive could move more tonnage than its predecessor, thus the economics of the fuel savings of the new locomotive were said to extend beyond just the face value of the fuel savings.

What was often times missed in the advertising was what railroads were really doing with their locomotives. Was the locomotive's use primarily for just switching? Was it a drag/transfer locomotive? Would it need to go out in branch line or local service, and if so, what type of speed requirements were there for the locomotive?

Since horsepower and speed are both integral parts of the tractive effort equation, both must be taken into account when considering a locomotive. If all that is needed is the ability to pull heavy tonnage at a very slow speed, then perhaps a lower horsepower locomotive with better adhesion capability at low speeds (i.e. a DC chopper equipped locomotive) will suffice. But what if we need higher speeds than say, 5-10 mph within a yard or industrial setting? The old adage that "horsepower is speed" has not changed. The better adhesion capability of DC choppers will not get us higher speed since this is directly tied to horsepower. While we may be able to start a heavier train, or manage a grade better through enhanced adhesion, the maximum speed is still tied directly to horsepower.

To illustrate, we will analyze some actual published data from the locomotive manufacturers themselves:

According to the EMD manuals for the GP38-2 2,000 HP locomotive built in the 1970's and 1980's, the standard GP38-2 with 62:15 gearing has a minimum continuous speed of 10.9 mph. The calculated tractive effort for a standard GP38-2 weighing 250,000 pounds at 10.9 mph is 56,514 pounds. (Interestingly, the extrapolated tractive effort for an unspecified weight GP38-2 as found in published EMD TE charts would only appear to be about 54,000 pounds, hence the need for better TE charts.) No Starting Tractive Effort is listed for the GP38-2 in either the operator's manual or the locomotive specifications brochure.

If we take the tractive effort curve for an NRE 2GS14B as shown in Figure 1, we see that the locomotive has a "Continuous TE" of 52,123 pounds, at what appears to be approximately 9 mph. If this is also the locomotive's minimum continuous speed, then our 1,400hp locomotive would appear to be able to pull almost as heavy a train as our 2,000hp GP38-2 locomotive, albeit at a slightly slower speed.

When we look at the "Dispatch TE" listed for the lower horsepower 2GS14B locomotive, we see that it is a very impressive 77,400 pounds, which just happens to be 30% of our locomotive weight of 129 tons (258,000 pounds). But where did this 30% adhesion number come from? Is it just an arbitrary number – how much tractive effort we can expect if we get 30% adhesion? Will the locomotive really do 30% adhesion? How does this differ from the fact that EMD as far back as 1954, almost 60 years ago, listed a 30% adhesion tractive effort number for its SW900 and SW1200 locomotives? Few CMO's would consider substituting a 1200 THP EMD SW1200 for a GP38-2! Yet with today's advertising, we are led to believe that a lower horsepower locomotive with new electronics can in fact replace higher horsepower units.

If we go back to the calculations, on paper, a 1400 THP, 77,400 pound TE locomotive can move a 25,000 ton train on level track at 8 mph. And in defense of the newer locomotives, the use of DC choppers and newer traction control systems which can control wheel slip can sustain true adhesion levels that a 1950's vintage SW1200 could never achieve. But as we add speed into the equation, or even the slightest grade, the horsepower requirements of our locomotive jump substantially. Suddenly, horsepower does become important! Our 1,400 THP locomotive at 10mph can suddenly only pull a 16,800 ton train with its available horsepower. But what could be missed is that the tractive effort required at 10mph to pull that 16,800 ton train is 41,730 pounds – which is more than the 40,000 pounds of available tractive effort extrapolated from the 2GS14B TE chart in Figure 1. So as higher speed plays into our equation, low speed tractive effort loses its appeal.

But what about our 2,000 THP EMD GP38-2? If the locomotive only develops the same 21% "All Weather Adhesion" of an SD40-2, our 250,000 pound GP38-2 can reliably give us 52,500 pounds of tractive effort. While this is not much more than the 52,123 pounds of tractive effort than the lower horsepower 2GS14B gives us at 8mph, at 10 mph, this 52,500 pounds of tractive effort is plenty enough to pull our 16,800 ton train, which is all the 3GS14B can pull at 10 mph. But at 10 mph our 2GS14B locomotive is maxed out. Our GP38-2 can pull this train on level ground up to 15 mph, which may be enough speed to make the locomotive suitable for branch line or local service where the additional 50% top speed means getting to and from the customer within the allotted crew time.

So which unit will do the job I need to do? Can tractive effort really replace horsepower? Based on the above scenario we learned three things:

Point 1: Based on charts, extrapolations, and calculations, the GP38-2 has better tractive effort at Minimum Continuous Speed than the 2GS14B at the same speed, despite the fact that the 2GS14B may be said to have a higher Starting Tractive Effort than the GP38-2.

Point 2: Based on published Starting Tractive Effort (STE) data and Dispatch TE (DTE) data, if in fact these refer to the same thing, we have no comparison of GP38-2 to 2GS14B because no STE data is provided by EMD. We simply know that the 2GS14B has published 77,400 lbs DTE @ ~5 mph – 20,866 lbs more than GP38-2 MCS TE at 10.9 mph (a 37% improvement over the GP38-2). But this still doesn't really tell us what we need to know!

Point 3: Using the Davis Formula it doesn't necessarily matter if we have better starting tractive effort or higher starting adhesion. We will still need more horsepower or locomotives on our train at higher speeds. We must take speed as well as tractive effort into our locomotive buying decisions.

Further expounding on Point 3, if our Davis formula calculations indicate that a single locomotive will not supply the horsepower requirements to move our train at the desired speed, then how important is the additional tractive effort of a single new generation locomotive if it will always be run paired with another locomotive? We effectively double our tractive effort by simply adding the second similar model locomotive, which in many cases gives us more than enough tractive effort to pull our train. This is not to say that we will not be able to use the additional tractive effort a newer locomotive provides in certain situations, but just having extra tractive effort does not mean we can necessarily change our locomotive consists from two units to a single unit.

So will the cost of expensive DC choppers, traction control systems, or other technology be worth the expense?

Tractive Effort – Concerns for Tomorrow

The LMOA New Technologies Committee has been on the forefront of new technologies that enhance the versatility of locomotives, including new technologies that have directly impacted tractive effort and reliability. These include technologies such as DC choppers, AC traction systems, and microprocessor based wheel slip control. The adoption of multi-genset and hybrid locomotives, with their associated traction and engine control systems, has been a consistent topic of papers from the New Technologies Committee. While reporting on these new technologies is important for keeping railroads abreast of new developments, the concern that now arises for the future is how do we set standards by which to measure these new technologies and compare them? This is critically important to CMO's and other purchasers who need to truly:

1. Understand what the locomotives they are purchasing can do;
2. Know what they will cost both upfront and to maintain;
3. Calculate the actual cost-benefit trade-off in implementing new technologies.

This white paper has looked at just one area, tractive effort. What has been shown is that the adoption of new technologies is changing the way we need to look at the most basic of locomotive performance characteristics, tractive effort being just part of the equation. As technology advances, should not the information available on new locomotives and the way it is presented also advance? But where do we start?

One suggestion is to develop a set of standard terms used when discussing locomotive performance characteristics. While no locomotive manufacturer can be required to use these terms, failure to do so could lead to a disadvantage to the manufacturer. A review of public technical and advertising information from different manufacturers shows clearly that there is no standard when it comes to locomotive performance characteristics (see tables in Figure 5 and Figure 6). With a standard set of terms, there will be no guessing about whether "Starting Tractive Effort" and "Dispatch Tractive Effort" mean the same thing. Locomotive manufacturers will be able to provide information on their product that requires no second-guessing on the part of the reader.

EMD	GE	NRE	Brookville	CLC
Starting Tractive Effort	Starting Tractive Effort	Dispatch Tractive Effort		Starting Tractive Effort
Continuous Tractive Effort	Continuous Tractive Effort	Continuous Tractive Effort	Gross Tractive Effort At 40 mph	Continuous Running Tractive Effort
Minimum Continuous Tractive Effort	Available Tractive Effort		Maximum Tractive Effort with Sand	Maximum Short-Term Running Tractive Effort
Developed Tractive Effort	Usable Tractive Effort			
	Average Usable Tractive Effort			
	Net Tractive Effort			

Figure 5 – Tractive Effort Terms: What Do We Really Call It?

EMD	GE	NRE
Available	Available	
Required	Static	
Developed	Slipping	
Dispatchable	Usable	
All Weather	Overall	
25% 30%		30%

Figure 6 – Adhesion: What Are the Classes of Adhesion?

A second suggestion has to do with the way the information is presented. There is no standard list of information that should be included in a tractive effort chart. For example, are all the manufacturers actually even using the aforementioned tractive effort calculation of TE = (HP x (Transmission Efficiency x 375)) / Speed in order to calculate a tractive effort curve? If a manufacturer is using this approach, what transmission efficiency is being used? Is the horsepower used in the calculation the actual engine brake horsepower, or is it the more precise traction horsepower which takes into account the expected loss of horsepower to the auxiliary equipment such as fans, traction motor blowers, air compressors, etc.? What efficiency ratings are used for the primary traction components, such as main generators, traction motors, and DC choppers or AC inverters? This plays directly into the tractive effort calculation.

Tractive effort charts usually include some information on minimum continuous speed ratings of the locomotive, continuous tractive effort ratings, and starting tractive effort. These are important features that give a picture of the locomotive's critical operational points. Are the traction motor characteristics being used to determine minimum continuous speed and/or minimum continuous tractive effort? If so, what model traction motor and what continuous amperage and/or short time rating is used?

While this might seem like a large amount of data to disclose, without this information the true operating characteristics of a locomotive are not really being disclosed by the tractive effort charts and comparisons cannot be made. When it comes to "designing for reliability", a CMO or other purchaser is not really getting the full picture regarding the locomotive. For example, many of today's multi-genset locomotives use DC choppers. These components are costly, and will require maintenance and possible replacement over the life of the locomotive. Without a set of standards for communicating locomotive operating characteristics, such as tractive effort, a purchaser cannot determine if the additional cost for components such as choppers really provides a return on investment. Is it truly worth spending an additional 10% or 15% for DC choppers if the locomotive only provides an extra 2% or 3% adhesion or tractive effort compared to a locomotive without choppers but with an advanced microprocessor controlled wheel slip system? Is the tractive effort of a DC chopper equipped locomotive really that much better than a locomotive without choppers that it justifies the additional maintenance or even reliability drop? Perhaps for some railroads it is. But for others, it may not be. Without a firm set of metrics, decisions cannot be made.

Is there a way to take all of this into consideration in tractive effort or horsepower charts? With today's modern computers and publishing systems, the ability to create truly meaningful tractive effort charts and performance data sheets is easier than ever. It is just a matter of taking the time and presenting the data in a usable and standard format. It might even be suggested that the days of the paper tractive effort chart are over. In the future, interactive electronic tractive effort charts may be preferable. A railroad could then look at the information from multiple angles and multiple manufacturers, interactively inputting speed and train tonnage information and seeing where it falls on the chart and whether the locomotive is even capable of performing to the railroad's needs.

Tractive Effort – Conclusion

When the New Technologies Committee began discussing the topic for this white paper, it was first suggested that it was time for a review of new traction control technologies, their track record now that they have been in service some time, and what the railroads are experiencing in regard to maintenance, reliability, and return on investment. It quickly became clear, however, that unless some basic metrics and reporting standards were established, the information gathered on current traction control technologies would have little practical application if it could not be properly quantified.

The advent of DC choppers, AC inverters, and advanced wheel slip / traction control systems, has added a new dimension to the control of tractive effort. This directly affects the tonnage that can be moved by a given locomotive and the ROI on new locomotive technology investments. Over the coming year, the New Technologies Committee hopes to further refine the tractive effort and locomotive traction characteristics reporting model to establish a model acceptable to railroad CMO's, locomotive purchasers, and locomotive manufacturers. This will assist locomotive component manufacturers and the locomotive builders that use these components to better communicate the capabilities of their products and their designs for reliability. It will also help to establish a common baseline for further reports on the available traction control technologies and locomotives that use these technologies.

This white paper is intended to be a first installment that will be followed next year by a white paper suggesting a new tractive effort reporting model, and may also attempt to demonstrate that model using real world examples of new technologies, such as DC choppers and advanced wheel slip traction control systems. Further input to this reporting model will be solicited from other LMOA committees as well as the railroads themselves.

Today's locomotive manufacturers and traction system component suppliers have produced an exciting new array of products. Today's locomotives are pushing the boundaries of performance, horsepower, and tractive effort. It is hoped that this consideration of tractive effort and reporting metrics will serve as a catalyst for future developments and purchases of high tractive effort locomotives designed to operate reliably and economically for the job they are intended to do.

A New Tier 0+ Solution EFI for EMD 645 Engines

Prepared by:
Jeff Clapper, Wheeling & Lake Erie RR

Why add EFI to Older Engines like the EMD 645 model?

There is still a large fleet of 645 equipped locomotives in operation across the nation. These locomotives are used in both line haul and switching service. With good maintenance these locomotives can provide reliable, economical, and vital service to the Class I roads, as well as, the short line and regional roads. With the existing EPA standards, these locomotives that were manufactured from 1973 through 1992, upon overhaul, must meet Tier 0 emission standards. With the emission standard revision in 2010 changing to Tier 0+, aftermarket suppliers of emission kits began looking at, and developing, overhaul kits that not only met the EPA standards but also improved fuel economy.

Locomotive fuel is the number one operational expense for railroads. Improvements to original locomotive designs for fuel savings have been made over the past years to reduce consumption along with reducing emissions. This is true for both new locomotives as well as retro fitting older locomotives. Some of these technologies used to retro fit older locomotives include; improved mechanical injector designs, Auxiliary Power Units (APU), Auto Engine Start/Stop systems (AESS), wayside plug in heating systems, etc. Most of the retro fitting that has been done to older locomotives has been with anti-idling equipment. Although anti-idling systems are mandated by the EPA standards, some of this equipment has been installed voluntarily for fuel savings.

Locomotive performance requires a maintenance program that, on most railroads, will over the years include several overhauls to the engine itself. Since 2000 these overhauls would include a certified emission kit that met the standard for the particular model locomotive. Unfortunately, some of these emission kits, whether from the OEM or an aftermarket supplier, came with fuel penalties due to injector timing changes for NOx reduction etc.

As a result, it became attractive to look at technologies that could meet the new standards without fuel penalties and/or costly to maintain and operate after treatment systems like diesel oxidation catalysts etc. The EFI system in this paper is one such alternative technology. The EMD 645 engine historically has used a governor controlled mechanical designed fuel delivery system. In some cases, to meet the fuel economy challenge, the focus was on engine pre-combustion, and combustion using more flexible and accurate microprocessor based fuel injection technology (EFI) versus rigid, complex, and inaccurate mechanical governors and injectors. Converting to an EFI system is relatively simple as far as the physical components and resembles the EFI systems of an EMD 710 engine. As for the EFI system being presented in this paper, in addition to meeting the EPA standards, it provides benefits of fuel savings through improved performance in fuel control with the ability to control injector timing throughout the full power range, enhanced engine protection, and improved diagnostic capabilities. Using microprocessors to control the engine and injection allows for more precise fuel to notch control taking advantage of maximum fuel economy in high use throttle notches, and improved regulation of low idle. There is also increased shut down times for longer durations when the locomotive engine is not in use over existing engine shutdown timers (EST) with the AESS option.

In 2010 this EFI solution for the Tier 0+ requirements was presented to the Wheeling & Lake Erie (W&LE) by Peaker Services Inc. (PSI) as a project to meet our needs and assist Peaker Services in further development through field testing. On April 2010 W&LE entered into a partnership with PSI on the EFI project. In June of that year the WE 6354, an SD 40-2, was shipped to PSI in Brighton, MI where the prototype engine and systems were installed and testing began.

The WE 6354 was returned to the W&LE in late November of 2010 to begin field testing and break in of the engine. After four and a half months of working on load control, excitation interface, and testing in the field the WE 6354 was shipped to Southwest Research Institute (SwRI) in San Antonio, TX for further testing. In October 2011 WE 6354 returned to the W&LE for revenue service and further fuel consumption testing in the field. *(figure 1)*

During emission testing performed at SwRI, data was also collected for brake specific fuel consumption (bsfc) and compared with other available bsfc test data from 16-645E3B engines. These results showed the PSI Tier0+ engine to have 5 - 8% less bsfc than baseline data. Similar results have been seen in the field and during Load Box tests at W&LE. (Additional tests are being run in the field at this time)

The Total Horsepower (THP) closed loop system with Electronic engine speed and load control along with configurable traction control interface logic, will work with standard dash-2 rack and other traction systems. The system also provides independent fan/shutter control, modulated low idle, tunnel mode, and data logging diagnostics. Optionally the system can be equipped with PSI's AESS system including APU backup capability. An HMI for monitoring alarm details, trending data, train line monitoring, and the Cell Modem/GPS option allows access for remote monitoring of alarms and other data. *(figure 2)*

In addition to the improved performance the system is providing, there is

an enhancement in engine diagnostic capabilities and engine protection. For emissions and engine control there are a number of electrical sensors applied to the engine to monitor and/or control the engine. In addition, these sensors enhance diagnostic capabilities and improve engine protection. These diagnostics can also be remotely monitored. The sensors monitor and/or control the following engine systems some with multiple inputs.

- Engine RPM
- Engine Oil Pressure and Temperature
- Engine Coolant Pressure and Temperature
- Engine Fuel Pressure and Temperature
- Engine Intake Air Temperature and Humidity
- Engine Air box Pressure and Turbo Speed
- Traction HP, Generator KW, and Run Hours
- Battery Voltage and Current
- With the AESS option Ambient Temperature, and Main Reservoir, Brake Pipe, Brake Cylinder PSI *(figure 3)*

The system has the option of Auto Engine Start Shutdown (AESS) or is configurable to work with other fuel saving equipment such as, add on AESS equipment, Auxiliary Power Units (APU), etc. The AESS system functions in the same manner as other AESS systems on the market with auto restarts and shut downs based on programmed parameters. Manual restarts are made with reverser being placed in a direction. The AESS system meets all AAR recommended standards.

The following components are part of the Peaker Services, Inc. Emission package PSI rebuilt Power assembles including: higher compression ratio pistons, custom honed liner finish and LOC ring set. High Performance Electronic Fuel Injection system includes: high fuel pressure electronic injectors, microprocessor-based control unit, higher flow and pressure fuel system, modified constant velocity cams, and heavy duty injector arm assemblies. Four pass improved flow after-coolers and locomotive excitation interface.

In Conclusion EFI is a viable solution to meet EPA standards and improve the EMD 645 engines efficiency and fuel economy.

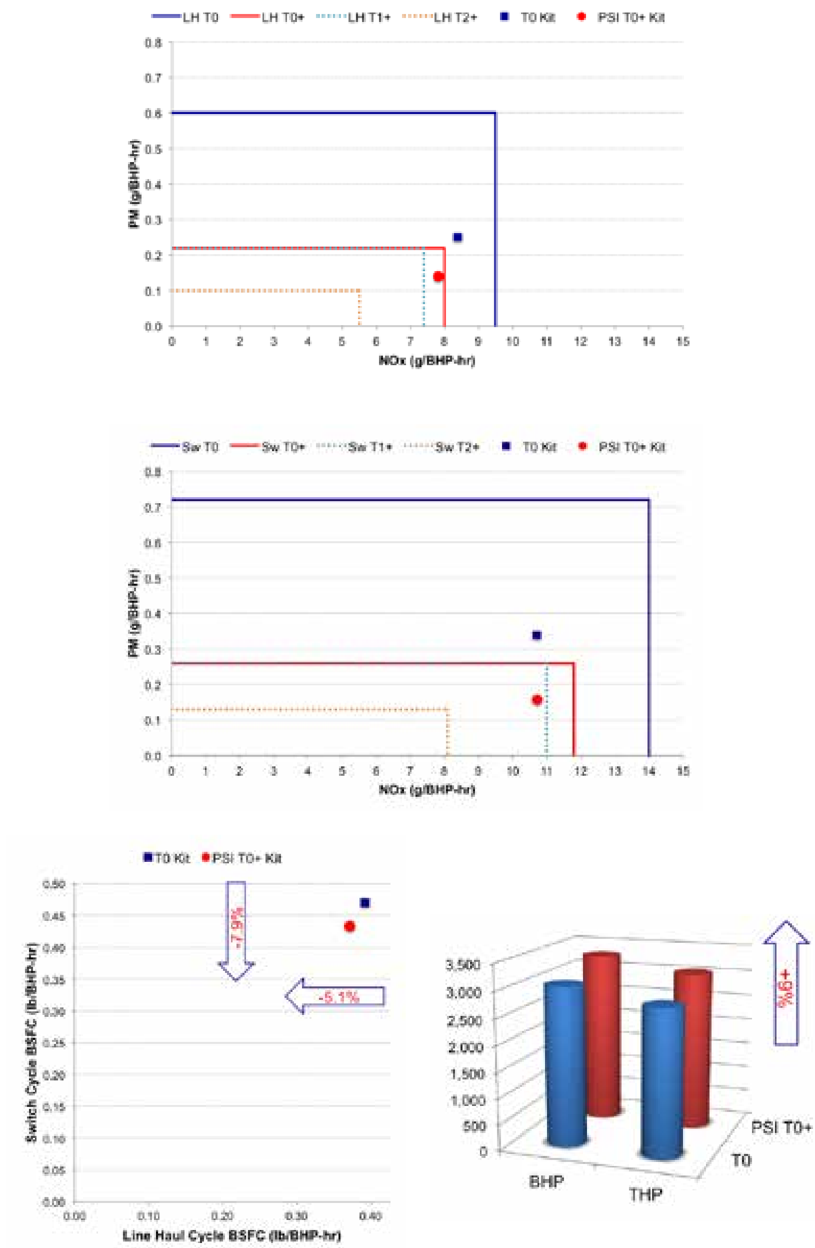

Figure 1 Benefits, Final Emission results
Fuel Consumption Testing

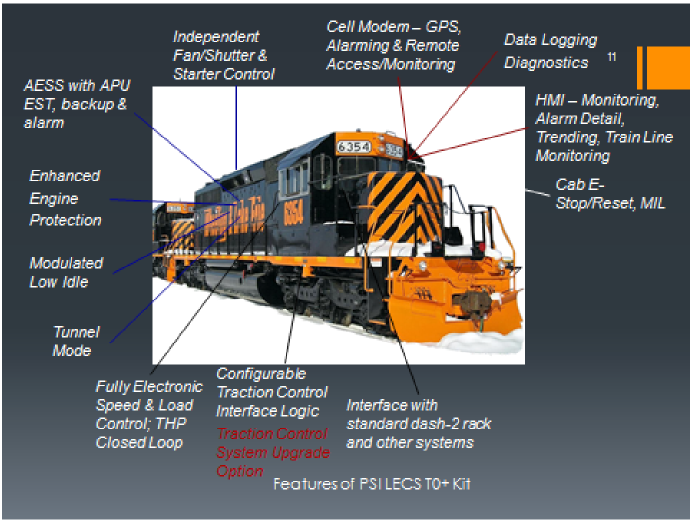

Figure 2

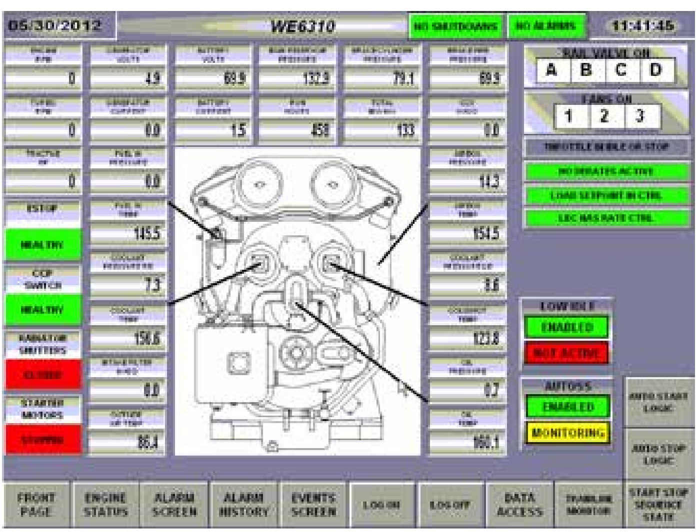

Figure 3 HMI screen shot

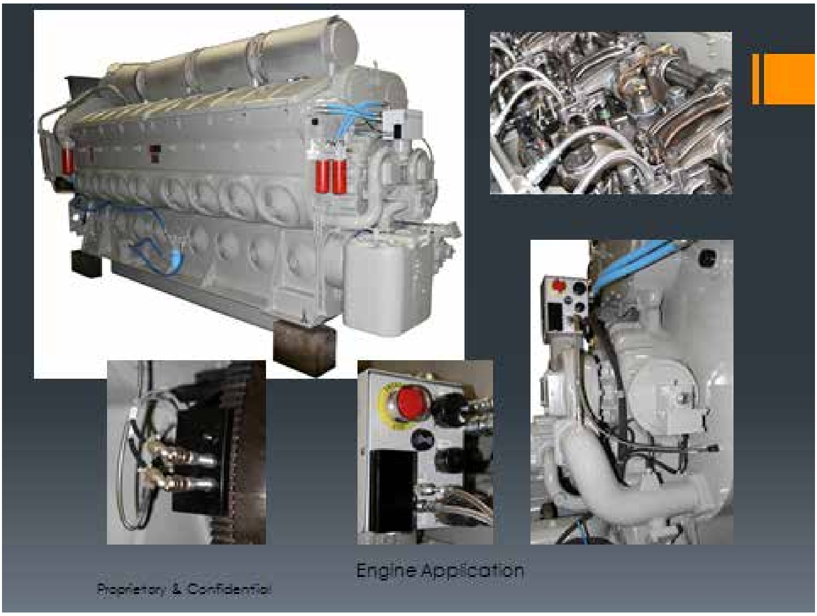

Figure 4 & 5 Engine Application Photos

Locomotive Repower with a High-Speed Engine and a Reduction Gearbox

Prepared by:
Bruce Wolff, MTU

Knoxville Locomotive Works (KLW) has placed into service an innovative repowered locomotive. Working together with diesel engine manufacturer MTU, this subsidiary of shortline family Gulf and Ohio Railways (G&O) started with a 1970s-built 2000-hp roadswitcher. As has been done in other examples, KLW repowered this locomotive with a new high-speed low-emission engine, in this case an MTU 12V4000R33 rated at 2250 brake horsepower at 1800 rpm. What is novel with this repower, though, is that KLW retained the locomotive's existing traction alternator, designed for a rotational speed of 900 rpm – half that of the MTU Series 4000 engine. To accommodate the different rotational speeds, KLW used a 2:1 reduction gearbox to match the new engine to the existing alternator.

Background – "Genset" Switcher Locomotives:

In recent years, there has been considerable activity in the switcher locomotive market. The multiple-engine "genset" switcher locomotive has promised significant reductions in emissions and in fuel consumption over the 1950s- to 1980s-vintage single-engine roadswitchers and demoted road locomotives typically used today as switchers. The "gensets" achieve these reductions through two principal means:

- The use of multiple engines allows the operation of only as many engines as are required to meet the locomotive's power requirement at any given moment. Especially when the locomotive is at idle, the fuel consumption and emissions from one small engine are expected to be far lower than the idle emissions from the single larger traditional locomotive engine in the older locomotive being replaced by the "genset".
- Each of the new, small engines uses advanced technology in air handling, fuel injection, and electronic controls to meet the current strict EPA emission regulations while also minimizing fuel consumption relative to the decades-old engine being replaced.

Sales of new "genset" locomotives have been enabled by government emission-reduction funding. In many areas of the United States with serious air-quality problems, government programs have covered most of the capital cost for the purchase of these locomotives. "Gensets" would otherwise have limited economic justification due to their high initial cost relative to older locomotives still capable of performing the work. Although "gensets" do provide operators with fuel savings relative to the older locomotives they replace, the inherently low fuel consumption in switching applications leads to very long investment return periods for railroads that would fund their own "genset" purchases.

Aside from capital cost, "gensets" have other characteristics that are less than ideal for switcher locomotives:

- They can exhibit slow throttle response due to the wait while additional engines are started
- They incorporate equipment that is new to the rugged operating environment of a locomotive, thereby giving the potential to negatively affect reliability
- They can pose a maintenance challenge to railroad crews unfamiliar with much of their on-board equipment

An Alternative Approach:

KLW envisioned a switcher / roadswitcher locomotive that would incorporate the advantages provided by modern diesel engine technology, while retaining as much as possible of the locomotive's original equipment. This would:

- Reduce the capital cost of the repower, reducing the reliance on government funding
- Provide the quick throttle response time characteristic of a single-engine locomotive
- Enhance maintainability
- Enhance reliability by reducing the number of components not proven in a rugged operating environment

KLW approached MTU to supply the prime mover, the Series 4000, which has been installed in over two thousand locomotives worldwide since its introduction in the late 1990s. Unlike similar repowers which couple a new high-speed alternator to a new high-speed engine, KLW chose to retain the locomotive's original traction alternator, which is both proven reliable and easily serviced by railroad maintenance shops across North America. A reduction gearbox would be used to adapt the 1800 rpm output of the MTU engine to the traction alternator's 900 rpm input. Even with the purchase of the gearbox, the overall repower is cost-competitive relative to a repower using a new high-speed traction alternator, and is expected to provide high reliability.

Drivetrain:

MTU's experience in rugged Coast Guard and commercial marine applications led to the selection of much of the drive train. This drivetrain includes:

- The aforementioned MTU 12V4000R33 diesel engine
- A ZF 7600 marine transmission, with a bell housing flanged directly to the engine's flywheel housing (This transmission serves as the 2:1 reduction gearbox between the engine and the traction alternator.)
- Resilient mounts from Rubber Design to support the engine and transmission (These mounts isolate

the locomotive frame from engine-generated vibration; isolate the engine block, bearings and crankshaft from stresses due to locomotive frame bending and twisting (over rough track); and support the engine and transmission against projected shock loadings.)

- A Geislinger steel-spring, oil-damped torsionally resilient coupling connecting the engine's flywheel with the transmission input (The specific Geislinger coupling was selected through the MTU torsional vibration calculation, and is tuned to reduce stresses in the rotating components to below allowable limits.)
- A Geislinger Gesilco "Butterfly" carbon-fiber misalignment coupling to connect the output of the transmission with the input of the traction alternator (This coupling allows for axial, radial and angular motion of the resiliently-mounted engine and transmission relative to the rigidly-mounted traction alternator. The "Butterfly" coupling is torsionally rigid, transmitting the full torque output of the transmission to the alternator.)
- A KLW-designed and manufactured bearing adapter (This converts the formerly single-bearing traction alternator into a two-bearing machine.)

MTU has considerable successful experience with the combination of Series 4000 engine, Geislinger steel-spring coupling and Rubber Design mounts in switcher, mainline freight and passenger locomotives. There is also considerable experience in marine applications of the above components combined with the ZF transmission and the Geislinger "Butterfly" coupling. These marine applications include Coast Guard and tugboat installations, where the entire drivetrain is subjected to shock loads in the vertical (heavy seas) and axial (hard impact of a tugboat and its barges) directions. These shock loads can be at least as severe as those encountered by switcher and road freight locomotives. In marine applications, the drivetrain components also withstand torsional shock loads which are absent in locomotives, such as sudden propeller reversals for collision avoidance, or the impact of a propeller blade with floating debris.

Auxiliary Components:

KLW selected a TECU locomotive control system from TMV Control Systems to integrate the MTU and ZF electronic controls with the existing locomotive control functions. Through the use of axle generators, this system also accurately monitors and adjusts for wheel slip, providing significantly improved adhesion over the pre-repower locomotive without the cost and complication of chopper controls.

The auxiliary generator, traction alternator blower and traction motor blower were retained in their original location above the traction alternator. Because the MTU engine does not have a PTO (Power Take-Off) above the flywheel to drive these components, KLW chose for the prototype installation to use a hydraulic system. Hydrostatic pumps on two engine PTOs on the far end of the engine drive a hydraulic motor attached to the auxiliary generator mounting bracket. Once the components were properly aligned and all connections secured, this hydraulic system has operated reliably. However, as many railroads are reluctant to use hydraulic systems on locomotives, an all-electric system will be used for production units.

The radiator compartment was modified to provide a separate coolant circuit for the engine's charge air cooler. This allows greater cooling of the charge air before entering the cylinders, as a strategy to reduce emissions of nitrogen oxides (NOx) to below the applicable limits.

The locomotive's accessory rack was abolished. The oil cooler and oil filters are incorporated into the engine, while the coolant reservoir / expansion tank was relocated into the locomotive hood ahead of the radiators. This opens up space below the radiators to access the hydraulic reservoir and cooler, the transmission cooler, the air compressor and the fuel prefilter. Coolant level can be checked visually from the locomotive deck, or electronically from the cab. Coolant filling can be performed either from the roof-top fill cap, or from a pressure fill connection accessible at deck height.

Maintainability:

Maintainability was a key factor in the design of this repower. KLW's experience as the principal locomotive maintenance facility for the G&O shortlines contributed to this aspect of the design. Access is simple and direct to all components requiring routine maintenance during the locomotive's life.

All maintenance of the MTU Series 4000 engine short of a complete overhaul can be accomplished with the engine in the locomotive. Pistons, connecting rods, cylinder liners and cylinder heads can all be replaced with the engine in place. MTU has a network of distributors across North America with Series 4000 parts and trained technicians. MTU aftersales services range from training of railroad shop personnel to allow railroads to perform their own maintenance, to comprehensive maintenance contracts.

During the life of the engine, the ZF transmission requires only routine oil changes. The Geislinger couplings are essentially maintenance-free. No components require servicing (beyond fluid level checks) outside 92-day service intervals; 184 day service intervals can be attained with minimal modifications.

Current Status:

The prototype locomotive is, as of this writing, demonstrating in daily service with a Class 1 railroad. It is performing reliably. The crews need little or no special training, as the control interfaces are unchanged. They have responded favorably to the throttle response time, noting that it is even faster than a standard non-repowered 2000-hp roadswitcher. One crew described it as being "like a Cadillac" due to the smooth and quiet operation allowed by the engine resilient mounts.

Next steps include adapting this repower package to the MTU's new 12V and 16V 4000 R84 engines. The goal is to allow locomotives in both the 2000 traction hp and 3000 traction hp ranges to meet not only the EPA Tier 3 limits, but also the California ARB ULEL limits, from a single engine with no aftertreatment.

Conclusion:

Working together, Gulf & Ohio Railways, Knoxville Locomotive Works and MTU have developed a competitive low-emission locomotive repower package designed to retain the performance, reliability and maintainability characteristic of traditional single-engine locomotives.

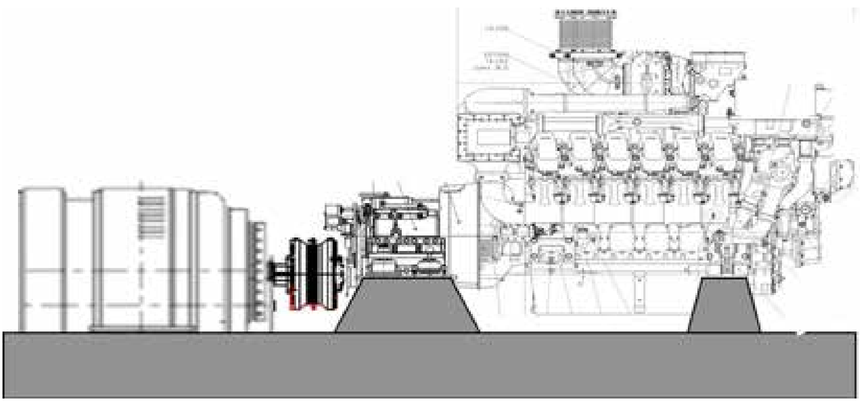

Figure 1 – Drive Train
Right to Left: MTU 12V4000 engine, ZF 7600 marine transmission, Geislinger "Butterfly" coupling, traction alternator

Figure 2 – Repowered Locomotive

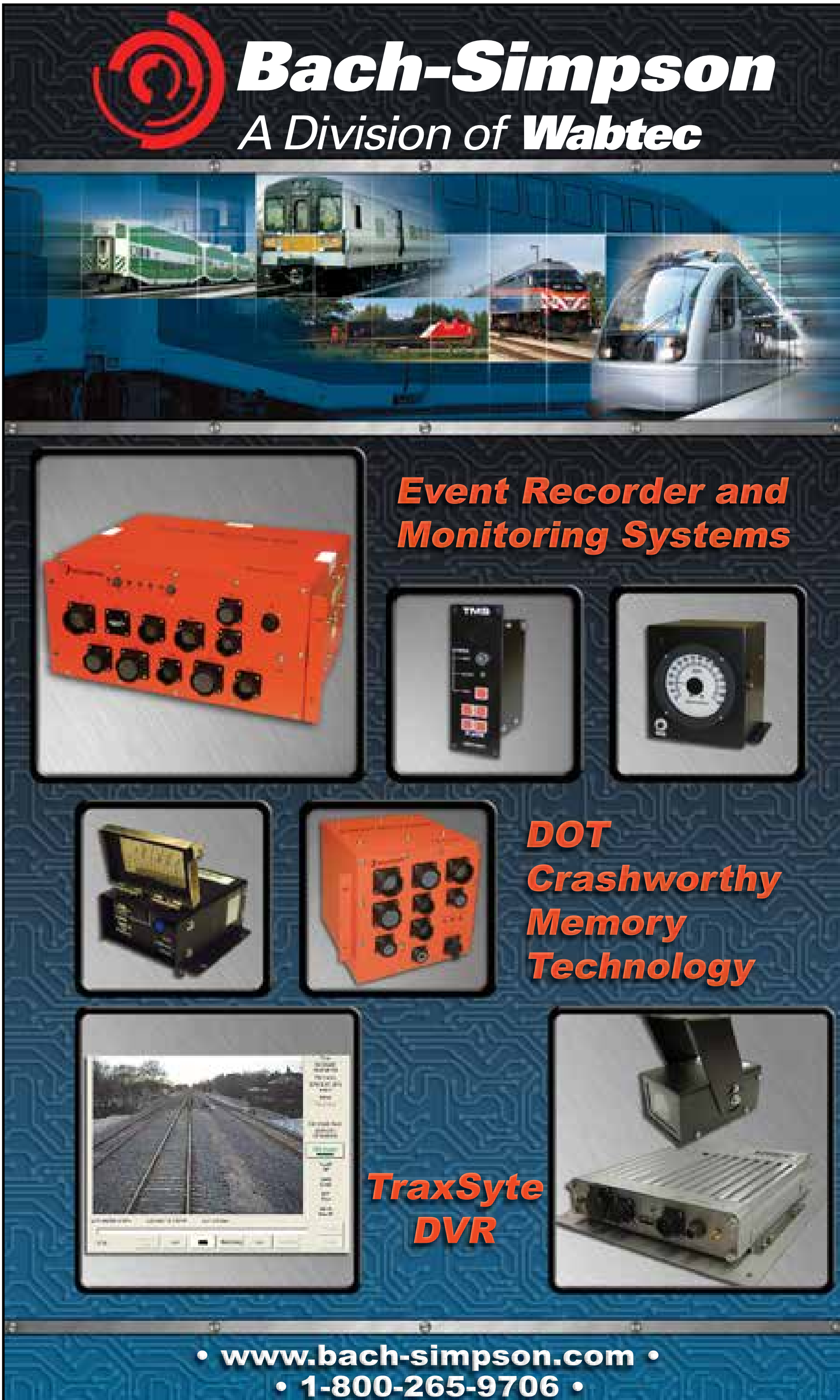
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Figure 3 – MTU 16V4000R84 engine (to meet Tier 3 / ULEL limits)

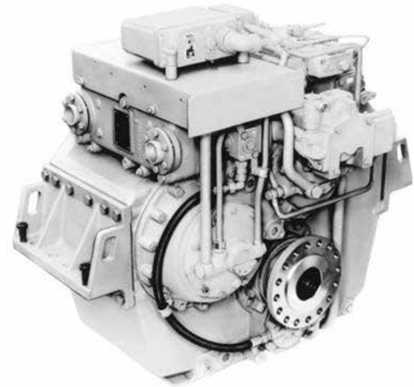


Figure 4 – ZF 7600 marine transmission

Figure 5 – Geislinger "Butterfly" coupling

Figure 6 – TMV TECU locomotive control system

The A3 Problem Solving Process in Action – a Case Study

Prepared by:
Tad Volkmann, Union Pacific Railroad

There are many variants of problem solving processes, of which there are varying numbers of steps. The process that will be described in the case study described by this technical paper is the A3 Problem Solving Process, which is an eight step process. The A3 process is used for complex problem solving by the major North American railroad in this case study.

Description of the Eight Step Problem Solving Process

The A3 Problem Solving Process steps are:

1.) Clarify the Problem – This is a detailed description of the problem and the expectation of what can be gained by solving the problem.

2.) Break Down the Problem – This is the most difficult part of the problem solving process. This step involves gathering and analysis of data, and allowing the data to determine the direction of the problem solving process. Manipulating the data to a preconceived notion will doom the problem solving process. The point of occurrence is identified by the end of this step.

3.) Set a Target – Once the problem is broken down, this step describes what improvement can be achieved from the information obtained while breaking down the problem. The root cause of the problem is identified and verified.

4.) Analyze the Root Cause - The root cause of the problem is identified and verified. The root cause of the problem is confirmed by a “why?” (reading down) and “therefore” (reading up) test. The test will be described in detail later in this paper.

5.) Develop Countermeasures – Once the point of occurrence and root cause of the problem are understood, both temporary and permanent countermeasures are developed in a value/difficulty matrix.

6.) See Countermeasures Through – The temporary and permanent countermeasures that were selected in the previous step are assigned to the person or persons who are responsible for implementation, with target dates for completion of each piece. The A3 owner monitors progress and follows through to completion of the deliverables.

7.) Evaluate Both Results and Processes – Improvement is measured compared to expectations set in step three. The process is monitored for improvement opportunities.
8.) Make the improved process standard.

Step One – Clarify the Problem

A major North American railroad has a fleet of newer locomotives manufactured by a major locomotive OEM. The unscheduled shopping (US) rate is higher than expected. Of the unscheduled shoppings, nearly one fifth of the unscheduled shoppings were due to problems that affected the operation and utility of the locomotives enough to incur a road failure. The desired outcome of this A3 exercise was to reduce road failure shoppings by 10%.

Step Two – Break Down the Problem

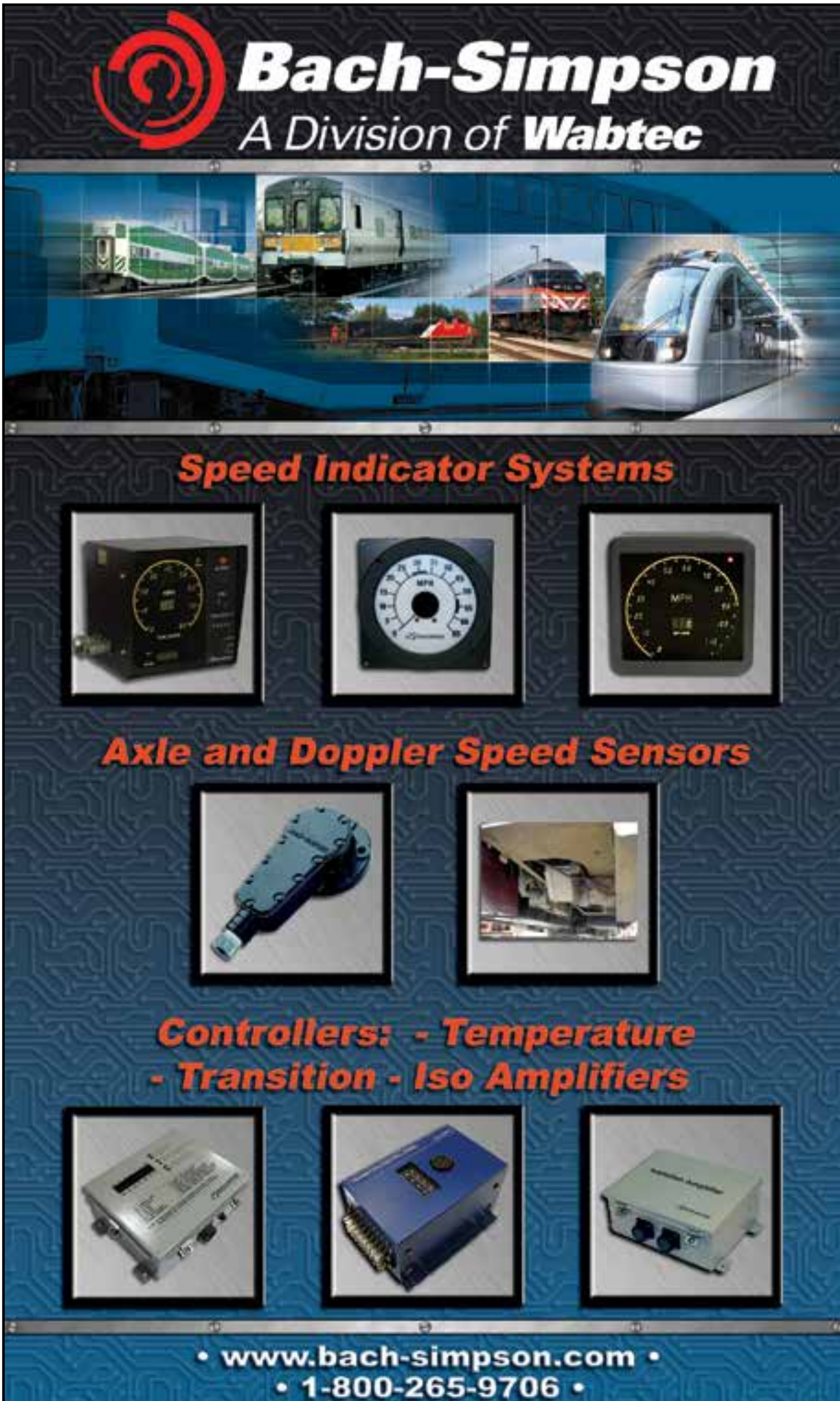
Breaking down the 1,848 road failure shoppings by locomotive system, it was determined that the largest failure driver was in the diesel engine system.

Breaking down the diesel engine system road failures, the largest driver emerged to be diesel engine sensor failures. At this point, the railroad got the OEM involved, shipping all diesel engine sensors removed due to road failure for analysis by the OEM. To the railroad's surprise, the OEM found that 85% of the returned diesel engine sensors were not defective. The railroad and the OEM traced back the diesel engine sensor signals that could cause an engine shutdown and noted that all engine sensor signals passed through an engine sensor wiring harness. As this analysis was progressing, the railroad started receiving reports from its locomotive repair shops that the engine sensor wiring harnesses were exhibiting degraded connectors and some harnesses had intermittent conductivity.

The railroad started sending all removed engine sensor wiring harnesses to the OEM for analysis. While the OEM found that the connectors were indeed degrading over time, the real cause of the intermittent conductivity problem was inconsistent and incomplete crimps in the wiring harness terminations. The OEM had already developed an improved wiring harness that had both crimped and soldered termination connections. The OEM issued a quality alert regarding this problem.

The railroad conducted a test to confirm the hypothesis that engine shutdown road failure events were driven primarily by engine sensor wiring harnesses with intermittent conductivity. The railroad arbitrarily replaced the engine sensor wiring harnesses on 20 bad actors for repeat diesel engine sensor faults. Fault counts for this group of locomotives dropped by 96% after the wiring harnesses were replaced.

Although the experiment did not prove that vast majority of road failures in which diesel engine sensors were replaced were actually caused by intermittent conductivity in the wiring harness, the connection was inferred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strongly enough that the railroad decided that it could avoid not only the engine sensor harness road failures, but also 85% of the diesel engine sensor road failures by upgrading the engine sensor wiring harness to a model with reliable and consistent conductivity. At the end of step two, it was known that the engine sensor wiring harness was the point of occurrence for this A3 problem solving exercise.

Step Three - Set the Target

Once the point of occurrence is known, it is possible to set a realistic target for improvement based upon what has been learned by breaking down the problem. In this case study, the potential for improvement has been identified as a reduction in 115 unscheduled shoppings, all of which had a serious enough operational impact to be classified as a road failure.

Step Four - Analyze the Root Cause

The root cause of the problem is confirmed by a "why?" (reading down) and "therefore" (reading up) test. The root cause in this case study is poor engineering and manufacturing of the engine sensor wiring harnesses.

Step Five - Develop Countermeasures

Possible countermeasures to reduce or eliminate the problem are evaluated in a matrix that compares reliability impact, ability to secure needed material, impact on locomotive repair shops, and speed of implementation. As an example, a crash program to replace all engine sensor wiring harnesses immediately would have the best reliability impact and speed of implementation, but would not be viable due to the OEM's inability to supply a large amount of material quickly, and such a program would be onerous to the railroad's locomotive repair shops.

After evaluation of the alternative countermeasures, select the temporary and permanent countermeasures with the highest value added and place into a flowchart.

Step Six - See Countermeasures Through

Specific activities to enact the countermeasures are then assigned to a person (or persons) for execution. Target dates with follow up help keep the activities moving toward completion.

Step Seven - Evaluate Both Results and Processes

Once the countermeasures are implemented, measures must be set up to determine the degree of success achieved as the countermeasures penetrate the fleet. The railroad compared the FLY (road failures per locomotive per year) rate and MMBF (mean miles between road failures) on locomotives that had been released from the reliability mod program, 90 days before entering the program compared to 90 days after release from the program.

The case study implementation measures indicate better than anticipated results are being achieved to date. The 0.5 FLY decrease in the post-mod fleet has the potential to save over 400 road failures per year and reduce overall fleet road failures by more than 20% when full penetration is achieved. Post-mod results to date have exceeded the A3 target by a factor of almost four.

Step Eight – Standardize the improved process. Start continuous improvement.

This step is currently starting in the instant case study. What is improved must be sustained by making the improvement standard throughout the organization. Then the A3 process starts over again by going back to the beginning and finding the next most significant driver to analyze and attack. There are a variety of problem solving processes to choose from. This particular railroad has found the A3 problem solving process to be effective.

Report on the Committee on Diesel Electrical Maintenance

Tuesday, September 25, 2012 at 9:15 P.M.

Chairman

Mike Drylie

Director-Electrical Systems
CSX Transportation
Jacksonville, FL

Vice Chairman

Tom Nudds

Quality Manager
ZTR Control Systems
London, Ontario

Commitee Members

C. Adams	Sales Rep	GNB Industrial Power	Aurora, IL
S. Alessandrini	Senior Rel Specialist	CN Rwy	Concord, Ontario
D. Becker	Design Engineer	Electro Motive Diesels, Inc	LaGrange, IL
B. Hathaway	Consultant		Port Orange, FL
M. Henry	Dir. Mech-Loco Engrg	Union Pacific RR	Omaha, NE
G. Lozowski	Tech Mgr-RR Prod.	Morgan AM&T/National	Greenville, SC
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K. Mellin	Sales Manager	Peaker Services, Inc.	Brighton, MI
S. Mueting	Field Service Engineer	Siemens	Aurora, CO
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Note: Jeremy Smith, BNSF, will be joining the committee, replacing Bud Wilds on this committee

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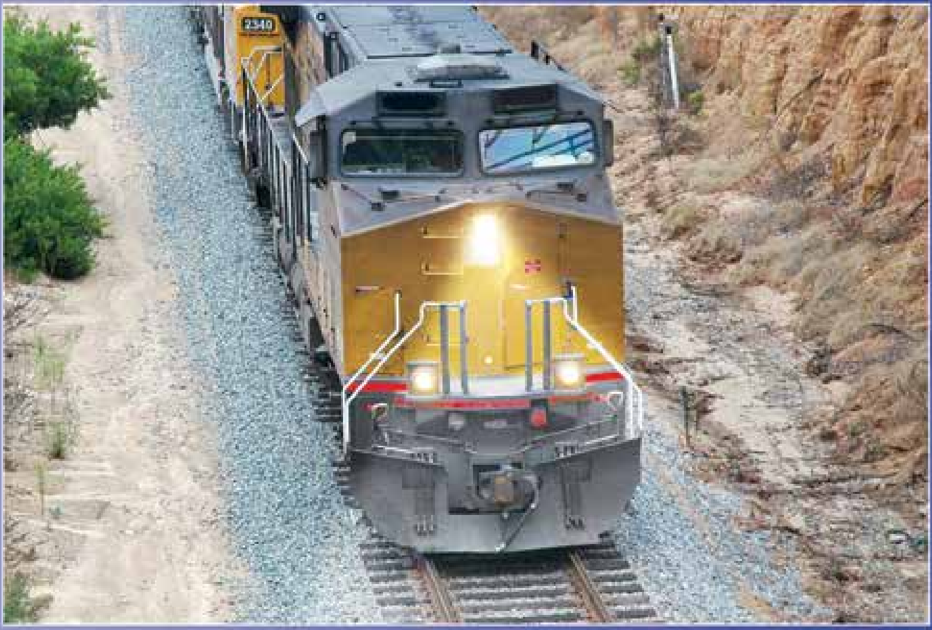


Amglo Kemlite Labs. Inc.
8787 Enterprise Blvd.
Largo, Fl 33773

www.amglo.com

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

PERSONAL HISTORY

Mike Drylie

Director-Electrical Systems
CSX Transportation

Mike Drylie was born in Ohio in 1956. He received an Associates of Arts Degree, General Studies from Kent State University in 1978, a Bachelors of Science, Electrical Engineering, from Ohio State University in 1983, and a Masters of Science Degree, Electrical Engineering from The Air Force Institute of Technology in 1986. Mike is a licensed Professional Engineer in the state of Florida.

Mike served in the US Air Force for many years as an aircraft electrical systems maintainer, radar systems design engineer, and guidance systems engineer on space launch vehicles.

Mike has been with CSX since January 1996. He has been on the mechanical departments engineering staff involved with improvements and modifications to locomotive systems. In recent years Mike has worked on the reduction of 92 day maintenance requirements and reducing locomotive Out of Service time through the use of development of reliable systems not requiring service and regular inspections or maintenance.

Mike is married to Debbie Anderson Drylie and they have 4 children, Tara, Michael Jr, Stephen and James. Mike and Debbie also have 5 grandchildren, Christian, Jacob, Edward, Sarah and James.

Mike's hobbies include going to the gym, visiting grandchildren, reading, various computer, number, and logic games.

The Diesel Electrical Maintenance Committee would like to thank the Union Pacific for hosting the committee's meeting on February 23, 2012 in Denver, Colorado at their Burnham Shop. Special thanks go to Mark Henry of the UP and Steve Mueting, Siemens Transportation for arranging all of the details.

The committee also wishes to express their sincere appreciation to the CSX for hosting the committee meeting on July 17, 2012 in Cleveland, OH. The committee had the opportunity to tour Interstate McBee on the afternoon of the 17th and to tour the facilities of Swiger Coil and Durox on July 18th. Special thanks to Bob Harvilla of Power Rail for hosting a dinner on July 17th.

We also wish to thank the BNSF and Brad Queen for hosting the joint technical committee meeting on May 7 and 8, 2012 in Overland Park, KS.

Extending Locomotive Maintenance to 184 day Intervals - Part II

Prepared by:
Mike Drylie, CSX Transportation

In 2008, the author presented a paper discussing a brief history of the Preventative Maintenance schedules and advocated for moving locomotive PMs from 92 day intervals to 184 day intervals. The rationale were that locomotives had become much more advanced since the last PM schedule change in 1980, the OEMs were establishing maintenance requirements at 184 days, and items requiring inspection/maintenance at 92 days had been eliminated or improved to no longer needing maintenance at 92 day intervals.

The FRA worked with the AAR and its member railroads to develop a new rule following a 2008 waiver request submitted by the BNSF Railroad and approved in 2009 as a test waiver. Since that time most Class I railroads have implemented 92 day inspections which covered the FRA requirements along with a 184 day inspection during a shopping.

Earlier this year, effective in June 2012 the FRA approved the extension of the PM to 184 days on locomotives equipped with diagnostic systems. At the time this paper was being written many of the details were still being worked out. The first locomotives placed under the 184 day rule were those that had a digital control system and an electronic air brake system. The steps being taken now revolve around specific classes of power and what is required for them to be used in a 184 day maintenance fleet.

This year we are looking at the new rule, its limitations/requirements, what it takes to get an entire fleet to 184 day maintenance intervals, the advantages of 184 day maintenance intervals, and what it takes to go beyond that. The FRA, instead of granting an extended waiver for various locomotive classes revised the periodic maintenance interval rule to be 184 days for microprocessor based locomotives with diagnostic capabilities.

As stated earlier, the first limitation revolved electronic air brakes. The first locomotives placed under the 184 day rule were those locomotives that have both Electronic Air Brakes and a microprocessor based control system.

The next limitation is there is an additional requirement that must be met for those locomotives under the extended periodic maintenance cycles. Whereas before all daily inspection could have been accomplished by locomotive crews, now at least once every 31 days a "qualified mechanical inspector" must perform this daily inspection. Documentation requirements of this inspection are still being worked out such as, does this inspection need to be listed in the cab, or can it be recorded in maintenance records that can be accessed if needed. If the 31 day inspection is not performed the locomotive reverts to a 92 day cycle until the next inspection.

There are some systems and components that remain on a 92 day interval. For now the air flow meter remains on a 92 day cycle. Automatic Train Control which was extended to 92 days via a test waiver remains under the 92 day rule, and event recorder testing requirements are an unknown at this time. The FRA requirements for event recorders is: If 90% or more pass tests during periodic testing than they can be tested during the periodic inspection and if more than 10% fail then the event recorder must be moved to a shorter duration. The railroads are asking suppliers of PTC and ATC to ensure that those systems meet 184 day maintenance requirements.

What does it take to build/rebuild/enhance a locomotive to meet a 184 day interval requirement? The first thing you need is a microprocessor based system. You need some type of electronic air brakes or possibly a digital device that monitors the brake system and provides fault data. Analog gauges appear to still require 92 day calibration if they are the main devices used by the crews to monitor brake function. A display or digital gauges have annual calibration requirements. Additionally, there are other systems that while not required for safety, impact whether a locomotive can be placed under 184 day maintenance. Traction Motor Lubrication, improved event recorders, fuel, oil and air filters with larger capacities, and either elimination of brushes or longer lasting brushes are necessary to allow a locomotive to extend beyond 92 days.

The Class I railroads have been rebuilding, and upgrading, locomotives with various control and braking systems for years. Pre Dash 2 and Dash 2 control systems have been getting replaced with microprocessor based systems since the 1990's. CSX has been installing Electronic Air Brakes in all their rebuilt locomotives. Whether this will be required for a locomotive to be under 184 maintenance intervals is still undetermined.

What are some of the advantages of having a fleet under a 184 day inspection interval as compared to a 92 day interval? While there may be others the primary ones are needing fewer locomotives in the fleet, having fewer locomotives in the shop, having more time to work on failed locomotives, a reduced opportunity for craftsmen to get injured, along with environmental advantages.

Assume your fleet contains just over 4000 locomotives. If all the locomotives are under 92 day maintenance requirements there would be 44 locomotives in the shop every day for inspection purposes. If they all could be moved to 184 day maintenance then only 22 locomotives would be in the shop every day for inspections. When fleet planning you need to plan for the extra 22 locomotives being in the shop, others coming to the shop, and yet others being returned to their service locations. The reduction of 22 inspections results in 22-30 (or more) fewer locomotives needed in the fleet. This would be a one time savings of 45-60 million dollars in locomotives not needing to be purchased in the year of change over.

With 1% of the locomotives in the shop on a 92 day interval and only 0.5% on a 184 day interval Out of Service time is reduced by 0.5%. If your railroads out of service rate was 6% it can now be 5.5%.

With fewer locomotives in the shop for inspections, there is more space and more time for management and craftsmen t concentrate on repairing the failed locomotives. This should lead to increased Quality on the repaired locomotives and this would result in further out of service reductions.

As stated earlier, injuries will go down as a result of 184 day maintenance. A person is less likely to be injured if they are not exposed to the hazard in the first place. This author is not prepared to make estimates on reduced safety indexes, but firmly believes safety will significantly improve quickly.

How will the 184 day interval affect the environment? With increased filter sizes there will be fewer filters thrown away. Often environmental costs are based upon the quantity of the filters, and other commodities, disposed of. This means throwing away 2 one pound filters costs more than 1 two pound filter. With fewer shoppings there are fewer load tests performed at the shops, yielding less emissions and fuel use. There are fewer washings at the wash rack resulting in less water that must be filtered and cleaned. The author is not knowledgeable enough to know all the different positive affects on the environment but is aiming at showing that there are positive impacts.

We have moved to 184 day maintenance intervals. Can we move beyond that and if so then by how much? Obviously, the railroads will/can not move without FRA approval. What would be required to get approval? Would the FRA be willing to allow the railroads to eliminate periodic inspections entirely? Probably not anytime soon. The OEMs have on-board diagnostic systems which predict failures and maintenance needs. If these systems were used to predict and prevent braking failures, train control or PTC failures, and were proven to work would that be rationale enough to move away from routine inspections? The author thinks it should be.

The future is bright for the railroad industry. The FRA, AAR and railroads worked together and with the locomotive builders to come to 184 day maintenance. It took 32 years. If the groups begin today they can develop a safer, faster, more cost effective railroad system in just a few years. The onboard diagnostic systems on board locomotives should be taken advantage of and expanded allowing railroads to move to the next step. The FRA's involvement should ensure safety is taken into account at every step.

All photos are of CSX locomotives and were taken either by the author or by other CSX employees.

Figure 1. A 184 day maintenance interval control system.

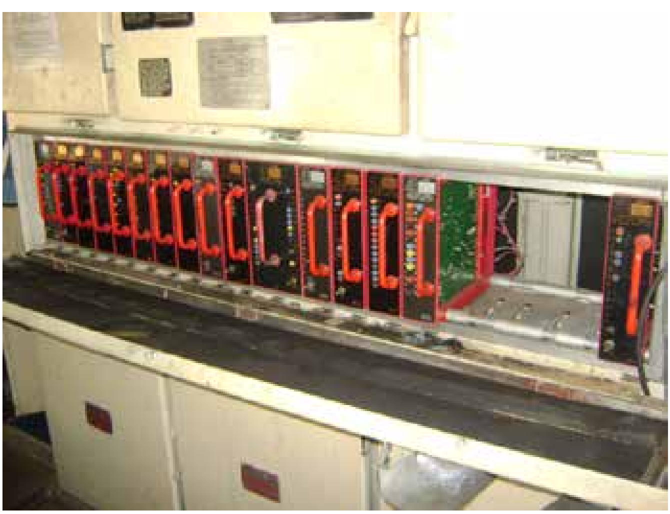


Figure 2. A 92 day maintenance interval control system.

Figure 3. A 184 day maintenance interval brake system.

Figure 4. A 92 day maintenance interval brake system.

Figure 5. A 184 day maintenance interval control stand.

Figure 6. A 92 day maintenance interval control stand.

Design for Reliability: Locomotive Lifecycle Approach

Prepared by:
Scott P. Werner, MotivePower

Introduction:

The locomotive life cycle represents an approach to locomotive reliability beginning at the conceptual design phase at the Original Equipment Manufacturer (OEM) and continuing through product obsolescence by the railroad. Reliability is an engineering science that aims at predicting, analyzing, preventing, and mitigating locomotive failures over time.

Reliability analysis must be an integral process throughout the locomotive life cycle. This paper reviews some benchmark concepts for implementing a reliability program, and elaborates on the primary mechanisms to achieve and maintain reliability goals throughout the locomotive lifecycle. Inherent reliability and reliability growth require a collaborative effort between the OEM and the railroad to achieve and ultimately exceed reliability goals.

Acronym List:

BOM: Bill of Materials
EMI: Electromagnetic Interference
FMECA: Failure Modes, Effects, and Criticality Analysis
FRACAS: Failure Reporting and Corrective Action System
MDBF: Mean Distance Between Failures
MTBF: Mean Time Between Failures
MTTR: Mean Time To Repair
OEM: Original Equipment Manufacturer
RAM: Reliability, Availability, and Maintainability
RBD: Reliability Block Diagram

OEM Benchmarks of Reliability Programs:

Benchmark reliability programs commence before the conceptual design phase. As a program initiates, customer performance and reliability expectations are well understood and prioritized. These expectations provide the basis for the program reliability goals. The reliability plan for the program establishes the reliability criteria and develops a roadmap to achieve performance goals.

Strong leadership prevails in addressing product reliability as part of the culture throughout the lifecycle. The development team employs system engineering and reliability engineering techniques. The corporate culture emphasizes that product decisions are based on data and lessons learned from previous projects. For example, the program team understands the locomotive operating environment and the consequences of failure. There is accountability at every level for the product safety, quality, and reliability throughout the OEM design and build process.

Upon arrival at the railroad, a failure reporting and corrective action system (FRACAS) is widely accepted throughout the OEM service and engineering organizations. Problem solving uses proper tools and techniques leading to quantifiable decision making. Failure analysis and data collection is routine, and results in appropriate reliability growth projects. The reliability growth process of trending and incorporating reliability improvements continues throughout the locomotive service life.

This paper will apply these benchmark concepts to the locomotive life cycle as a design for reliability process. The recommended reliability techniques will be defined for each phase with an emphasis on early reliability analysis.

Locomotive Lifecycle:

The overall locomotive lifecycle is provided in Figure 1. The nine phases are listed in terms of the specification development, engineering, production, test, in-service, and obsolescence phases. The cost associated with fixing reliability issues increases exponentially as the design progresses through the life cycle. Therefore, the predominant reliability activity should reside with the OEM conceptual and preliminary development phases to be most cost effective. The reliability stewardship is a collaborative effort that begins with the OEM development and is maintained and improved by the railroad or its corresponding maintenance provider. The effectiveness of the collaboration between the OEM and railroad will ultimately lead to the product reliability. When this relationship is healthy, a locomotive that exceeds reliability expectations is likely.

Figure 1 - Locomotive Life Cycle

Contract / Notice to Proceed:

The reliability program plan should be initiated within the contract review phase. This plan includes:

- Reliability Goals;
- Reliability Allocation;
- Lessons Learned;
- Reliability Prediction;
- Failure Modes, Effects, and Criticality Analysis (FMECA);
- Verification Testing;
- Locomotive performance support plan throughout locomotive life cycle.

Customer expectations are derived from the technical specification. The locomotive systems / subsystems are developed, and new technology requirements are defined as the OEM initiates the project.

The foundation of the reliability plan is the customer technical specification and the established reliability, availability, and maintainability (RAM) goals for the project. The main objective of the Reliability Plan is to provide a fleet of reliably operating locomotives with performance levels that will allow the railroad to meet its timetables for moving passengers or freight between stations within its operation system. The plan is developed in coordination with the railroad to ensure the system goals. The plan should comprise the support of the locomotive throughout the locomotive cycle. Typically, the OEM will develop a reliability plan for the development phases and extend through the warranty cycle. The OEM and railroad must concurrently develop the plan for the full service life and eventual obsolescence of the locomotive.

Reliability Goals:

Based on the customer requirements, a set of reliability, availability, and maintainability goals must be established. The classical definition of reliability is the probability of successful operation over a given period of time. Utilizing mathematical reliability distribution functions, this probability can be converted to a Mean Time Between Failure (MTBF). The primary in-service reliability performance metrics include MTBF and Mean Distance Between Failure (MDBF). Regardless of the reliability metric selected for the project, a clear definition of failure is required by the reliability plan. Normally, the failure definition is documented as part of the technical specification:

- Hardware failure that occurs during operation within the operational parameters;
- Degraded locomotive operation, including hardware and software, that requires corrective maintenance;
- Repeated loss of functionality of any portion of the locomotive;
- Improper maintenance of any portion of the locomotive;
- Consumable items requiring replacement before the scheduled maintenance interval.

Other reliability related goals include locomotive availability, which measures the amount of time the locomotive is available for operation versus the downtime. The downtime represents the amount of time the locomotive is shopped for preventive (92 Day) or corrective maintenance. Some railroads utilize On Time Performance (OTP) as a measure of reliability / availability. Maintainability is also a common metric that calculates the Mean Time to Repair (MTTR). The MTTR is defined as the average time to complete a repair and return the locomotive to service following a failure event.

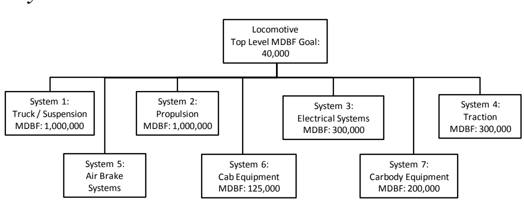
Reliability Allocation:

Based on the reliability goals, a reliability allocation model is established. This model is essentially the reliability budget for the locomotive. The model takes a Top-Down approach, meaning that the allocation is based off the reliability goal and the systems are assigned a reliability value that together will meet this goal. Figure 2 demonstrates this concept. Each system that comprises the locomotive receives a portion of the reliability budget in terms of a MDBF value. The inverse of MDBF is defined as a failure rate, which is the number of failures over a given time period or distance.

$$Failure\ Rate = \frac{1}{MDBF} = \frac{Number\ of\ Failures}{Total\ Time\ or\ Distance\ Traveled}$$

This value is an approximation that is based upon the system service history or based on overall reliability risk. The failure rate of the overall locomotive equates to the sum of the system failure rates. In order to meet the top level locomotive reliability, the subsystems are assigned a significantly higher MDBF.

Figure 2 Reliability Allocation Model



Top Level MDBF	40000	
System:	MDBF	Failure Rate
Truck	1000000	1.00E-06
Propulsion	1000000	1.00E-06
Electrical	300000	3.33E-06
Traction	300000	3.33E-06
Air Brake	300000	3.33E-06
Cab Equip	125000	8.00E-06
Carbody	200000	5.00E-06

Lessons Learned:

A critical aspect of the new product development is lessons learned from previous generation designs. Lessons learned are issues identified during service that provide engineering with input to environmental conditions or design methods that must be considered for the locomotive design to succeed within locomotive operating conditions. The OEM may utilize technical specifications and FRACAS databases to record these lessons learned. It is strongly suggested that the lessons learned be considered in the design review process.

Reliability Prediction:

As the system design matures, it is possible to develop a reliability prediction model for the locomotive design. MIL-STD-338 identifies an approach to reliability modeling. The reliability prediction model estimates how well the locomotive will perform in terms of MTBF or MDBF by evaluating systems and components in a Bottom-Up approach. The results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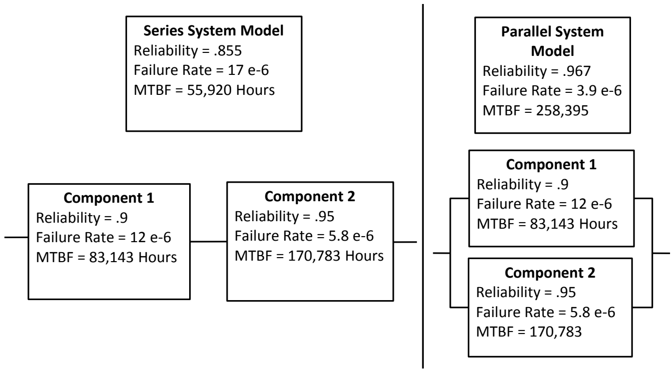


Figure 3 - Series and Parallel Reliability Model

of the reliability prediction model are then compared to the initial reliability allocation model to determine if there are any reliability deficiencies in the design. Performance gaps should be addressed by design change or preventive maintenance.

The locomotive reliability prediction model is based on the design Bill of Materials (BOM) for each system within the engineering block diagrams. This means that the system reliability values are estimated from a compilation of their respective component reliability values. The locomotive and system level performance is calculated within the Reliability Block Diagram (RBD) of the system. A starting point for the RBD is the reliability allocation model as exemplified in Figure 2. The purpose of the RBD is to provide a functional representation of a system design in terms of how the subassemblies and components interact from a reliability perspective. The reliability model evaluates the system performance in terms of system reliability, maintainability, and availability using the RBD as the foundation.

In looking at the locomotive system and subsystem design, the system complexity can be staggering and pose significant challenge for a reliability model. The RBD model must be reduced to the critical subassembly and component diagrams for the modeling purposes. The RBD is generally reduced into series and parallel design elements as demonstrated in Figure 3. For a series connection within the RBD, the system reliability can be calculated by the product of all component or subsystem reliabilities. The parallel connection denotes component or system redundancy and reflects a higher MTBF than a series reliability model.

The overall system reliability can be calculated by the MTBF (or MDBF) using units applicable to the system design. For the rail transportation industry, it is generally accepted that the complete system reliability complies with an exponential failure distribution, which allows use of these equations and provides an underlying assumption for the reliability prediction model.

System Maintainability and Availability Analysis:

The preventive maintenance activities are those that occur at predefined intervals such as inspection, service, and overhaul activities. These activities are established by the design team to create a balance between maintenance costs and unexpected failure warranty costs and are considered as scheduled maintenance activities and consequently lower system availability. The preventive maintenance activities can be simulated by an expected time to perform the preventive maintenance activities including maintenance tasks and validation of performance after completing the work.

Conversely, upon failure, the system shall undergo a necessary shopping or corrective maintenance procedure. The Mean Time To Repair (MTTR) of a given subassembly or component shall be used as the unscheduled downtime impact in the availability calculation. The MTTR consists of time to troubleshoot the failure, obtain a spare part, install the part, and validate system performance after repair. Similar to the system failure rate, the system maintainability has an expected time distribution. An assumption for this approach is the MTTR also follows an exponential distribution function, meaning the repair time is constant. The system repair time equates to the percentage of the overall failure rate times the expected time to repair for the subassembly.

The system availability accounts for both the system corrective maintenance activities and the system preventive maintenance activities, which comprise system downtime. The remaining time shall be considered productive time. The ratio of the productive time to the total system time is considered the equipment availability.

$$Productive\ Time = Total\ Time - Down\ Time$$

$$Availability = Productive\ Time \,/\, Total\ Time$$

The system availability can also be calculated by splitting the maintenance into the corrective and preventive activities. The system availability due to corrective maintenance activities (Availabilityum) can be calculated from the system MTBF and MTTR.

$$Availability_{um} = MTBF \,/\, (MTBF + MTTR)$$

The denominator in the MTBF and MTTR figures is the number of failures in the system, leaving the equation with the system productive time from MTBF and unscheduled downtime from the MTTR. This equation, however, does not account for the downtime due to the preventative maintenance activities. These equations can be used by the OEM to validate the maintainability and availability of the proposed system design to ensure the locomotive will meet the design targets. Processes and systems can be simulated using this approach to determine the key factors in the availability and maintainability calculations to drive product improvements. Software packages are available for the RAM modeling process.

Failure Modes, Effects, and Criticality Analysis

The reliability plan indicates which reliability analysis tools and techniques will be employed to analyze the design. Among the most common and beneficial techniques is the FMECA. The FMECA is a process used to evaluate all failure modes of the locomotive.

- Define the locomotive systems;
- List all failure modes of the locomotive (Failure Modes);
- Evaluate the system response to the failure (Effects);
- Rank the failures based on the risk (Criticality);
- Identify further actions necessary to mitigate the risk (Analysis).

Ideally, the FMECA is applied early in the design phase and iterated throughout the design process. As the system matures, additional details concerning the system interfaces and software detection of faults are incorporated into the analysis. The FMECA has two general approaches to the analysis:

- Hardware Approach: The hardware approach utilizes a Bill of Materials or hardware list and investigates failure modes on an individual basis;
- Functional Approach: The functional approach utilizes the system requirements or technical specification to determine failure modes.

A preliminary FMECA might consider the functional aspects of the system design while the software matures. The software design specification evaluates the FMECA for input on hardware failure detection and reporting by the software. The software might also consider adding a level of fault reporting, which is a system alarm intended to notify the operator of a potential problem with the system.

Testing:

The reliability plan includes the testing strategy for the locomotive. The tests are categorized as either Type Tests or In Process Tests. The reliability validation test is the primary

- Type Test: A qualification test of a locomotive function or system. This is normally conducted on the initial pilot locomotives;
- In Process Test: A production test performed on every locomotive to ensure the manufacturing quality and verify the installation.
- The reliability test plan identifies the strategy to validate the reliability performance of the locomotive.

Locomotive Support Plan:

The OEM should develop a Failure Reporting and Corrective Action System (FRACAS) program to monitor and manage reliability through field service reports at the operational level during the warranty support period. The FRACAS program should be capable of supplying specific reliability reports, such as categorizing failures as relevant and non-relevant as mutually agreed upon with the railroad, identifying MDBF at system, subsystem or component level, and categorizing to allow Pareto analysis of repeat failures. The program shall also track corrective action status through complete implementation and closure of the reliability growth project.

The plan should also recommend a review board forum to discuss reliability with the customer. This board should include maintenance officers, OEM field service representatives, and OEM reliability engineering. The Reliability Engineering Group responsible to support the necessary failure analysis, perform the required investigations to determine root cause of failures, and coordinate the implementation of corrective actions in order to achieve the specified reliability requirements.

Summary of Notice to Proceed:

The initial phase of the reliability program provides the foundation by developing the entire reliability program plan. The specific tools necessary to implement a successful reliability program have been provided above. Each step in the locomotive life cycle adds detail and refinement to the reliability analysis.

Design Phase – System Definition:

The system design phase from a reliability perspective applies the tools defined in the reliability plan to ensure the locomotive is suitable for the technical specification performance requirements. The engineering specification and design must consider the worst case operating environment as one of the critical aspects of reliability performance. For example, electrical system reliability must consider voltage, power quality, vibration, and temperature for the expected mounting location. While the product may be robust with service proven history, the environment can adversely affect component reliability performance. Device reliability tends to decrease exponentially when the operating environment exceeds the maximum rating of the device.

Effort must be taken to characterize and test the component in a similar environment to the locomotive. Development of the test plans should also begin at this phase and must consider testing at the worst case design boundaries.

The design activity should be performed in parallel with the reliability analysis. Initially, a system functional description is created to capture the design details including the reliability analysis. The specification should also consider lessons learned and service history as part of the design documentation. Components and system designs should employ appropriate safety of margin in the design.

Iteration of the design based on the lessons learned, reliability prediction modeling, and FMECA are sometimes necessary. Several reliability design reviews are conducted to ensure the required reliability considerations and failure mode mitigations are designed into the product from the beginning.

- Conceptual Design Review: Reliability allocation model, and lessons learned;
- Preliminary Design Review: Reliability prediction model compared to allocation model, lessons learned, initial FMECA, and initial test plan;

- Final Design Review: Finalized reliability prediction model, lessons learned, FMECA, and test plan.

Design Phase – Electrical System Development

MIL-STD-338 provides overall system reliability processes for electrical / electronic systems. The component reliability should be based on service history and is also supplemented by component reliability values as defined by resources such as MIL-STD-217.

Electrical designs should consider the following reliability design factors:

- It is common to "derate" a component in terms of maximum rated voltage or temperature;

  Component selection is vital to the electronic system reliability. Electrical components should be selected with a factor of safety on critical performance parameters, such as temperature. This safety margin effectively derates the component.

- Protection from voltage transients caused by switching loads;

  Electronic designs are vulnerable to short duration transients generally caused by switching loads. Diode suppression is one common transient protection method. Ideally, components selected for the application have integrated suppression circuits.

- Boundary condition analysis

  Electronic device parameters should be designed to operate within the device tolerance limits. Incorporating a safety margin in the parameters will lead to a more robust end product. Boundary conditions should be incorporated into test plans where appropriate and can also be used to implement a highly accelerated life test.

- Electromagnetic Interference

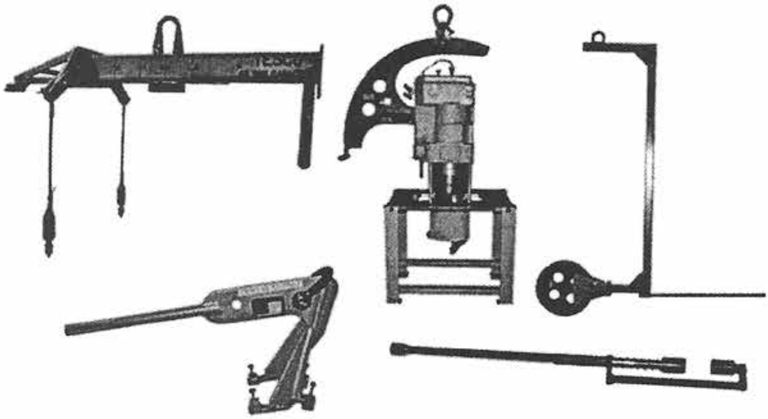
  Shielded housings and cables divert potential EMI sources to an alternative circuit path. Proper signal line shielding with conductive wires surrounded by an outer conductive sheath is a necessity.

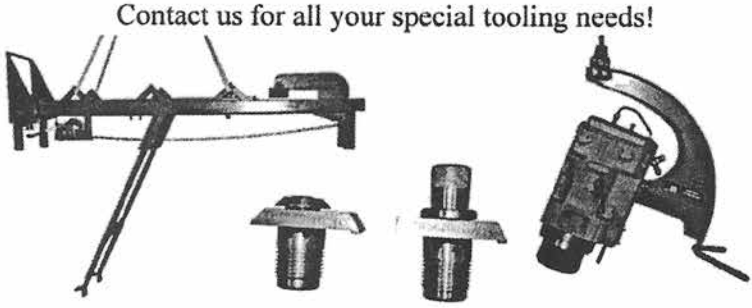
- System redundancy

  In the case where a single point of failure is deemed unacceptable, device redundancy can be an effective design tool. Redundancy signifies that if a component within a system fails, there is an alternative path or system available. From the reliability model perspective, this is a parallel system.

Locomotive Verification and Validation:

The design and reliability teams together create a verification and validation plan. The System V model (Kennedy, 2011) provides a visual process for implementing the verification and validation for a new locomotive design as shown in Figure 4. Verification is the process of evaluating a locomotive design to ensure it complies with the technical design specifications, FMECA, or other design criteria during the initial development





phases. The validation is the process of evaluating a system or component, and generally occurs at the end development phases.

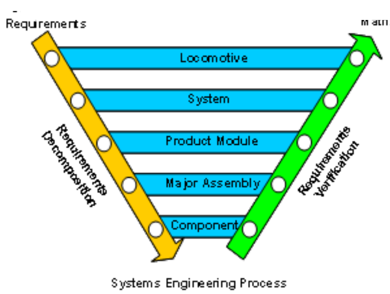


Figure 4 - System V Diagram (Kennedy, 2011)

Manufacturing / In-Process Tests / Functional Tests:

The manufacturing life cycle phase identifies issues such as tolerance and system interaction that are difficult to ascertain during the engineering development phase. Therefore, a direct engineering interface with manufacturing in the form of a liaison engineer is necessary to ensure the design intent. The Liaison Engineer monitors locomotive production failures as an early indicator of potential failures once the locomotive is placed in service. The reliability and quality teams are also involved at this phase in terms of Non-Conformance (NC) issues with the build and test process. The Pareto analysis of these items can further identify failure modes that should be addressed by engineering change before the locomotive leaves the OEM facility. Supplier Quality Engineering provides critical support during this phase in terms of performing failure analysis at the supplier site and ensuring adequate corrective actions are implemented as a result of the failure.

Similar to the manufacturing phase, the In-Process test phase provides valuable data in terms of component / system failure. Similar support activities are conducted to address component failure at this time.

Customer Validation:

The arrival of the locomotive at the railroad initiates the FRACAS program. The reliability engineering focus shifts to a reliability demonstration and growth methodology. The overall process of FRACAS and its primary objective of reliability growth are implemented by a collaborative effort between the railroad and the OEM supplier.

Initially, certain type tests, such as the overall reliability demonstration test or Reliability Growth Test (RGT) are better suited to be conducted at the railroad upon delivery of the initial locomotive. The reliability demonstration test will utilize in service performance and failures to validate the locomotive reliability to the customer's satisfaction. Failures that occur during the test are subjected to a root cause analysis process.

Root Cause Analysis / Problem Solving Process:

The initial task of the root cause analysis process is to define the problem / failure in quantitative terms. This definition includes the frequency of occurrence, the conditions surrounding the failure mode, and severity or consequence of the failure. Essentially, the definition needs to document the who, what, when and where facts surrounding the failure. The information provided within the failure definition must be fact based. A concrete problem statement is created based on this information.

The root cause analysis of the problem begins with the identification of potential causes. The specific root causes of the problem are those that, when addressed or removed, result in permanent elimination of the problem. There are multiple techniques that can be employed to identify potential root causes:

- 5 Why's: Ask the why question five times with respect to the problem statement. This is best done in a group setting.
- Fishbone / Ishikawa Diagram: A systematic method of analyzing cause-and-effect relationships to identify the root cause.
- Is / Is Not Analysis: A subsequent analysis that uses a process of elimination to determine where the root cause investigation should focus.

There are many other problem solving techniques available. This paper will focus on the Ishikawa diagram, as introduced by Kaoru Ishikawa in 1982 as provided in Figure 5. The methodology starts with the problem statement and identifies major cause categories that could contribute to the failure, such as machine / equipment, environment, man power, management, materials, and methods/procedures. Figure 6 demonstrates some possible secondary causes of each major cause category.

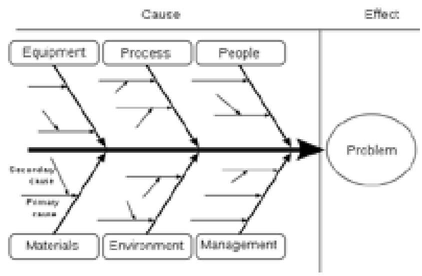


Figure 5 - Ishikawa Diagram

When finished with the potential cause categories, data is used to identify root cause. Usually, this process requires additional testing or information to validate the true contributors to root cause.

The corrective action process is initiated once the root cause contributors are confirmed. Potential solutions can take the form of design change, process change, or training. Tools such as an engineering design decision matrix can lead to the appropriate solution for the problem. The solution should be agreed with the customer and engineer and must consider the cost, timeliness, effectiveness, and downtime that will be incurred during implementation.

Revenue Service / Warranty:

Revenue service operation must employ reliability tracking databases at both the railroad control facility and by the OEM supplier. It is vital that the railroad and OEM work together to quantify the performance metrics for

Figure 6 - Major Root Cause Categories

the locomotives to ensure satisfactory reliability performance. The metrics also serve as validation of the reliability plan for the OEM supplier. The Pareto Analysis of the fleet performance separates the critical few reliability growth opportunities from the secondary problems. The revenue service operation utilizes the same techniques identified during initial locomotive delivery to analyze problems. The joint review board continues throughout the warranty phase. New lessons learned are documented as a result of the joint review board and placed in a database for future development projects.

Service Life through Obsolescence

Where appropriate, the railroad and OEM continue the performance review board partnership beyond the warranty period. Performance trending by the railroad continues and can be used as justification for purchasing the next generation locomotive.

Conclusion:

Design for Reliability is a critical aspect of each step in the locomotive life cycle that requires collaboration between the OEM supplier and the railroad as the customer. The initial reliability program planning phase establishes the foundation for a locomotive to meet or exceed the customer's performance goals. Reliability analysis and lessons learned programs during the design phase program lead to a robust end product. As the locomotive enters service life, the partnership between the OEM and railroad results in a data driven reliability growth program. Improvement programs utilize root cause analysis techniques. The end result is a locomotive that achieves the railroad's reliability, availability, and maintainability goals.

Report on the Committee on Shop Safety, Processes and Equipment

Tuesday, September 25, 2012 at 10:45 A.M.

Chairman

Bill Peterman
President
Peterman Railway Technologies, Inc.
Baie D'Urfe, Quebec

Vice Chairman

Tom Stefanski
President
Tom's Locomotive and Cars
Plainfield, IL

Commitee Members

R. Begier	Consultant		Broomfield, CO
D. Bossolono	Shop Supt.	BNSF Rwy	Kansas City, KS
R. Collen	Project Mgr.	Simmons Mach. Tool Corp.	Albany, NY
R. Covert	Product Manager Frt. Rail	Macton Corp.	Oxford, CT
C. Fette	President	TESCO	Erie, PA
J. Morin	Director-Sales	Socofer	Tours Codex, France
M. Scaringe	Dir. Locomotives	Amtrak	Beech Grove, IN (Past President)
S.G. Smith	Engr. Lean Prod. Systems	Norfolk Southern	Chattanooga, TN

PERSONAL HISTORY

Bill Peterman

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

Currently Bill is President of Peterman Railway Technologies a company specializing in assisting with Rail Maintenance designs, equipment and processes, providing specialized rail maintenance serves and acting as a liaison between railway and non railway entities.

He has been Chairman of the Shop Equipment & Process Committee for several years. Bill lives in Montreal and is married with 5 children and finally has 2 grandchildren.

The Shop Safety, Processes and Equipment Commitiee would like to thank the Norfolk Southern for supporting the commitiee meetings in November 2011 in Atlanta, Georgia and for shop tours in both Atlanta and Chattanooga,Tennessee diesel shop. Special thanks for Stephen G. Smith for arranging all of the details at this meeting.

We would also like to express our sincere gratitude to the BNSF and LMOA 1st VP Brad Queen for hosting the LMOA joint technical commitiee meetings in Overland Park, Kansas on May 8 and 9, 2012.

Application of Machine Vision Technology in Train Inspection

Prepared by:
Kambiz Nayebi and Sam Williams of Beena Vision Systems, Inc. USA

1. Abstract

In this paper, we present automated machine vision based systems that are designed to inspect train and rolling stock components in an effort to detect defective components, improve maintenance procedures and prevent derailments caused by such defective components. Application of machine vision technology in the rolling stock inspection has been on the rise in recent years. Inspection of wheels, brake shoes, friction wedge and springs, safety appliances, coupler securements and other train components have proven quite successful. [1], [2], [3]

We present a summary of what is currently available and what is being worked on to be deployed in the near future.

2. Introduction

Significant increase in deployment of automated machine vision based inspection systems for freight cars and locomotives using machine vision systems is a clear indication of their enormous potential. Using cameras to inspect train components may have been limited to (OCR) reading of car numbers and similar applications, but later cameras were successfully used in systems like rail profile measurement systems and human based visual inspection systems.

Systems that nowadays are increasingly being utilized are more of the automated systems where the inspection system can automatically measure or inspect relevant components. With such systems, a complete report is generated for each train and immediate alarms are sent to the customer to take necessary actions. Some alarms must be acted upon immediately to prevent derailments or follow FRA/AAR rules, and others may be used for improved maintenance purposes.

For example, if the coupler securement fails during train operation, then the coupler will "pull out" of the car in a draft situation, and in all probability this will result in the coupler falling between the cars and into the gage of the track. In almost all cases, if the train is operating at track speed, this will result in a derailment. In the best case scenario, it will at least result in a separation that will cause a significant delay to train operations.

Another example of a catastrophic failure is when a wheel on a train is broken. Detecting such wheels before a related derailment can be a huge saving for any railroad operator. Current state

of the art systems are capable of detecting and reporting such defects given sufficient number of these systems are deployed in the railway network.

Other systems such as wheel profile measurement systems, brake inspection systems are more of condition monitoring type systems where the condition of components can be monitored and possibly trended for timely maintenance.

In the remaining part of this paper, several systems with their corresponding capabilities are presented. Also, the current condition of machine technology in the railroad industry is explained and a prediction of the potential future deployment of these systems is given. Because of the space limitations of this paper, details will be presented at the meeting.

3. Wayside Detectors

In the context of machine vision systems, wayside detectors may be divided into three different groups of systems:

- **Measurement systems** such as wheel profile or brake shoe measurement systems. These systems are used to measure the size or shape of a component
- **Inspection systems** such as a detecting a missing bearing cap bolt or a bent ladder tread
- **Monitoring systems** which gather visual data for further human inspection and defect detection and verification

The following figure shows a major machine vision detector site in New Mexico where five machine vision based detectors are deployed side-by-side. As the effectiveness of these systems is becoming evident, the number of these types of sites is growing rapidly in North America.

Following is a list of train/locomotive/car components that may be inspected using vision based detectors. The list is more descriptive and by no means complete and is intended to show the potential for vision based systems.

A typical multisystem detector site (All vision based system located at Gallup, NM on a BNSF track)

Wheel and Axle
- Wheel Profile, B2B, Diameter
- Surface condition such as surface grooves, thermal cracks, shelling, etc.
- Broken flange
- Wheel roundness
- Sliding wheel
- Built up wheels

Bearing
- Bearing cap bolts
- Bearing heat signature

Truck
- Angle of Attack
- Truck geometry
- Suspension (springs, friction wedge, etc.)
- Side bearings
- Side frames (cracks, mismatched, etc.)

Brake
- Brake shoe and key condition
- Dynamic application condition
- Brake beams and rigging components

Car
- Safety appliances
- Doors (hopper, side)
- Dynamic: Loading and leaning
- Undercarriage components
- Car identification

Locomotive
- Wheel profile and parameter trending (to be used by turning machines)
- Witness groove reading (Wheel diameter)
- Back to back
- Sand hose
- Leaking lubricants

Deployment of machine vision systems in any railroad environments such as North American Freight tracks has proven to be extremely challenging. The main reasons are conditions such as train speed, vibrations, shock, environmental and weather conditions, abundance of dust and lubricants, hanging objects from trains, wide maintenance vehicles, etc.

In the last decade significant progress has been reported in machine vision related components such as cameras, available lighting types and quality, structured lighting methods, processing algorithms, storage and processing capacity. This improvement in the quality and cost of the components along with the accumulated experience of the industry in how to deal with extreme conditions have resulted in innovative and effective vision based wayside detection systems. With no doubt, the investment made by the railroad operators and organizations like AAR and FRA has been a very crucial factor also.

Following is a summary list of these contributing factors:
- Gained experience and lower cost of components
- Camera and other critical components' quality and reliability
- Effective optical systems
- Improved lighting systems such as lasers, LED's and IR/UV lighting
- Customer understanding of great potentials
- Investments and proven track records
- Sophisticated image processing techniques
- Extensive data availability after system installations

In the remaining part of the paper, a number of systems are introduced and explained.

4. Examples of Vision Based Wayside Detectors

A couple of examples of vision based detection systems are described here. Details of these and other detection systems will be presented in detail at the meeting.

4.1. Automatic wayside wheel profile measurement system (e.g. WheelView) is designed to operate at normal track speeds and acquire wheel images and measure the wheel profile and its associated parameters. This system deploys a sophisticated high speed, high quality digital imaging and laser illumination system for maximum accuracy and efficiency. The product benefits from sophisticated image processing algorithms to measure the wheel profile data from acquired images with a very high success rate.

Measured data on standard system includes:

- Full Wheel Profile
- Flange Height
- Flange Width (Thickness)
- Flange Slope
- Tread Hollow
- Rim Thickness
- Back-to-Back Measurement
- Tracking Position (wheel lateral position)
- Approximate Wheel Diameter

4.2. Coupler Securement Inspection System (CouplerView) is an automatic wayside coupler securement inspection system developed mainly for freight operators in North America. This system is designed to handle inspection of both E-type and F-type couplers securements. It alerts the customer if a coupler securement is in distress, usually before it reaches catastrophic failure condition. CouplerView-Pin is designed to detect the following plate defects:

1. Missing coupler pin plate
2. Leaning coupler pin plate
3. Missing fasteners
4. Rotated coupler pin plate
5. Combination of any of the above

Other type of CouplerView (for E-type couplers) is designed to perform the following checks:

1. Classify E-type and F-type couplers
2. Find missing cross (draft) keys
3. Find missing retainer-pin (T-Pin)
4. Find missing cross key retainer washer
5. Find missing cotter key
6. Coupler draft gear plate inspection

5. Other systems to be discussed

Examples of other vision based systems that have been installed and proven successful are

- Brake shoe and operation
- Friction wedge, springs, and bearing cap
- Truck geometry measurement
- Undercarriage
- Safety appliance
- Wheel surface, built up tread and sliding wheel
- Door and other latches

Principles of operation and their detection performances will be presented at the meeting.

6. Potential Future of Machine Vision in Railroads

The future of the machine vision seems to be moving towards integrated solutions where a number of tasks can be performed with a single system or at least in an integrated site. Towards this goal, systems are developed where a train is fully scanned with 360 degrees coverage. This data can then be used to automatically assess many components of the rolling stock. A sample of such a system is shown below:

Details of these types of systems and their potentials will be presented at the meeting.

Figure: TrainView and CSCView systems installed at TTCI and BNSF

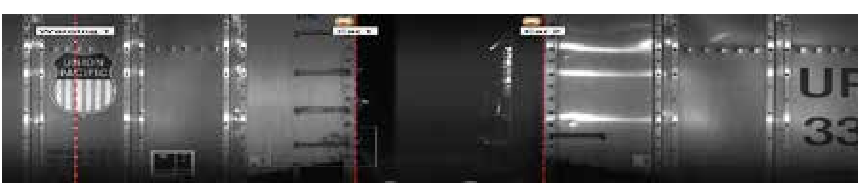


Figure: A typical image generated by TrainView system

7. Conclusion

This paper presents current condition and potential future of machine vision based systems capable of automatically detecting defects in rolling stock which can cause catastrophic results if left undetected. These systems are designed to support rail operator's maintenance staff in a very effective manner. Many of these devices are deployed in numbers and have proved to be an integral part of the future of train inspections and maintenance practices. High availability and reliability of these machine vision systems is becoming a valuable and cost effective asset for railroad operators.

In the near future, several other vision systems will be introduced which have already shown their effectiveness in detecting dangerous defects in rolling stocks.

6. References

[1] Jim Robeda, Kari Gonzales, and Mary Clara Jones, Development of Automated Inspection of Structural Components Algorithm, Technology Digest TD-12-001, January 2012, Transportation Technology Center, Inc., USA

[2] Daniel Machalaba, The Little Engine Really Could, The Wall Street Journal, May 2, 2011

[3] Kambiz Nayebi, Vision Systems Tracks Troubles with Trains, Vision Systems Design Magazine, June 2012, 28-31

Smart Technologies for Locomotive 92-Day Inspections-Automate or Semi-Automate Wheel Measurement Gauges

Prepared by:
James Skaggs, Director Railway Technologies
Presented at September 2011 Convention in Minneapolis, MN

What is a 92-Day Inspection? As defined by the Code of Federal Regulations (49CFR 229.23 it is "The interval between any two periodic inspections may not exceed 92 days. This inspection shall be performed by a qualified person or a qualified maintenance person. This record shall be retained for at least 92 days at the place where the inspection has been conducted."

One of the requirements is that a complete wheel inspection report must be prepared. The objective is to return the locomotive to revenue service as soon as possible.

Typically, wheel measurements and reports are performed by two people with mechanical gauges (finger gauge) and these measurements are written down on forms (figures 1 & 2).

Standard AAR steel wheel gauges provide unreliable wheel measurements. There are five typical reasons for this:

- It's all in the wrist-mechanical manual gauges are difficult to read even when placed properly on the wheel (figure 3).
- Reasonable men can disagree-rounding errors produce reliably unreliable results
- Dirt and grease - dirty, greasy wheels are hard to inspect and measure
- 10% transcription errors-smudged pencil marks and typographic errors
- Black lines on gray background - difficult to read in poor light, even in good light

Semi-automatic solution: Electronic wheel measurement gauge (figure 4).

- **Origin of Electronic Wheel Gauge**: During the 1980's, a major railway began inputting wheel measurement records into their newly acquired IBM supercomputer to get benefits of statistical analysis. The first result reported: 40% of wheels in the fleet are growing.
- **Challenge**: Eliminate possibility of human error and routine mistakes made with the AAR "Finger" Steel Wheel Gauge. The first electronic wheel gague was deployed in 1987
- **AAR Approval**: Electronic wheel measurement gauge received AAR approval on September 28, 1990 (figure 5)
- "**Mini" EWG**-Electronic wheel measurement gauge was also approved by AAR on September 28, 1990

It was introduced in 2005. It was cable less, wireless (IrDA), connectorless, smaller, thinner, lighter and self contained (figure 6).

- Existing Practices: Typical maintenance procedures were designed to accommodate inaccurate or unreliable wheel measurements including:
  1. Multiple measurements of marginal wheels
  2. Premature turning of wheels for fear of not passing next inspection
  3. Rounding conservatively in all measurements
  4. Removing more metal than necessary to restore the profile
  5. Maintain higher inventories of replacement wheels than necessary

- Solution: Replace the steel wheel "Finger" gauge, originally designed in 1923, with an electronic wheel measurement gauge (figures 7-12)
  1. Guaranteed accurate, reliable wheel measurements
  2. Only one person needed to measure flange thickness, flange height, rim thickness, etc.
  3. Measures in less than 1/4th the time as the finger gauge
  4. Eliminate possibility of errors on forms and reports
  5. Saves time and money

Why are wheel measurements important? Wheels continue to be a major cost center. It is a major safety issue. Necessary to conform to AAR/FRA standards and regulations.

Measurements vs. Forecasting:

- Level of measurement detail-Full profile vs. AAR required measurements.
- Predictive maintenance
- Frequency of measurement
- Location of measurement

Range of Solutions:

- Portable hand-held gauges
- Wayside ITB systems
- Machine based - wheel truing machine mounted
- Emerging on-board trends: smart sensors, in-vehicle measurements, etc.

Additional Wheel Inspection Technologies:

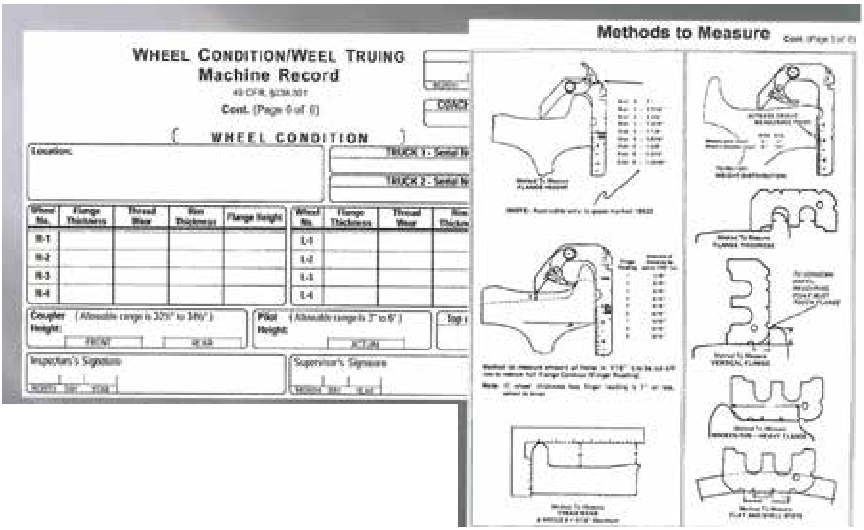
- Flat spot and roundness measurements systems (figure 13)
- Tread crack detection systems (figure 14)
- Infra-red thermal-imaging systems (figure 15)

Improved Results with Automatic or Semi-Automatic Locomotive Wheel Measurements @ 92-day Inspections:

- **Safety**-Identify worn wheel conditions and wear limits and reduce potential of unexpected wheel failure and costly derailments.
- **$Savings$**-Accurate data results in improved efficiency of operations and allows predictive/preemptive wheel truing, avoid FRA infractions.
- **Service**-Reduce the percentage of service interruptions due to faulty inspections, erroneous measurements, and factors of human error.

QUESTION: How can railways meet requirements for increasing safety and efficiency, while reduction locomotive dwell time and returning unit to revenue service sooner?

ANSWER: Automatic and semi-automatic wheel measurement gauges based on modern technology is the solution.



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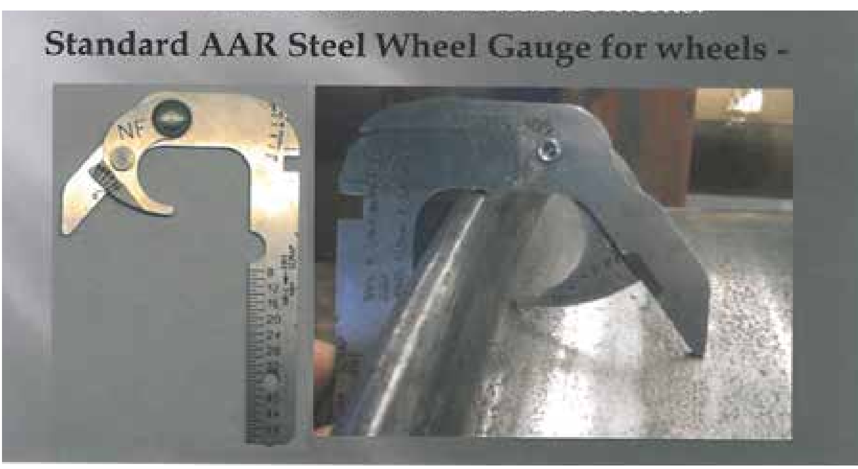

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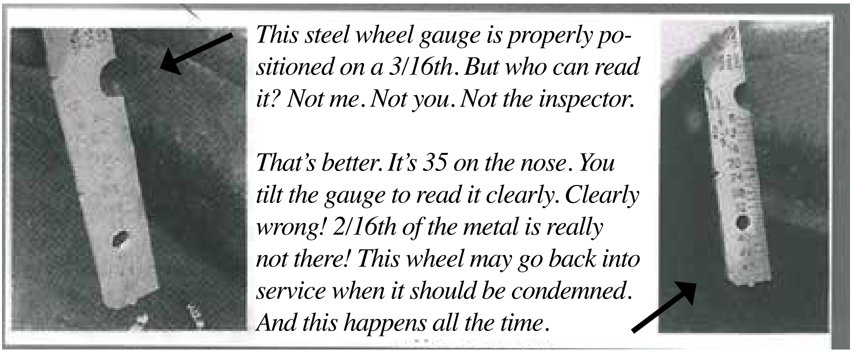

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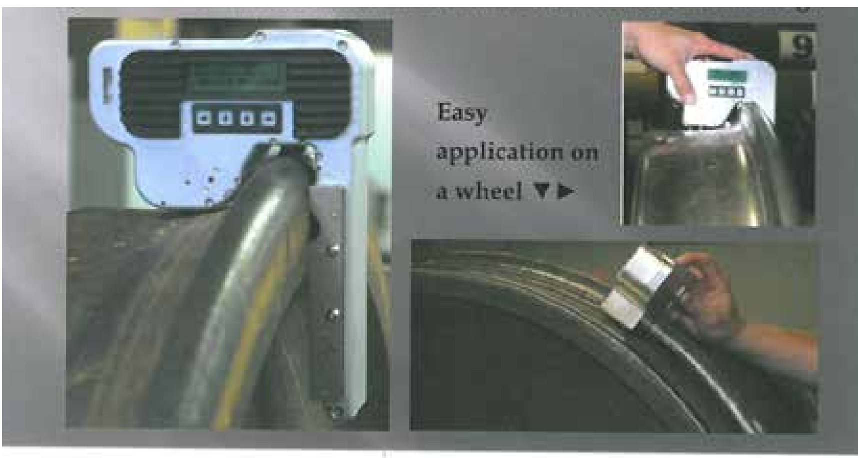

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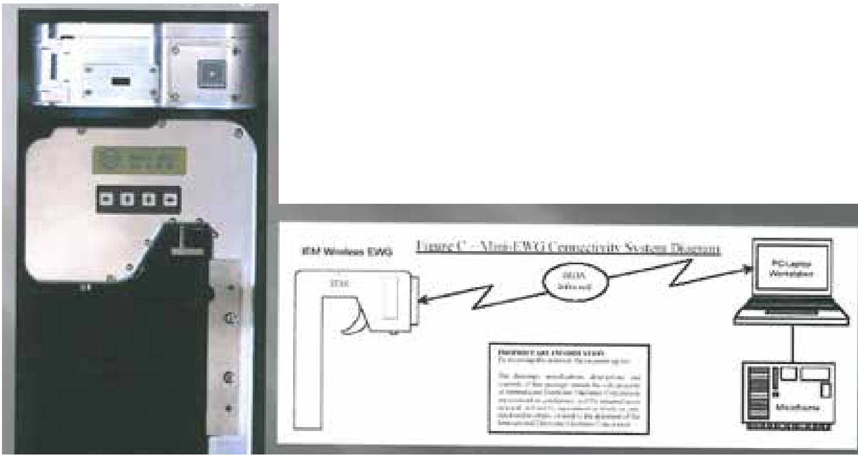

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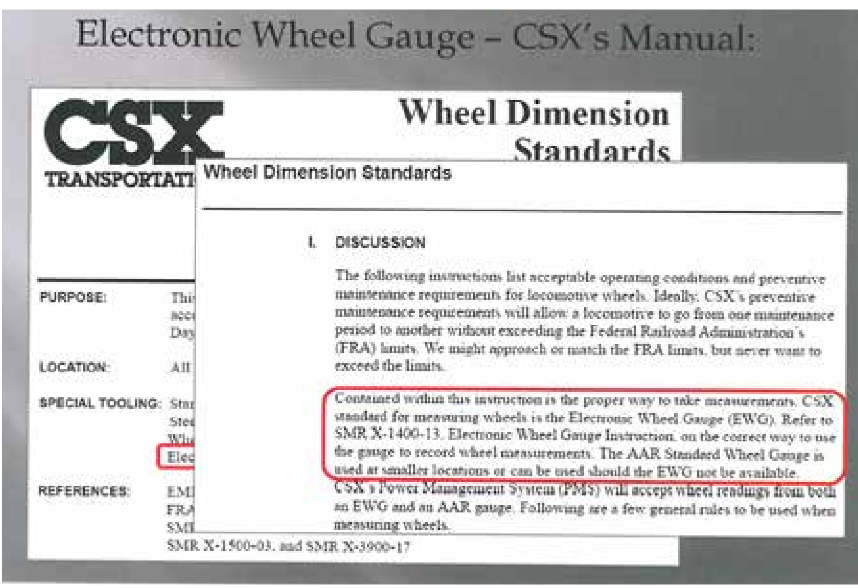

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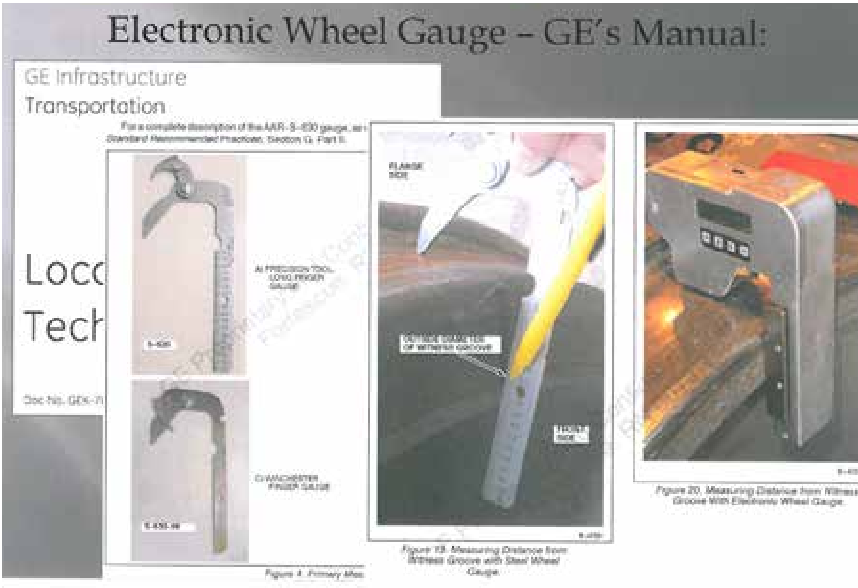


Figure 8.

Figure 9.

Figure 10.

Figure 11.

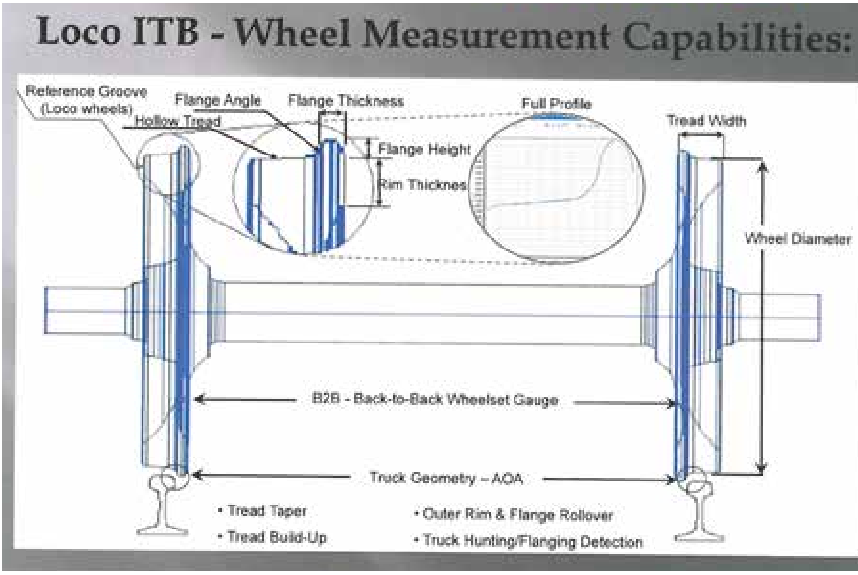


Figure 12.

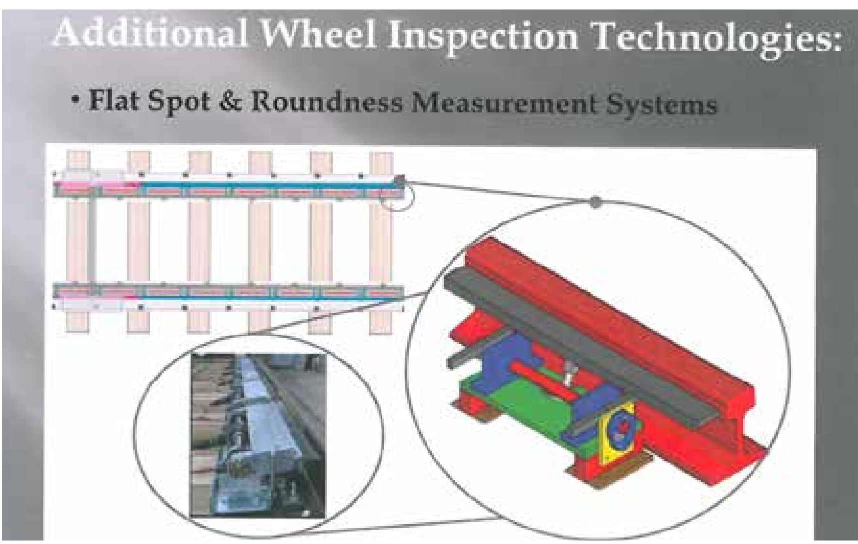


Figure 13.

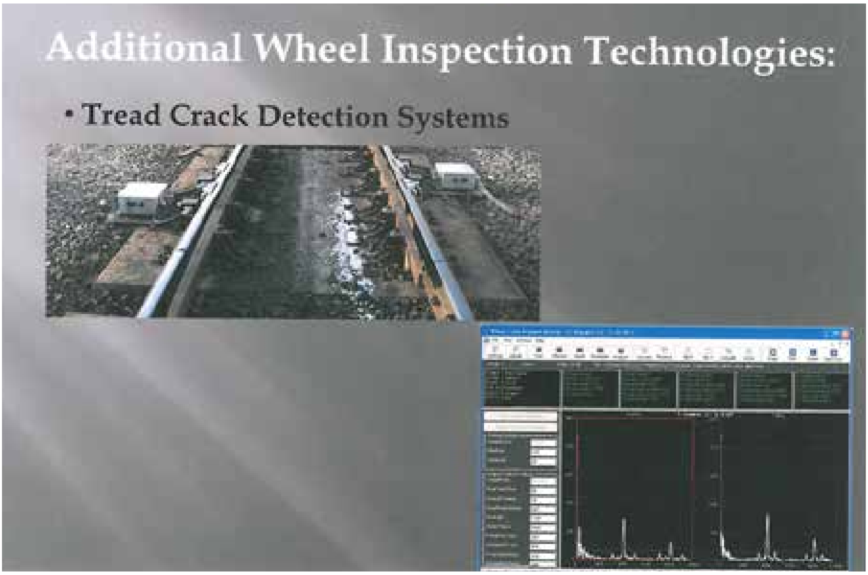


Figure 14.

Figure 15.

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.

American Flyer, Pre-War, Standard Gauge, No. 4692

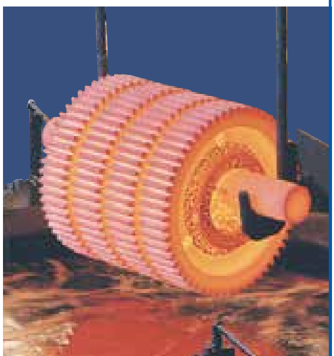
You'll Find PMC Gears and Pinions Turning the World's Finest Locomotives.

PMC doesn't toy around. We make the full size ones!

No one is better qualified to supply locomotive gears and pinions than Penn Machine. With over 90 years of manufacturing experience, Penn Machine makes gears and pinions of the highest quality for use on locomotives from all the leading manufacturers. We manufacture over 120 bull and engine gears and 80 pinions. The most popular ones are in stock.

Our gears and pinions are made from triple alloy steel and carburized/hardened in our in-house heat treating equipment. They provide up to 50% longer wear life than standard heat-treated gears. And they are AAR certified and come with a 5-year limited wear warranty.

Not getting replacement gears when you need them can result in costly downtime. That's why delivering to meet your schedule is our way of doing business.



PMC
Since 1920

For more information, call or visit us online.

Penn Locomotive Gear
A Division of Penn Machine Company LLC
Blairsville, PA, U.S.A.
814-288-1547 ext. 211 • sales@pennlocomotivegear.com
pennlocomotivegear.com

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