LMOA

Locomotive Maintenance Officers Association

Proceedings of the 82nd Annual Meeting

ORIGINALLY SCHEDULED FOR
SEPTEMBER 9-11, 2020 • CHICAGO, IL
MEETING CANCELLED DUE TO COVID-19

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2019 LMOA MVP RECIPIENTS

The executive board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable Person (MVP) of their respective committees for 2019:

NAME	COMMITTEE	COMPANY
Michael Cleveland	Mechanical Maintenance	BNSF Railway
Steve Mueting	Electrical Maintenance	Siemens Mobility
Connie Nordhues	Locomotive Software and Systems	Wi-Tronix
Anju Singla	Fuel, Lubricants and Environmental	American Refining Group
Michael Zerafa	Facilities, Material and Support	PowerRail, Inc

This honor is bestowed on an annual basis to those individuals who perform meritorious service and make significant contributions to their respective committees. The honorees receive a plaque that is presented to them by their supervisors.

LMOA EXECUTIVE COMMITTEE

THE LMOA EXECUTIVE BOARD WOULD LIKE TO THANK OUR PAST PRESIDENT, DWIGHT BEEBE, OF TEMPLE ENGINEERING FOR HOSTING THE EXECUTIVE COMMITTEE MEETING AND LUNCHEON ON TUESDAY, SEPTEMBER 24, 2019 AT THE MINNEAPOLIS CONVENTION CENTER IMMEDIATELY FOLLOWING THE CONCLUSION OF RAILWAY INTERCHANGE 2019.

WE SINCERELY APPRECIATE ALL OF THE SUPPORT YOU HAVE GIVEN US, DWIGHT, FOR SO MANY YEARS.

LMOA EXECUTIVE BOARD

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.
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1958	F.E. MOLLOR (Deceased) Supt. Motive Power, Southen Pacific Co.
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1959	E.V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry.
1960	W.E. LEHR (Deceased) Chief Mechanical Officer, Pennsylvania R.R.
1961	O.L. HOPE (Deceased) Asst. Chief Mechanical Officer, Missouri Pacific R.R.
1962	R.E. HARRISON (Deceased) Manager-Maintenance Planning & Control, Southern Pacific Co.
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.
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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
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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, (Deceased) Senior Vice President Equipment, Trailer Train Company, 289 Belmont Road, King of Prussia, PA 19406
1980	J.H.LONG (Deceased) Manager-Locomotive Department, Chessie Systems
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1982	N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
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1985	D.M.WALKER, Retired, Asst. Shop Manager, Norfolk Southern Corp, 793 Windsor St, Atlanta, GA 30315
1986	D.H.PROPP, Retired, Burlington Northern RR, 10501 W. 153rd St, Overland Park, KS 66221
1987	D.L.WARD (Deceased), Coordinated-Quality Safety & Tech Trng, Burlington Northern RR
1988	D.G. GOEHRING, Retired, Supt. Locomotive Maintenance, National RR Passenger Corp, 1408 Monroe, Lewisburg, PA 17837
1989	W.A.BROWN, Retired, I&M Rail Link, 9047 NE 109th St. Kansas City, MO 64157
1990	P.F.HOERATH (Deceased) 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
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1994	M.A.COLES, Retired, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
1995	C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
1996	G.J.BRUNO, Retired, Supt.-Mechanical, Amtrak 14142 S.E. 154th Pl, Renton, WA
1997	D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
1998	H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
1999	JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak, 25531 NE 138th St., Salt Springs, FL 32134
2000	RON LODOWSKI, Retired Production Mgr, CSX Transportation, Selkirk, NY 12158
2001	LOU CALA, Retired, Duncansville, PA 16635
2002	BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
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2005	TAD VOLKMANN, Chief Consultant, Tadco Railroad Consultants, Omaha, NE 68179
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2007	LES WHITE, Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
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Topeka, KS

2019 State of the Union Address

Ian Bradbury
Minneapolis Convention Center
Tuesday, September 24, 2019

Good afternoon ladies, gentlemen, committee members and members of the executive committee.

It has been a great honor to serve as your President for the last year and is humbling to join the past presidents' club. I heard a rumor that there's an action movie script circulating – this would clearly be a blockbuster.

I would like to start by saying thank you to my wife Kathy as well as my sons, James and George, for their love and support.

I would also like to recognize the stalwart efforts of our Secretary, Ron Pondel, who is tireless in keeping the organization glued together and a font of institutional memory.

We held a very successful joint meeting in Kansas City in April this year. I would like to thank 1st VP Tom Kennedy for organizing the meeting with the local support of Jeff Bink as well as Jack Kuhns, Mark Duve and Michael Cleveland for facilitating the BNSF Argentine yard, Mid America Car, NS wayside charging system and Wabtec Global Services tours. It's always great to see different operations and spur ideas for improvement back home.

Many railroads are currently dealing with the disruptive change coming from the adoption of Precision Scheduled Railroading (PSR) as a new operating model. A core element of PSR is improving operating ratio by running fewer heavier trains faster and on schedule. In such an environment, the buffer of locomotives previously absorbing variability in schedule, service time and locomotive reliability is reduced. Therefore, consistency of service and repair operations and reliability of locomotives become critical for the effective functioning of PSR.

As I mentioned in my acceptance speech last year, I believe that the LMOA is an organization that exemplifies many ideals:

- We provide a mechanism for cooperation across the industry on problems of common interest
- We provide opportunities for our members to learn from the knowledge and experience of each other
- We provide a collegial professional development environment for research and exposition of ideas as well as helping our members become a more effective presenter
- Our members are a pleasure to work with

If we continue our work on sharing knowledge and practices that improve locomotive reliability and maintenance operations, we will be a critical organization to the effective implementation of PSR. All of the committees have papers directly addressing improved locomotive reliability or service dwell time.

Over the last year we have developed and deepened our relationships with other industry organizations to improve the benefit that the LMOA provides to the rail industry. The Gen. VI lube oil standard is a great example of a need being identified by members of our Fuels, Lubricants & Environmental Committee; they are taking a knowledge leadership role in developing a proposed standard to meet that need and then working with the AAR to obtain industry adoption. This has been continued with work on AAR M-963-84 all-year journal box lubrication spec, which was the subject of a presentation this year. LM (locomotive docket)-013 “locomotive emissions” and LM-126 “alternative fuels issues” are called out specifically on the locomotive committee docket for coordination with LMOA. Additionally, LM-139 has been set aside specifically for project coordination between the locomotive committee and LMOA.

At the recent meeting in Calgary, the LC made a request that LMOA study the energy footprint and additional cab heat rejection required from the addition of numerous electronic systems, such as those required for PTC.

This reminds me of a story that Russ Ackoff used to tell about an American fork lift manufacturer who had been dominant in their industry for years. They started to see loss of market share to a Japanese competitor, who was selling competitive fork lifts for less than their internal cost. The initial response was that they must be dumping to gain share and that trade protection would be an appropriate response. Then they purchased one of their competitor’s fork lifts and performed a tear down evaluation. The competitor’s fork lift was able to be produced at significantly lower cost, but with the same function and performance. What they came to see was that over the years they had solved many problems, patching one solution on top of another. Their competitor had taken a clean sheet approach (what Ackoff called idealized redesign) which allowed many of the patches and functions to be integrated into simpler solutions of multiple problems or requirements. The AAR LC’s request of LMOA is an opportunity to both quantify the costs of the locomotive electrical design that has resulted from incremental problem solving as well as stepping back and thinking about better systems design alternatives.

I also mentioned last year that I would like to explore ways in which the LMOA can improve how it supports the professional development of its members. A couple of ideas in this area are formal mentorship and classes offered to pass on the wisdom of our most distinguished fellows. If our new President, Tom Kennedy, wishes, I will continue to work on this next year.

I am glad to report that the state of the union is strong.

2019 Acceptance speech

Tom Kennedy
Minneapolis Convention Center
Tuesday, September 24, 2019

Good morning ladies and gentlemen. It is with great honor that I stand before you today accepting the position of President of the LMOA. The LMOA is a distinguished organization engaged in the railroad industry to promote safety, reliability, performance and regulatory compliance, just to name a few. Integral to these activities the LMOA is also engaged in enhancing our members technical knowledge and capabilities to the benefit of the railroad industry. Many dedicated people preceded me in this role and have contributed greatly to our organization. It is my objective to do likewise.

As I reflect upon my time in the railroad industry (18 years) and LMOA (13 years) I have observed and participated in many changes, some good and some not so good. Pulling from this experience there are areas that can be focused on to further improve the contribution that the LMOA provides to the rail industry.

The first area I want to highlight is the declining participation of the Class 1 railroads. To improve Class 1 railroad engagement, we must approach and address topics relevant to the railroads. In the past we have met with the CMO's to solicit their input and include them in the process of identifying areas and topics that the LMOA committees address. The LMOA must maintain it's independence and objectivity but cannot operate in a vacuum. One complicating factor to this symbiotic relationship are the changes brought into the process such as Precision Scheduled Railroading. However, we are going to reach out and try to re-engage the Class 1 CMO's. To achieve this objective, we will use our resources like Dwight and Ian and others to help develop a strategic plan and tactics.

Secondly, we have a small participation of short lines and regional railroads and even less participation of foreign railroads and foreign suppliers. This is another area of opportunity to grow. This year I attended the short line show in Orlando and had the opportunity to talk with many people and there is much that can be shared and learned from each other. We will attempt to enhance communication and coordination between our two organizations.

Thirdly, today the technology is much more complex and highly integrated than in the past, and thus each committee needs to address this new technology in their respective spheres of responsibility, especially since there is no longer a separate New Technology Committee. Also, with the highly integrated systems it is imperative that the committees coordinate their research and papers with each other, i.e., Mechanical, Electrical and Software where mechanical systems are controlled by software via sensors and electrical actuators and servos. As an example, mechanical hysterias has to be considered in the software design.

Fourth, training is a big opportunity for the LMOA to enhance value. We have a tremendous resource in our members for developing training programs using their immense technical knowledge and experience. As many of you may recall George King presented a paper in 2007 on the aging workforce and the resulting loss of technical capability. George's paper was dead on with the loss being created by retirements, attrition, reorganization, and poor knowledge transfer from experienced personnel to the younger less experienced personnel. There are several areas that training programs could be focused on, such as:

- Systems Engineering
- Failure Modes Effects Analysis
- Sneak Circuit Analysis
- Safety Hazard Analysis
- Software Capability Maturity Model
- Reliability Growth Testing

These are a few areas we could start on to provide very proactive tools to deploy on these high technology content and highly integrated systems for safety, performance and reliability enhancement.

The last topic I want to address is increased participation and coordination with agencies such as AAR, FRA, EPA etc. The Mechanical Committee has pioneered this with active coordination with the EPA and AAR to improve understanding of emissions regulations. These organizations should be viewed as partners, not opposition. In the meetings held between the mechanical committee and these agencies much has been shared and all parties have learned a great deal. This type of coordination and cooperation should be encouraged and expanded to the other committees as applicable.

Well I better wrap this up as I see a few eyes glazing over and some may be wondering, "Who invited the engineer" to this meeting? Seriously, I hope I have challenged many of you to think about industry paradigms and your own paradigms that should be challenged and perhaps broken. We had a saying at Case, "That big bang you just heard was a paradigm shifting without a clutch". At the end of the day the future for the LMOA is bright and in our own hands. Thank you very much and I'm pleased to be your new President and look forward to working with you all to maintain and improve our organization. Thank you.

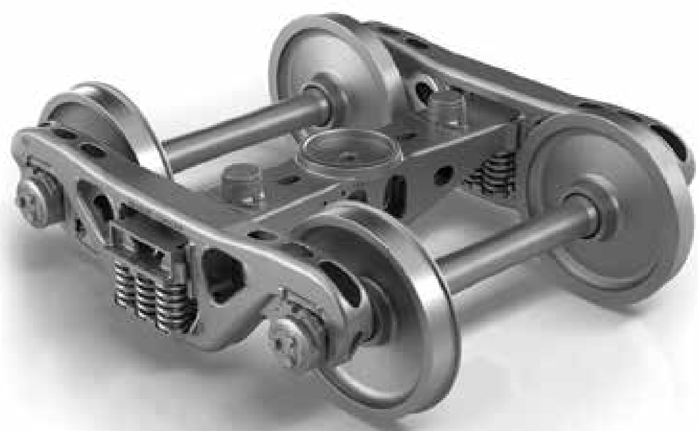
LMOA Executive Board meeting held immediately after the conclusion of Railway Interchange 2019 in Minneapolis, MN on September 24th

Outgoing President Ian Bradbury presents gavel to newly elected President Tom Kennedy which was witnessed by Past President Tad Volkmann

Past President Dennis Nott presents LMOA watch to outgoing President Ian Bradbury. Past Presidents Dwight Beebe (left) and Dave Rutkowski (right) witnessed the ceremony

Outgoing President Ian Bradbury receives Past President's Pin from Past President Les White. Newly Elected Tom Kennedy (left) and Past President Bob Reynolds (right) witnessed the ceremony

Past President Bob Runyon places LMOA Blazer on newly elected 3rd VP Tim Standish. Newly elected 2nd VP Mike Hartung congratulates Tim



Back Row: Ian Bradbury, Les White, Dwight Beebe, Dave Rutkowski, Tom Kennedy, and Bob Reynolds
Front Row: Tim Standish, Mike Hartung Bob Runyon, Tad Volkmann, Dennis Nott and Tom Gallagher

Report on the Committee on Fuel, Lubricants and Environmental

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Railroad Sales Specialist
American Refining Group, Richmond, VA

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O. Ferguson		Polaris Labs	Indianapolis, IN
S. Fritz, P.E.	Manager-Research & Development	Southwest Research Institute	San Antonio, TX
T. Gallagher	Global Railroad Technical Liaison	Chevron Oronite Co, LLC	Commerce, Mi (Executive)
F. Girshick	Principal Technologist	Infineum USA, L.P.	Linden, NJ
C. Koglin	OEM Relations Specialist	Afton Chemical Corporation	Southfield, MI
S. Koshy	Mechanical Engineer	Amtrak	Wilmington, DE
D. McAndrew	Consultant	Dennis McAndrew, Inc.	Waterford, PA
D. Pelletier	Equipment Builder Engineer	Exxon Mobil	Durham, ME
K. Pecinovsky		Afton Chemical Corporation	Richmond, VA
L. Rasmussen	Product Engineer-Engine Systems	Progress Rail-Electro Motive Diesel	LaGrange, IL
K. Ravn	Rail Application Engineer	Cummins, Inc.	Minneapolis, MN
G. Smith	Chief Mechanical Engineer	Argus Consulting, Inc	Overland Park, KS
D. Tuttle	Director-Railroad Sales	American Refining	Atlanta, GA
P. Whallon	Strategic Account Manager	Parker Filtration Clark	Lancaster, PA

PERSONAL HISTORY

Anju Singla

Railroad Sales Specialist
American Refining Group

Anju joined American Refining Group (ARG) on August 27, 2018 in her current position as Railroad Sales Specialist. She is responsible for developing and managing existing and new Class 1 and short line railroad accounts and is responsible for sales in the marine industry.

She has 8 years of lubricant sales and 13 years of Research & Development (R&D). She previously worked for Soltex Inc of Houston as a sales representative.

Anju holds a BS degree in Chemistry from St. Louis University and received an MBA from Averett University in Virginia. Additionally, she has a Bachelors and Masters degree in Theology.

Anju currently resides in Richmond, Virginia. In her spare time, she preaches to inmates at the City Jail and at the local Assisted Living Facility in Richmond. She is an avid runner and participates in 5K, 10K and half marathon events.

She is a widow. Her beloved husband, Gus, passed away in 2000.

THE FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE WISH TO EXPRESS THEIR SINCERE APPRECIATION TO THE SOUTHWEST RESEARCH INSTITUTE FOR HOSTING THEIR COMMITTEE MEETING IN SAN ANTONIO, TEXAS ON FEBRUARY 19-21, 2020.

SPECIAL THANKS TO STEVE FRITZ AND MARY RAMOS FOR MAKING ALL THE NECESSARY ARRANGEMENTS.

Locomotive Engine Fuel Economy Testing

Prepared by:
F. W. Girshick, Infineum USA, L.P. and
T. M. Kelly, Infineum UK Ltd. (ret.)

ABSTRACT

Following last year's Locomotive Maintenance Officer's Association; Fuels, Lubricants, and Environmental Committee (LMOA FL&E) presentation detailing a field test to compare fuel consumption and lubricating oil consumption of a multi-grade oil and a mono-grade oil, there was a request from the audience for more information about fuel consumption response to load or throttle position. This paper presents work measuring fuel consumption in stationary "load-test" mode for one SAE 40 and two SAE 20W-40 oils as a function of load (*a.k.a.* "throttle notch"). Results were statistically fit to predict "real-life" expectations for line-haul and switcher services and are compared to real-world field results. Multigrade (SAE 20W-40) provides better fuel economy than monograde (SAE 40) at all conditions, and the benefits are larger at lower notch settings.

BACKGROUND

A paper was presented by the Fuels, Lubricants, and Environmental Committee at the 2019 Railway Interchange in Minneapolis showing the results of a one year-plus field test comparing two different viscosity engine oils. To control as many variables as possible, the oils were blended using the same additive package and same base stock slate. The same locomotive model with the same model engine, in the same service were used for this comparative testing.

The SAE 20W-40 oil resulted in 1.4% lower specific fuel consumption and 37% lower specific oil consumption, compared to the SAE 40 oil. This paper was originally published by CIMAC (formerly, Congrès International des Moteurs A Combustion, now the International Council on Combustion Engines) at their 2019 Congress in Vancouver, British Colombia, Canada, June 2019[1], and was re-printed with their permission, as this subject is of interest to the LMOA community.

That nature of testing in "real-world" commercial service, therefore, represents a weighted average over all notches (engine speeds and loads).

1 Girshick, F. W., "Engine Oils for Improved Fuel Economy and Oil Consumption in Railroad Service," paper 238, 29th CIMAC World Congress, Vancouver, British Colombia, Canada, 10 – 14 June 2019.

Following the 2019 presentation, there were questions from the audience about how the rate of fuel consumption depends on engine operating conditions, particularly load. The current paper shows work done in a static engine to address those questions.

The reader is directed to the 2019 LMOA paper, *"Engine Oils for Improved Fuel Economy and Oil Consumption in Railroad Service,"* for an introduction to lubrication theory, engine oil properties, engine operating conditions, and how they affect fuel economy.

The current work builds on the fact that lower viscosity fluids, in general, means less energy lost moving the fluid and greater fuel efficiency. How the increase in efficiency depends on engine operating conditions, particularly load (or throttle notch), is the focus now.

EXPERIMENTAL

Methodology

The experiment documented in the 2019 paper used 18 four-stroke locomotives in commercial service – nine locomotives with each oil – which resulted in the overall average fuel and oil consumptions with two oils of different viscosity grades (SAE 40 and SAE 20W-40).

The current experiment was performed in a two-cylinder, two-stroke research engine mounted in a dynamometer stand to compare fuel consumption rates for three oils (one SAE 40 reference and two SAE 20W-40 candidates). This configuration, although less realistic than on-road real-life service, allowed greater control of speed and load. This level of control enabled investigation of fuel consumption dependence on load, which is the objective of this work.

Test Engine

The test engine properties are shown in Table 1. This is the same engine used by one of the engine manufacturers as an engine performance screening tool.

Parameter	Units	
Cycle		2-stroke
Cylinders		2
Bore	inch	8.5
	mm	216
Stroke	inch	10.0
	mm	254
Displacement	litres	18.5
	cubic inches	1135
	cu. in per cyl.	567
Compression Ratio		16:1
Rated speed	rpm	835

Table 1. Test engine properties

The engine was run at three "notch" settings, as shown in Table 2.

Test Oils

The three test oils are described in Table 3. The reference oil was an SAE 40. Two candidate SAE 20W-40 oils were developed – one using the same additive technology as the reference oil, and another using a different additive technology. The two multi-grade oils used different viscosity modifiers[2]. All three oils used the same API Group I (solvent extracted) base stock slate. As explained in the 2019 paper, the mixture of base stock "cuts" must be different for the different viscosity grade oils.

		Notch Setting		
Parameter	Units	2	4	8
Speed	rpm	344	515	835
Power	kW	14	60	154
	Hp	19	80	207
	% of max	9%	39%	100%
Fuel consumption (FC), nominal	g/hr	5352	14,741	42,540
Specific Fuel Consumption (SFC), nominal	g/kW-hr	378	247	276
Oil temperature, nominal	°C	60	71	91
Water temperature, nominal	°C	47	64	79
Air Box temperature, nominal	°C	50	60	77
Air Box pressure, nominal	mm Hg	51	81	173

Table 2. Test engine parameters

Property	Method	Units	Reference	Candidate 1	Candidate 2	Limits
Viscosity Grade			SAE 40	SAE 20W-40	SAE 20W-40	
Additive Technology			A	A	B	
Viscosity Modifier			None	X	Y	
Base stock slate			Same			
Viscosity at 100°C	D445	mm^2/s	14.58	14.47	14.50	13.9 – 16.3
Viscosity at 40°C	D445	mm^2/s	152.1	127.3	121.6	
Viscosity Index	D2270	none	94	114	120	
Viscosity at –10°C	D5293	mPa-s	---	3630	3120	≤ 4500
Viscosity at –15°C	D5293	mPa-s	---	7260	6340	≤ 9500
Viscosity at – 20°C	D5293	mPa-s	---	14,500	12,900	≥ 9500
Viscosity at 150°C	D4683	mPa-s	4.30	3.86	3.83	≥ 3.7

Table 3. Test oil properties

All three oils targeted kinematic viscosity at 100°C of 14.5 mm^2/s, which is near the middle of the SAE 40 range[3]. Cold Cranking Simulator (CCS) viscosity for the two multi-grade oils met both the SAE limit at –15°C and the railroad limit at –10°C. CCS viscosity was also measured at –20°C to verify the oils were

2 Also known as Viscosity Index Improvers, or VII.

3 The Society of Automotive Engineers (SAE) Engine Oil Viscosity Classification (SAE J300) defines SAE 40 to have kinematic viscosity at 100°C between 12.5 and 16.3 mm2/s. The North American railroad engine manufacturers set a minimum of 13.9 mm2/s. Some railroads have their own, more restrictive, limits within this range.

not SAE 15W–40, as required by SAE practice[4]. All three oils meet the SAE requirement for High–Temperature High–Shear (HTHS) viscosity at 150°C.

The three oils for the fuel economy test are considered experimental and were not processed through the bench tests required for OEM approval, although the additive packages had been approved in other formulation blends, and similar oils are in commercial service.

Test Procedure

The test engine was run at three conditions – Notches 2, 4, and 8 – with each of the three oils, and repeated five times in specified order, for a total of 45 measurements, shown in Table 4. As much as possible, the order of tests was arranged to ensure each oil would be preceded by and followed by other oils – including itself – at least once; there is only one exception. This ordering was done because "carry-over" effects are well-known in fuel economy testing[5], although usually associated with friction modifiers, not purely viscometric effects, as tested here. Data analysis did not detect any effect of run order.

Candidate 2			B			B	B			B				B	
Candidate 1		A			A			A			A				A
Reference	Ref			Ref					Ref			Ref	Ref		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Run number														

Table 4. Order of testing

Results

The raw data and summary statistics are in Table 5.

Both multi-grade oils showed lower rates of fuel consumption (*i.e.*, better fuel economy) at all notch settings. The improvements were greater at the lower notch settings, in both absolute and relative terms. It is well-documented in the literature that viscometric effects have larger influence on fuel economy at lower loads, due to the operation being higher on the Stribeck Curve[6].

4 The "maximum with no minimum" definitions of "W" grades in SAE J300 results in oils meeting more than one "W" grade. SAE J300 requires oils to be labeled as the lowest "W" grade they meet. Therefore, strict adherence to practice requires demonstrating an SAE 20W-40 oil fails the SAE 15W-40 limits.

5 Waddey, W. E.; Deane, B. C.; Shaub, H.; Carley, R. A.; "Testing of Engine Oils Having Carryover Fuel Economy Effects," SAE 810317, 23 – 27 February 1981

6 Girshick, F. W., "Engine Oils for Improved Fuel Economy and Oil Consumption in Railroad Service," LMOA, September 2019

	Brake Specific Fuel Consumption (g/kW-hr)								
	Reference Oil			Multigrade Oil 1			Multigrade Oil 2		
	Notch			Notch			Notch		
Run number	2	4	8	2	4	8	2	4	8
1	532	260	271						
2							468	251	266
3				516	254	268			
4	604	257	268						
5							487	251	266
6				530	252	266			
7				503	254	266			
8							488	253	270
9	608	258	270						
10				549	255	268			
11							492	247	263
12	538	254	264						
13	563	254	266						
14				524	248	264			
15							532	252	268
Mean, g/kW-hr	569	256	268	525	253	266	493	251	266
Std. Dev., g/kW/hr	36	2.9	2.9	17	2.7	1.5	24	2.3	2.7
Coefficient of Variation	6.3%	2.8%	1.1%	3.2%	1.1%	0.6%	4.8%	0.9%	1.0%
BSFC improvement, g/kW-hr	---	---	---	44	3.8	1.6	76	5.9	1.6
BSFC improvement, %	---	---	---	7.8%	2.3%	0.6%	13.3%	3.1%	0.6%

Table 5. Test results

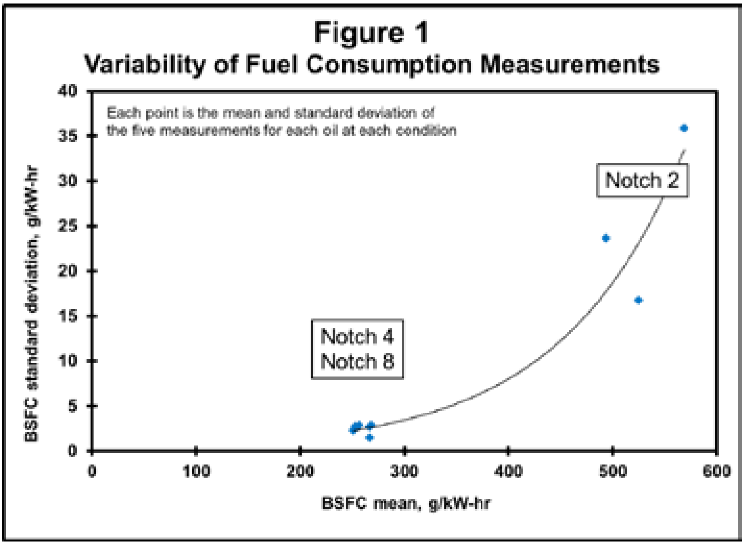
The measurements are most variable at Notch 2 where, presumably, it is more difficult to control fuel rate at the lower load. This suggests it would be very difficult to measure viscometric effects at idle or Notch 1. The Stribeck Curve hypothesis also suggests viscometric-related fuel economy changes would be the largest at idle or Notch 1. Both Notch 4 and Notch 8 have very good precision, as seen in Figure 1.

Both multi-grade oils have lower specific fuel consumption (i.e., better fuel economy) than the mono-grade oil at all conditions, and the lower the load the more the benefit.

Candidate 2 has better or equal fuel economy than Candidate 1 at all conditions. This could be due to the additive package or the viscosity modifier. Unfortunately, in this limited study, the additive package and the viscosity modifier are confounded variables: these results cannot differentiate the two factors. Again, the lower the engine load, the greater the difference.

Analysis and Application

The results, as fuel economy benefit relative to the monograde reference oil, are plotted in Figure 2. Eventually, fuel economy improvement over a typical duty cycle will be calculated. Ideally, testing should be done at every notch and fuel flow condition (e.g., idle, dynamic braking) to allow the weighted average calculation. In the absence of a full dataset, various approximations and assumptions were used, recognizing these add uncertainty to the final conclusions.



Smooth trend lines were added for each multigrade oil, which allow interpolation and extrapolation to notch settings not tested. With only three points per oil, there are a limited number of curves which can be fit and the three-parameter equation

$$y = a + b \cdot e^{\left(\frac{-Notch}{c}\right)}$$

was chosen. No two-parameter equation fit the data in a realistic way. Using three parameters to fit three data points does not allow estimation of variability or error. Extrapolation from the data – with a lower bound at Notch 2 – to Notch 1 or below introduces additional uncertainties, as discussed below.

The approximate amounts of time spent in each notch are estimated by the U.S. Environmental Protection Agency (EPA) for switcher service and line-haul service[7]. Figure 3 shows these two duty cycles as both the fraction of time spent in each throttle position and the approximate fraction of fuel used in each position.

Applying the fitted curves from Figure 2 to the weighting factors from Figure 3, it is possible to estimate the total fuel savings for switcher and line-haul service. Idle and dynamic braking are treated as Notch 1 and Notch 2, respectively. Idle is likely to be "lower than Notch 1" and therefore have higher fuel economy, but the uncertainly due to incorrect "Notch assignment" was judged to be lower than the uncertainty due to further data extrapolation. Although Idle accounts for significant amounts of time for both Switcher and Line-Haul service – 60% and 38%, respectively – it accounts for a small amount of fuel burned – 3% and 0.3%, respectively.

These theoretical fittings predict fuel economy savings shown in Table 6.

During the Fuels, Lubricants, and Environmental Committee review of this paper, an alternate prediction method was suggested[8], to "group" the in-service notches and sum the EPA weighting factors, as shown in Table 7. This method has the advantage that a mathematical functional form, such as that in Figure 2, does not have to be selected, which is itself a subjective judgement.

The results of the "grouping" analysis method are shown in Table 8. In all cases, they are higher than the "fitting" method, due to decreasing the weight of Notch 8, with the lowest fuel economy benefit (more significant for line-haul service), and increasing the weights of Notch 1 and dynamic braking (in switcher service). This can be seen in Figure 4.

It may be possible to find weightings or grouping that more accurately match field results, but this begins to become "cherry-picking" – knowing the desired answer and manipulating the analysis to match. As discussed below, it is recommended for future studies to measure more notch conditions; this approach has been used for on-highway diesel engines[9].

A Class I railroad compared this same reference oil and Candidate 2 in one locomotive with a 16-cylinder, 169 litre, two-stroke engine in line-haul service and reported fuel economy improvement of 0.9 – 1.0%.

The 2019 Fuels, Lubricants, and Environmental paper showed fuel economy difference between an SAE 20W-40 similar to Candidate 2 and a different SAE 40 of (1.42 ± 0.35)% in nine (each) four-stroke engines in line-haul service.

7 "Locomotive Emissions Standards: Regulatory Support Document," National Service Center for Environmental Publications (NSCEP), 1998, nepis.epa.gov/Locomotive Emissions Standards: Regulatory Support Document
8 Fritz, S. G, personal communication
9 Girshick, F. W.; Laufer, C.; Brass, D.; Devine, M.; Boese, D.; "Improved Fuel Economy and Measurement Precision with New Diesel Engine Oils," Society of Automotive Engineers, High Efficiency Internal Combustion Engine Symposium, Detroit, MI, 2 April 2017

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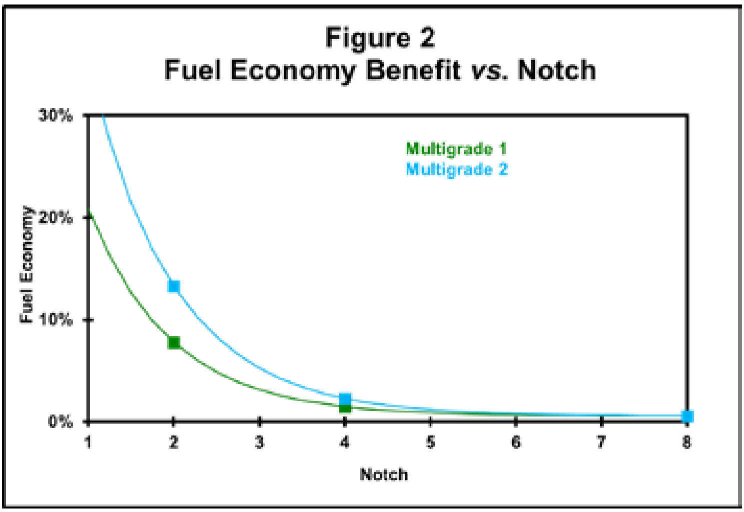
It appears the current methodology of testing fuel consumption at three notches and fitting to a statistical model is in reasonable agreement with Class I line-haul service.



Duty Cycle	Candidate 1	Candidate 2
Switcher	(2.8 ± 1.3) %	(4.5 ± 2.1) %
Line-haul	(1.0 ± 0.5) %	(1.3 ± 0.6) %

Table 6. Estimated results for EPA cycles ± s.d.

Recommendations for Future Work

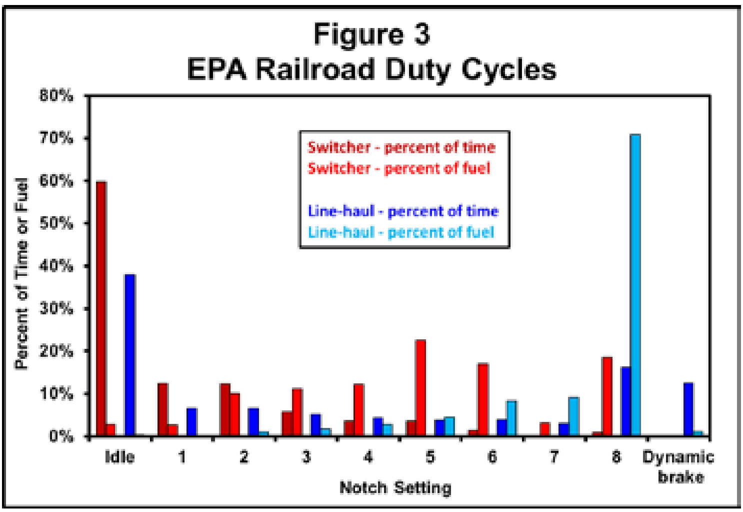
In hindsight, for such stationary dynamometer testing – with the same total number of runs, and therefore project cost – it is recommended to test more notches with fewer repeats at each condition. This would allow better fitting to statistical equations and forecasting.

It would be beneficial for the statistical modeling to have data at Idle and Notch 1, although Figure 1 suggests measurements at these conditions would be extremely variable.

Conclusions

Two multi-grade oils showed improved fuel economy compared to a mono-grade oil. In addition to viscometrics, additive and viscosity modifier chemistries appear to be significant contributors.

The multi-grade oils showed improved fuel economy at all notch conditions, and improvement was higher at lower load settings.



		Weighting – time		Weighting – fuel	
Group	Notches included	Switcher	Line-haul	Switcher	Line-haul
Notch 2	Idle dynamic braking Notch 1 Notch 2	84.5%	63.5%	40.3%	8.2%
Notch 4	Notch 3 Notch 4 Notch 5	13.0%	13.4%	25.7%	7.1%
Notch 8	Notch 6 Notch 7 Notch 8	2.5%	23.1%	34.0%	84.7%

Table 7. Weighting factors for "grouping" method

Stationary testing in a small test engine seems reasonable to estimate the fuel economy benefit realized in full-size locomotives in commercial service, although the fit can be dependent on data analysis methods.

The current methodology is a useful research tool, with the understanding that the results should be interpreted as directional, and not as absolute predictions of expected in-service results.

Duty Cycle	Candidate 1	Candidate 2
Switcher	(3.9 ± 3.6) %	(6.3 ± 3.0) %
Line-haul	(1.3 ± 1.9) %	(1.8 ± 1.5) %

Table 8. Estimated results for "grouping" method ± s.d.

ACKNOWLEDGEMENTS

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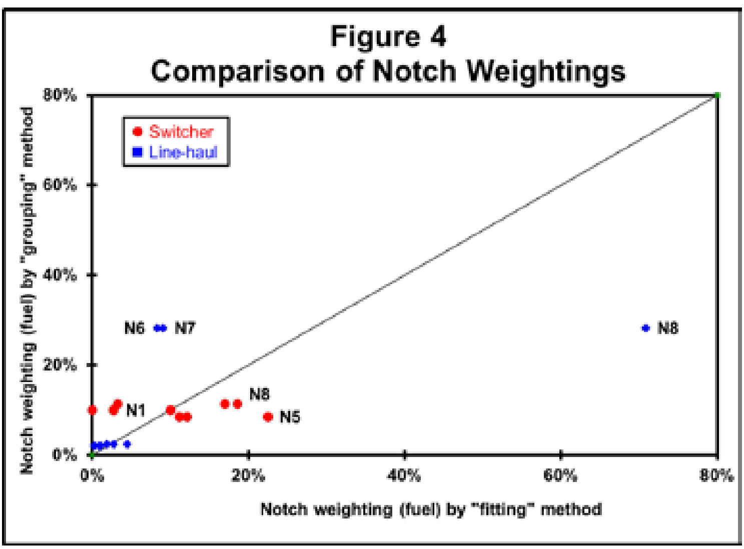

Figure 4
Comparison of Notch Weightings

Locomotive Engine Coolant – Best Practices

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Abstract

Anecdotal evidence has suggested there is "room for improvement" (aka 'saving money' and 'increasing reliability') in locomotive cooling system maintenance. Prior LMOA papers have focused on foundational information, however this paper focuses on "Best Practice" recommendations based on a recent survey of current Class 1 locomotive coolant maintenance. Locomotive cooling system health (or damage, read "cost") is related to the cumulative average coolant quality over the lifetime of the locomotive. Maintaining coolant 'health' will provide many benefits over the lifetime of the locomotive. These benefits will most likely not be noticeable in any one factor on any specific locomotive, but will improve many aspects of locomotive availability, reliability and efficiency over the entire fleet.

Background

In 2017, the LMOA Mechanical Committee presented the paper, "*Water Treatment of Cooling Systems*[1]." The paper gave a good foundation on the subject, covering base cooling water requirements, what water treatments do, how to check cooling system inhibitors, and what can happen to engine and cooling system components if proper maintenance is not performed.

This Fuels, Lubes & Environmental (FL&E) Committee paper builds on the 2017 paper, with a focus on "best practice" recommendations based on a recent survey of current Class 1 railroad practices.

The corrosion inhibitor used in water-only cooling systems traditionally found in EMD and GE locomotives is commonly referred to as a Supplemental Coolant Additive (SCA), and is generally a nitrite/borate or nitrite/molybdate/borate formulation. The recommended concentrations can vary depending on formulation and manufacturer, so it is best to check with your supplier for recommended testing methods, target treat rates, and concentrations in treated water.

Cooling system damage may manifest in many conditions other than cooling system leaks. Many of these manifestations are slight reductions in operating efficiency or longevity (read: slightly increased cost of operation) over the lifetime of the locomotive, as opposed to sudden catastrophic failures on any given day. Examples include engine overheating due to plugged coolant passages in radiators, cylinder Head / Liner / Piston (HLP) damage due to localized 'hot spots' from scale build-up, and loss of 'core value' due to excessively corroded/damaged components. Additional considerations are lower fuel efficiency and/or lower engine power output due to inability to maintain proper engine operating temperatures cooling fans having to work harder and more often. Ancillary component damage – shorter life of O-rings, gaskets, water pump seals/impellers, transfer pipes, etc. due to both excessive heat and accelerated corrosion.

It is entirely possible, even likely, to enter a 'vicious circle' of locomotive coolant quality, where poor coolant quality leads to a higher rate of engine downtime and more time spent on large / major repairs. More time spent on large repairs means less time available to troubleshoot small leaks. Small leaks mean more coolant top-offs and fills, increasing the likelihood the locomotive will be topped off with 'tap water' to 'get by' until the next shopping. Topping off frequently with alternate coolant / water sources leads to poor coolant quality. The cycle repeats.

There are three categories of specifications applicable to locomotive cooling water. Each category of specification is roughly aligned with the state of water or coolant at the particular point in the process:

1. "Raw Water" - Untreated water that is subsequently mixed with SCA to make Treated Water.
2. "Fresh Locomotive Coolant" - Fully additized and SCA treated water used to fill or top-off locomotive cooling systems.
3. "In Service Locomotive Coolant" - SCA treated water that is already in the locomotive cooling system.

Raw Water Specifications

It all starts with the water - raw water quality is very important to the locomotive coolant quality, which in turn affects locomotive cooling system performance and longevity. Assuming that because your water supply may meet drinking water standards and therefore must be good enough for the locomotive cooling system, may not be valid in many cases. Table 1 lists the ASTM D6210 specifications for raw, untreated water used as the basis for coolant in diesel engine cooling systems. Wabtec (GE) maintenance instructions MI-09500, Rev. F, and Progress Rail (EMD) Maintenance Instruction 1748, Revision I, both include the same requirements as ASTM D6210 Specifications, except neither specify a pH value.

Table 1. ASTM D6210 Raw Water Specifications

Property	**Specific Values Test Method**	**Test Method**
Total Solids, g/g (ppm), (grains/gal)	340 (20) max	Fed Method 2540B
Total Hardness, g/g (ppm), (grains/gal)	170 (10) max	D1126
Chloride (Cl), g/g (ppm), (grains/gal)	40 (2.4) max	D4327
Sulfate (SO4), g/g (ppm), (grains/gal)	100 (5.9) max	D4327
pH	5.5 to 9.0	D1293

Raw water quality varies greatly by region. One property of water many people are familiar with is hardness, which is the amount of dissolved calcium and magnesium in the water. Why be concerned about the hardness of the water? When hard water is heated, such as in a locomotive engine, solid deposits of calcium carbonate can form. This scale can reduce the heat transfer of radiators and oil coolers and can reduce water flow as it clogs pipes. Figure 1 shows a map of water hardness in Canada, and Figure 2 for the lower 48 United States, and shows significant areas of the country indicating very hard water (> 240 ppm, or >10.5 grains/gallon), which exceeds the ASTM D6210 Total Hardness specification, and large additional areas where water is considered hard at 7 to 10.5 grains/gallon. In San Antonio, Texas, the municipal water supply hardness is typically 15 to 20 grains per gallon, nearly twice the maximum allowable level in D6210.

So, what does this mean for our LMOA members? Know your water. Look at the map in Figure 1 in relation to where your locomotive shops are located. If it is in a red or orange hard water region, ask some questions of your facilities team about the water supplied to filling locomotives. Is it raw municipally-supplied water? Or is it processed through a water softener to reduce hardness? And if so, is that system regularly maintained? One sure way to assess if your raw water supply used to fill locomotives is "fit for purpose" is to take samples for ASTM D6210 analysis.

Most locomotive cooling system treatments are formulated assuming that the raw water meets ASTM D6210 specifications. Having your raw water tested by a reputable laboratory will help determine if additional steps are needed before the additive blending process can begin.

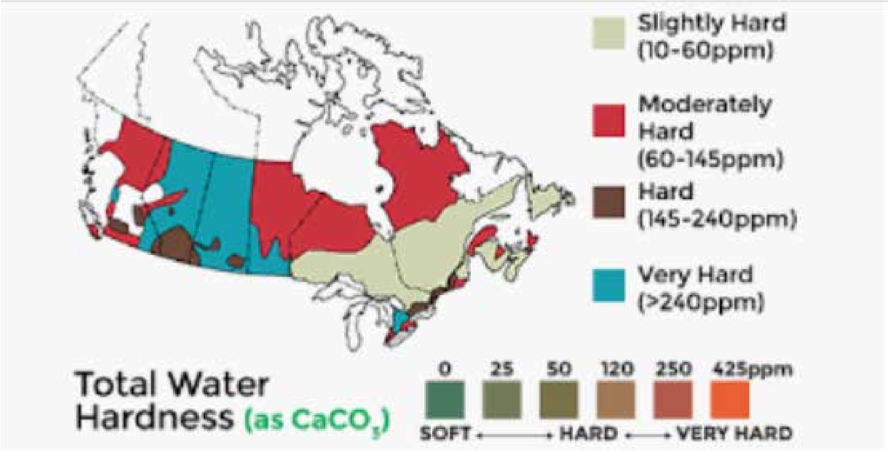

Figure 1. Water Hardness Map in Canada

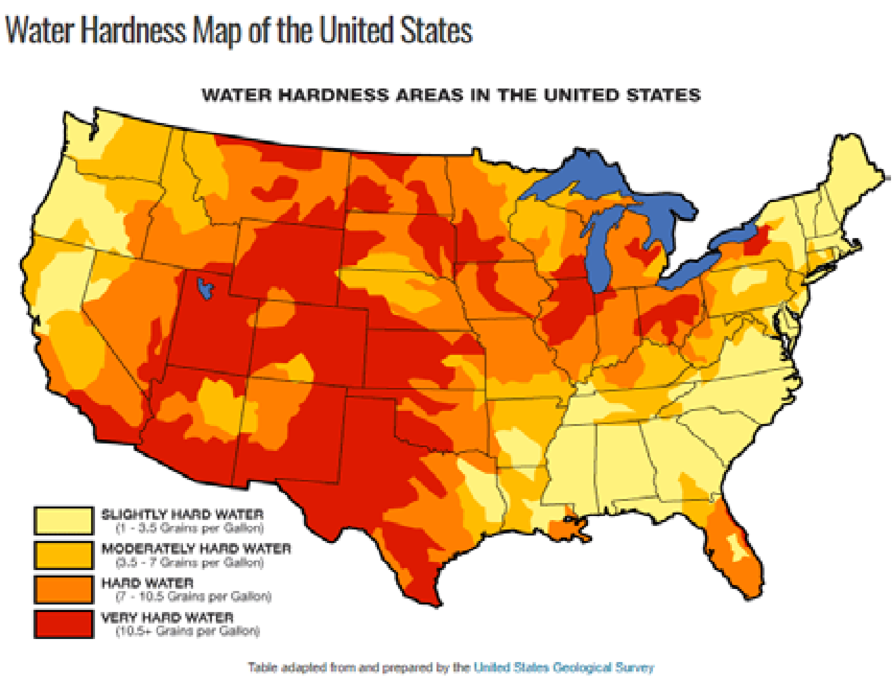

Figure 2. Water Hardness Map in the United States

Up to this point, the focus has been on raw water hardness, simply because this water property is very familiar to many people. Other key factors to consider when assessing raw water quality include:

Sulfate: May promote the formation of Sulfate Reducing Bacteria (SRB), which can combine with calcium to form calcium sulfate scale.

Chlorides: Corrosive to metals

pH: Low pH (acidic conditions) can promote corrosion of metals.

Best Practice:

If your raw water does not meet ASTM D6210 specifications, two main options are available:

1) Check with your coolant additive vendor to assess if the treatment you are using is compatible with your raw water. If not, other coolant additive treatments may be available that will work better with the raw water available at your facility.
2) Consult with water treatment professionals in your area to determine if a pre-treating step such as filtering, water softening, deionizing or other steps can allow your water source to meet ASTM / OEM requirements for raw water.

Locomotive Coolant - What is being done now?

Current North American railroad industry practice often relies on either locomotive cooling water color or a conductivity measurement of a coolant sample to determine if there is enough additive in the locomotive cooling water. Most inhibitor packages have a dye or indicator blended into their package. Dyes color the solution and the color is roughly indicative of how much additive is in the cooling water. Indicators are representative for both how much additive is in the cooling water, and if the additive is at an effective concentration. If released into the environment, the dye will remain visible until it is diluted to the point at which it is no longer visible or “weathers” away. An indicator will turn clear when the solution is no longer effectively preventing corrosion. A simple color chart can be employed to determine if the treatment has fallen below recommended levels and how much additive should be used to replenish the system.

Figure 3 shows a locomotive cooling system sight glass that is full of “coolant”, suspected to be low on water treatment, based on near lack of color. Although color is rudimentary, it is a quick way to identify a potentially low treatment level and possibly get the system dosed (sweetened), especially if there is an obvious lack of treatment. This method is invaluable for locomotives that have significant coolant leaks. After filling a low cooling system with raw water, the mechanic can add a base amount of additive, allow the coolant to recirculate and then submit a sample to the laboratory for a more definitive analysis.

Figure 3. Locomotive Sight Glass with Suspected Low Level of Water Treatment

The argument can be made that this method thwarts efforts to identify coolant leaks in a locomotive fleet. Depending on whether the mechanic logs the maintenance activity of adding water and coolant treatment, and if that railroad's procedures include submitting lab samples before or after "sweetening" with coolant additive, coolant additive trend analysis by the laboratory can easily be confounded. Management will have to determine the priority of maintenance and weigh the risks of having an unprotected cooling system vs. the diagnostic advantage that can be gained by using a trend analysis to identify leaking cooling systems.

Conductivity measurement is a more accurate measurement of corrosion inhibitor in the system compared to color. Conductivity meters are rugged enough to be used in a shop environment yet accurate enough for laboratory use. If the meters are to be used in the field, a program must be put in place to calibrate them on a regular basis. Most reputable corrosion inhibitor providers have dosage charts prepared that compare conductivity to inhibitor levels in the water.

Conductivity measurements are affected by the water used to fill the locomotive. In general, poor quality water has a high conductivity which in turn skews the amount of corrosion inhibitor that is called for by the analysis. In closed cooling systems, a "concentrating effect" of the contaminants that cause poor water quality is not anticipated. It is believed that when the water leaks from a locomotive, it takes with it the corresponding amount of water impurities. One caveat is that the water impurities react to form scale or sludge, and are therefore removed from the water and no longer affect the conductivity measurement.

There are much more accurate methods for determining corrosion inhibitor levels. The method that is most used (behind color and conductivity) is a measurement of nitrite (as Sodium Nitrite - $NaNO_2$) concentration. Nitrite is an important part of most locomotive cooling water treatment - corrosion inhibitor packages. Analysis of nitrite is usually not affected by water quality and is a direct measure of the capacity of the inhibitor in the cooling water to protect ferrous metals. Dropwise titration nitrite test kits for the field are relatively inexpensive, accurate, and simple. Laboratory nitrite tests can be performed with an auto-titrator yielding quick, inexpensive testing for a large number of samples. Before implementing a nitrite analysis based program however, check with your water treatment - corrosion inhibitor provider to ensure the inhibitors in the package they are providing degrade at the same rate or slower than the degradation of nitrite.

Two other methods of assessing locomotive cooling water that are of note are dye-traced inhibitor packages, and laboratory analysis of inhibitor concentrations. In dye traced inhibitor packages, a tracer dye is added that corresponds to the level of the inhibitor. The water is analyzed by a pocket size instrument that gives a very accurate analysis of inhibitor level based on the concentration of dye in the sample. This analysis is not affected by raw water quality. A drawback of using tracer dye is that if other inhibitor packages are added to the coolant (e.g., the locomotive was filled on a different railroad), the level of inhibitor present may not necessarily correspond to the concentration of tracer dye.

Laboratory analysis of inhibitor concentrations is used in trucking and industrial closed loop cooling systems. The tests provide levels of all inhibitors in the system, as well as other parameters that are indicators of cooling water suitability. In addition, metal concentrations can be monitored in the cooling water to see if there is corrosion or erosion damage being done to any of the cooling system components. This program has proven to be cost effective in systems that do not routinely leak. In the trucking industry, mechanics are able to "sweeten" their systems with specialized inhibitor packages designed to replenish the inhibitors that have become depleted as indicated by laboratory analysis. Current experience is that locomotive cooling systems are prone to leaks which makes laboratory analysis more challenging.

Over the years, there have been several issues concerning dye and color indicators in locomotive cooling water. The function of the both is to a) make it easier to read the coolant level in the sight glass and b) quickly determine if the system is treated and to get a rough indication of what level of treatment is present.

The use of a pH sensitive indicator (phenolphthalein) has seen prevalent use in the industry. There are several advantages of a pH sensitive indicator:

1) As the inhibitor package becomes depleted in the system, the coolant becomes clear indicating it is no longer effective. For cooling water that has been treated with dye, the water becomes gradually clearer in a linear trend as the inhibitor becomes depleted and may have an observable color at ineffective inhibitor concentrations.
2) If the coolant is released to the wayside, it will quickly become clear as the coolant "weathers."
3) Because the dyes used are persistent, the water drained at maintenance facilities often has to be treated to remove the color before it can be released either to a waterway or local sewer system. Usually this involves activated carbon adsorption. This can affect serviceability between railroads because different colors and concentrations of dye are used by other railroads and another railroads facility may not have the capability to treat the dyed cooling water. Phenolphthalein indicator on the other hand turns clear at neutral pH's.

There have been complaints about phenolphthalein indicators turning clear even when there was adequate treatment and the pH of the cooling water was at a level that the phenolphthalein indicator should have turned pink. There have been theories that this was caused by a depletion of the azole in the cooling water, which has not been verified. One inhibitor package manufacturer has made claims that they have proprietary technology that prevents "clear coolant."

Best Practice:

Analyzing coolant water inhibitor strength by conductivity remains the most expedient method. Inhibitor packages should have a dye or indicator to aid in reading the sight glass and determining if there is inhibitor present. Maintenance managers will have to decide if their procedure will call for "sweetening" base on color observations. Laboratory analysis of cooling water can be used to investigate recurring issues.

Railroad Survey

In preparing this LMOA paper, a targeted informal survey was made of the Class 1 railroads, plus a large passenger railroad, and a commuter railroad. Survey response was good, with all but two Class 1 railroads responding. Presented below is a summary of the locomotive coolant practices for each railroad surveyed.

Railroad A - Annual inspection includes a Task for signs of visible coolant leaks along with a cooling system pressure check. There is no routine sampling of coolant at a central lab. A Task listed for each locomotive shopping event includes an "eyeball" look at the coolant level sight glass for level and for color, and note pink, brown, or clear. If the coolant level is low, and/or the color suggests inadequate water treatment, fill the system with water then draw a sample from sight glass and run a conductivity check. The Task for that locomotive should include a chart with what the conductivity should be, and if low, how much water treatment to add based on reading. The mechanic is supposed to retest and log after fill + treatment.

Water dumps in cold weather offer a chance for a fresh treated water charge. However, if it dumps in a location without water treatment, it will get plain water.

If coolant is drained for engine maintenance, it will get a fresh water charge with treatment at that shop.

Railroad A has experienced some events of OEM feedback on severely rusted cores returned for UTEX, judged too badly damaged, resulting in scrap. It is difficult to quantify actual dollar amount these issues have cost

Railroad B - This commuter railroad takes a coolant sample every 92-day inspection and checks for Nitrites. They sweeten the coolant with bags of water treatment as needed, based on these measurements. During maintenance events which require draining the coolant, they sometimes capture the coolant and reuse in the locomotive.

Railroad C - Has a very comprehensive locomotive engine coolant monitoring program, drawing a coolant sample every 10-days concurrent with a lubricating oil sample. Both samples are sent to a central lab for analysis. The lab runs a conductivity test, and based on those results, will issue a work instruction to add a specific amount of water treatment to the locomotive at the next shopping event.

Railroad D - Takes a very different approach, draining the coolant on each locomotive at 6-month intervals and replacing it with fresh water and water treatment.

Railroad E - The concentration of the water treatment is checked every 15 days for conductivity by the laboratory, and when instructed, appropriate additions of water treatment must be made each time a locomotive is shopped for maintenance or whenever water additions are required. If the lab visually notes heavy sediment, they recommend back to the shops to change the coolant. When heavy sediment is noted, it is often due to rust, carbon, or oil.

Railroad F - Coolant levels are checked as part of service island inspections and topped up as required. This railroad does not have an active coolant sampling program in place. This railroad reports they are in the process of upgrading their shop water systems to improve filtration and coolant chemistry with inline monitoring. The program will extend to service islands in 2020. Some of the shops have continued with pH testing, but this practice is not consistent from location to location.

Railroad G - Is a passenger railroad that operates using water-based and glycol-based cooling systems. They test the glycol-based coolant for each locomotive. Coolant samples are taken annually and sent to a laboratory for analysis of Freezing Point (ASTM D-3321), pH (ASTM D-1287), Reserve Alkalinity (ASTM D-1120), and Spectro Analysis (ASTM D-6595). Water-based coolants are not lab tested. Locomotive coolant level and color are checked daily.

Best Practice:

Based on the informal survey results, the FL&E Committee recommends that railroads should consider routine coolant testing, and respond to those test result with the correct course of action.

Processes for Cooling Water Treatment Maintenance:

A systematic overview of the processes involved in Cooling Water Treatment Maintenance can be found in Appendix A. This overview discusses the options for each process and weighs the pros and cons. A list of recommendations is also listed to provide guidance for Engineering Staff determining their Maintenance Program.

Coolant Sediment Analysis:

SwRI performed an analysis of three locomotive coolant samples that exhibited sediment in coolant samples. Two of the three samples are shown in Figure 4 before and after shaking to agitate sediment that was clearly evident in the samples.

Figure 4. Locomotive Coolant Samples before and After Shaking Sediment

A WITS (what is this stuff?) analysis was performed on the sediment. The coolant samples were filtered and analyzed by *ASTM D5452 - Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration*, with the results given in Table 2. Note that ASTM D5452 is normally used for determining particulate contamination in aviation fuels, but was a readily available procedure to quantify particulate contamination in the locomotive coolant samples. Table 2 shows that the particulate concentration ranged from 44.3 to 121.6 mg/L. These results are presented for reference, as there is nothing to compare them against other than themselves, but all three samples had clearly visible sediment in the coolant samples drawn. The lab also reported that these were "heavily contaminated samples", but if they normally see aviation turbine fuels, maybe that is a good thing.

Table 2. Particulate Contamination of Three Locomotive Coolant Samples

ASTM Test	Description	units	Sample A	Sample B	Sample C
D5452	**Contamination**	**mg/L**	44.3	121.6	95.3

Next, the particulate samples from the three filtered locomotive coolant samples were analyzed using XRF for metals, and the results are given in Table 3. The high concentration of oxygen is expected with an elemental analysis such as XRF if the compounds expected are oxides, like iron oxide (Fe_2O_3) (rust) or silicon oxide (SiO_2) (quartz - sand). Locomotive A appears to have notably higher rust levels than the other two locomotives. Also, for locomotive A, the presence of calcium and magnesium suggest the possibility of hard water being added to the system at some point.

Table 3. Locomotive Coolant Sediment XRF Results

Lab ID	51453	51454	51455
Element	Conc, wt. %		
O	51.9	63.7	73.4
Mg	5.9	1.8	4.8
Al	0.4	0.6	0.9
Si	13.9	18.9	15.9
P	ND	ND	0.2
S	5.3	6.0	2.3
Ca	5.3	0.4	0.4
Fe	12.9	1.5	1.9
Cu	3.8	6.5	0.3
Zn	0.7	0.7	0.1
sum	100.0	100.0	100.0
Loco Age	23	5	18

X-ray diffraction analysis of the sediment from one locomotive revealed chemical compounds such as sodium borate and sodium nitrite, as expected from the corrosion inhibitor package. Compounds such as iron oxide "rust" were also identified suggesting 'typical' corrosion in the system. However, compounds such as copper sulfide, iron sulfide and sodium iron silicate were also identified which suggested a much more complex corrosion mechanism, possibly involving sulfide forming bacteria.

This testing may not be indicative of solids you may find in your system. It does however show different techniques that can be used and what conclusion can be drawn based on the analysis.

<u>Best Practice:</u>

The presence of solids and the determination of the makeup of these solids can help determine key practices for maintaining the cooling system such as: A) the additive package used and B) if the water needs to be conditioned and C) if the systems need to be flushed on a regular basis.

Protecting Locomotive Cooling System Components

Locomotive cooling systems are very susceptible to leaks. Minimizing the amount and severity of leaks requires a disciplined approach that takes into account the age of the component and the level of care it has received, the metallurgy and design of the components, the elastomers that join the components together and the corrosion inhibitor package being used as well as how the inhibitor levels are maintained.

A wide variety of metals are used in the cooling systems (See Table 4). This varies based on manufacturer and locomotive model. Each of these metals has particular properties that were taken into consideration when designing the system.

Table 4. Materials Commonly Found in Locomotive Cooling Systems

Metal	Type	Component
Yellow Metals (Copper Based)	Red Brass, Admiralty Brass, Brazing Filler Metals	Radiator, Oil Cooler, Fuel Heater Heat Exchanger and Brazed Joints of These Components
Ferrous Metals	Gray iron, cast iron/ carbon steel, Low carbon steel, Cast iron, Alloyed cast iron, stainless steel	Heat Exchanger Block Water Pump, Pump Impeller Thermostat Housing Coolant Transfer Pipes
Fusible Metals	Lead, Tin	Solder Joints – Radiators, Some Heat Exchangers

It should be noted that at this time aluminum is not used by the major OEM's for locomotives. This may change in the future but concerns over durability and compatibility with cooling water chemistry have been cited in the past as reasons for not using aluminum. In addition, because locomotives are generally not concerned with component weight there has been no clear advantage to switching to aluminum components as seen in trucks and automobiles.

Because each metal has specific characteristics, the corrosion inhibitor should provide protection for all metals used. Inhibitor manufacturers will blend several chemicals into a "package" that provides corrosion protection for all the metals listed. To test the efficacy of the corrosion inhibitor package a glassware corrosion test should be performed as set forth in ASTM 1384 "Corrosion Test For Engine Coolants in Glassware." The OEM's have set requirements for this test to include the metals to be tested and the level of metal degradation that is allowed.

Failing to protect the metal components can lead to sludge, scale, and corrosion. Inspection of failures can provide insight to your maintenance program. If there is a recurring failure, the program should be reassessed.

Figures 5 and 6 provide a good example of locomotive cooling system corrosion, with Figure 5 showing a GE FDL engine water header with what appears to be a small hole -- *"It doesn't look too bad - from the outside. Just one tiny leak."* Figure 6 shows the inside of that same pipe, with severe corrosion.

Figure 5. GE FDL Engine Water Header

Figure 6. Corrosion Inside GE FDL Water Header Shown in Figure 5

In addition to metal surfaces, the cooling system also has elastomers such as O-rings and gaskets. Examples include Nitrile, Silicone, Fluorocarbon and Styrene-butadiene. Each of these is susceptible to chemical attack by the additive package and should be tested. The OEMs have specific standards set out for testing corrosion inhibitors which include methods to be used and specific elastomers to be tested.

Impact on Component Core Values

Some railroads identify costs associated with 'corrosion' (only), including for example replaced radiators, coolant pipes, water pumps, and overheated engines. Other component costs impacted by deteriorated coolant might include seals, gaskets, and hoses. The challenge is that cooling system health is due to the average coolant conditions over a multi-year time frame and may mean that a radiator that is expected to last 8 years only lasts 5-6 years. Any given coolant-related failure may necessarily not be due to 'poor' coolant quality in the locomotive on that day.

New Developments

The US railroad industry has lagged behind when implementing new cooling inhibitor technology. This is partly due to the nature of the engines needing constant replenishment due to leaks and dumping of cooling treatment in cold weather with "Guru Valves".

Concentrated borate/nitrite formulation is a recent development. Sodium Nitrite is very soluble in water, but solubility changes notably with temperature:

Sodium Nitrite Solubility in Water

71.4 g/100 mL (0 °C)

84.8 g/100 mL (25 °C)

160 g/100 mL (100 °C)

Very concentrated solutions can be made - approaching 85 g/mL, but the concentrate may be susceptible to solids falling out of solution particularly in cold weather.

One advancement widely used in long-life antifreeze for automotive and on-highway trucks is Organic Acid Technology (OAT). In areas with strict environmental regulations, operators have had to switch to this technology, as both boron and nitrite have faced environmental restrictions. The advantage to OAT inhibitors is their low treat rate and long life. The disadvantage is that they are not compatible with traditional Borate/Nitrite treatments.

A "hybrid" OAT/Borate/Nitrite treatment (also called "stabilized nitrite") has been used in other industries over the past 20 years. It offers the long life of OAT but is also compatible with other Borate/Nitrite corrosion inhibitors.

These treatments offer some reduction in “sweetening” because of their long life. As OAT technology becomes more prevalent, the pricing of these products has become more competitive. Hybrid treatments usually have superior corrosion inhibition as compared to traditional borate/nitrite. A bonus advantage is that the OAT passivation layer on the metal surfaces continues to protect the system even when the corrosion inhibitor level drop below effective treat rates.

Conclusions

Locomotive cooling system health is related to the cumulative average coolant quality over the lifetime of the locomotive. Maintaining coolant ‘health’ will provide many benefits over the lifetime of the locomotive. These benefits will most likely not be noticeable in any one factor on any specific locomotive, but will improve many aspects of locomotive availability, reliability and efficiency over the entire fleet.

Effective water treatment serves many functions, including corrosion inhibition, reducing scale build-up (hard water deposits), and reducing ‘impingement’ / cavitation damage.

An informal survey of five Class 1 freight railroads, and two passenger railroads reveal that current locomotive coolant maintenance practices vary significantly.

Overall Best Practice Recommendations

The LMOA FL&E Committee recommends the following related to locomotive water-based coolant systems:

- Have a locomotive coolant maintenance plan for your railroad and strive to follow that plan.
- Compare your railroad’s plan against OEM cooling system maintenance recommendations.
- “It all starts with the water” - assess the raw water at your various service locations compared to the ASTM recommendations in D6210. Pick hardness as a starting point.
- If your maintenance facilities have water treatment systems for the raw water used to fill locomotive cooling systems take steps to make sure they are being properly maintained.
- Review the guide in Appendix A of this paper for troubleshooting and a process guide.

Process	Options	Pros	Cons	Recommendations
Source Suitable Water	Analyze water at each location to determine if it meets ASTM 6210 requirements (See Table 1)	Provides best corrosion control Makes cooling water treatment last longer Provides consistent water quality at all locations	Water softeners are expensive Water softeners require periodic maintenance and consumables	Softening may be required
	Use Tap Water	Easiest Cheapest	Impurities can contribute to scaling, fouling, incorrect dosing of inhibitors, premature inhibitor depletion	Contact your coolant provider to determine if the package is suitable for your water (hard water tolerant)
Refill Empty Locomotive	Fill with pre-diluted coolant	This is the best option if you have facilities (a "make-down" system that dilutes concentrated corrosion inhibitor to recommended levels) available.	May not be available every time a locomotive needs coolant.	Fill empty coolant systems with pre-diluted coolant.
	Fill with fresh water and dose full system with concentrate	Does not require make down system	Not as precise as a make down system Not as convenient	Acceptable, but requires knowledge of cooling system capacity and dosing rates to compute the proper amount of additive.

Process	Options	Pros	Cons	Recommendations
Fill Coolant System that is Low on Water	Top off with fresh water and sweeten	Quick and minimizes immediate engine down-time.	May not adequately protect the system from corrosion.	Requires knowledge of cooling system capacity, amount of water added and dosing rates to compute the proper amount of additive
	Drain and fill with pre-diluted coolant	Provides the correct amount of treatment	Wastes time, and coolant	Not recommended unless the facility has a coolant recycling system. However, simplifies the task greatly
	Top off with pre-diluted coolant	May not provide the proper overall treatment level	Will provide some additive to the system	Will likely provide adequate protection but an analysis will be required to determine actual inhibitor levels
Sweeten Full System	Drain and fill with pre-diluted coolant	Provides the correct amount of treatment	Wastes time, and coolant	Not recommended unless the facility has a coolant recycling system. However, simplifies the task greatly.
	Add concentrate	Quick brings systems that are low on additive up to recommended levels	Requires dosing charts or lab test to determine Proper dosing	The best option, especially when in areas that are not climate controlled
Set Interval for Checking Cooling System - Water Level	At every refueling or Sand, Fuel & Service event (SFS))	Provides a convenient interval to monitor coolant level	Because most of the time the coolant level is correct it can lead to complacency	Checking the cooling system level at each fueling will ensure that the system has enough water on hand and eliminate shutdowns. This is especially important during the winter when the system may be automatically drained because the coolant got too cold

Process	Options	Pros	Cons	Recommendations
Set Interval for Checking Cooling System - Inhibitor Concentration	In synch with taking oil analysis	Convenient interval and provides a reasonable level of control of cooling systems that are in good repair	Interval may not provide the level of control needed to provide consistent treated coolant to leaking systems	Take coolant samples whenever taking oil analysis samples.
	Check for color every time system is checked for water level	Provides mechanics with a quick snapshot of whether there is water and inhibitor in the water	Color analysis is not precise and prone to providing false positive and negative results	Check for color every time the system is checked for water level. Laboratory technicians should report when they have analytical results that don't correspond to the visual inspection of the sample

Process	**Options**	**Pros**	**Cons**	**Recommendations**
Determine the Amount of Coolant in the System	Color	Quickest method and allows for immediate additions to protect cooling systems	Least accurate method of determination. Depends on the judgement of any given individual observer.	
	Conductivity	A more accurate method of analysis. Can be used in the field or in a laboratory.	Contaminants in the system will result in false readings.	Conductivity provides a good all-around analysis with reasonable accuracy. The equipment is rugged enough for field use
	Nitrite Test	Accuracy of +/- 5% or better, contaminants generally do not result in false readings. Available in test kits for the field or automated systems for laboratories	Requires expertise to perform the test in the field, or a laboratory controlled test.	Nitrite is a superior method for testing inhibitor concentration. Mechanics may find the field test tedious. laboratory analysis can be done efficiently with an auto-titrator
	Laboratory Analysis	Most accurate. Can provide a more complete overview of the condition of the coolant and the cooling system	Cost and time delay between obtaining the sample and receipt of the results.	Laboratory analysis provides the most comprehensive snapshot of the coolant and the cooling system. Because it is expensive, laboratory analysis may be employed just on systems that are problematic

Drain Coolant System	Every 6 months if not already done by cold weather dump	Ideal from a 'planned maintenance' perspective.	Some locomotives may not be protected for the entire 6-month period, or some locomotives may still have adequate protection at the end of the 6 month interval.	Draining the cooling system routinely prevents solids from building up which can foul heat transfer surfaces and wear soft metal cooling system parts
	Drain only as needed	Optimal use of resources - additional steps are performed only on an 'as needed' basis.	Requires frequent testing / analysis of the coolant and routine maintenance to insure corrosion inhibitor levels are maintained.	In northern zones where the coolant is dumped in the winter, draining may not be necessary. For locomotives that are captive in southern climates and there is visual evidence of solids in coolant samples, periodic draining is recommended
Flush Coolant System	Only if solids are present in sample	Optimal use of resources - additional steps are performed only on an 'as needed' basis.	Requires testing / analysis of the coolant to make a determination.	Flushing will help remove built up solids and improve the efficiency of the system
	Every time the system is drained	Best way to ensure the system is as clean as possible.	Added time / effort / money required.	Recommended if hard water is used to fill the system.
	Every time the system is removed from long term storage	Ensures the system is as clean as possible. Removes build up formed due to potential improper storage	Added time / effort / money required.	Flushing will help remove built up solids and improve the efficiency of the system
	Not Flushing System	No immediate downtime.	Can lead to issues such as overheating due to plugged coolant passages. Unplanned downtime.	Mechanical staff should determine this based on tear down inspections of the locomotive. If the radiators or lines have a build up of solids then flushing should be part of the regular maintenance schedule.

Performance Review of OEM Specifications for Traction Motor Support Bearings

Prepared by:
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Abstract:

Recent investigations into prior traction motor support bearing failures have led to questions regarding the performance of OEM recommended traction motor support bearing (TMSB) oils in relation to journal box bearing (JBB) oils. Specifically: "is it acceptable to use TMSB oils in traction motor support bearings as well as journal box bearings?" and "Will problems arise when using JBB oils in a traction motor support bearing?". This was answered in the 2019 paper presented to Locomotive Maintenance Officer's Association: Fuels, Lubes and Environmental Committee (LMOA FL&E) - REVIEW OF AAR M-963-84 All-Year Journal Box Lubricating Oil specification.

The following report details background, research, discussion, and recommendations of the FL&E Committee regarding the OEM recommended oils to be used for lubricating traction motor suspension sleeve bearings with felt wick lubricators. TMSB bearings were discussed in the paper mentioned above. The last time both OEM specifications EMD EMS 1002 and GE DE50E14 were last revised was approximately 20 years ago; both of which recommend specific oils to be used for TMSB.

Background:

In 2019 a paper on journal box bearing oils was presented at 2019 Railway Interchange in Minneapolis. This paper detailed a short line railroad which experienced a failure of a locomotive traction motor support bearing (TMSB). Subsequent examination and failure analysis concluded the root cause of the failure was due to a combination of excessive surface roughness of the axle finish in combination with plugging of the lubricating wick. This plugging of the lubrication wick was a direct result of the incorrect lubricant being used. The lubricant contained elevated levels of sulfated ash which likely came from higher levels of zinc and calcium. The oil reportedly in use carried the AAR M-963-84 All Year Journal Box Lubricating Oil specification, but did not meet either OEM specifications for TMSB oils.

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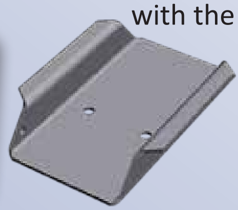

Hyatt Converted to GG Standard

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During the 2019 investigation into one OEM approved TMSB oil, a potential performance concern regarding four-ball wear led to further inquiry and testing which is the basis for writing this paper.

Preliminary Research:

There are two main OEM specifications identified for traction motor support bearings – GE 50E14 and EMS 1002. The GE 50E14 (see Appendix 1) specification is identified as a refined mineral oil specification used for lubricating traction motor suspension sleeve bearings with felt wick lubricators. The GE specification requirements also meet the AAR M-963 specification, however the AAR specification does not meet Specification D50E14. In summary, the EMD/GE TMSB specifications meet AAR, but the AAR specification does not meet GE/EMD.

Table 1: AAR-M-963, EMS 1002 & D 50E14 Specification Comparison

Properties	Test Method	AAR-M-963	D50E14	EMS 1002
Aniline Point °F (°C)	D-611			200 (93)
API Gravity at 60°F	D-287			26.5-29.5
Ash, % (max)	D-482	0.10	0.10	0.05
Flash Point, °F (°C) min	D-92	350	350	380 (193)
Pour Point °F (°C) max	D-97	-35	-35	-35 (-37)
Pentane Insolubles	D-893			0.10
pH	D-664			6.5 (9.0)
Viscosity				
SUS 100°F (38°C)	D-445		260-340	240-340
cSt at 100°C	D-445		8.0-9.4	
SUS 210°F (40°C)	D-445	53-58	52-66	53-58
Viscosity Index (min)	D-2270	100	100	100
Sulfur (max)	D-129		0.80	
Water (max)	D-95	0.10		0.10
Humidity Cabinet Test 120°F (49°C)	D-1748			
100% R.H., 100 hours				3 dots
Rust Protection in Distilled Water	D-665			Pass
Foaming	D-892			no continuous layer
Residuals				
Calcium, ppm				10
Zinc, ppm				10
Water Compatibility Test for Oil				
(Standard Laboratory Practice #117)				1 ml cream
Load Wear Index, kg (min)	D-2783		37	
Weld Point, kg (min)	D-2783		200	
Lubricity, Four-Ball, mm (nominal)	GE-E4B6			
40kg, 1 hr, 75°C, 600rpm	~D-2266		0.35	

Due to the performance concern discovered during the 2019 paper, it was determined running a Four-Ball Wear Test could provide insight into the performance of each oil in a typical traction motor bearing. Several oil candidates were selected and tested to determine if they meet the GE specification. These oils are denoted as Oil A, B, and C and are listed in Table 3.

The Four-Ball Test method ASTM D4172 was used during this study as the GE method E4B6, referred to in Table 1, is no longer available and states D4172 as a replacement. The Four-Ball Test can be used to measure the performance of the lubricant, in this case the TMSB oil, with respect to wear (See Figure 1). During the test the upper ball is rotated against the rest of the balls that are fixed (See Figure 2). The load is performed at fixed conditions for load, temperature, and speed. The rig was set up with the options called for in the test 75°C (standard to D4172), 40 kg (standard to D4172) and 600rpm (modified to E4B6 and 1 hour).

Figure 1: Four-Ball Test Rig

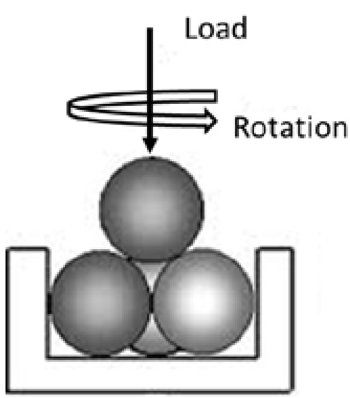

Figure 2: Four-Ball Test Detail

Table 2: Results of Four-Ball Wear Test

Four-Ball Wear Test (600 rpm/40kg/75°C/1 hour)						
Oil	A	A	B	B	C	C
Lab	1	2	1	1	1	2
wear scar, mm	0.417*	0.480	0.383*	0.376	0.348*	0.4

**average of 3 results*

Table 3: Qualification Summary

	AAR-M-963	D50E14	EMS 1002
Oil A - recommended oil	Pass	Pass*	Pass
Oil B	Pass	Pass*	Pass
Oil C	Pass	Pass*	Pass

**See test results on Four-Ball Test based on the nominal lubricity value of 0.35mm*

Three oils were run in two different labs during this investigation. Oil A is on the GE OEM recommended list. Oil B and C are commercially available oils that are believed to perform similarly to Oil A but are not OEM recommended. Due to the repeatability and reproducibility of this test, it is recommended that the oils are run three times and the values of the test are averaged. The typical repeatability of a Four-Ball test is 0.12mm and typically reproducibility is 0.28mm. All results generally fell within the nominal range of 0.35mm.

Conclusion:

Reviewing the Four-Ball Test data, Oil B and Oil C performed better than Oil A. Currently, Oil A is extensively used in TMSB applications without any known issues. Therefore, the Four-Ball Wear Test may not be the best indicator of lubricant traction motor support bearing performance.

Oil A, B, and C all met the physical and chemical properties outlined in both OEM specifications. The three oils were compared using the Four-Ball Wear Test ASTM D- 4172. In the resulting data, only one data point met the GE specification for lubricity wear scar. Considering all historical field performance available and the results of this study, the Four-Ball Wear Test may need to be reevaluated as a performance indicator for TMSB oils.

Recommendations:

There are several tests on the GE specification that are no longer available. One example is a compatibility test that uses a full-scale journal and a section of the babbitted bearing. Therefore, the overall performance of the oils could not be evaluated in this study.

It is recommended that the specification be updated to reflect tests that are currently available as of the publishing of this paper. During this investigation it was discovered, that one of the oils in the recommended list is not available. It is also recommended that the OEMs update their recommended oil lists.

Appendix 1: GE D50E14 Specification

SUPERSEDES ISSUE DATED 12/6/93	GENERAL ELECTRIC	D50E14
	TRANSPORTATION SYSTEMS BUSINESS DIVISION	S 5
	SPECIFICATION AND PROPERTIES	Orders and Correspondence Must Specify Complete Number
TITLE SUSPENSION BEARING OIL		

Specification D50E14 identifies a refined mineral oil used for lubricating traction motor suspension sleeve bearings with felt wick lubricators. This material meets the AAR-M-693 Specification, but the AAR Specification does not meet Specification D50E14. Oils meeting only AAR-M-963 Specification should not be used for traction motor suspension bearings.

Mineral oils meeting this Specification must contain fatty acid and/or fatty oil additives, or additives that provide equivalent performance to help lubricate the bearings under all load conditions.

Materials meeting this Specification are not to be mixed with other oils unless compatibility tests with and without water contamination, up to 10%, show no deleterious effects.

Compatibility

Materials will be considered compatible (stable) if when mixed with a second journal oil (with and without water), the lubricating properties are not altered. This includes both chemical and physical properties. There shall be no reactions or interactions that cause a precipitation or the formation of other compounds, such as carboxyl salts (soaps). All future lubricant request for approval must demonstrate compatibility with the currently approved materials.

Performance testing requirements:

- A performance or screening test must be performed by the vendor, and observed with the data reviewed by GE Transportation Systems Engineering.
- The test will utilize a full-scale journal and a section of the babbitted bearing lubricated under load and speed conditions to simulate railroad service with felt wick lubricators.
- The test will be a comparative test with an approved oil, and comparative measurements of friction and temperature will constitute the test.
- Engineering may provide temporary approval of a candidate oil for field testing, only after successful completion of performance testing with the precise conditions to be mutually agreed upon at the time of approval.

DATE OF ISSUE 3/31/94	WRITTEN BY D.K. Kuhn	APPROVED BY R. B. Foster	PAGE 1	CONTINUED ON PAGE 2

TSBO-2092-A (9-81)

SUPERSEDES ISSUE DATED 12/6/93	GENERAL ELECTRIC	D50E14
	TRANSPORTATION SYSTEMS BUSINESS DIVISION	S 5
	SPECIFICATION AND PROPERTIES	Orders and Correspondence Must Specify Complete Number

TITLE
SUSPENSION BEARING OIL

PROPERTIES	TEST METHOD	AAR-M-963	D50E14
Flash point, COC, F	ASTM D-92	350 min.	350 min.
API Gravity @ 60F	ASTM D-287	---	27-31
Pour Point, F	ASTM D-97	-35 max.	-35 max.
Viscosity (Kinematic)			
cST @ 40C	ASTM D-445	---	52-66
cST @ 100C	ASTM D-445	8-9.4	8-9.4
SUS @ 100F	ASTM D-2161	---	260-340
Viscosity Index	ASTM D-2270	100 min.	100 min.
Ash, %	ASTM D-482	0.10 max.	0.10 max.
Sulfur, %	ASTM D-129	---	0.8 max.
Load Wear Index, Kg	ASTM D-2783	---	37 min.
Weld Point, Kg	ASTM D-2783	---	200 min.
Lubricity, 4-Ball, mm 40 Kg, 1 hr., 75 C, 500 RPM	GE E4B6 (a)	---	0.35 nominal
Compatibility	GE 41A330698	---	Pass

(a) Similar to ASTM D-2266

Manufacture

The oil shall consist of a well-refined petroleum product free from water, sediment and resins, and shall be free from contamination (less than 10 PPM) with calcium and zinc as determined by Spectrometric analysis.

DATE OF ISSUE 3/31/94	WRITTEN BY D.K. Kuhn	APPROVED BY R.B. Foster	PAGE #2 CONTINUED ON PAGE

TSBO-2092-A (9-81)

Report on the Committee on Locomotive Software and Systems

Chair

Viktor Gvelesiani

Director-Strategic Business

ZTR Control System

London, Ontario

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J. Stratman	Mech Loco PTC Onboard Systems	Union Pacific Railroad	Omaha, NE
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PERSONAL HISTORY

Viktor Gvelesiani

Director - Strategic Business Development, ZTR
London Ontario, Canada

Viktor Gvelesiani is a Director of Strategic Business Development at ZTR. He has been working in the railroad industry for 25 years. His extensive work experience has been primarily focused on locomotive modernization, such as diesel-electric and electric locomotive overhauls, modernization of electrical and control systems on locomotives, manufacturing and field service.

Viktor has worked with major railroads all over the world and has in-depth understanding of challenges railroads are facing in today's world. He is actively involved with the AAR Locomotive Committee and Railway Electronics Standards Committee and various task force groups.

Born in Georgia, Viktor obtained Bachelor's Degree in Engineering at Kiev Polytechical Institute (Ukraine) and Master's Degree in Business Administration at Laurier University (Canada). He is a registered Professional Engineer currently residing in London Ontario, Canada with his wife Gillian and daughter Anna. His son Dennis works as a marketing team lead in Toronto, Ontario. Viktor enjoys being outdoors, especially camping, hiking, biking and golfing.

THE LOCOMOTIVE SOFTWARE AND SYSTEMS COMMITTEE WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO WI-TRONIX FOR HOSTNG THE COMMITTEE'S MEETING AT THEIR HEADQUARTERS IN BOLINGBROOK, ILLINOIS ON MARCH 9-10, 2020.

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COVID-19 and Short Line Railroads

Prepared by:
Peter Scholtens
Integrity Rail

Introduction

Like the rest of the world, the North American rail industry has been dealing with the fallout of COVID-19 for some time now. While the world is still trying to adjust and sort some things out, we've been at this long enough now to look back and learn some lessons from our experience. One of the advantages for the rail industry in general is that there are organizations that bring folks together. They can encourage members to spread best practices and solutions that can benefit others in the industry. More specifically, organizations like the ASLRRA and the LMOA can promote and disseminate operational and mechanical best practices. This is particularly true during times of crisis like with the COVID-19 pandemic.

One of the best practices in dealing with times of uncertainty is to arm yourself with the best possible information. This will help you to make decisions quickly and to avoid compounding problems due to a lack of clear understanding and accessibility. I surveyed many contacts in the short line industry to get their feedback on the impact of COVID-19, and to see what kinds of recommendations suppliers might make, especially on the use of technology.

Short lines - Initial Impact

Transportation

During the last two weeks of March and for early April, generally short lines did quite well. Volumes did not decline. In fact, some of the railroads that I contacted said that they were busier than usual. They attributed that to the fact that the Class I railroads had already experienced significant reductions in traffic, especially from unit trains. This resulted in greater fluidity on the Class I networks. As a result, the short lines received their general goods traffic more quickly. The only railroad that I spoke to that was beginning to see reductions early in April was a railroad that was switching autoracks. The automotive industry was hit early and hit hard. That particular railroad was anticipating a 30% reduction in traffic, and planning to park locomotives and furlough transportation staff as a result.

Mechanical Teams

The mechanical staff that I spoke to said that they were dealing with some issues, but overall, they were coping. Many shops reported that they allowed staff who were worried to stay home. However, this added to the workload of those who chose to stay.

I asked all railroads if they had any staff that had tested positive for the virus. One mentioned that two members of his team had symptoms and then were tested. However, 10 days later they hadn't received results yet. So he had staff that were in quarantine, and everyone else was anxious because they didn't know whether they had been exposed or not. It turns out they tested negative. Another stated that the bulk of his time had been taken up trying to find disinfectant spray in bulk, spray bottles, and dealing with the logistics of diluting the concentrated spray and putting it into bottles for his staff.

Mechanical teams implemented split lunches and coffee breaks to keep staff apart. If they had multiple shifts, they separated when shifts came and went, all to reduce congestion and maintain physical distancing. They also maintained physical distancing during their work as much as possible. Locomotive cabs were cleaned and disinfected between crew changes and before maintenance was done.

Sourcing

For the most part no one reported any instances of trouble sourcing material initially. Most suppliers were open, as the railroads asked them to be essential businesses. There were only a couple of instances that I heard about in Canada where suppliers needed to get special permission to reopen as essential business after being closed for a few weeks.

Technology

The short lines contacts I spoke to said that their use of technology hadn't really changed. They were too busy dealing with the immediate impacts of the pandemic to consider these issues.

Short Lines - Medium Term Impact

Transportation

After 4-6 weeks I reached out to my customers again. This was after the Class I railroads were reporting reductions in volume of 15-20% year over year. The results from the short lines were mixed. This was to be expected. Some were staying steady, with minimal declines. These roads were servicing essential businesses, particularly those related to the food supply chain.

Most were seeing declines in the 10-15% range. It was often related to a plant shutdown related to the automotive industry. However, other railroads were seeing significant declines in volume. One railroad, based in New York City, saw drops in volume of almost 50%. A significant part of their freight was construction and demolition debris. Since New York City shut down the entire construction industry, that traffic dried up entirely.

Mechanical Teams

Most railroads kept their mechanical teams at full capacity. They did more work themselves and were less likely to send out machining and fabrication work to outside vendors. That way they were able to minimize layoffs. The other factor that helped to minimize the need for layoffs was the collapse of fuel prices. Railroaders told me that prices dropped from $2.20 per gallon to less than $1 per gallon. Since fuel and labor are the two largest costs to a railroad, the collapse of fuel prices helped to balance the loss of revenue from the reduction in freight.

Within the short lines I spoke to, there were no active cases of COVID-19. I also spoke to someone at the ASLRRA early in May and they reported very few cases in the industry at that time. In addition, they said that there were very few layoffs in the industry. They noted that there was only one railroad that had laid off staff, and that the overall impact was less than one percent of overall staff levels.

I heard from a large Class I railroad that they had a couple of cases at their shops and for the first time since the shops opened 80 years ago, the shops were closed for 2 days to be disinfected.

Sourcing

For the most part, supply chains were fine. However, there were some reports that the larger OEMs had longer lead times. Apparently, they had closed some facilities and were consolidating, although it wasn't clear whether it was because of the pandemic or part of their ordinary business planning.

Technology

Again, most companies are not increasing their use of technology in the short line sector. While they can appreciate the benefits of being able to lower the risk of infection and increase physical distancing during the pandemic, the reduction in traffic has reduced budgets. Mechanical staff have had capital projects cancelled or delayed.

However, those that did have newer remote monitoring technologies found that they were quite helpful. They were able to track events on locomotives more effectively. There were reports that mechanical staff received notice of potential failures even before crews reported issues. In addition, in personal conversation with staff from Wi-Tronix, a large remote monitoring vendor, they noted that a lot more information was being downloaded than during pre-pandemic times. Evidently those with remote monitoring capabilities were taking advantage of it.

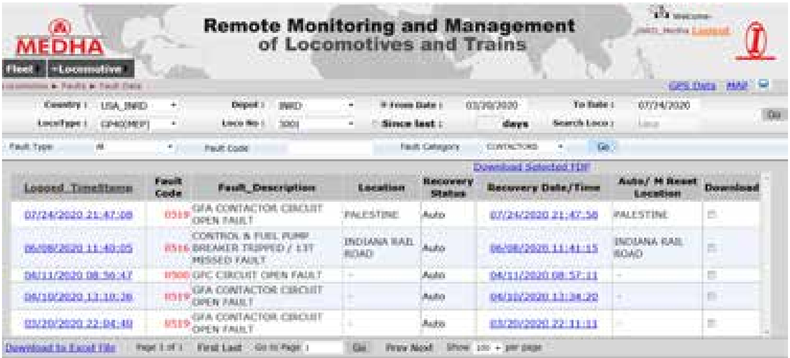

Figure 1: A list of faults available from the remote monitoring of the control system on a mother-slug unit on the INRD

In addition, I spoke to Dan Hamilton from the INRD (Indiana Railroad). He mentioned a specific situation that he believed was of significant importance during the pandemic. Remote monitoring equipment was able to save them significant time and allow them to maintain physical distance with their locomotive maintenance. They were using a locomotive control system with remote monitoring. He received an alert from the remote monitoring system. The issue was significant enough that it meant that the locomotive was down. However, in this case, the fault was also specific enough that his staff knew exactly which part to bring to the locomotive. It saved them extensive time sending a team out to the stranded locomotive and diagnosing the issue.

In Dan's own words, "Locomotive electronic control system technology allows us to reduce the time field personnel interact. By remotely diagnosing road failures we ensure we have the correct parts needed to expedite repairs prior to leaving the shop. Time spent in the locomotive cab troubleshooting and making repairs has been reduced significantly."

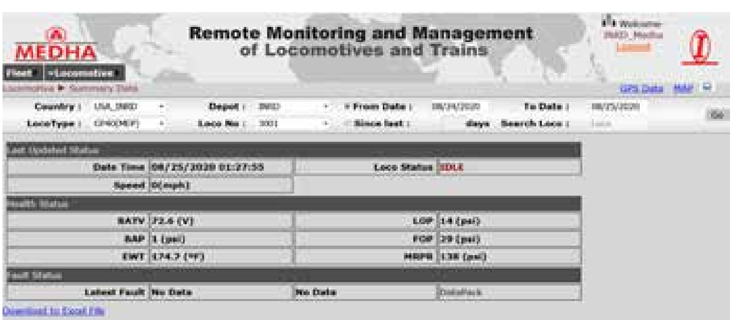

Figure 2: A more detailed view of a fault as seen on the INRD GP40 mother-slug with a control system installed

The specific incident was the identification of PSR contactor stuck situation. With the Locomotive Remote Monitoring System (LRMS), they had prior knowledge of the problem and had the solution ready before the locomotive actually came back to the shop. It took one person about a half hour to fix the problem. Under normal circumstances, this identification of problem and addressing it could have taken two people on the locomotive for maybe about 2-4 hours. As a result, there was significant time savings, as well as a reduction of time working together. This also reduced possible exposure to the virus.

Short Lines - Long Term Impact

Transportation Volumes

As I continued to keep in touch with short lines into late May and early June, freight volumes continued to drop. It was the rare exception to hear about railroads that didn't have drops in volume (although there was one railroad in the northern USA that continued to grow). However, once we were into June, railroads were reporting that they freight volumes reached a bottom and had started to recover. They certainly weren't back to pre-COVID-19 levels, but numbers had stopped dropping.

Mechanical Teams

The reports that I was hearing was that things were largely unchanged. Staff that stayed home had returned because much of the fear was gone. Railroads continued to practice physical distancing, working with separate shifts, separate breaks and lunches, and even keeping teams separate during shifts. This was all to minimize the impact of an infection if one were to occur.

I asked about the general morale. Overall things were good. A number of CMOs reported that they felt that things were better than usual. Their staff were more focused than usual, and there was less goofing around. Whether that was because of the physical distancing or because of fewer distractions in the rest of life, they said it was a pleasant change.

Sourcing

Overall, sourcing seems to have stabilized. Railroads were no longer reporting issues with longer lead times from the larger OEMS. Overall, my sense is that with the reduction in traffic and budget cuts, inventories were restocked and lead times were reduced significantly.

Technology

Overall, technology use remained low. The only bright spot was the same northern railroad that reported increased traffic. They were purchasing new locomotives and having cameras installed from Progress Rail Industries. They were looking forward to having an app on their phones that would have remote access to the data. That way the managers and train masters could make decisions


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about the necessity to drive out to an incident depending on its severity. They already had access to the data during normal times and even more so when crises situations arise, so they didn't have to drive out to download the data. The CMO spoke with enthusiasm about the potential for this technology to save time and money, and increase safety by minimizing the need for interactions between different members of the team.

Conclusions

And perhaps that's a good thought to conclude with. Those railroads that were experiencing success were often the same railroads that were using technology. Having access to technology can make you better and more effective. It can also help to minimize the impact of crises. If you have technology in place, you can take advantage of it when crises hit. It's unlikely that you will be able to purchase and implement it when the crisis hits because of its impact on your time and your budget.

What locomotive technologies should you take advantage of? Remote monitoring and management technologies that simplify the maintenance of the locomotive should be the focus of these upgrades in the future. By remotely diagnosing road failures, you can save significant time and effort diagnosing and replacing parts. It allows you to reduce time spent in the locomotive cab troubleshooting and making repairs.

If you're not realizing the significant benefits that can accrue to your bottom line, your processes, and peace of mind, perhaps it is time to investigate for yourself how much of a positive impact remote health monitoring of your locomotive assets can add – not just for emergencies or pandemics, but for your normal operations. Remote monitoring of locomotive health, fault data management and off-line analysis of fault data packs is truly a "Best Practice" – not for the future, but for the present.

Editor's Note: The short line convention (ASLRRA) scheduled to be held in Texas in May 2020 and the RSI Expo and Education Conference scheduled to be held in Chicago in September 2020 were both cancelled due to COVID-19.

Report on the Committee on Electrical Maintenance

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Amarjit Soora

Senior Manager of Engineering

ZTR, London, Ontario

Vice Chair

Jason Fox

Senior Manger-Mechanical Loco

Union Pacific Railroad, Omaha, NE

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PERSONAL HISTORY

Amarjit Soora, P. Eng

Senior Engineering Manager, R&D and Project Management
ZTR, London Ontario

Amarjit (Am) was born in London England but has spent most of his life in London Ontario, where he went the University of Western Ontario. After obtaining a Bachelor of Science degree in Electrical Engineering in 1996, Am went to work with the Electromotive Division (EMD) in London. While there he had roles within the Engineering team, including Manufacturing Engineering and the Controls Group.

After three years Am joined ZTR, with whom he has been with for the past 20 years. While at ZTR Am has had several roles within engineering including R&D, Applications Engineering and Product Management. For the past ten years Am has managed various teams for domestic and export development projects, and has also led several long term control system programs.

Am currently lives in London with his wife Kulvinder of 23 years, and his daughter Parveen and son Amit. His passions outside of family and engineering include fitness, photography, soccer and the Indian Classical Instrument the Tabla.

THE ELECTRICAL MAINTENANCE COMMITTEE WOULD LIKE TO EXTEND THEIR SINCERE APPRECIATION TO SID BAKKER AND THE TRANSPORTATION PRODUCT SALES COMPANY TEAM FOR HOSTING THE COMMITTEE'S MEETING AT THEIR OFFICE/PLANT IN O'FALLON, MISSOURI ON FEBRUARY 26, 2020.

THANK YOU SID FOR YOUR HOSPITALITY.

AESS & Battery Health Task Force Study

Prepared by:
Sid Bakker – Transportation Products Sales Company

Abstract

The AAR Locomotive Committee created a Task Force to study the existing Automatic Engine Start Stop (AESS) & Battery Charge settings and their effectiveness for the paradigm shift of the locomotive battery application from a "near float" application to a "cycle" application. Today's locomotive lead acid batteries are well suited for both float and cycle applications. However, the charging algorithm must adapt and AESS settings must be optimized to achieve goals for battery maintenance, battery performance, and battery life. These goals must be balanced with EPA compliance and the benefit of fuel savings.

The committee is comprised of railroads, battery manufacturers, locomotive Original Equipment Manufacturers (OEMs), AESS manufacturers and others. The committee researches existing practices, identifies key problem areas, and proposes new strategies and standards to optimize AESS and charge settings.

The Task Force completed a 12-month study where 5 railroads installed the ARMS Locomotive Battery Monitor (ALBM) on 14 different locomotives to capture empirical battery data. This paper reports key findings of the study in the following sections:

- Describe the ALBM test setup and list the participating railroads with various locomotives and batteries being monitored.
- Present example data sets that characterize the battery applications of the various locomotives under test. Provide analysis of the charge algorithms, AESS settings, and onboard battery monitoring equipment.
- List key findings from the study including lessons learned and recommended actions.
- Prioritize a list of short-term and long-term objectives that will have the most impact on improving life and performance of the locomotive battery.
- Conclusions

Acronyms

AESS	Automatic Equipment Stop Start
ALBM / LBM	ARMS Locomotive Battery Monitor / Locomotive Battery Monitor
LVD	Low Voltage Disconnect
SOC	State-of-Charge
DOD	Depth-of-Discharge
Ah	Amp-hours

Locomotive Battery Monitor Setup

The pictures in Figure 1 show ALBM installations on the 5 participating railroads. The install team was able to install an ALBM on up to three locomotives at a given shop in 2 days.

The ALBM is a stand-alone data acquisition unit equipped with GPS positioning and a cellular modem to backhaul captured data to a cloud-based dashboard for viewing. A battery wire harness with sensors was installed on each battery to measure and record Voltage, Current, Temperature, and Electrolyte Level (flooded batteries). The harness connects to the ALBM and uses the data to calculate State of Charge (SOC), Total Ah drawn, Mid-point Voltage, and other battery information. It compares the data and calculations against programmed thresholds and will alarm for certain conditions such as Low SOC, Mid-point voltage error, Low Electrolyte Level…etc. The information is uploaded to a cloud server and can be displayed in dashboard visualizations including graphs, statistics and alarm logs. These graphs served as the primary reporting mechanism for the Task Force.

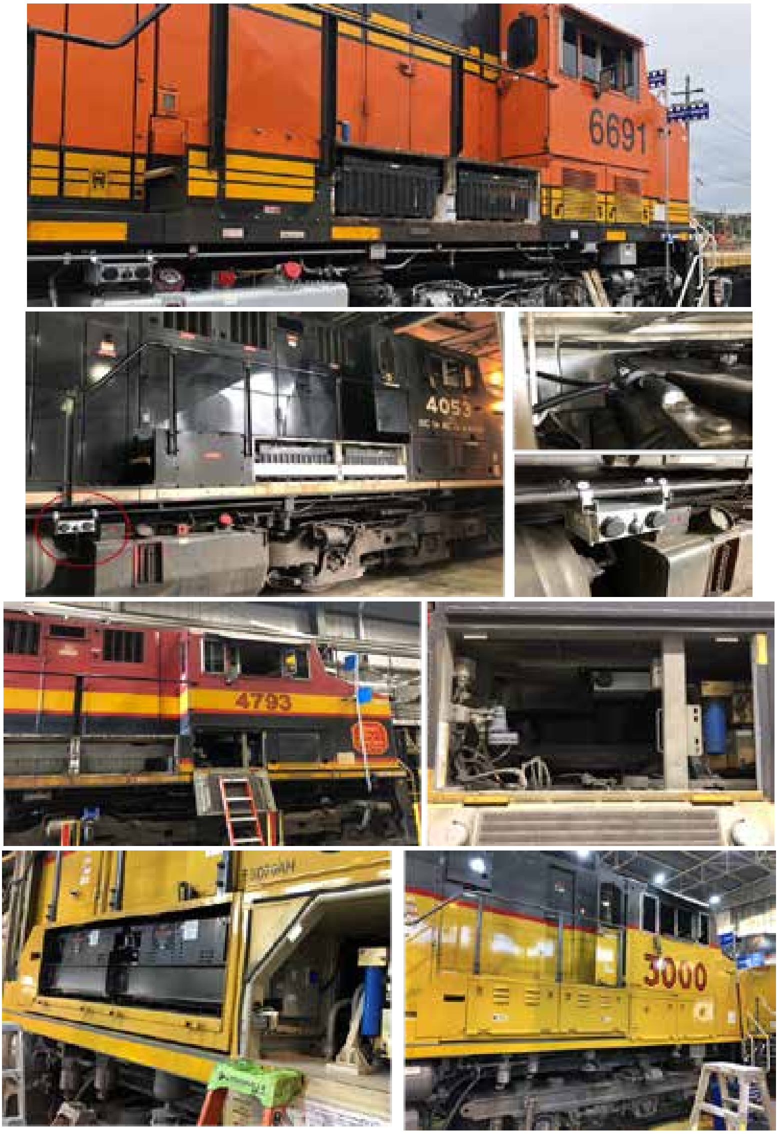

Figure 1 - Participating Railroads in Study

Table 1 lists the 5 participating railroads that equipped 14 locomotives with battery monitoring equipment for the 12-month study. It summarizes key battery statistics Total Days on Test, Total Ah Drawn, and Average Ah / Day.

Total Days on test ranged from 36 to 447 days with an average of 237 days per locomotive. The range was due to different start dates and a few ALBMS stopped reporting before the testing was complete due to locomotives moved into storage or damage to an ALBM. Regardless, useful data was captured for analysis. The testing days for all 14 locomotives totaled 3,314 which equates to more than 9 years. Six locomotives were under test for all four seasons and provided insight into how AESS and railroad practices affect battery cycling.

Total Ah Drawn is the amount of battery life taken from a battery's Total Lifetime Ah. It is based on ideal temperature, proper charging, optimized AESS settings, and a complete recharge between cycles. As these conditions shift away from ideal, the Total Lifetime Ah is reduced.

The Average Daily Ah is an indication of the depth of discharge (DOD) that battery experiences each day. Key finding: The average of the 14 locomotives is only 80.3 Ah per day. The highest Average Daily Ah was on KCS #4793 at 157.4 Ah or roughly 24% DOD on average. Let's say a given battery is rated at 500,000 Lifetime Ah and the temperature, charging, and AESS conditions were ideal. This cycling application in ideal conditions could see 8 years of life (500,000 / 157.4 / 365). Realistically, the locomotive environment does not match laboratory ideal conditions, so the expected Lifetime Ah will be less. The strategy should minimize each factor that adversely affects lifetime Ah. Emphasis is on proper charging algorithms, optimized AESS settings, and improved recharge time. The rail industry recognized this over five years ago, implemented improved charge algorithms, and adjusted AESS settings on prioritized fleets. Due to the associated time and cost for a software upgrade, not all locomotive systems have been corrected.

RR / Unit #	Locomotive	Battery (Ah)	Install Date	Finish Date	Total Days On Test	Total Ah Drawn (Ah)	Avg AH/Day (Ah)
NS 9366	GE D9 44CW	GNB 650	3/29/2019	6/18/2020	447	-14,718	32.9
NS 4053	GE AC44C6M	GNB 650	4/11/2019	4/9/2020	364	-24,978	68.6
NS 7000	EMD SD60E	GNB 650	6/6/2019	8/7/2019	62	-3,791	61.1
BNSF 760	GE D9-44CW	GNB 650	5/20/2019	1/13/2020	238	-14,785	62.1
BNSF 6341	GE ES44AC	GNB 650	5/21/2019	6/21/2019	31	-3,545	114.4
BNSF 6691	GE ES44C4	GNB 650	5/21/2019	6/18/2020	394	-50,549	128.3
CP 8106	GE AC4400CWM	GNB 650	6/19/2019	5/31/2020	347	-14,098	40.6
CP 9352	GE ES44AC	GNB 650	6/20/2019	6/18/2020	364	-32,576	89.5
CP 8109	GE AC4400CWM	GNB 650	7/25/2019	6/18/2020	329	-23,799	72.3
KCS 4793	GE ES44AC	GNB 650	9/12/2019	5/29/2020	260	-40,911	157.4
KCS 4121	EMD 70Ace	GNB 500	9/12/2019	2/24/2020	165	-10,585	64.2
UP 8105	GE ES44AH	GNB 710	10/14/2019	11/19/2019	36	-2,405	66.8
UP 4382	EMD SD70Mac	GNB 650	10/14/2019	6/18/2020	79	-4,623	58.5
UP 3000	EMD SD70Ace-T4	GNB 710	12/3/2019	6/18/2020	198	-21,301	107.6
				Total	3,314	-262,664	1,124
				Average	237	-18,762	80.3

Table 1 - Locomotive Battery Monitor Summary Statistics

Data Collection, Analysis, and Key Findings

This section analyzes collected data sets that support key findings of the study.

Charging and Discharging

The graph in Figure 2 shows a 24-hour 32A deep discharge which removed 768 Ah (118%) from a 650 Ah flooded battery. Improper shutdowns without active AESS restart or a Low Voltage Disconnect (LVD) are a risk for severe discharges. Frequent severe discharges have an adverse effect on battery life and performance. In this case, the excursion was only a few hours and was quickly recharged. A battery left at a discharged state for a long duration will have a permanent degradation of life and performance.

The recharge voltage setting is 72 volts and took 9.5 hours to reach 95% SOC. This represents a single stage float charge algorithm. A more efficient charge setting would be at 74 VDC to reduce recharge time and improve balance of individual cell voltages. The charge current peaks at 260 A, which is over the recommended current limit of 130A for a 650 AH flooded battery.

Figure 2 - Severe Discharge Followed by Recharge

Figure 3 below shows a 6 month graph which includes 6 discharges from 20 – 40 % DOD and 2 severe discharges over 100% DOD. Figure 4 zooms into the first severe discharge showing a 109-hour discharge which removed approximately 800 Ah (123%) from a 650 Ah flooded battery. This example shows another case of a severely discharged battery and a low recharge voltage.

To improve either of these two systems, consider a load shed device or auto start to prevent discharges below 20% SOC, increase float voltage to 74.0 VDC, limit the current to 130 A.

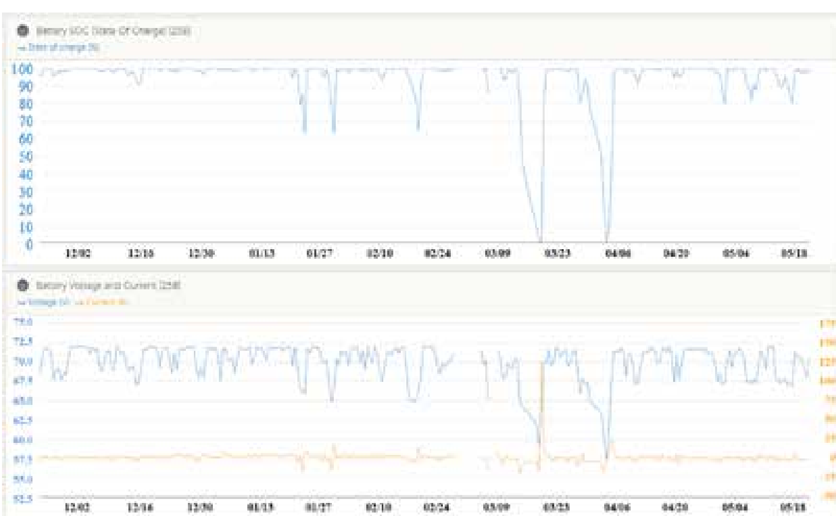

Figure 3 - 6-month of ALBM Monitoring

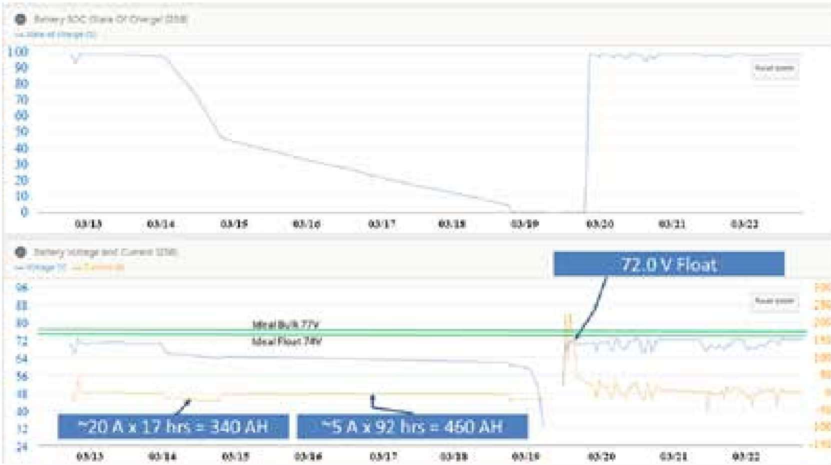

Figure 4 - Severe Discharge

Figure 5 shows an example of a locomotive charging algorithm that meets the battery manufacturer's recommendation of 77 VDC for bulk charge. The 72 VDC float charge is a little lower than the ideal 74 VDC. Raising this to 74 VDC would make the recharge more efficient.

A 3-stage I-E-E charge algorithm is recommended for today's locomotive battery applications. It is ideal for cycling and float applications.

Figure 5 - Locomotive Charge Algorithm Meets Manufacturer Recommendation

Temperature Study

Newer locomotive charging systems have implemented temperature compensation (TC) to their charging algorithms to lessen the impact on life and performance from high and low temperatures, especially in the extremes of the locomotive's operating environment. Battery manufacturers state that TC should be based on battery temperature, not ambient. This study compared battery and ambient temperature. The ALBM included a probe for battery temperature which was placed between the middle 4 cells of the most positive battery. A second probe for ambient temperature was positioned just outside of the case on the most negative battery.

In Figure 6, the lower graph compares the ambient temperature plot of May 22 through July 1 to the battery temperature in the upper graph for the same period. Notice the daily swings are typically 20^{o} C. Due to the larger mass, battery temperature swings are much smaller and delayed from ambient swings.

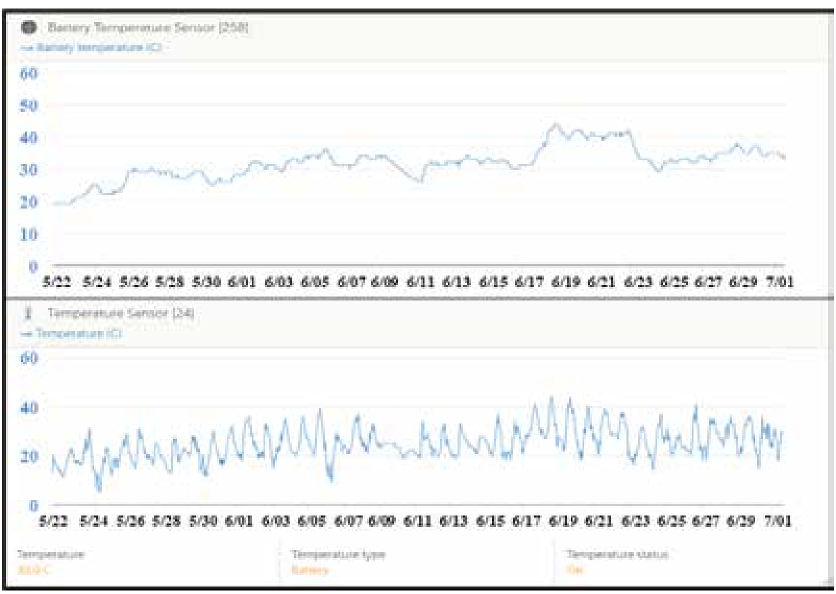

Figure 6 - Battery Temperature vs. Ambient Temperature

Figure 7 illustrates a substantial difference of 42^{o} C between ambient and battery temperature on January 14th as a locomotive traveled in the Canadian province of Saskatchewan. If TC using battery temperature were added to this locomotive, the float charge voltage would be correctly adjusted to 74.4 VDC. If ambient temperature were used, the float charge voltage would be incorrectly adjusted to 77.1 VDC and overcharging by 2.7 VDC.

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RBS sales are managed by Transportation Products Sales Company (TPSC).

Figure 7 - Low Temperature Variation of Battery Temp vs Ambient

Figure 8 illustrates an example of a charging algorithm correctly using TC on a VRLA battery. The results of this graph are encouraging as it matches the battery manufacturer's recommendation charge algorithm. On December 24th, the battery temperature was 25° C and the float voltage was ~74.0 VDC (2.25 VPC) which is the baseline for temperature compensation. As temperature decreased, charge voltage increased and vice versa.

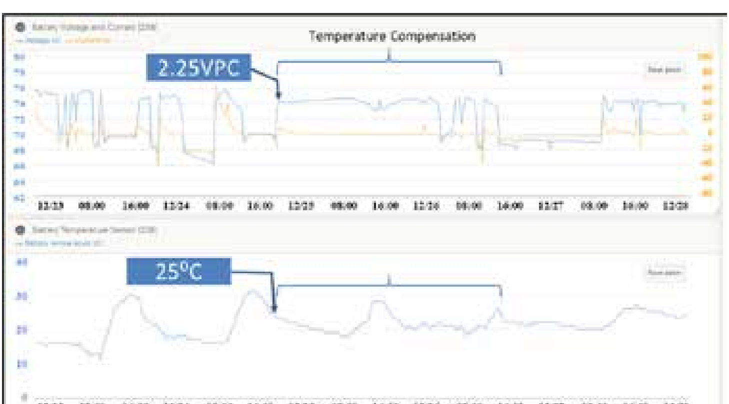


Figure 8 - Proper Charge Algorithm with Temperature Compensation

Not only is the battery temperature important for proper charging, it is important for monitoring equipment such as the LBM to alarm for temperature thresholds, log history and calculate specific battery parameters such as state of charge (SOC) and AH Capacity.

One temperature probe failed during the 12-month study. Careful selection of a robust temperature sensor as well as smart software to detect a failed sensor should be a priority for the designer. When the software identifies a failed sensor, it should automatically failover to the sensor in the second battery.

Locomotive Battery Monitor

The 12-month study also included evaluation of the locomotive battery monitor (LBM) to assist in the creation of a recommended standard for future battery monitoring devices and to identify the data to collect and deliver. The LBM used in this study was a comprehensive stand-alone device with cellular connectivity to a 3rd party dashboard that displayed the most recent 6 months of data for all locomotives including the most recent battery summary, battery history, alarm logs, Electrolyte Level, Mid-point Voltage, and graphs of SOC, Voltage, Current, Temperature. This LBM was suitable for the study and provided insight to future device requirements.

Table 2 illustrates an abbreviated alarm log from a locomotive in the study. The logs identify the following issues that should have an action taken once the alarm was received.

- The **Battery Monitor Low state-of-charge alarm** indicates a severe discharge below a defined SOC along with the amount of time it was low.
- The **Digital input – Electrolyte1 [3]** and **Digital input – Electrolyte2 [2]** alarms indicate low electrolyte in battery 1 and battery 2. It provides the date of alarm and once the battery is watered, the alarm is cleared. This information can be used to optimize watering intervals. Note the shaded Electrolyte2 alarms point out repetitive alarms due to the sensors in and out of contact with the electrolyte in short periods. A developer of next generation LBM should filter out repetitive alarms over some period of time (e.g. once per day).
- The **Digital input – Midpoint Alarm [1]** is active for a difference of 3 volts between the two batteries. Frequent alarms indicate mismatched batteries and should be investigated during next shop visit.
- Finally, the **Unknown No data alarm** indicates the communication path has been interrupted for the listed time shown in the **Cleared after** column. The ALBM utilized built-in cellular service and experienced several coverage gaps for this locomotive's travel.

Device	Description	Started at	Cleared after
Battery Monitor [258]	Low state-of-charge alarm: Alarm	5/24/2020 17:59	6d, 17h, 59m, 28s
Battery Monitor [258]	Low state-of-charge alarm: Alarm	4/20/2020 23:15	2d, 4h, 12m, 55s
Digital input - Electrolyte1 [3]	Digital input alarm: Alarm	5/29/2020 13:48	Active
Digital input - Electrolyte1 [3]	Digital input alarm: Alarm	5/28/2020 23:30	12h, 4m, 26s
Digital input - Electrolyte2 [2]	Digital input alarm: Alarm	5/29/2020 13:38	Active
Digital input - Electrolyte2 [2]	Digital input alarm: Alarm	8/6/2019 11:51	36d, 22h, 56m, 10s
Digital input - Electrolyte2 [2]	Digital input alarm: Alarm	8/6/2019 11:51	12s
Digital input - Electrolyte2 [2]	Digital input alarm: Alarm	8/6/2019 11:47	3m, 10s
Digital input - Midpoint Alarm [1]	Digital input alarm: Alarm	5/29/2020 4:03	7h, 31m, 8s
Digital input - Midpoint Alarm [1]	Digital input alarm: Alarm	5/28/2020 16:40	1h, 55m, 4s
Unknown	No data alarm	5/31/2020 12:14	Active
Unknown	No data alarm	4/30/2020 4:26	8h, 46m, 45s

Table 2 - Alarm History Log

The SOC and Voltage and Current graphs of Figure 9 identify a shortcoming of the LBM's calculation of SOC during an open circuit self-discharge. Note the voltage decreases from 68 Volts to 63.0 over 9 days, but the current is steady at 0.0 Amps and causes the SOC to remain at 100%. The LBM calculates SOC by subtracting Ah drawn from Ah capacity of the battery. Ah drawn = A x h. Therefore, 0 x 216 = 0, and no decrease in SOC. The next generation LBM must have a solution for monitoring self-discharge as well as load discharge.

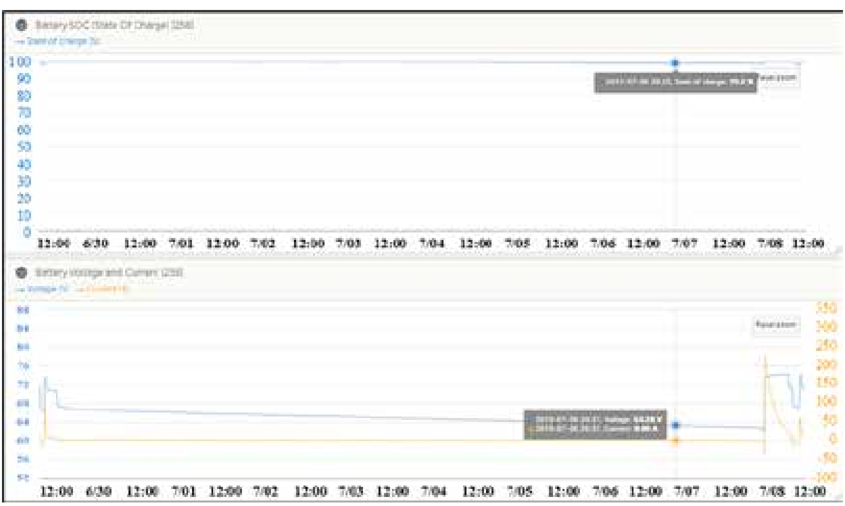


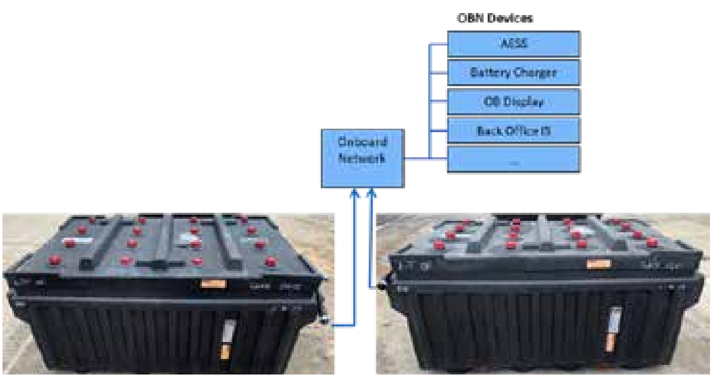
Figure 9 - SOC Calculation for Self Discharge

A second challenge for the LBM is the resolution, accuracy, and calibration of the current sensor. A hall effect sensor was chosen for this study with a range of +/-350 Amps to capture maximum positive charge currents and negative discharge currents. In general, the larger the range, the less resolution and accuracy. This study identified instances where small positive charge currents

3-5 A were being measured as small negative discharge currents and vice versa. If this is a significant amount of time at these levels, the Total Ah Drawn, Total Recharge Energy, Total Discharge Energy, and SOC values will not be accurate. Total Ah Drawn is compared to Lifetime AH for remaining life and the SOC value is essential to improve charging and optimize AESS settings. Designers of next generation LBM's need to be aware of these challenges.

Next Generation LBM Concept

Figure 10 illustrates a basic concept of a next generation LBM shown with example parameters to collect and deliver to the onboard network. These parameters are to be used by devices related to battery monitoring, control, and asset management. Whether the data is collected by a computing device on the individual batteries, the onboard computer, or a device in between, the collected battery information will be used to improve battery charging, optimize AESS operation, and enable condition monitoring to prevent failures.



Measure	Value
Battery Setup	
Battery ID	GKX1241
Battery Type	Flooded
Battery Nominal Capacity (AH)	650
Battery Nominal Voltage (V)	32
Realtime Measurements	
Voltage (V)	37.1
+/- Current (A)	-16.1
Temperature (C)	27
Electrolyte Level (OK/LOW)	OK
SOC (%)	96

Figure 10 - Next Generation LBM Concept

Conclusion and Key Recommendations

This section provides key recommendations for three groups responsible for improvements in locomotive battery performance and life. Keep in mind, ideal settings are given to maximize battery life and performance for this application. Some adjustments to the recommendations are appropriate, but the consequences, if any, should be understood.

Onboard System Strategies

- Use battery supplier recommended I-E-E charge algorithm.
- Include a Low Voltage Disconnect (LVD) for load shedding or battery disconnect to prevent SOC levels below 20%. Identify essential loads that must remain on the hot side of the switch and minimize the current draw.
- Optimize AESS settings. Recommend discharge value to be no lower than 40% SOC for a restart due to low battery. Recharge battery to 95% SOC minimum prior to allowing another shutdown. Allow a 12-hour recharge to 100% SOC if one has not been performed in 2 weeks.
- Be conservative on selecting essential loads for the hot side of the switch.
- Use battery temperature, not ambient temperature

Locomotive Shop Strategies

- Ensure that water quality, watering interval, and proper water level practices are adopted. Consider implementing a Single Point Watering System.
- Implement Opportunity Charging at locomotive shops.
- Battery Testing Stations to identify batteries that need to be sent in for service.
- Store batteries in a cool dry location.

End User Strategies

- Reduce Improper Shutdowns.
- Avoid excessive discharges below 20% SOC. Especially for long durations.
- Avoid storage of batteries in high temperatures as it can reduce life.
- Avoid storage of batteries in low temperatures, especially at low SOC for fear of freezing and damaging the battery.

Battery Monitoring System

Create a standard for an LBM Device and a data standard for the locomotive onboard network. Refer to "Locomotive Data Publication Standard S-XXXX. V1.0" by Cody Fischer - Canadian Pacific Railway. 2019 LMOA Proceedings.

Special Thanks

- AAR Locomotive Committee – AESS & Battery Health Task Force
- Study Participants: NS, BNSF, KCS, CPR, UPRR
- Mark Duve – Consultant
- Dan Taschler - ARMS
- Steve Plummer - GNB
- Ed Mattan – GNB

Recommended Reading

"Locomotive Data Publication Standard S-XXXX.V1.0" by Cody Fischer - Canadian Pacific Railway. 2019 LMOA Proceedings.

"Battery Temperature Performance Study with Strategies to Optimize Charging and AESS Settings" by Jason Fox – Union Pacific Railroad and Sid Bakker – Transportation Products Sales Company. 2018 LMOA Proceedings.

"A Study of Locomotive Battery Charging and Performance" by Jason Fox – Union Pacific Railroad and Gibson Barbee – Norfolk Southern. 2017 LMOA Proceedings.

"AESS (Automatic Engine Start Stop)" by Mike Drylie - CSX Retired. 2017 LMOA Proceedings.

"Three Stage Battery Charging for EMD Locomotives" by Bud Wilds – BNSF Railway. 2011 LMOA Proceedings.

Table of figures

Compressor Control Reliability Improvement for GE locomotives

Prepared by:
David Pettengill, Senior Account Manager, Dayton-Phoenix Group
Mike Ayette, Engineering Manager, Dayton-Phoenix Group

Abstract

Certain railroads found the original OEM contactors were not providing reliable operation. Solid-state devices and improved contactors offer railroads improved reliability. This paper discusses the commercial alternatives currently available.

Background

Prior to the end of the 2000s, certain Class 1 operators investigated different means of improving locomotive compressor reliability. Several options explored ranged from swapping the entire compressor assembly out to changing the components of the compressor control scheme. While newer technology compressors offer certain advantages over traditional oil lubricated reciprocating compressors, it would take some time to determine if the additional up-front expense would provide the necessary reliability improvements.

As the root cause of failures were further investigated, reliability conversations began focusing on the compressor motor and the associated motor controls found in the control area 9, RAD CAB cabinet. The general feeling was that while the compressor system in its entirety might be good for 2 to 3 years of reliable operation, the compressor itself was quite capable of going to locomotive midlife overhaul if properly maintained. Motor solutions ranged from offering a larger air gap between the rotor and stator to more robust installation interfaces.

As attention turned to the controls, suppliers developed improved solutions based on more robust contactors as well as replacing the contactors with solid-state solutions. This paper discusses commercially available alternatives to improve compressor control reliability. Improvements in this area significantly reduce single-phase motor failures and other electrical issues due to bad acting contactors.

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Figure 1: Dash 9 Contactor Panel

Investigation

Field tests were conducted to identify the inrush current associated with compressor motor startup. Figure 2 presents this data.

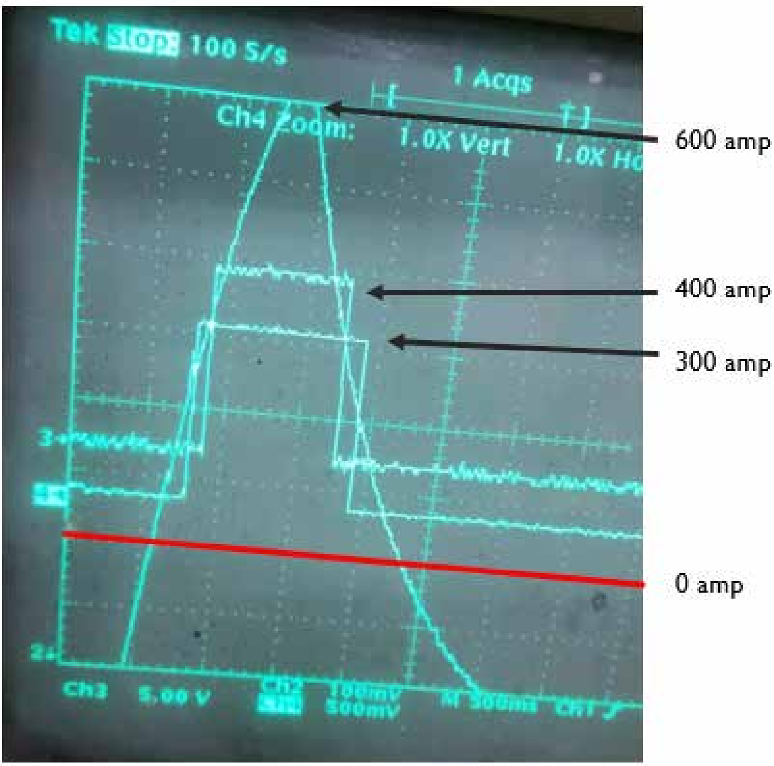


Figure 2: MDAC Inrush current

In addition to researching the power requirements, suppliers also had to understand the feedback circuits as well as differences in layout and circuitry between the various generations of GE locomotives. Figure 3 presents the basic system block diagram for the compressor control system when controlled by contactors.

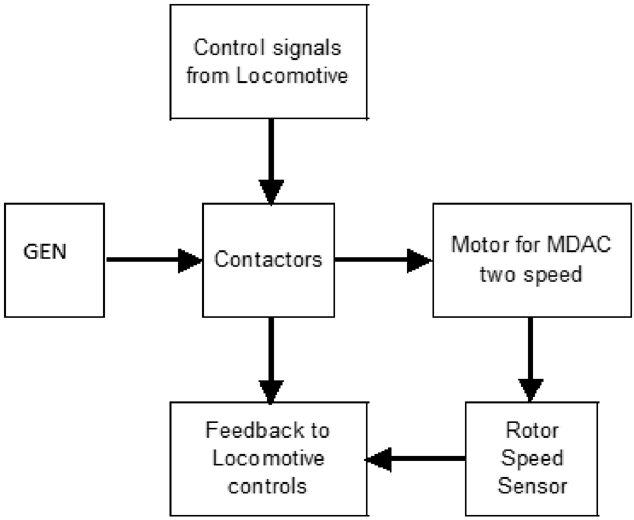


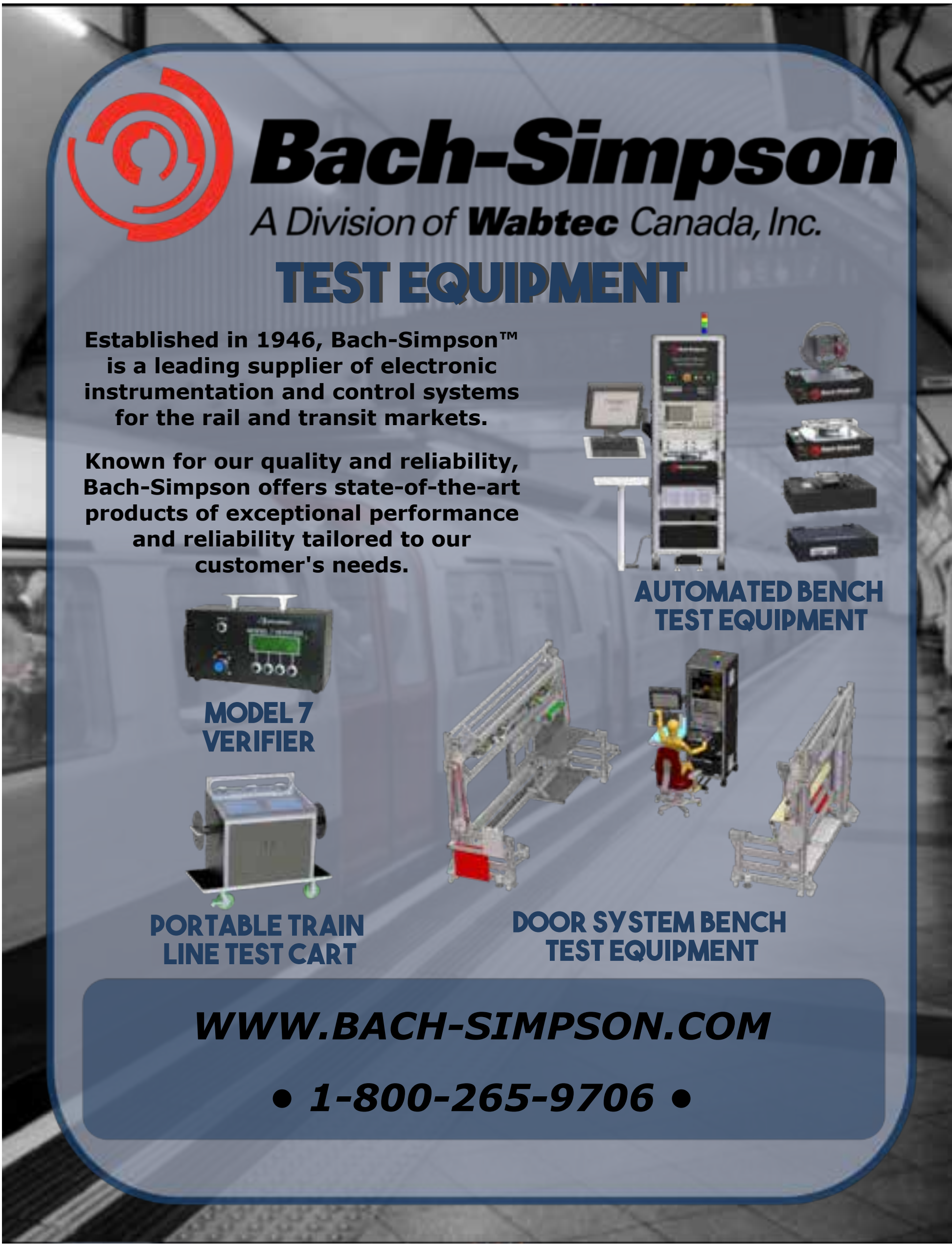
Figure 3: Block Diagram, Contactor Controls

In this arrangement, contactors connect generator output to the MDAC motor. As summarized in figure 4, contactors are switched based on locomotive engine rpm ranges to optimize train air delivery. When the locomotive engine is in low rpm range the MDAC runs in high speed mode when required. When train air is required while engine rpm is high, the MDAC runs in low speed mode.

Locomotive speed	Notch	Pole	hz	voltage	compressor motor
low speed locomotive	1-3	6p	30-60	100-200	high speed
high speed locomotive	4-8	12p	70-120	200-400	low speed

Figure 4: Modes of Operation

Contactor state and rotor speed are both reported back to the locomotive control system.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Contactor Solutions

Reliability improvements from contactor-based solutions are primarily brought about by using more robust contactors with higher power ratings. One manufacturer claims 60% more current carrying capacity when compared to the original OEM contactors. In addition to the increased current capacity, the solution also appears to be "plug and play" as no modifications to the locomotive seem necessary. Figures 5 and 6 present information from one manufacturer of improved contactors.

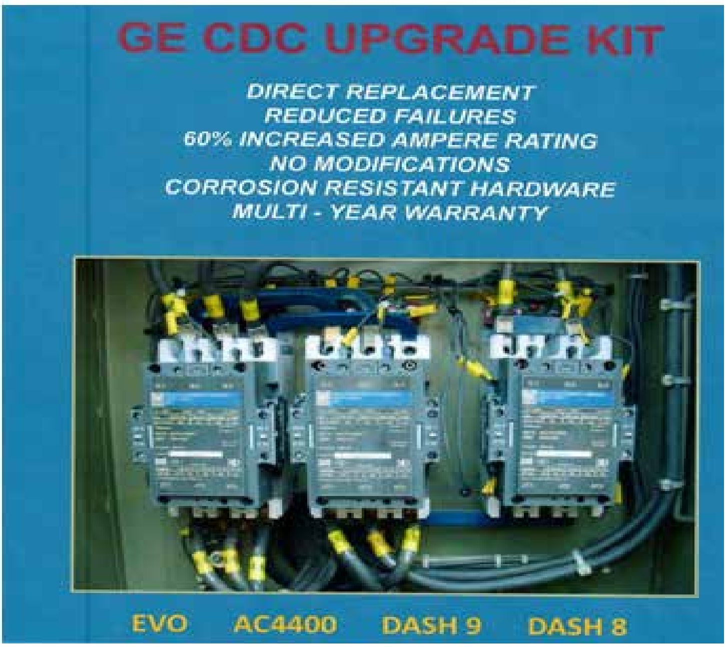


Figure 5: Improved Contactor Information

OEM	Aftermarket
NEMA size 3	NEMA size 4
90mm frame	180mm frame
G.P. 120 amps	G.P. 230 amps
30HP @ 240vac	50HP @ 240vac
600v max	690v max
AC-3 90 amps	AC-3 180 amps
Surge 800 amps	Surge 1800 amps
Coil P.U. 295 watts	Coil P.U. 500 watts
Coil Hold 4.5 watts	Coil Hold 2 watts
Length 7.07 in	Length 7.72 in
Width 4.58 in	Width 4.50 in
Height 5.98 in	Height 6.29 in
Weight 8.2 lbs.	Weight 7.1 lbs.

Figure 6: Improved Contactor Information

Solid-State Solutions

At least one supplier developed a solid-state solution called the Smart Compressor Control (SCCST). This device uses silicon-controlled rectifiers (SCR) to replace the high-powered contactors that pass full motor line current. This fixes the problem of failed contactors typically due to tip wear over time and associated maintenance requirements. The block diagram shown in Figure 7 shows the system is transparent to the locomotive controls.

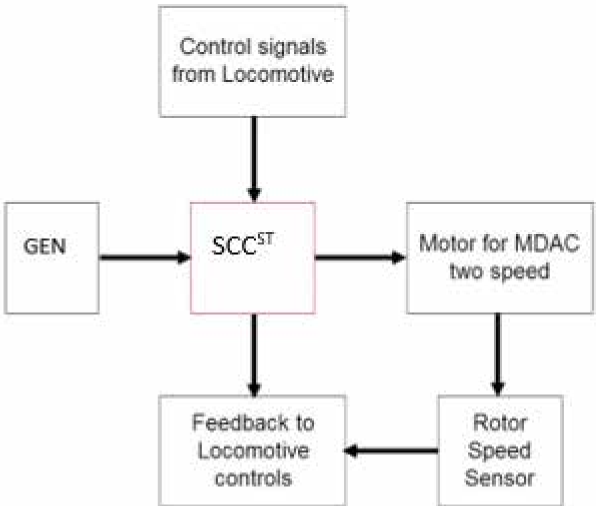


Figure 7: SCCST Block Diagram

Although a delta to wye contactor is included, it is switched under no load conditions when both turning the compressor motor ON and OFF. This is in contrast to the standard contactor scheme that has unpowered switching for OFF to ON but not from ON to OFF.

The SCCST controls provide additional benefits to end users such as the ability to detect a stalled compressor faster, greatly reducing motor heat stress from a locked rotor condition. Should this situation occur, the SCCST will detect it and shut the compressor down to prevent additional damage. Two trigger points exists, if either are exceeded the system will react. In addition, the system measures current between motor phases facilitating prevention of motor single-phase failures. Temperature checks are also part of the system. Figures 8 a&b show the logic diagram and Figure 9 shows fault control and system status information available to the end user.

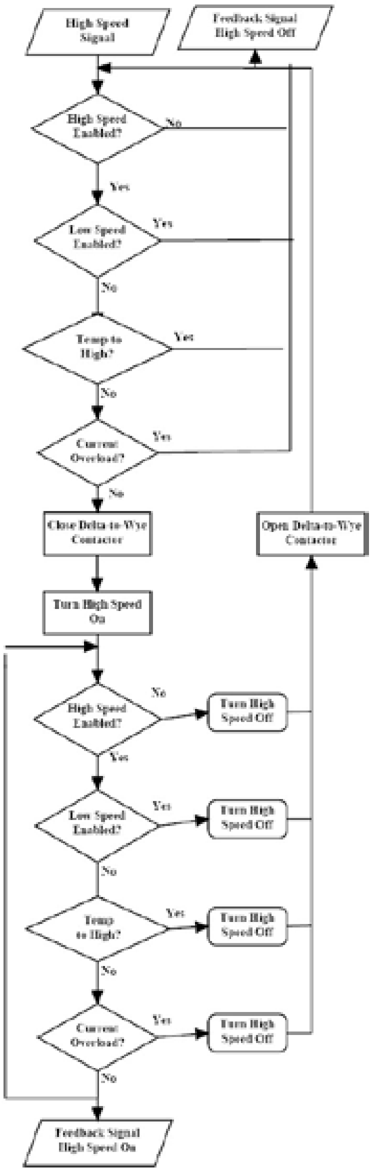


Figure 8a: SCCST High Speed Logic Diagram

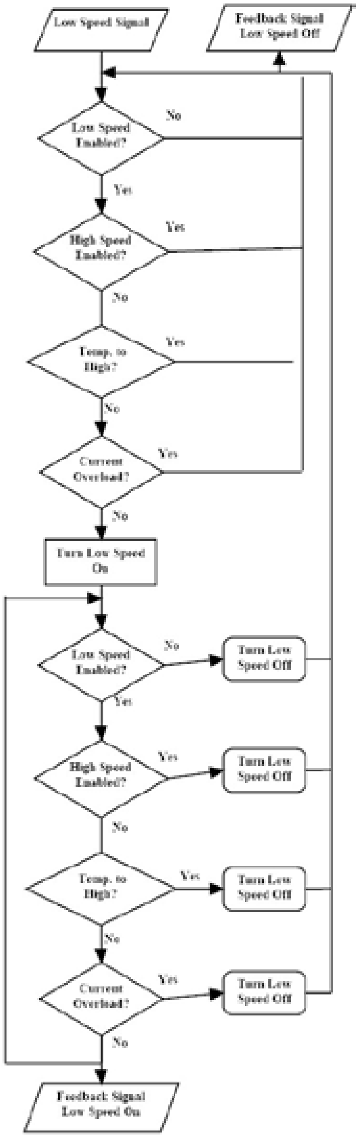


Figure 8b: SCCST Low Speed Logic Diagram

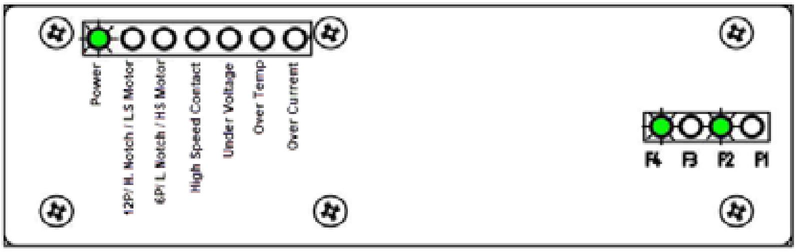


Figure 9: Fault Control Status Indicator Panel

While contactor based solutions tend to be plug and play, the SCCST requires modification to the cabinet for installation. Both types of upgrades can be completed during maintenance shopping or upgrade program. Figure 10 shows the basic view of the SCCST and Figure 11 shows the SCCST installed on an AC4400 locomotive.

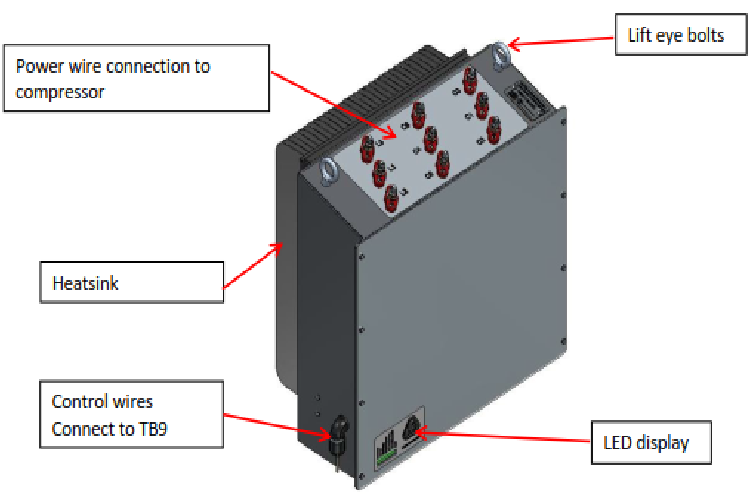


Figure 10: Solid-State Compressor Control, SCCST

Figure 11: SCCST installed on AC4400

Summary

Various approaches to improving compressor reliability have entered the market over the past several years. The compressor control system can be upgraded with either more robust contactors or with solid-state systems. Either of these approaches have much lower initial cost impact than replacing the entire compressor assembly. With over 700 systems installed across a broad array of GE locomotives, the solid state SCCST approach has proven successful. To learn more about contactor based solutions, the authors encourage interested readers to reach out to contactor suppliers with such offerings.

References:

Locomotive Relays Home, http://www.relaysystemsofamerica.com/ [accessed 2020 June 5]

Dayton-Phoenix Group, https://www.dayton-phoenix.com/productCategoryDetail.php?categoryId=138 [accessed 2020 June 2]

Distributed Power Consists Set-Up

Prepared by:
Shane Sledge, Norfolk Southern Corporation

Abstract — This paper will discuss the setup for Distributed Power (DP) and troubleshooting tips. DP is used to run longer trains by placing remote locomotive either mid-train, rear or both. Railroad Industry personnel have experienced a lot of set up issues when it comes to DP. This paper will explain how to condition the remote(s) and the lead unit for the proper operation.

Background — DP is used to run longer trains by using remote locomotives either mid-train, rear or both.

Conclusion — The industry sees a lot of setup issues when it comes to DP. This paper will explain how to condition the remote(s) and the lead unit for proper operation.

As an industry, one of the main issues related to distributed power is setting up the consist correctly. This paper is intended to give step by step instructions on this process.

Single Locomotive Validation:

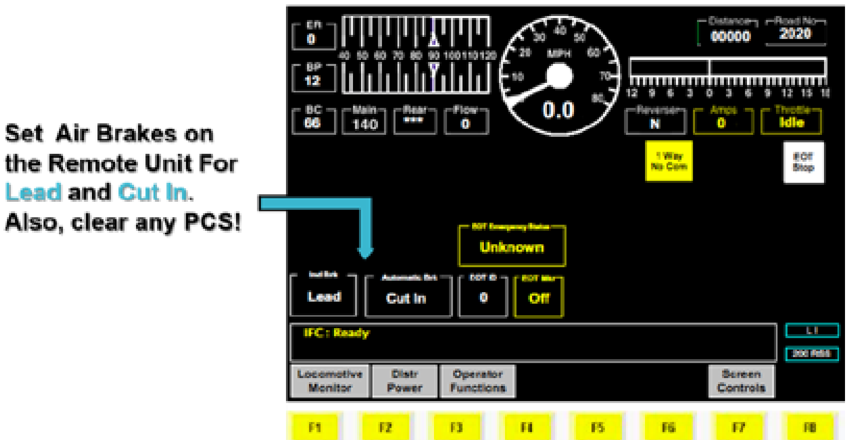
If no other unit is available to link to for testing purposes, you can use the LOCOTROL test box to validate the DP system.

- Test Set verifies DP communication:
  - Over antenna
  - Over BP
- With locomotive as lead
- With locomotive as remote
- Can check tractive effort
- Ideal for routine maintenance or when another locomotive isn't available

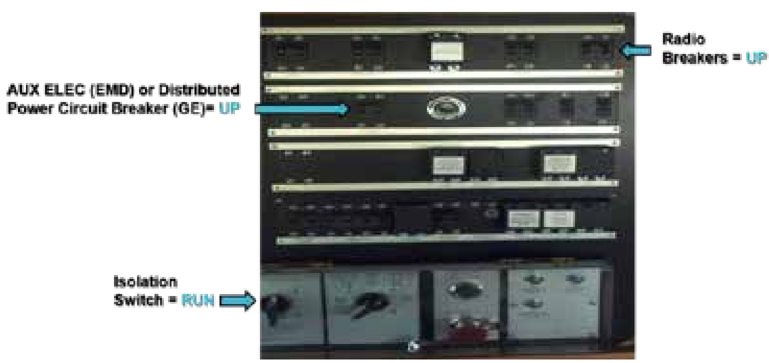
DP Remote Setup:

It is important to note that setting up the remote(s) must be done FIRST before conditioning the lead DP unit. Below is the process:

- Verify lead locomotive and cab direction prior to setting up remote locomotives.



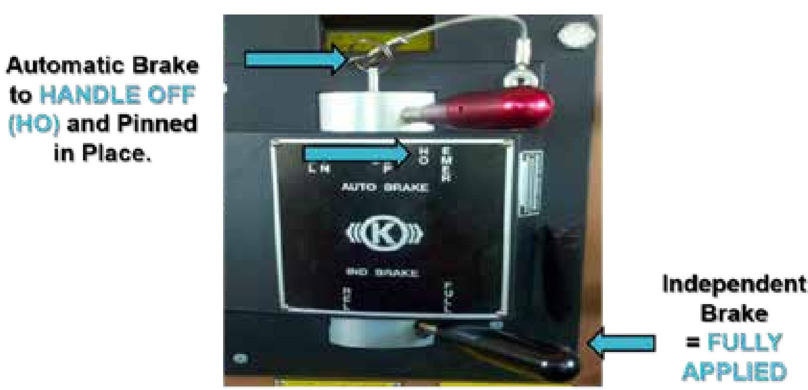
- Ensure the brake is coupled between each unit and all angle cocks are open. If DP radio communication failure occurs, BP air is the backup form of communication.
- Ensure MU cable is disconnected in between the lead units and remote units. If MU cable is connected through the entire consist loading command will be sent through MU cable instead of DP system, masking a DP failure if it exists.



Ensure the following are set:

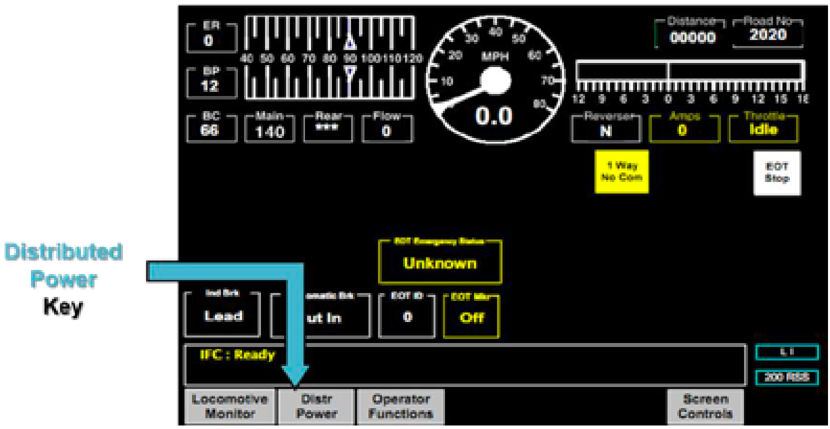
- Engine Run and Control Fuel Switches = UP
- Generator Field = DOWN
- Dynamic Brake Cut-out Breaker = UP
- Throttle = IDLE
- Reverser = CENTERED and REMOVED

- Ensure the Automatic Brake = HANDLE OFF (HO) and pinned in place as shown, and that the Independent Brake is fully applied
- NOTE: Do not cut out the automatic brake



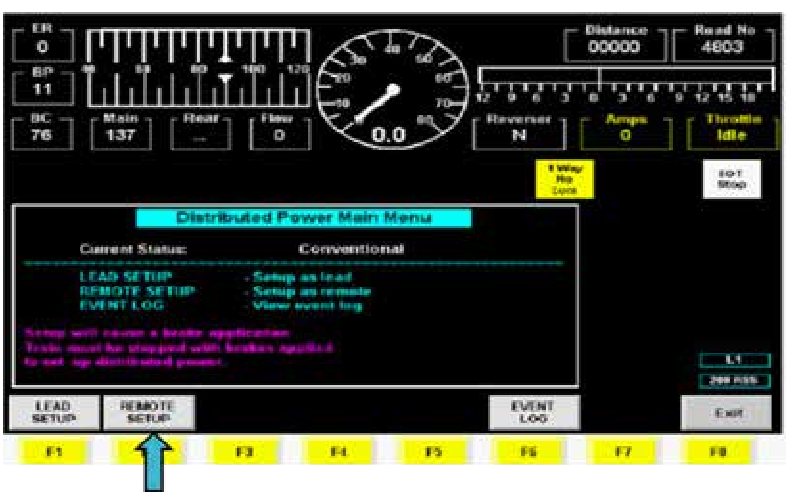
Begin Set Up

- Select the **Distributed Power Key**
- If the Distributed Power Key does not appear, Select The **More Menu Key**



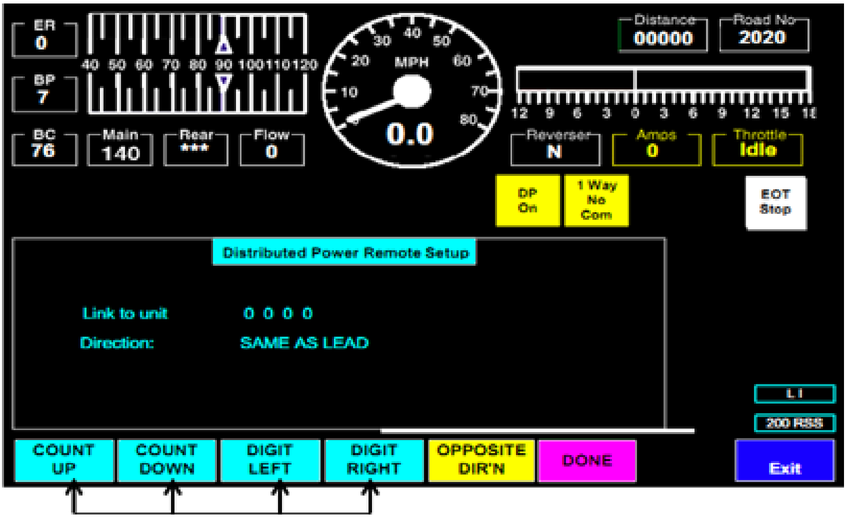
Remote Setup

- Select REMOTE SETUP
- If the locomotive screen shows a Radio Remote or a Wire Remote, select Radio Remote Key (continued…)



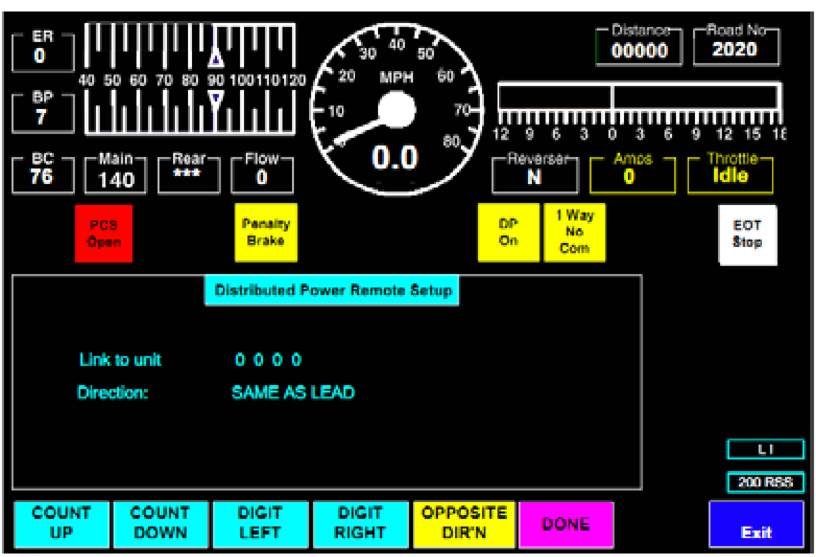
Enter Lead Unit Number

• Utilizing the soft keys, enter the LEAD Engine #

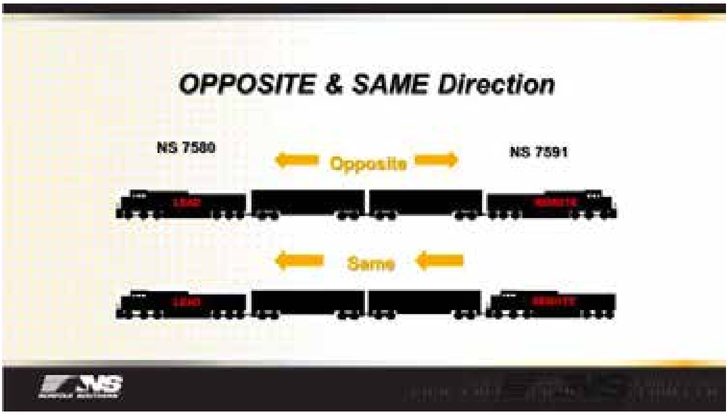


Select Direction:

• After entering the LEAD ENGINE #, Select OPPOSITE DIR'N if reversed from LEAD. Please Review Next Slide for clarification. Once the direction is correct, select EXECUTE and/or DONE.

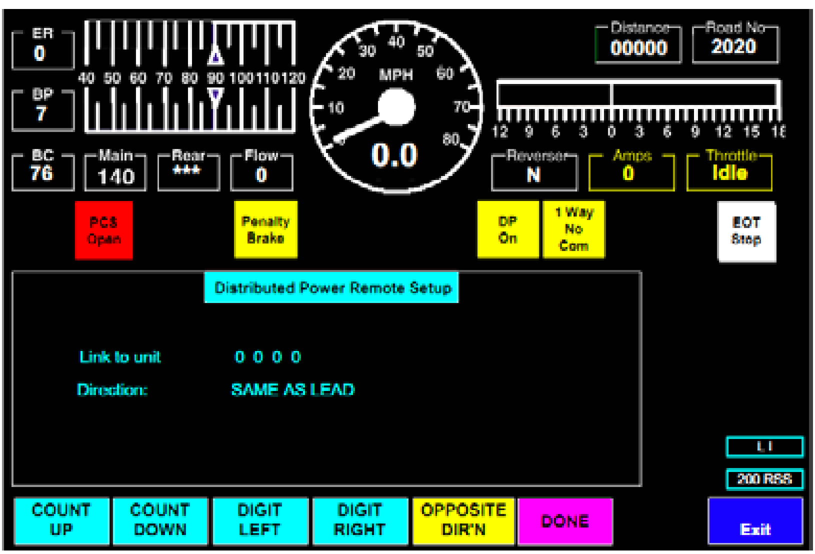


Example of setting up direction:



PCS Activation:

- Once ACCEPT (GE) or DONE (EMD) is selected, the Remote Unit MAY receive a penalty brake application. DO NOT ATTEMPT TO RECOVER.

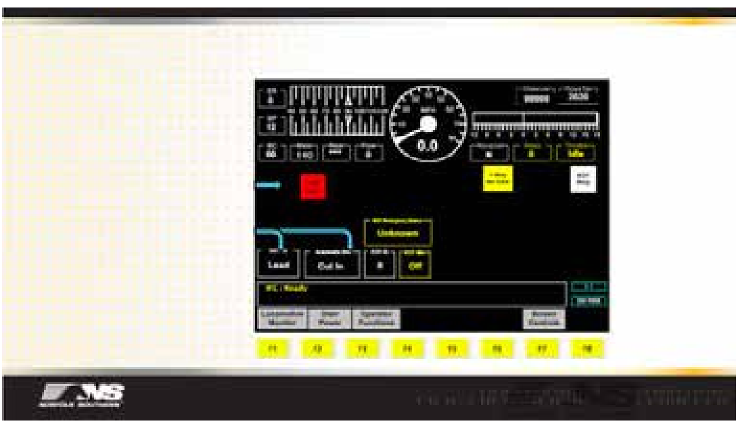


Finalizing Remote Set Up:

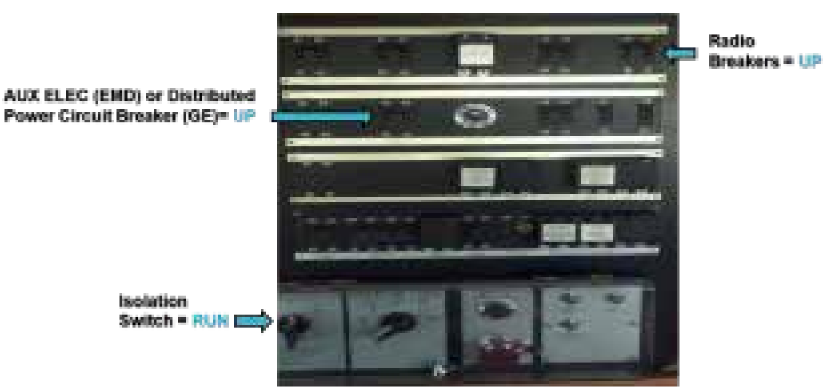
- Move independent brake handle to release
- Isolation Switch to "RUN"
- Place trailing headlight on DIM of rear engine
- Lock engineer's seat so it does not swivel
- Close cab door and lock locomotives after completing set-up
- Release handbrakes on all engines in remote consist
- Now let's move to the LEAD UNIT

DP Lead Set UP:

- Ensure PCS is cleared before starting and the Air Brake system is LEAD and CUT IN

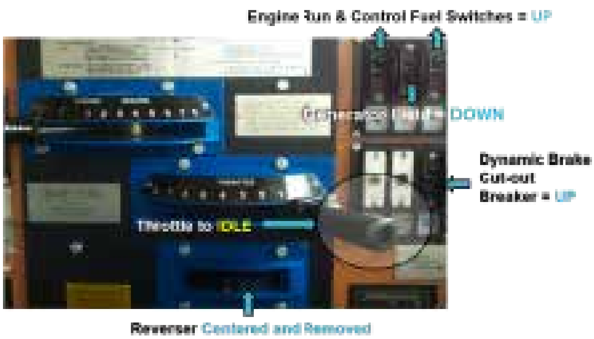


- Ensure breakers are in the correct position.



Ensure the following are set:

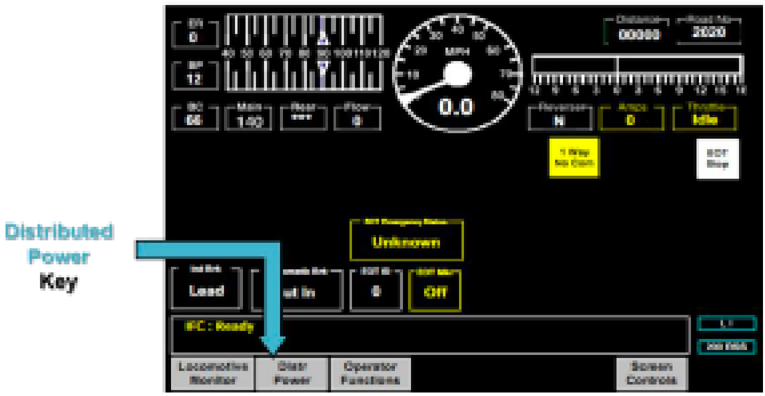
- Engine Run and Control Fuel Switches = UP
- Generator Field = UP
- Dynamic Brake Cut-out Breaker = UP
- Throttle = IDLE
- Reverser = CENTERED



- Ensure the Automatic Brake = MIN service and that the Independent Brake is fully applied.
- NOTE: Do not cut out the automatic brake

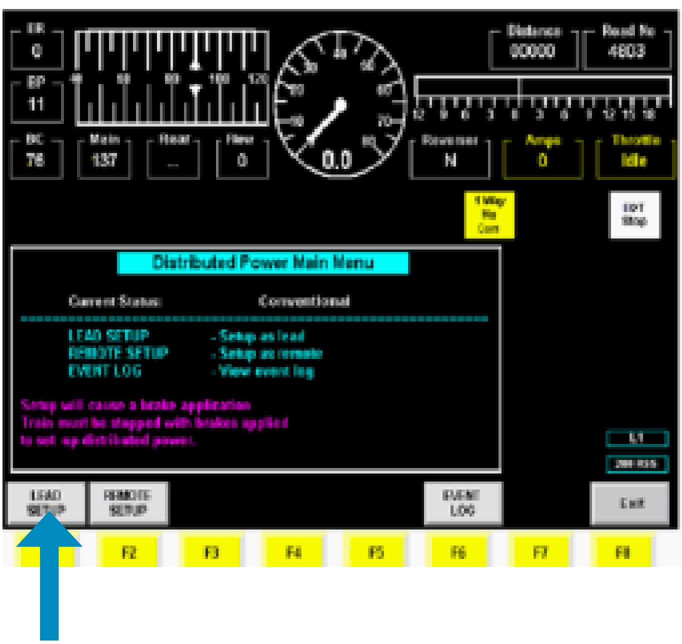
Begin Set Up

- Select the **Distributed Power Key**
- If the Distributed Power Key does not appear, Select The **More Menu Key**



Select lead SetUp

Note: If locomotive screen shows Radio Lead or Wired Lead ONLY select Radio Lead. Wired is for ECP only.



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Entering the Remote Unit Numbers to Link to:

- GE interoperability preference: Link BNSF locomotive first.
- If linking to a foreign locomotive, the operator can change the railroad initial to the desired carrier.
- If the remote has a road number with only 3 numbers , use zero as the first digit
- Utilizing the soft keys, enter the REMOTE Engine #.

- Once the Remote Unit has been entered, select the LINK button. After it is linked, it will show "LINKED OK" and you **MAY** receive a penalty brake application.

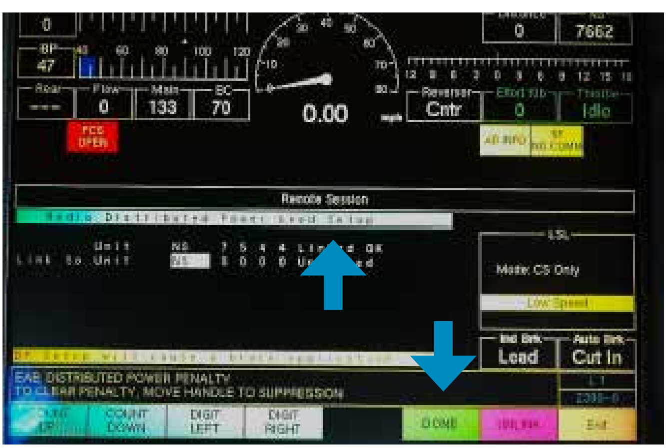
Linking Additional Remotes:

- Repeat steps for all other remote units going from front to rear to complete remote linking process
- GE interoperability preference: Link BNSF locomotive first

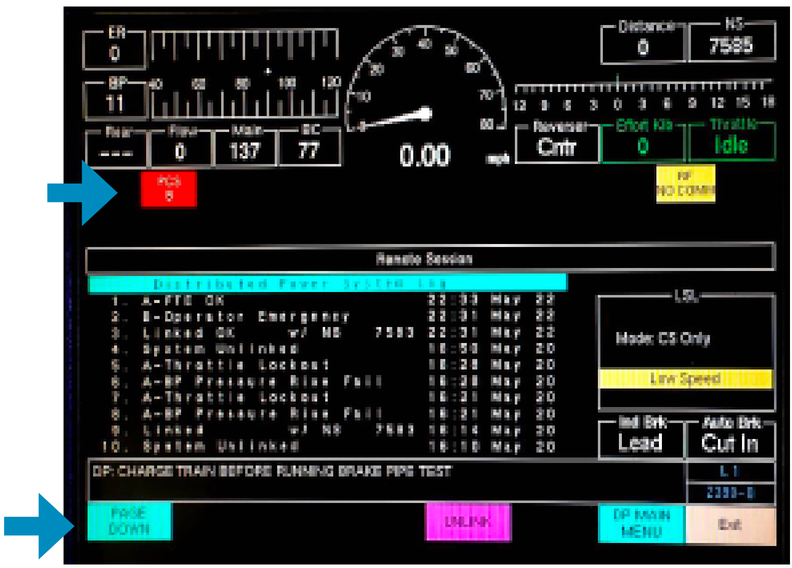
PCS Recovery:

- Once the lead unit and remote unit are linked together and there are no other units to link up, Select DONE and Place Automatic Brake handle to SUPPRESSION in order to clear the penalty.

Note: PCS opens as a result of the lead unit taking on the conditions of the remote unit.

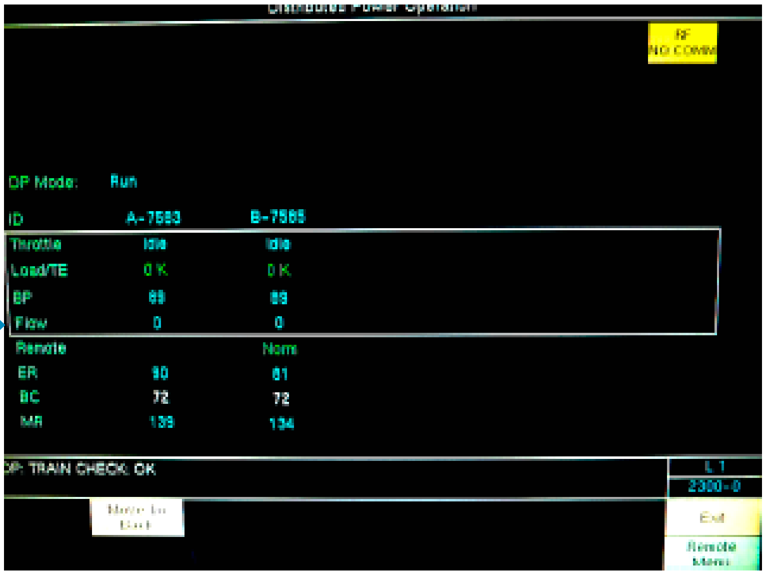


- Once the below message appears, the engineer will notice the A disappears and only PCS B remains. PCS B will clear when the automatic brake is moved to release.
- Do not notch up the engine to help build air. Selecting any throttle position other than idle will not allow for the BRAKE PIPE TEST to appear
- Do not touch the Automatic Brake Handle until the computer screen states “Charge Train Before Running Brake Pipe Test ”
- Once the message “CHARGE TRAIN BEFORE RUNNING BRAKE PIPE TEST” appears, the Engineer can move the Automatic Brake Handle to RELEASE and charge train.



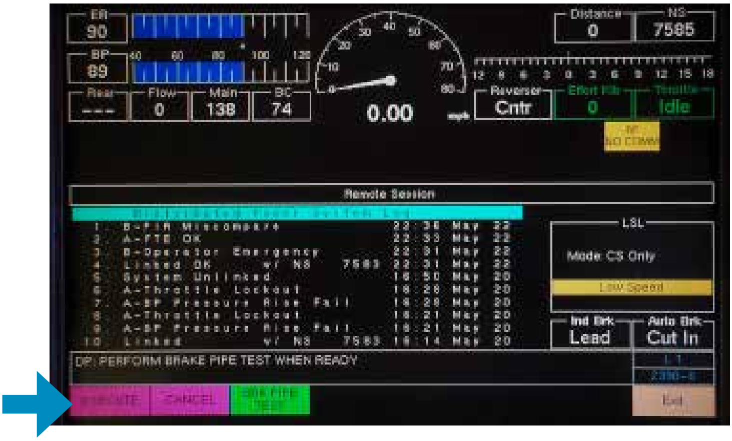
Performing the Brake Pipe Test:

- Wait for airflow to be below **20 CFM** or airflow to be stable for 90 seconds
- From the DP Example Screen below, the Lead and Remote units are below the Flow requirement and ready for Brake Test.

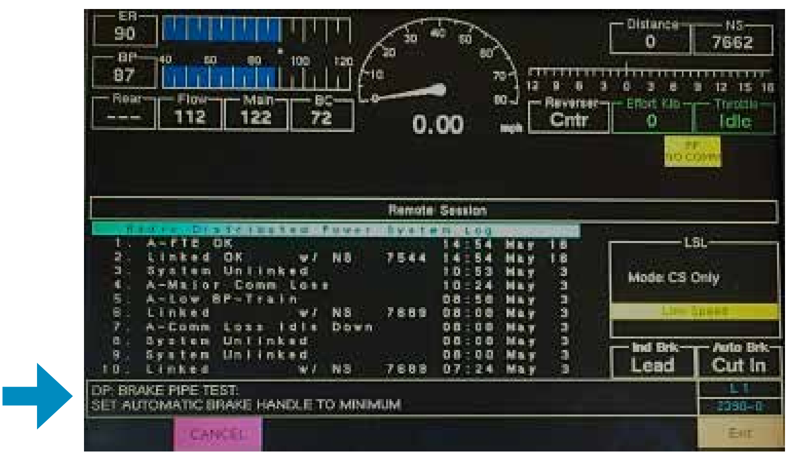


- Select Brake Pipe Test

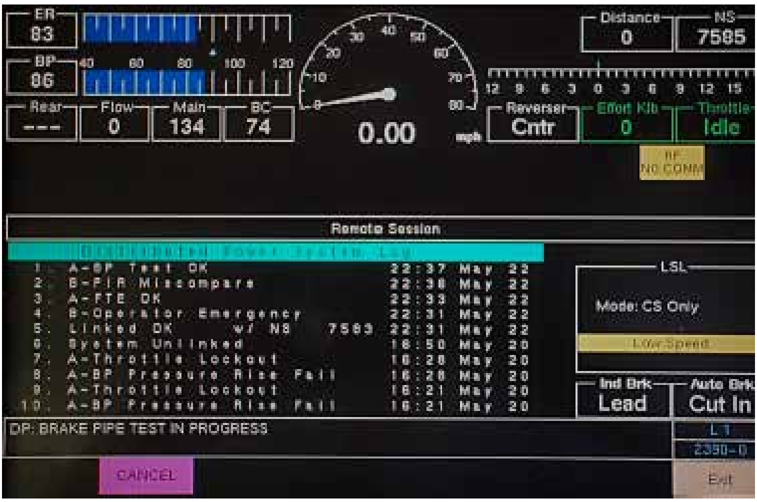
- Once **BRAKE PIPE TEST** is selected, the **EXECUTE** button must be selected within 15 seconds in order to activate the Brake Test.



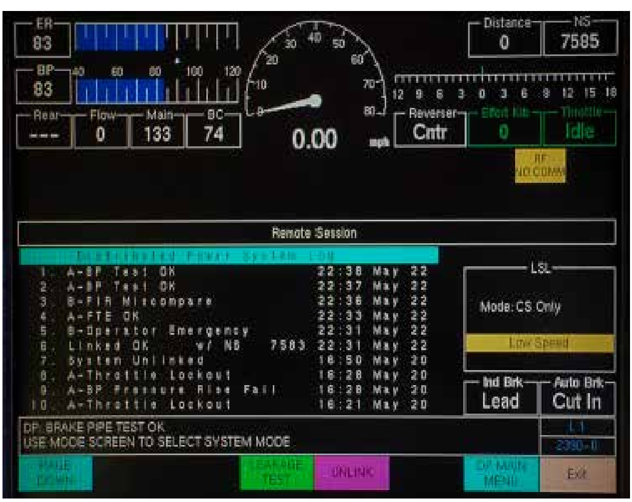
- Set Automatic Brake Handle to **MINIMUM**.



- **"BRAKE PIPE TEST IN PROGRESS"**
- Wait for automated brake pipe test to complete.



- **Brake Pipe Test OK** will appear.
- Press the **DP MAIN MENU** key, then **MODE** key, then press **RUN**, then press **EXECUTE**.



Line of Road Troubleshooting:

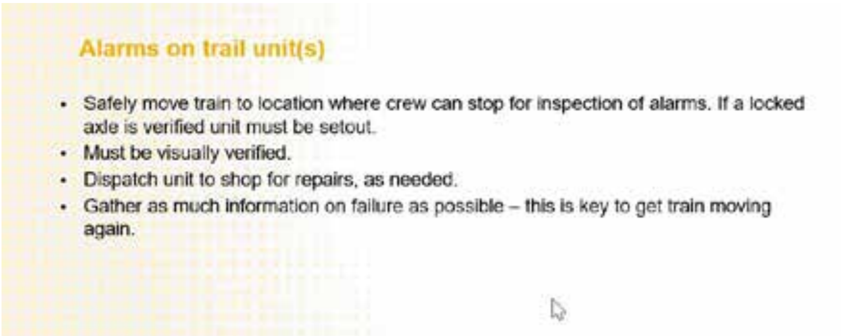
DO's	DON'Ts
DO exercise patience during a COMM LOSS and give DP a chance to reestablish communication	**Don't** unlink DP on line of road
DO when exiting set-out mode, select "normal" then "execute" before opening the angle cock	**Don't** stop the train if safe train handling can be maintained during COMM loss
DO provide as much information as possible for proper reporting	**Don't** become alarmed by yellow and red COMM loss lights. The red COMM loss will be eliminated with future software upgrades
DO reposition an isolated Remote unit that is shutdown and won't restart to head-end or setout	**Don't** cycle the computer breakers for troubleshooting.

If you encounter a Comm Loss while the train is moving:

- **Never un-link DP on line of road. Do not cycle locomotive computer breakers.**
- Ride through the COMM loss, give DP a chance to re-establish communication: Do not stop train if safe train handling can be maintained.
- During DP COMM LOSS, the remote will continue to operate according to the last command received up to 90 minutes, OR until either the COMM is restored, OR there is a change in brake pipe pressure.
- If the remote is in idle down once communication is re-established, hit the "Normal" key and release the automatic brake (DP needs to see an increase of 3 psi or greater) for remote to return to operation.
- The only difference between a (Momentary) Yellow and (Sustained) Red COMM loss is the amount of time of the COMM loss.

If you encounter a Comm Loss while the train is moving in DB:

- During a DP COMM Loss while operating in dynamic braking, the remote consist will remain in Dynamic Brake until COMM is restored, OR until the train is brought to a stop and the brake pipe is reduced to zero via an emergency brake application (**After Stopping the Train**).
- Then restore brake pipe pressure. Once the brake pipe pressure reaches 60 PSI the remote consist will go to Isolate with the brake valve cut out and the independent brake will release with an automatic brake release. The remote consist will operate like boxcars in this state (Isolate, Brake Valve Out).
- Once communication is re-established, hit the "Normal" key and release automatic brake (DP needs to see an increase of 3 psi or greater) for remote to return to operation.
- The only difference between a (Momentary) Yellow and (Sustained) Red COMM loss is the amount of time of the COMM loss.



In Conclusion:

Setting up Distributed Power correctly is essential to getting these trains down the road. Following the setup process and troubelshooting steps outlined in this paper will ensure that DP will work as intended and minimize train delays.

Reference: NS Training Code 21112 DP Training

The Evolution of Traction Motors

Prepared by:
Randell Honc, Southwest Research Institute
Derya Ferendeci, ABB
Ron Delevan, Morgan Advanced Materials
Douglas Johnson, Morgan Advanced Materials
Eugen Grecu, VIA Rail Canada Inc.

Abstract:

This paper is written with the goal of discussing the traction motors used in the railway industry. It will analyze the operation of DC series and AC traction motors and compare the two technologies. The authors considered worthwhile taking some time to delve into the history of electricity, underlining the important milestones that marked the invention of motors. Over the span of several decades in the 1800s, scientists, inventors, and entrepreneurs, worked feverishly to gain an understanding of electricity and to master it by developing useful applications. Building a motor that would eventually replace the horse was a preoccupation from the very beginning. Twenty years after Théophile Gramme designed the first commercially useful generator in 1871, George Westinghouse came up with the first enclosed DC series motor for traction. This fundamental design lasted for more than one century on DC traction motors. The 3-phase AC motor revolutionized the industries at the turn of the 20th century. It waited for almost one century to challenge and win the race against the DC motor in locomotive traction systems. The development of power electronics made possible the smooth speed control of the AC motor turning it into a winner. And thus, dawned the era of AC traction.

Brief history of electrical motors from the beginnings to modern designs

Eugen Grecu

In the second half of the 18th century, Luigi Galvani, an Italian physicist and biologist, discovers the animal electricity in his experiments. This sparks the interest of other physicists of his time, who experiment and theorize on the subject. Among them, Alessandro Volta, another Italian physicist and chemist, hypothesizes that the electricity in Galvani's experiments is being produced by an electrolyte and two dissimilar metal electrodes. He builds one of the first electrical batteries, the voltaic pile, by using two electrodes, one made of Copper, and the other made of Zinc, immersed in a solution of brine, or of sulphuric acid. See Figure 1.

Figure 1: Voltaic pile

Experimenting with electricity, around the year 1820, Hans Christian Orsted, a Danish physicist and chemist, discovers that a magnetic compass needle is moving when current is flowing through a nearby wire. His results are further experimented with by Michael Faraday who in 1821 obtains the first electromotive force with his homopolar electric motor. See Figure 2.

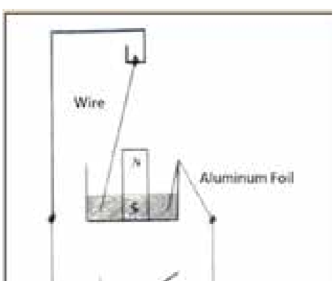


Figure 2 – First homopolar motor experiment

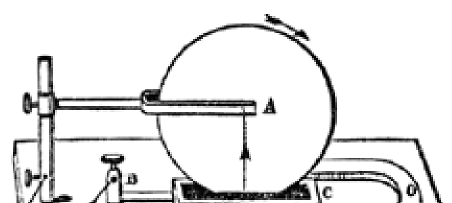


Figure 3 – First homopolar motor

In 1822, Peter Barlow, an English mathematician and physicist, invents the Barlow's wheel. The first homopolar motor. See Figure 3.

By 1831, Michael Faraday defines the law of electromagnetic induction and he builds the first homopolar generator. See Figure 4.

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

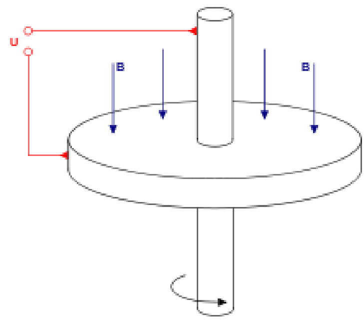


Figure 4 – First homopolar generator principle

In 1832, the Scottish physicist William Ritchie (Sir John Herschel), builds a rotating electromagnetic generator with four rotor coils, commutator and brushes. He is followed by Moritz Hermann Jacobi, a Russian engineer and physicist who creates the first usable electromagnetic motor[1]. See Figure 5.

Figure 5 – First electromagnetic

1. Origin of the Electric Motor

Figure 6 - Thomas Davenport, motor model

The potential of electricity and the emerging electrical motors fascinated the minds of many scientists and entrepreneurs. In 1834, on the other side of the Atlantic, Thomas Davenport, a blacksmith and entrepreneur from Vermont, builds the first DC motor that he patented in 1837.[2] He uses it to power a model train and machines in his workshop. See Figure 6.

Figure 7 – First electric car model

In 1835 in the Netherlands. Sibrandus Stratingh and Christopher Becker build an electric motor that powers a small model car, driving for 20 min on a full charge. The motor was an improvement of Jacobi's motor. See Figure 7.

2. KIT - The invention of the electric motor 1800-1854

The imagination of many scientists and entrepreneurs is captured by the idea of building vehicles powered by electric motors.

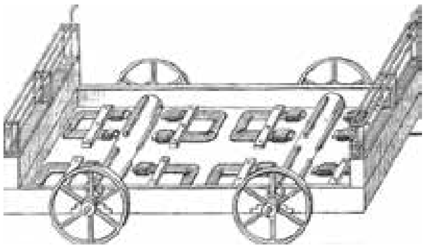


Figure 8 – Robert Davidson's first electric locomotive

Thus, in Scotland, inventor and entrepreneur Robert Davidson develops electric motors for a lathe and model vehicles. In 1839 he builds the first electrically powered car. In 1840, he presents his achievements at the public "Electromagnetic Exhibition" in Aberdeen. Among them, the model electric locomotive that could carry two people.[3] In 1842 he tests a 5-ton, 16ft (4.8m) long locomotive between Edinburgh and Glasgow. The test locomotive is equipped with a 1HP engine (0.74 kW) and travels at a speed of 4 mph (6.4 km / h). See Figure 8.

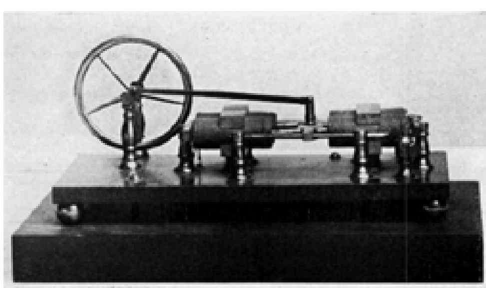


Figure 9 – Page's reciprocating motor, model

In 1841, on the American continent, Charles G. Page, inventor, physician, chemist, and entrepreneur, builds his axial, reciprocating motor (axial engine) with solenoids.[4] See Figure 9. He experiments with axial engines of up to 8HP.

[3.] KIT - The invention of the electric motor 1800-1854

[4.] Origin of the Electric Motor

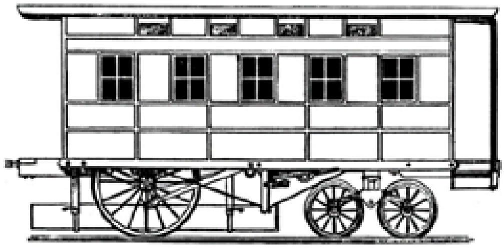


Figure 10 – Page's EM locomotive

In 1851 Page enlarges his motors to 20 HP. On April 29, the same year, Page tests a 21,000lb (10 ton) electromagnetic locomotive with nitric acid batteries, traveling on the route from Washington DC to Bladensburg, Maryland in 19min. See Figure 10. His vehicle reaches a top speed of 19mph (31 km/h). The batteries fail on route, and the solenoids fail due to back EMF discharge.

Between 1854 and 1871, the design of electric machines is maturing fast, to building usable electrical generators and motors.

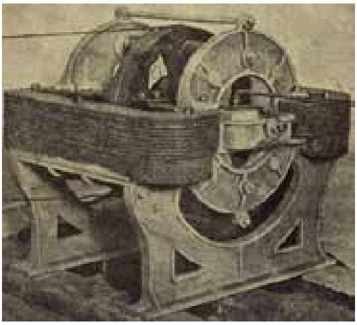


Figure 11 - Søren Hjorth's dynamo

In 1854, the Danish inventor Søren Hjorth patented the first self excited dynamo. See Figure 11.

From amongst many entrepreneurs on both sides of the Atlantic who work fervently and contribute to the maturation of the electrical machines, we just have space to mention the Belgian Zénobe Théophile Gramme who builds in 1871 the first dynamo, known as the Gramme machine. He presents it to the Academy of Sciences in Paris. This is the first generator to produce power on a commercial scale for industry. See Figure 12. Figure 13 explains the dynamo's induction principle.

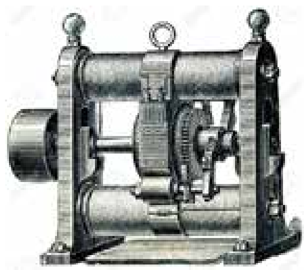


Figure 12 – The Gramme dynamo

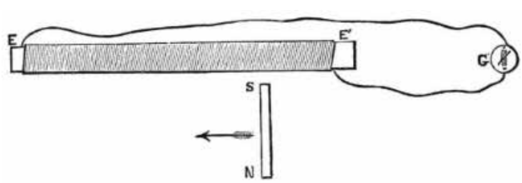


Figure 13 – The Gramme machine principle of operation

Figure 14 – The Gramme's motor, model

In 1873, Gramme reversed the dynamo operation resulting in the first successful electrical motor. See Figure 14.

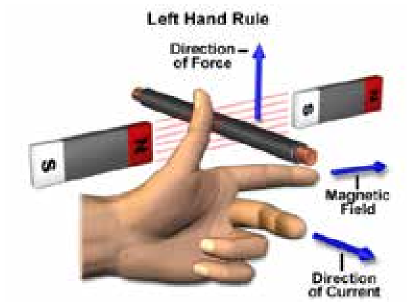


Figure 15 – the Left-hand rule

By now, the science reaches a deeper understanding of the physical laws of the electrical and electromagnetic fields.

Sir John Ambrose Fleming (UK) defines the left-hand rule to figure out easily the relationship between the direction of current, the magnetic field, and the EM force. See Figure 15.

In 1861, James Clerk Maxwell, a Scottish theoretical physicist, unifies the electric, magnetic, and optical fields in a set of equations that provide a mathematical tool for further scientific study.

One important progress in the evolution of electrical motors was marked by the work of Frank Julian Sprague, an American naval engineer, in the 1880s.[5] He invents the constant speed, non-sparking motor with fixed brushes. Edison Electric Company sells 250 motors. He designs the regenerating operation of motors and develops an improved field winding to maintain a fixed non-sparking position of commutator brushes.

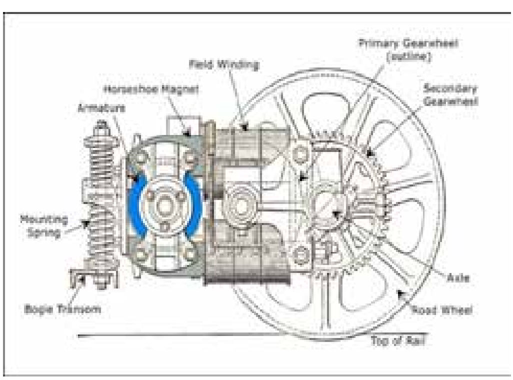


Figure 16 – Sprague's wheelbarrow motor

5. Seldom Told Tales of Sharon (Book Three)

Sprague develops a three-point, wheelbarrow suspension of axle-mounted geared motors for electric railways, for trolley-car equipment. The motor is mounted under the vehicle, closest to the wheels (#6 motor with a 2-gear ratio 12:1). See Figure 16.

Between 1887 and 1888 he develops the first trolley line in the world in Richmond (VA) for the Union Passenger Railway.

Eight years later, electric street cars powered by Sprague's motors, are used in the first underground service in Boston.

In 1890, Sprague Electric Railway & Motor Company is bought out by Edison General Electric Company, which manufactures most of Sprague's electric equipment.

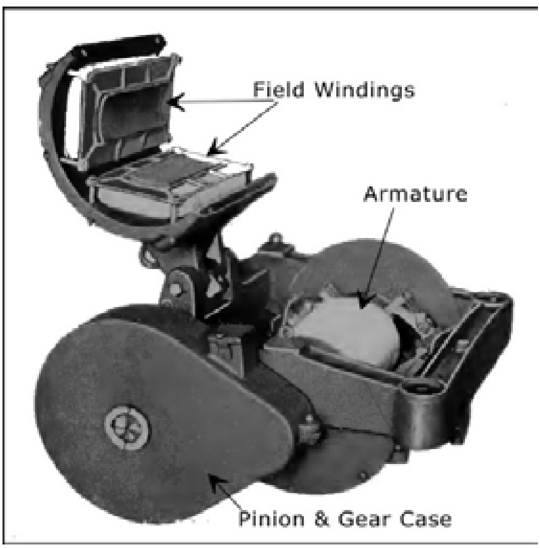


Figure 17 – Westinghouse's #3 motor

In the 1890's, George Westinghouse, another prolific American engineer and entrepreneur from Pittsburgh Pennsylvania, learning from his predecessors' design short-comings, makes the first enclosed motor to protect against snow, water, mud, and dust (No 3 motor). See Figure 17. He designs the series-wound motor and speed control with series resistors, cut out in a few steps to increase speed. This is the design lasting throughout the remaining history of DC traction motors.

Charles J. Van Depoele, a Belgium born engineer, is credited with the invention of carbon brushes and solving the fast wear problem of Copper and Brass brushes in use until then.

Figure 18 shows the series DC traction motor's major components[6]:

- Main field coils
- Interpole coils to improve commutation:
  - o Nullify the effect of armature reaction by creating a compensating electromagnetic force in the interpolar zone, proportional to the armature current
  - o Reduce (cancel) sparking between brushes and commutator, thus extending the motor's life
  - o Reduce heat developed in the short-circuited coils
  - o Reduce damaging back emf that can adversely affect the switch gear and power supply.
- Armature, wound, equipped with a commutator.
- Brushes. Placed at the magnetic neutral axis, where the emf is zero, and the resulting current is also zero.

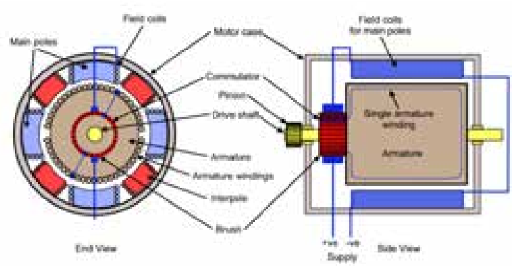


Figure 18 – DC traction motor

[6] The Railway Technical Website - Electric Traction Control

Introduction to Diesel Electric Propulsion

Randell Honc

Diesel–electric propulsion was first used in submarines in the 1920s. A diesel–electric transmission system is composed of a diesel engine connected to an electrical generator which then powers electric motors. The beauty of this system is that the electric motor speed is independent of diesel engine speed and the diesel engine can be run at an optimum speed for either power or fuel economy. Railroads adopted this technology because it offered greater flexibility and performance than steam locomotives, as well as lowering operating and maintenance costs.

Locomotive traction motors come in two varieties, direct current (DC) and alternating current (AC). Both types of traction motors can supply full rated torque at 0 RPM. In addition, they can be used as generators during braking in a process known as “dynamic braking”. Dynamic braking reduces wear on friction material brakes by dissipating forward momentum into heat that is released into the atmosphere.

Modern locomotives use AC traction motors. AC traction motors can be individually controlled which eliminates wheel slip and can compensate for weight transfer which improves adhesion levels up to 100% greater than its DC counterparts. In addition, AC traction motors do not utilize a motor commutator and brushes which reduces maintenance requirements.

DC Traction Motors

Randell Honc

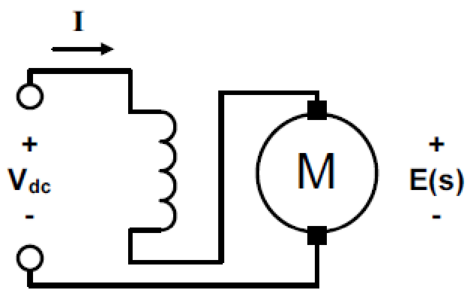


Figure 19. Series-wound DC Motor

DC traction motors provide high torque at low speeds for acceleration, and declining torque as speed increases. Traditionally, locomotives utilize series-wound brushed DC motors. In a series wound motor, the field coils are connected electrically in series with the armature coils (via the brushes). A diagram of a series-wound DC motor is presented in Figure 19. The spinning of the motor produces a voltage, known as the back EMF. The back EMF is proportional to armature speed or Revolutions Per Minute (RPM). The DC motor's torque is proportional to armature current. When power is first applied to a motor at a standstill, the counter EMF is zero and the only factor limiting the armature current is the armature resistance. Hence, the traction motors will produce their highest torque and maximum tractive effort during start up, enabling it to overcome the inertia of the train. As the traction motor speeds up, the internally generated voltage (the resultant back EMF) rises, less current passes through the motor and the torque drops. Thus the traction motor naturally stops accelerating when the drag of the train matches the torque produced by the traction motors.

Wheel slip may result if too much torque is applied to the wheels and the turning force applied to the wheels exceeds the opposing friction force of the surface of the rail. The inductance of the series field coil helps to smooth out large changes in current and consequently torque of the traction motor. However, wheel slip can still occur resulting in damage to the locomotive and the rails.

When wheel slip does occur, the locomotive must back off the power to the wheels by a process called engine de-rate. Engine de-rate is accomplished by reducing the main generator power output by varying its field excitation and hence the degree of loading applied to the engine. Since locomotives have either four or six traction motors coupled to the main generator, de-rating the engine for one traction motor results in reduced power to all traction motors.

DC traction motor wheel slip can be detected by observing the back EMF voltage and armature current in each traction motor and comparing both to the other traction motors. If a traction motor starts slipping, then it will speed up and the back EMF voltage will rise. In addition, the traction motor cannot transmit as much torque to the wheels and the armature current naturally falls off. A wheel slip bridge circuit is used to compare back EMF voltages and is presented in Figure 20. In this example, we are comparing the back EMF voltages of traction motors 3 and 6. If the voltages are imbalanced, then a current is induced across the WS36 relay field coil and the relay will pickup. This will cause an engine de-rate.

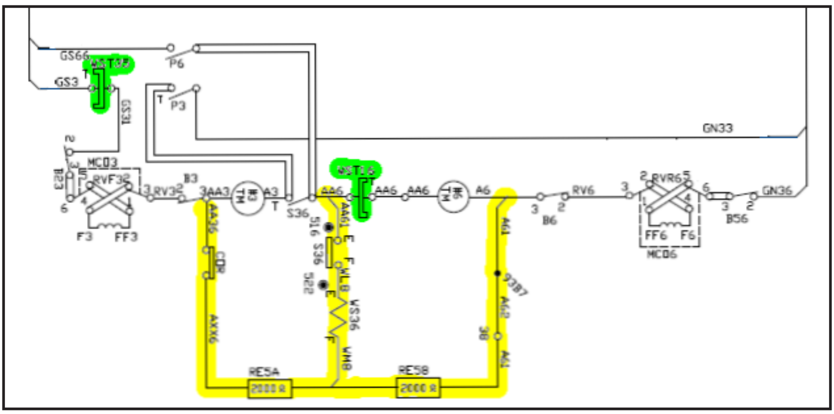


Figure 20. DC Traction Motor Wheel slip Bridge Circuit and Wheel slip Transductors

Traction motor armature currents are also compared. DC current will produce a magnetic field proportional to the amount of current flowing through the circuit. The magnetic field can be measured using a current transductor. However, if two cables are run opposite to each other through a current transductor then the magnetic fields will cancel each other through a process called current nullification. Two wheel slip transductors are shown in Figure 20. If traction motor 3 and 5 armature currents are equal the WST35 will not sense any magnetic field. The same is true for WST16 if traction motors 1 and 6 armature currents are balanced. Note that traction motors in different circuits are compared to ensure that all the traction motors are operating similarly and not slipping.

At low track speed and full horsepower, main generator output voltage is relatively low, while main generator output current is relatively high. Since traction motor torque is related to the armature current, high main generator current means more tractive effort at the wheels. Ideally all power should be split equally between all the traction motors. However, if two traction motors are placed in series then for a given power level both traction motors operate at twice the armature current as opposed to each traction motor being directly connected to main generator output. An example of a series configuration is presented in Figure 21.

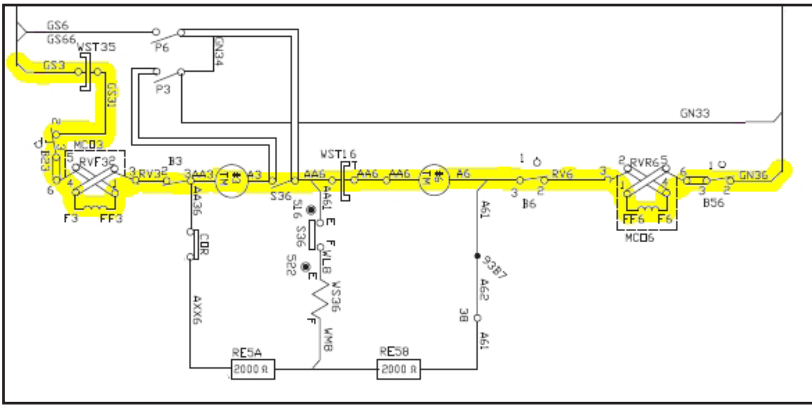


Figure 21. Two Traction Motors Connected in Series to Main Generator Output

As track speed increases, the main generator output voltage increases and output current decreases for a constant horsepower. Since the traction motor speed is limited by the applied voltage, the series traction motor configuration would be limited in speed. By reconfiguring the P and S contactors it is possible to connect both traction motors directly to main generator output and increase track speed. An example of a parallel configuration is presented in Figure 22.

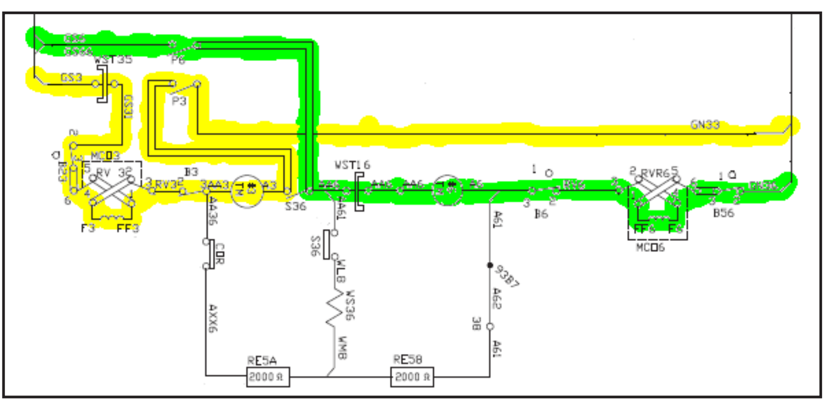


Figure 22. Traction Motors Connected in Parallel to Main Generator Output

Two traction motors are placed in series for starting the train when lots of torque is needed to accelerate from stop and later switched to a parallel configuration to enable high speed. The traction motors stop accelerating when the drag of the train matches the torque produced by the traction motors and maximum velocity is achieved.

Dynamic braking is an electrical arrangement used to change some of the mechanical power developed by the momentum and downhill force of a moving train into electrical power. The electrical power is converted into heat which is expelled into the air. Traction motor armatures, being geared to the axles, rotate whenever the locomotive is moving. During dynamic braking, the traction motors become electrical generators, and the electrical output of the motor armatures is connected to fan cooled resistor grids. Armature output is determined by the speed that the armature rotates (track speed) and by the amount of current flowing in the traction motor field coils. This arrangement reduces the amount of physical braking by the brake pads and reduces brake pad wear. Brake pads are consumable items that require periodic replacement and maintenance so dynamic braking results in lower maintenance costs.

Carbon Brushes

Ron Delevan, & Douglas Johnson

Carbon brushes or brushes as they are known today look nothing like a brush following the definition of the word. Nor do they resemble the original brushes used as the DC motor was developed. The main purpose of the brush in the DC motor is to reverse the direction of the armature current in the armature windings. This process is called commutation. Ideal commutation is sparkless to the naked eye and occurs inside the neutral zone. It seems simple, but as the DC motor developed into the workhorse of American ingenuity, ideal commutation became more and more difficult. The problem would plague early trolley motors for years before an acceptable solution would be presented.

What was the original brush? Likely a single copper wire laid across the commutator and sometimes dipped in mercury. And it was effective for low voltage, low current, low HP machines of the day. Eventually the wire would wear away stopping the machine immediately, a fatal flaw. Next, several wires were laid across the commutator. Finally, many small hair-like wires were constructed much like a paint brush and placed on the commutator. See US Patent 189997A by Charles F. Brush in Figure 23 below:

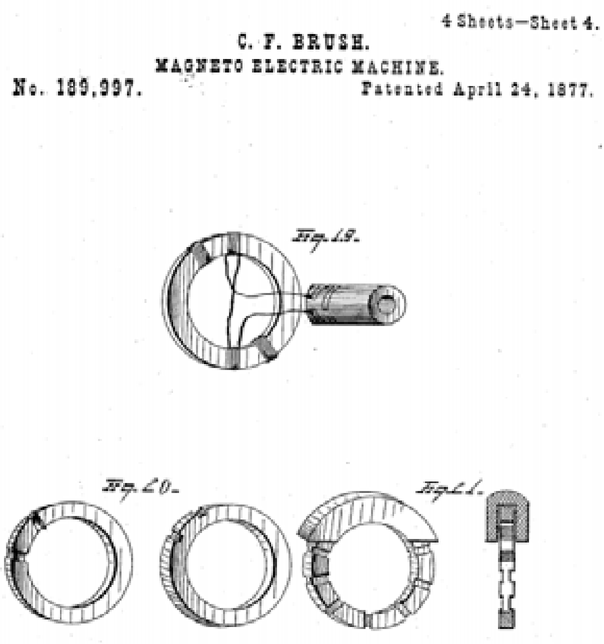


Figure 23. US Patent 189997A Page 4

This is where the name brush comes from; a slightly amusing coincidence. By this time brushes were the limiting factor stopping the advancement of the DC motors of the day. The sparking at the brush commutator interface was horrendous. Brushes wore quickly and destroyed the commutator. It is said that copper dust of both the brush and commutator littered the early rail tracks of the first trolley cars.[7] The conventional wisdom was to further reduce the brushes' resistance to try and eliminate the sparking. This was attempted with both finer brush hairs and lower resistance metals. Even brushes resembling steel wool were tried. Trolley motors of this time were located in the cab because of the large amount of maintenance required to keep the motor performing. DC motor pioneers had realized that the neutral zone is electrical and moves with the rotational speed of the motor. To keep the brushes in the neutral zone, the trolley operator manned a bar that allowed the moving of the brush rigging. Today's innerpoles attempt to do the same thing electrically without having to adjust the brush rigging. Engineers knew the optimal location for the traction motors was at the wheels, but the brush technology at the time prevented this from happening.

The first patent of the carbon brush, #1288, belongs to Professor George Forbes of Scotland (1885). Charles J. Van Depoele is thought to have first applied carbon brushes in Chicago, though not on a commercial scale. There is some controversy whether Van Depoele or Frank J. Sprague should be credited with the first successful application of the carbon brush. In 1888 the Thomson-Houston Company purchased all of Van Depoele's railway patents and brought him to Lynn, Mass. to work with Elihu Thomson and E.W. Rice, Jr (later president of General Electric Company).

Thomson and Rice, now aided by Van Depoele, worked diligently to mount the trolley car motors at the axle which was already done by Frank J. Sprague in Richmond, VA. Unsatisfactory commutation continued to plague their new designs. Eventually, Van Depoele suggested the use of carbon as a brush as he had tried in Chicago. This suggestion was quickly met with astonishment as carbon has a resistance 1000x that of copper. Carbon brushes were constructed from old batteries and tested with exceptional results. At the time a large commutator was laughable, but soon became the norm to dissipate the heat produced by the higher resistance carbon brushes. In 1914 Rice, before the Society of Electrical Managers, said, "…in fact, I believe that the whole traction industry, as we know it and as it developed, would have been impossible without the discovery of the carbon brush"[8].

The carbon brush was not finished evolving. In 1904, Peter J. Mulvey applied for a patent to "treat" carbon brushes by dipping them in oil and then baking them. It was an accidental discovery by Mulvey. The traction motor he was adjusting would not stop sparking. He removed the brush and flung it across the shop where

7. Men and Volts

8. The Beginning of the Carbon Brush

it landed in a vat of oil. Not wanting to waste company property, he removed the brush and took it home. In an effort to save the brush he "dried" it in his oven. When he returned the brush to service the next day, he noticed the sparking was greatly reduced. Patent 949, 988 was issued in 1910 and a sparking problem was solved, for the moment.

The tamped connection was first invented in 1907, patent 938,604. The tamped connection would later take the place of the riveted connection in most traction motor applications by providing a connection capable of better withstanding the vibration found in traction motors. Electro-graphitic brushes were first seen in 1910 providing longer brush life. They are so named because of the method of extreme heat the brushes are put through during production. If not carefully encased in coke the brushes would burn into a pile of ash. In 1937 the first split brushes were installed, patent unknown, to aid in commutation. In 1956 rubber hard tops were added to dampen the vibration of the traction motors. This aided commutation and reduced sparking. Many other brush patents exist to further improve commutation and brush life. Treated carbon brushes have evolved many times since Mulvey's first accidental experiment. Brush holder angles and brush constructions have also been effectively modified through the years.

Todays carbon brushes are similar only in name to the original carbon brushes. They are a testament to the many inventors and scientists who have spent countless hours developing them. Their ultimate goal: to improve commutation and reduce the chance of the dreaded flashover. The carbon brushes of today are application specific to suit the traction motor's needs. For example, long haul locomotives are often equipped with a different carbon brush grade than yard locomotives. Some brush grades are even traction motor specific.

AC Traction Motors and Controls

Derya Ferendeci

Since the late 19th century, the relative characteristics of three types of traction motors were generally understood. These motors were DC, single phase AC, and three phase AC. Regardless of their strengths and weaknesses, the choice of electric motor in early rail applications was determined more by the power supply and control of the motors than the characteristics of the motors themselves. Due to comparatively primitive control schemes, initial motor application to traction was achieved using DC or single-phase AC motors. However, over the past few decades, new control systems using thyristors, GTOs, and lately IGBTs have allowed better controls to be applied to three-phase AC motors. See Figure 24.

Figure 24 – AC Traction Motor (ABB)

Three-phase AC motors can further be divided into two types: synchronous and asynchronous. In synchronous AC motors, the rotational speed (RPM) is exactly determined by the supply frequency. It is the asynchronous or induction motor which has excellent characteristic for traction application. In an asynchronous induction motor, as its name applies, the rotational speed (RPM) is lower than the synchronous speed by an amount called slip. The rotating electromagnetic field is "induced" by the three- phase stator windings that are evenly distributed in a sequence around the iron core. The rotor is made of an iron core, and several half windings/bars short circuited together on either side. They look like a squirrel cage, from where it takes its name. Imagine a squirrel running inside a metal circular treadmill. Unlike a DC motor which uses conducting brushes to commutate electrical power to the switching electromagnetic field in the rotor, the asynchronous AC induction motor has no physical electrical connection between the stator and rotor.

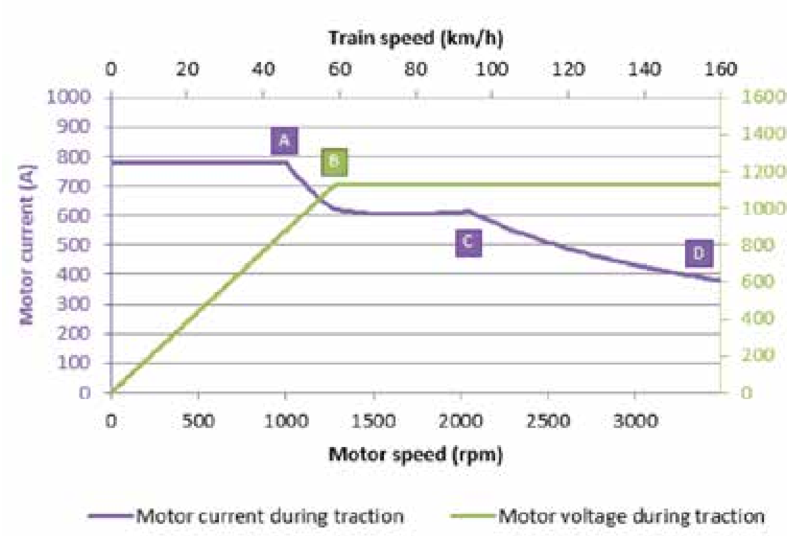


Figure 25 – AC Traction Motor, Voltage/Current versus speed

This squirrel cage rotor is composed of closed turns of conductors and as the magnetic field rotates outside relative to the rotor, currents are created or "induced" in these rotor conductors. Due to these currents, rotational or torsional forces act on these conductors, creating the classic motor effect causing the motor to turn. The torque exerted on the rotor itself depends on the difference between the rotor speed and the speed of rotation of the magnetic field created by the three-phase stator. This difference is expressed as electromagnetic "slip", not to be confused with classic mechanical wheel slip common in rail vehicles.

Mathematically, it can be shown that the speed of the rotor is proportional to the frequency of the current supplied to the motor, to the slip, and inversely to the number of poles on the stator. Under steady running conditions, this electromagnetic slip is only one or two percent of the physical speed, so varying the slip does not offer much for speed control. In early versions of three-phase control systems, the frequency of the supply to the motor was the same as the frequency of the power supplied to the motor and was fixed.

The only way to vary the speed of the motor was by changing the number of poles. Even by regrouping the poles by different connections, it was only possible to get three or four steady running speeds. It was this limitation and speed control which hindered the development of three-phase AC traction motor. It was only possible to vary the frequency of the current supplied to the motors using rotating machinery. This could only be achieved by a large rotary converter. However, such a cumbersome rotary converter reduced the advantages of the three-phase motor itself.

Figure 26 – AC Traction Motor (EMD)

In the late 1960s and 1970s the development of new high-power transistors known as thyristors opened a new future for these induction motors. With their ability to switch high current on and off quickly and very precisely, thyristors can be used to invert DC to AC by interrupting a DC supply. By inverting three circuits with an interval of one-third of a cycle between each, a three-phase AC supply can be produced, and it is relatively simple to vary the frequency of the supply within wide limits. This is the key to controlling the speed of an induction motor, by varying the frequency of the current supplied to it. Furthermore, this variation can be stepless, that is it can be varied gradually without any discontinuities.

In any motor control system, the effects of steps or sudden changes in motor current are critical because they can create mechanical wheel slip. With thyristor control, the three-phase motors were able to be worked much closer to the limit of adhesion than other types, not only because wheel slip is less likely to develop, but it is also self-correcting. If a pair of wheels loses its grip on the rails, it accelerates slightly, thus reducing the electromagnetic slip, and reducing the torque transmitted. This reduces the tendency for the wheels to lose their grip, so the wheel slip becomes self-correcting.

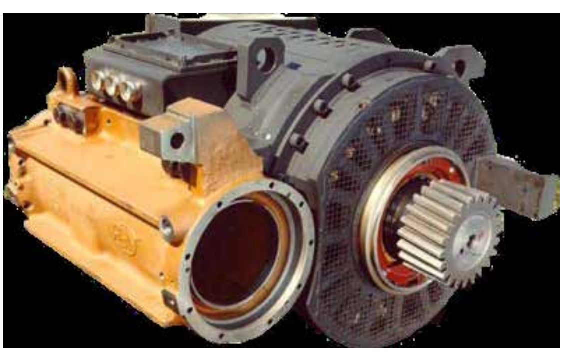


Figure 27 – AC Traction Motor with U-Tube

Additionally, as a train begins to accelerate on a downgrade, the rotor accelerates and overtakes the speeding of the rotating field. The electromagnetic slip changes direction and the motor exerts a braking force rather than driving torque, becoming essentially a three-phase alternator. In this instance, electrical energy is produced in the motor and can be fed back to dynamic braking, or back to the overhead catenary and to the power grid. Similarly, by using these control characteristics, the electromagnetic slip can also be reversed by slowing the rotating field and causing a reversal of the electromagnetic slip to bring the rail vehicle to a halt without using any mechanical braking at all.

AC Traction Motor Development in North America

In the 1980s, EMD was the first to start investment to develop AC traction for the special requirements of heavy haul rail application for North American railroads. This was in axle loads of 32 metric tons and required sustained high tractive effort levels for pulling long heavy freight trains up to 18,000 metric tons in total draught weight.

In 1987, EMD tested the first AC locomotive in North America with six powered axles (C-C). This test locomotive had one AC inverter per axle (known as axle control in AC traction). Following this development, in 1989 EMD built the first new locomotive designed for North America with AC traction, this was in collaboration with Siemens. This was the F69PHAC, a four-axle (B-B) passenger locomotive. Two of these were built and were subsequently loaned to Amtrak. The F69s had one inverter per two axle truck (known as truck or bogie control in AC traction). Then in 1991, EMD built the first heavy-haul freight locomotives in North America with AC traction; these were four SD60MAC (C-C) locomotives with one inverter per three axles (again known as truck/bogie control). The four SD60MAC demonstrator prototypes were the first true heavy-haul AC locomotives in North America, which ran on Burlington Northern. The SD60MAC was a new page in North American locomotive history. Previously, dispatchable adhesion for DC locomotives was typically less than 30 percent. With the SD60MACs, dispatchable adhesion was raised to 35 percent or higher. The SD60MAC demonstrated an unprecedented adhesion level of 45 percent for starting trains, thus setting the stage for consist reduction on heavy-haul trains. Burlington Northern followed with an order for 350 SD70MAC models. In regular operation, three SD70MAC AC locomotives replaced five SD40-2 DC traction locomotives.

So, why is the adhesion so high in AC locomotives? The speed-torque characteristic of AC motors promotes higher utilization of adhesion. High speed control computers which control and fire the PWM (Pulse Width Modulation) power signals on the inverters and sophisticated wheel creep control have been developed. Evolving beyond the classic rigid truck of previous generation of locomotives, new radial self-steering trucks overcome wheel slip in curves, so even the most minute wheel slip is virtually eliminated. The natural tendency of the AC motors to avoid wheel slip now allows all the wheels to better grip the rails. Thus, the performance advantages of AC Traction include higher wheel-rail adhesion and higher tractive effort. In addition, not needing brushes, AC traction motors offer significantly reduced traction motor maintenance costs. At overhaul, AC motors generally require only stator and rotor bearing attention. Train handling advantages include low speed dynamic braking, roll back and opposite direction braking, and no issues for dead-in-consist travel. Unlike DC motors, unlimited stall time in AC motors also reduces or eliminates the possibility of motor burnout.

In summary, locomotives equipped with AC traction motors offer increased tractive effort leading to reduced number of locomotives needed in a consist for the same dispatched tractive effort as compared to DC. Significantly reduced maintenance cost also has a big impact on long-term ownership costs. AC traction is now the most commonly preferred platform for both new-build as well as upgrade/retrofit locomotive orders.

DC/AC Traction Motors Comparison

The two traction motor technologies each has advantages and disadvantages[9]. Refer to Table 1 for a brief comparison.

Table 1 – DC versus AC Traction Motors Comparison

Feature	DC traction motors		AC traction motors		Comments
Design complexity		👎		👍	The DC traction motors
	Wound rotor	👎	Squirrel cage	👍	
	Commutator	👎	Not required	👍	
	Brushes	👎	Not required	👍	
Control complexity	Low	👍	High	👎 👍	The power electronics evolution made the use of AC traction motors both possible and affordable over the last three decades
Wheel slip/slide control	Modulates power to all motors at once	👎	Modulates power to each motor individually. Individual axle control possible and preferred.	👍	The individual power modulation of the AC traction motors allows a higher adhesion due to a finer adhesion control. Due to induction AC motor, wheel slip becomes self correcting.
Tractive Effort	Good		Better	👍	Much better speed-torque characteristics and significantly reduced wheel-slip provides for nearly 40 percent increase in tractive effort, leading to 3-for-5 reduction in units-per-consist
Starting Tractive Effort			Much higher	👍	
Minimum Continuous Speed			Very low minimum speed possible	👍	
Train handling			Much improved	👍	Better control across the speed spectrum with AC
Dynamic Braking	Recuperation of energy can be achieved	👍	Recuperation of energy can be achieved.	👍	Dynamic braking down to near zero mph possible with AC. The power electronics controls make possible the partial recuperation of the energy generated by the traction motors in DB mode.
Maintenance	Requires periodic inspections and brushes change out	👎	Reduced maintenance effort	👍	

9. AC Traction versus DC Traction

Conclusions

The progress of power electronics and their manufacturing cost reduction over the years made the AC traction motor a preferred technology for locomotives. The simpler construction, lack of commutation elements (commutator and brushes) make the AC traction motors more robust, less prone to environmental factors, thus more reliable. The maintenance requirements, and associated costs, are significantly reduced. The AC traction motor has therefore a definite advantage over its DC counterpart. We can confidently say that we stepped into the AC traction motor era, and that the DC traction motor that served well the railroads for more than one century is now approaching the end of the road.

Credits

Special thanks to people who kindly offered they guidance when needed:

- Stéphane Demers
- Timothy Standish
- Brian Marty

We thank also the many people working hard behind the scenes, adding valuable information on public web sites. These were a valuable resource for our search.

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Report on the Committee on Facilities, Material & Support

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NOTE: Jeff Clapper, Vice Chair, retired from the Wheeling & Lake Erie on July 15, 2020. We wish Jeff all the best on his retirement.

PERSONAL HISTORY

Bob Harvilla

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

Bob and his wife Barb have been married for 43 years and have two sons, Rob and Ryan, and two grandsons Max 9 and Griffin 6.

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A Comparison of UTEX, Repair & Return, and Fleet Maintenance Process Flows

Prepared by:
Craig Opacic – Sales & Business Development
R&W Machine Company

On the surface, the supplier customer relationship is simple. The customer has a requirement for parts or services necessary to support their operation. The supplier has the capability to provide a product or service that fulfills this need. The transaction is initiated by a request for a quotation that contains basic information including price, delivery, and payment terms. Any applicable technical specifications or drawings are provided and taken into consideration when formulating the quote. The customer deems the quotation acceptable and issues a purchase order. The supplier manufactures the items or provides the service required and delivers the component(s). It seems pretty simple.

The complexity comes from which of a number of options the transaction is based. This is especially true for more complicated components. The options include Outright Purchase, Repair & Return, UTEX (Unit Exchange), and Fleet Maintenance, which is sometimes referred to as Core Component Management. Each indicates a distinct expectation on behalf of both the customer and supplier and contributes greatly to customer's satisfaction and supplier performance.

Individual customer requirements dictate best approach. What type of product or service is required? What type of railroad does the customer operate? The needs of a Class I can differ greatly from a Short Line due to differing operating conditions. Are the parts or service for a long-haul application or a yard locomotive? In what type of environment does the locomotive operate? Does the railroad have a core pool to draw from?

Economic considerations are tied into some of the above considerations. What cost to the customer is appropriate for the application? Is the locomotive part of a newer fleet in long haul service that is critical to the railroad's operating plan and therefore quality and life span are key or is it an aging yard locomotive that is used infrequently? What is the railroad's cost of having the locomotive out of service compared to the initial savings of a lower priced product with a lower level of quality?

Communication is key from the inception of the relationship. My comments regarding requirements and economics are stated in the form of questions. This is intentional. It is critical that the supplier understands and the customer communicates their expectations from the outset. Can the transaction be fulfilled without a clear understanding of the situation? Yes, it can. Does the relationship between the customer and supplier benefit from mutual knowledge afforded by open communication? Most certainly.

Diving deeper into the type of railroad the customer operates can further determine best approach. Class I, Regional, Short Line, and Passenger present different scenarios. Some of the differences include:

- Size of locomotive fleet
- Locomotive mix
- Available resources – shops, personnel, time, expertise
- Geography: Depending on the type of product or service, freight costs can be significant and proximity to the supplier can to a certain extent mitigate this expense.

Communication is a two-way street, and it is important that the supplier provides critical information that can affect their ability to perform to the customer's expectations. This information includes:

- Capacity
- Quality Certifications
- Expertise
- Access to required components

The focus of this paper is on rotable parts. By definition, a rotable part is:

A component or inventory item that can be repeatedly and economically restored to a fully serviceable condition. Servicing method in which an already-repaired equipment is exchanged for a failed equipment, which in turn is repaired and kept for another exchange.

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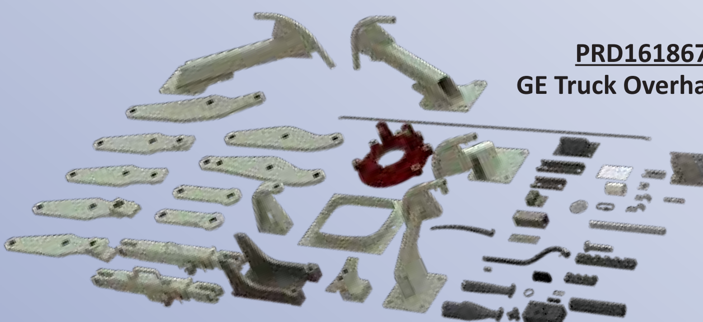

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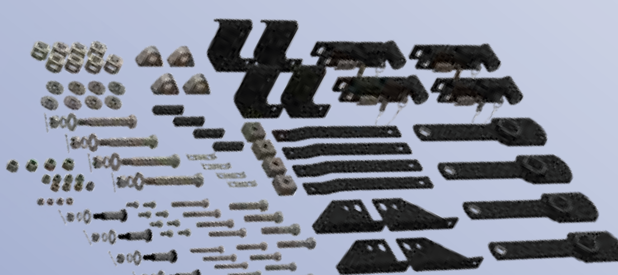

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Governors
Generators/Alternators

Four unique ways of constructing the transaction between the customer and supplier exist. They are:

- Outright Buy
- UTEX
- Repair & Return
- Fleet Maintenance

Options are always beneficial, unless a lack of understanding creates confusion. The expectations and conditions mentioned earlier determine which approach will work best. The following explores what each option offers.

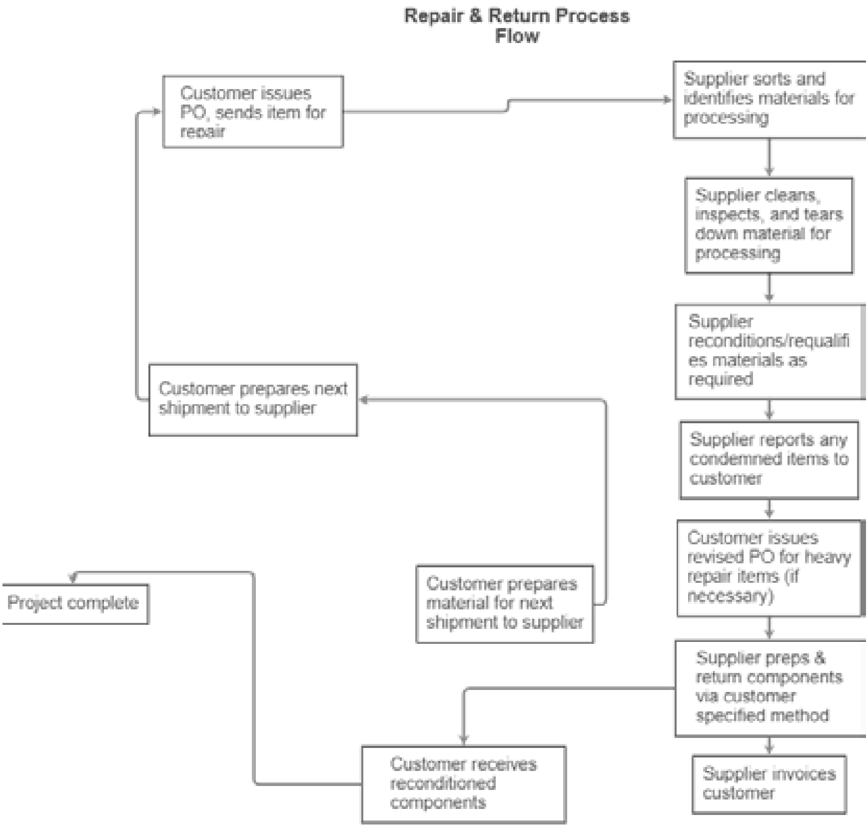
Outright Buy

This is the simplest transaction. Product can be new or remanufactured. All replacement parts are either new or requalified. 100% of the responsibility for quality and delivery is on the supplier. The product should be fully warranted. Core material not necessary. The lead time is dependent on the supplier's shop load and access to material.

The other three options provide scenarios with increased complexity but also increased flexibility that eliminates downtime and lost revenue. The flow charts presented offer an idea of how the organization that I work for handles the process flow.

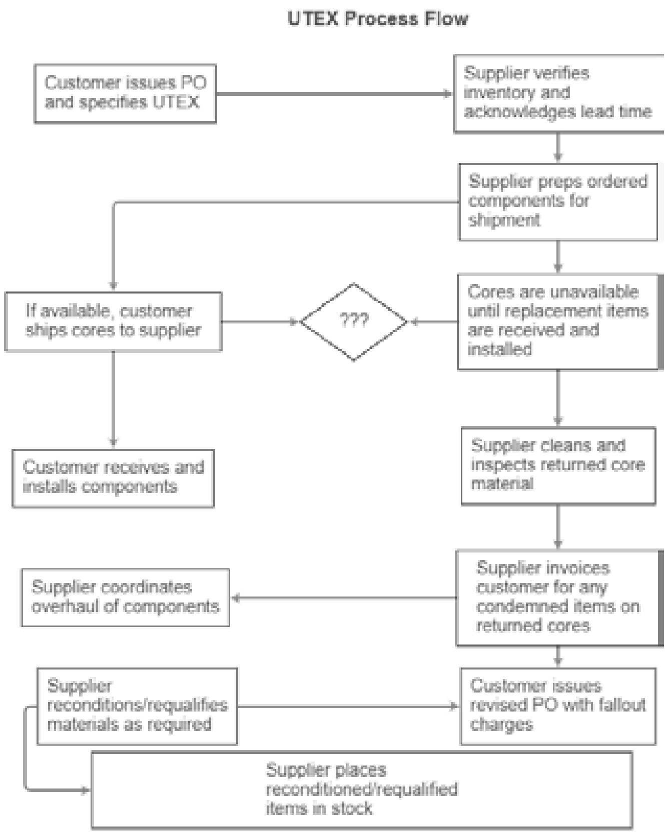
Repair & Return

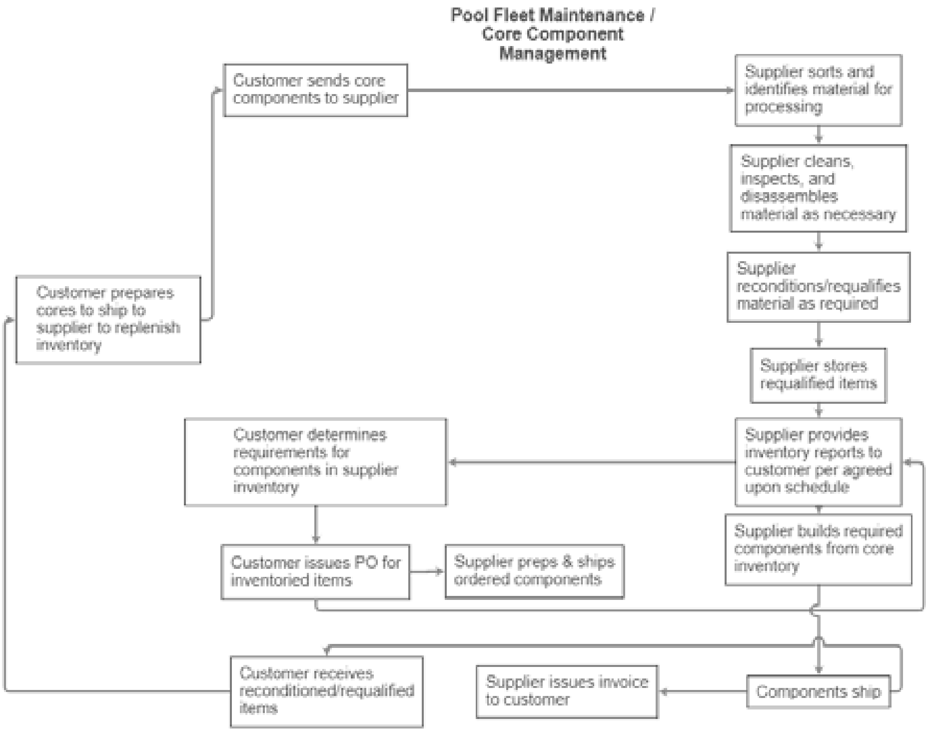
This, like outright buy, is a straightforward transaction. The customer's knowledge of the items maintenance history (traceability) and, unlike some of the concerns that customers have with UTEX, is not inheriting someone else's problems. The level of repair can be specified, through either providing a detailed technical specification or agreeing to a level of repair with the supplier. The age of the locomotive and type of service in which the locomotive is used can also be taken into consideration. The allowable lead time should also be considered when determining if Repair & Return is the best fit. The selling price from the supplier is a simple calculation of time and material.



UTEX

Unit Exchange (UTEX) is applicable when replacements are required and waiting for repair is not an option. In this approach the supplier is responsible for establishing/maintaining core pool. This can be accomplished either by receipt of similar cores from ongoing business with other customers or the purchase of cores from industry sources. While there is some flexibility on the level of repair to be performed by the supplier, the nature of a UTEX arrangement relies heavily on the supplier providing work to an industry standard (AAR) or internal specification. The age and model of locomotive has direct effect on core availability. Newer technology is less likely to have core material available due to time in service and older technology can present a challenge in core acquisition as the population of the locomotive diminishes over time. The cost to the customer has to take into account the condition of the returned cores and parts & labor required to repair. This is commonly referred to as fallout. Different suppliers view this situation differently and different components are more subject to fallout than are some others.





Fleet Maintenance

This method of facilitating customer requirements is sometimes referred to as Core Component Management. The approach is an enhanced form of Repair & Return with immediate access to item. To utilize this approach, the customer needs to commit to maintaining their core pool onsite at the supplier. The supplier can then react quickly to purchase orders for reconditioned or requalified items from this inventory. The benefits of this arrangement are similar to those of a Repair & Return method. The level of repair can be specified to customer, supplier, or industry standards. As mentioned earlier, the customer knows the history of the requalified or reconditioned component. Cost is based on material and labor. In certain situations where appropriate, the customer/supplier may exchange parts from other core material in the pool in order to minimize the cost of replacement parts for heavy repairs. Another way the railroad benefits is the elimination of the need for some inventory management resources. Periodic inventory reports provided by the supplier are an important part of any Fleet Management program.

Conclusion

The unique requirements of individual customers and capabilities of suppliers need to be understood in order to determine best fit. Understanding the advantages and disadvantages of each method can facilitate a better customer/supplier experience.

Recommendation

Both sides need to clearly and concisely communicate requirements and capabilities so that the appropriate procurement method can be determined and executed. Having these discussions at the inception of the relationship on both sides will avoid problems later.

Bar Coding in Railroad Emission Consideration

Prepared by:
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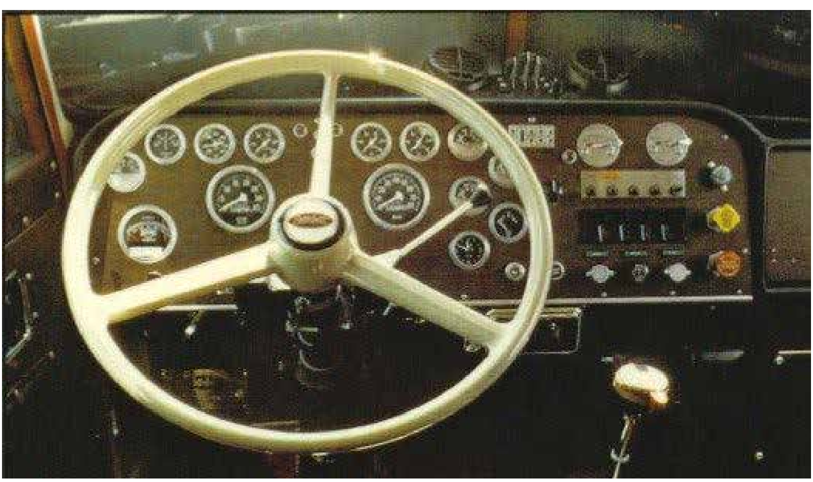
Manager Traction Products, Morgan Advanced Materials
Greenville, SC

THE TIMES THEY ARE A CHANGING!

Perhaps you may recall your Grand Parents' old 1950's car with the very large steering wheel or you have seen an old tractor trailer with the very large steering wheel. These vehicles, for the most part, took considerable thought in maneuvering, backing up or parking. As we progressed in time, power steering, power brakes, changes in transmissions and suspensions made the newer vehicles much easier to drive. Oh yes, even vehicles that can park themselves!



1950's Tractor Trailer Steering Wheel Over Thirty Inches Wide

Thinking about traveling experiences with Garmin and other trip devices: You may have had the "recalculating experience" which caused frustration. Todays driving apps are much friendlier and are packed with useful information like Speed Limit where you are currently driving, road warnings and shorter routes. You can find service plazas, shopping, hotels, motels, dining and sites all on your cell phone in a MAPS or Driving app.

A lot of things have changed.

In the past we have presented information on Bar Coding and RFID (Radio Frequency ID) as options for control and inventory. Are these systems relevant today? Has there been any technological advances of new systems that might be viable today? Some systems that might be advantageous to new issues like emissions?

Federal Emission Laws are dealt with differently at the State Level. In Pennsylvania, up until recently, vehicle emissions were looked at on basis of no "check Engine" light illuminated and a test of the gas cap. Now more attention is given to 'OEM' or as built equipment (exhaust, intake equipment, etc.) Sometimes, the place of your inspection could be advantageous and now the tests are being followed more closely by State Inspection. Interestingly, a new Chevrolet Diesel powered pickup arrived at a local dealer with newly installed "performance modifications". The inspection team checked the usual items; brakes, tires, lights and raised the truck up on the lift. It was quickly lowered, the hood was opened and closed. The truck was then moved out of the shop and parked. The owner was then notified of inspection failure due to non-complying modifications. That is "FAILED INSPECTION for Emissions"! Quite a difference from inspections of prior years. Currently, the railroad industry is faced with other issues like emissions.

Locomotive and railcars have gone through many technological changes over the years. Technology continues to amaze us. AC Traction, Emission Controls, Battery Powered Vehicles, Alternative Fuels, Larger and Heavier Rail Cars, Traffic Control and Safety Systems have all improved by quantum leaps. Emission rules and laws are continuing to evolve as well. Railroads may need to consider what will be their responsibility and at what pain. Remembering that Innovations continue to provide issues and opportunities to our industry at large and those issues have to be controlled, where possible.

Because, for the most part, railroads cover large vast areas, maintenance will be performed at multiple locations and properties as possible. Leasing and other methods of power sharing is an everyday occurrence and can be the norm. If OEM or Certified emission parts or locations are a part and driver of compliance, then what steps could be or should be considered to maintain control?

This paper is solely intended to reflect on the latter. That is, how can Railroads provide self-check, verification or validation? One way is with a possible flood of "paperwork" and follow-up or certification of work completed. Perhaps even follow up shopping involving in depth verification. It could involve a system on railroad property using RFID tags and remote scan and read to take and verify. In any case, a scanning and reading equipped system could present the opportunity to offer potential solutions to emission verification if required.

The following presents that opportunity. Remember, remote is the key. For the purpose of shortening or eliminating out of service time, we prefer hands off. If it was possible to pass by a capable reader or even have a walk around scan, the answer becomes obvious. Less time and more accurate data are a key.

RFID devices typically have two identifiers. The first being an identifier used to "single" out that device from the population. Secondly, a user reprogrammable portion that can be used to hold identifying information for the item to which the tag is attached.

A reading of the tag can be done at any time and using a data program, we can access the part Serial Number or other pertinent information. That data from the reading or scan can be used to certify the item's authenticity.

Thus, in a matter of seconds, verification of all such devices on a piece of equipment can be accomplished. As such, power assemblies, turbochargers, emission control (future possibility) and other desired devices can be inventoried and compared to history for that locomotive. Such a program and system could be viable as, in this case, possible certification method. Maybe an interesting and viable option to empower control.

So, Who Is Doing This?

Somewhat in the same vein: NASCAR! In short, NASCAR can use a handheld PDA running Microsoft Windows to enable RFID Tag reading at the track. This can happen any time like in the pit during the race or in pre-race check outs. NASCAR looks at safety issues, suspension, chassis, spoiler wings, etc.

The following is a copy of the NASCAR case study using RFID:

Franwell

Case Study: RFID Enters a New Race

NASCAR

NASCAR – Car of Tomorrow

In NASCAR's pursuit of a common car for use in the NASCAR NEXTEL Cup Series, the design of the car addressed many safety concerns, as well as providing cost reduction and other benefits, such as enhanced camera locations. Since safety was a primary objective in designing the new car, NASCAR also was concerned about making sure the newer, safer components were used as designed and that all race teams remained in compliance with rules set forth by the sanctioning body. When looking for a method to certify parts and follow that certification with a quick, effective method of verification at the track, RFID was a logical choice.

Lakeland, FL-based Franwell, Inc. was selected to develop the certification and tracking system to be used on NASCAR's "Car of Tomorrow" (COT). Franwell is a leader in the area of RFID solutions and integration. Our products and services include a complete set of RFID integration services for a variety of diverse industries.

Project Objectives

NASCAR wanted a solution that could identify compliant parts for their "Car of Tomorrow". The system was to function as an information repository to record certain activity associated with a tagged part. The tracking process begins at NASCAR's Research and Development Center in North Carolina, where the part is initially certified. Once certified, the tagged part can be verified at key points at race events, such as, inspection, practice, pit road, and after the race.

NASCAR determined the initial implementation for tracking parts would include wings and chassis and that each part would need to be identified uniquely. In addition, NASCAR officials wanted to be able to use a handheld device at race events to lookup an item's relevant information and to cross-reference the manual certification form. Finally, the system had to be designed to allow for the inclusion of additional compliant parts such as: restrictor plates, fuel cells and shocks. An RFID solution was proposed and accepted which met NASCAR's project requirements.

Challenges to Overcome

Although Franwell had considerable RFID experience, working with the race industry had its own unique challenges. The items to be tagged were not RF friendly. The harsh environment made it apparent the tag itself would need to be protected from the environment. The Franwell team discussed several viable options with NASCAR before finalizing the technology requirements. Franwell recommended the tags and handheld readers that would work best with the compliance parts and the environment in which they needed to function.

Pre-Implementation Proof-of-Concept Testing

The project team that included Franwell, NASCAR, Sprint Nextel and Crawford & Crawford Composites, worked together to select the optimal combination of tags and readers. A considerable amount of time was spent looking into how the tags could be attached to the parts. During the initial testing, a tag was successfully embedded into a carbon-fiber wing. For the chassis, a tag was chosen that would be rendered unusable once removed and for added security, a hologram label is applied over the tags. The frequency selected had to work with the metal content of the chassis and the carbon-fiber in the wing.

To allow race officials to verify items during a race event, an application was developed to work on a handheld PDA running the Microsoft™ Windows™ Mobile 5 operating system. To enable RFID reading of the tags at the track, a compact flash RFID reader is used in the PDA. Due to low frequency's range limitations, the tags can be read from only a few inches; however, this still met NASCAR requirements.

Initial Implementation

NASCAR began certifying chassis at the end of 2006 and continues with this certification process as part of the COT program. This process involves the attachment of 10 unique tags to the chassis. These tags are placed at prescribed locations after the chassis has passed certification. The RFID tags are read and each tag is associated with that chassis as the final step of certification.

In order to ensure compliance, only certified wings are allowed to be used during a race. Therefore the wings are closely controlled and assigned at each race. Late last year, Crawford began embedding RFID tags in the wings for the COT. These embedded tags will be used to issue and collect the wings from the teams. Prior to a race, a wing is issued to each team and this assignment is tracked by scanning the RFID tag in the wing. When the wing is collected at the end of the race, the tag is again read, to indicate the wing has been returned.

Results and Future plans

Due to the success of the initial implementation, NASCAR is now expanding the program and is currently also tagging fuel cells. NASCAR expects to expand its use of RFID technology in many additional areas. NASCAR is scheduled to run the "Car of Tomorrow" in 16 races in 2007 and all 38 sanctioned NEXTEL Cup Series events in 2008. The certification system developed by Franwell will be in use at each of these races. The mobility represented by the use of the Sprint Treo, SD/RFID reader module and the Sprint nationwide EVDO network means that future implementations will allow the RFID data to be transmitted directly to NASCAR headquarters or anywhere in the world.

NASCAR's success with RFID certainly validates the systems' potential. The benefits in quick and accurate recording and data manipulation with real time results have been demonstrated in this sport.

Considerations In Choosing RFID Tags

As noted, RFID stands for Radio Frequency ID. There is large number of configurations that are available but not all are viable on railroad equipment and not all are worth consideration.

LF, or low frequency, is a very cost effective option. It is limited to reading one tag at a time at close range. LF is virtually not affected by environmental conditions. Note again, one reading at a time.

HF, or high frequency, can be read from a distance of a few inches, allows for more data transfer than LF and processing speeds allow for more data transfer and storage.

UHF, or ultrahigh frequency, is where the action is, now and in the future. Reading goes from inches to up to 25 feet (currently), reads multiple tags at same instance and can read an entire truck load of tagged items in a few seconds. On the downside, UHF is sensitive to environmental conditions.

Overall, RFID in the UHF presents the most respectable performance for reading and communicating high numbers of tag reads per locomotive and even more so with a consist or many consists.

Data can be downloaded quickly and provided to programming to identify and report changes in historical files per locomotive.

Note: If your organization already uses RFID – you may look at using tags that are compatible with your existing system.

High Temperature RFID Tags

The most attractive characteristic of these RFID tags is their remote reading abilities as noted. This allows for immediate, no touch transfer of data and ID information with no cleaning or handling. The latest tags have been developed to withstand higher vibration and shock applications. These improvements are due to better potting materials and construction design changes. This indicates survivability on Locomotive Diesel Engines and accessory equipment is very favorable. Currently, such RFID tags are used in Gas and Oil drilling and manufacturing, military, etc. The same type tags are also being found in automotive and over highway trucking and construction equipment applications.

Mounting High Temperature RFID Tags:

There are a number of optimal mounting methods depending on where the tags are mounted.

- Glues and adhesives that are designed for use in certain environmental conditions
- Screws and rivets – tags are available with pre-drilled mounting holes
- Welding – some tags come with mounts that can be welded in place
- Embedding – tags may be sealed within cavities of components

Environmental Conditions and RFID Tags:

Most environmental issues are to be taken into account and may be handled by encapsulation.

- Consideration of environmental conditions like vibration and impact
- Considerations of environmental conditions like moisture, chemicals and oils
- Tags will degrade with higher temperatures over time

Overview of Two Available Types of RFID Tags:

Notice the size and READ DISTANCES.

Overview:
RFID Model A

1. Read distance 25 feet when mounted on metal
2. Mount area covered 1.02 square inch
3. Rugged application for vibration, impact and higher temperatures
4. Operating Frequencies ASTI 174-0100 (with cover)
5. Applications Include: construction equipment, tool and die, yard management / logistics, military, oil and gas, etc.
6. Mounting via screws or adhesive
7. Temperature max 200 C

Overview:
RFID Model B

1. Read distance 9 feet when mounted on metal
2. Mount area covered 1.05 square inch
3. Rugged application for vibration, impact and higher temperatures
4. Operating Frequencies 900 to 935 MHz
5. Applications Include: manufacturing, medical devices, rental, Military
6. Temperature max over 200 C

Conclusion

RFID use in Emission and other maintenance applications warrants consideration. Many opportunities and examples in RFID and BAR CODING are available in industry, military, medical, inventory management, retail sales and warranty tracking to review the systems' values.

Control of Emission Verification would most likely not warrant further action. It is very obvious that the experience that was shared with the inspection of the Chevrolet truck would be better than a "Stop Here for Emission Check" along the right of way.

The drive for new non-fossil fuel sources may have powerful influences in the future. Since we do not know the timing for completion of that alternative, we may be well advised to look at options such as RFID.

A complete file on the information gathered is available to the CMO's.

Thank You

Report on the Committee on Mechanical Maintenance

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John Hedrick

Principal Scientist

Southwest Research Institute, San Antonio, TX

Vice Chair

Eric Dillen

Advanced Engineering Leader

Wabtec Corporation-Frt Divn, Erie, PA

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R. Wullschleger	Chief Mechanical Officer	New York & Atlantic Rwy	Glendale, NY

PERSONAL HISTORY

John Hedrick

Principal Scientist
Southwest Research Institute
San Antonio, TX

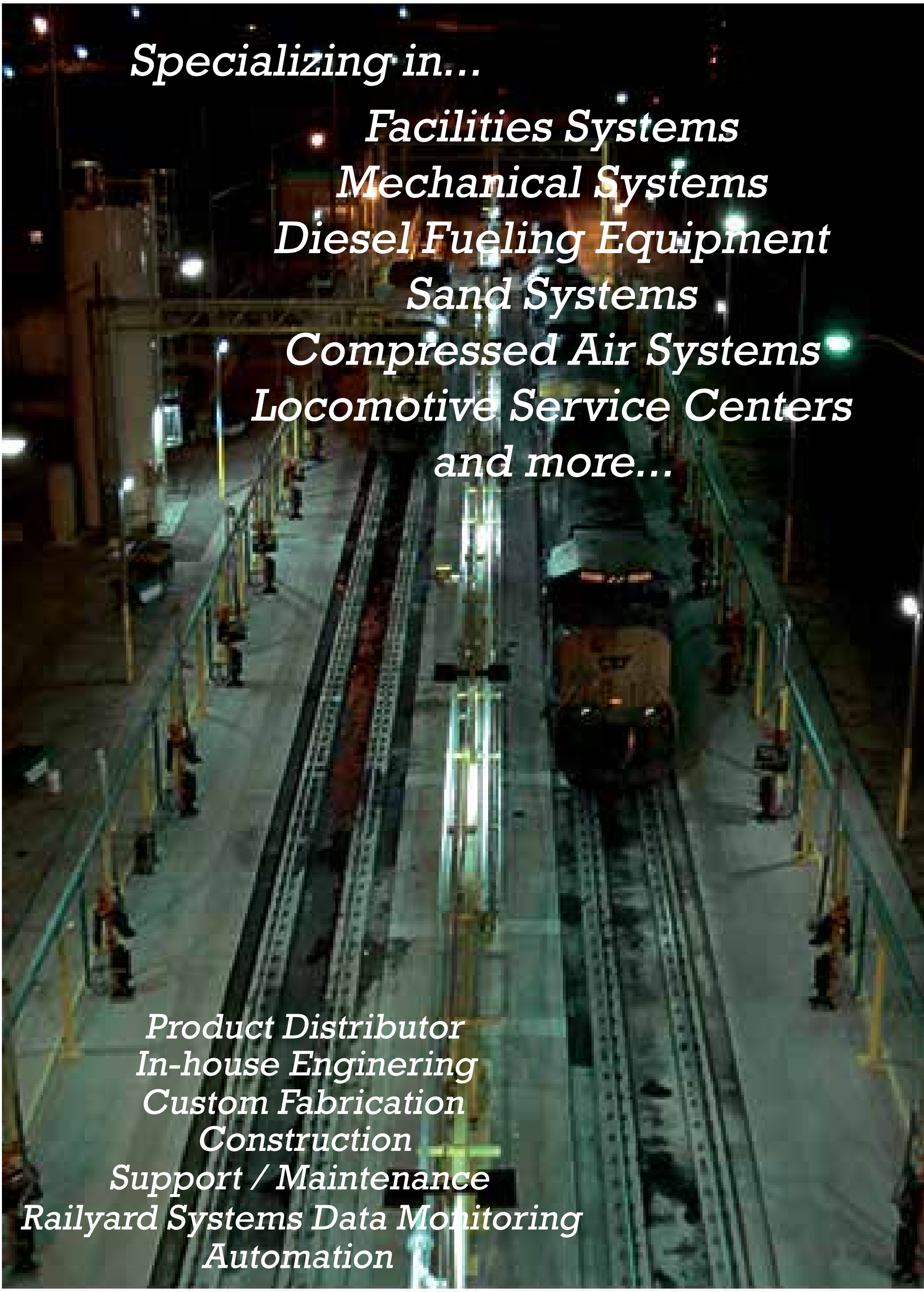
John Hedrick has spent over 30 years at Southwest Research Institute (SwRI) conducting research, development and testing on medium speed and high horsepower engines. The focus has been on the effect of lube oil on fuel economy and emissions, facility engineering for a high horsepower large engines, assist in the development of a high-pressure, late cycle, natural-gas injected engine, and worked as a consultant to large-bore/medium-speed engine users in the industrial, marine, rail, and nuclear power plant settings to reduce emissions and determine causes of various engine failures.

Most recent focus has been targeted on performance and emissions related to medium speed engines used in locomotives, stationary power generators, and marine applications. He has also become a Test Inspector for European certification of railroad engines by the International Union of Railroads (UIC 623 & UIC 624 tests). Also awarded eleven US Patents that focus on engines and their supporting systems.

Married to his "Better ¾", Peggy and they have two grown sons. Graduated from Texas A&M University in 1989 with a Bachelor's Degree in Engineering Technology with a focus on Thermal and Fluid Systems.

THE MECHANICAL MAINTENANCE COMMITTEE WOULD LIKE TO THANK TRANSPORTATION TECHNOLOGY CENTER, INC (TTCI) FOR HOSTING OUR MEETING ON FEBRUARY 25, 2020 IN PUEBLO, COLORADO.. WE WANT TO EXTEND OUR SINCERE APPRECIATION TO OUR HOST BRIAN SMITH AND ADAM DAVIDSON FOR MAKING OUR MEETING A SUCCESS.

THE COMMITTEE WAS ABLE TO TOUR THE TTCI FACILITY ON FEBRUARY 26, 2020.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AAR RP-589 Locomotive Compressor Load

Prepared by:
John Hedrick
Southwest Research Institute, San Antonio, TX - USA

ABSTRACT

The AAR Locomotive Committee is exploring the possibility of adding a fixed 30 SCFM air leak to their Recommended Practice (RP) 589, titled *"Rating for Specific Fuel Consumption of Diesel Electric Locomotives."* This paper describes a system that can control the air leak flow rate, developed ways of calibrating the system, and recommendations on system setup. Preliminary locomotive fuel economy testing results with and without the 30 SCFM air leak show that the 30 SCFM air leak will affect the fuel economy on the order of two percent for a line haul duty cycle and four percent for a switch duty cycle.

BACKGROUND

The AAR's RP-589, titled *"Rating for Specific Fuel Consumption of Diesel Electric Locomotives"*, provides a method of rating specific fuel consumption of diesel electric locomotives.[1] The basis of comparison is Net Traction Specific Fuel Consumption (NTSFC), where the fuel mass flow is divided by Net Traction Horsepower (NTHp). The equations are:

NTHp = (Traction Amps * Traction Volts) / 745.7
NTSFC = Mass Fuel Flow / NTHp

The NTSFC does not include the power for:

- Radiator fans.
- Generator excitation.
- Air compressor.
- Blowers.
- Battery charging.
- Fans / blowers.
- In-cab heaters or air conditioners.

AAR RP-589's standard reference conditions are very specific to assure that tests can be directly compared. The standard conditions are:

- Barometer = 28.86 In-Hg
  - Representing approximately 1,000 foot altitude.
- Air temperature = 77°F.
- Fuel temp = 90°F.
  - Recently changed from 60°F.
- Fuel
  - Specific gravity = 0.845
  - Density = 7.0543 lb/gal.
  - Lower heating value = 18,358 BTU/lb.

The current RP-589 procedure requires that the air compressor be locked out to prevent it from operating during the test. The typical ways to prevent the compressor from cycling are:

- Supply external compressed air to the test locomotive's Main Reservoir (MR), at a high enough pressure to prevent the air compressor from activating.
- Mechanically locking out the air compressor.
  - Shop air is typically supplied to the locomotive to allow pneumatic controls to operate normally, i.e.:
    - Shutters.
    - Jacket water control valves
- Replacing the air pressure sensor with a series of resistors so that the locomotive thinks that the air pressure is high enough that the compressor does not need to be operated.
  - Again, some shop air is typically supplied to the locomotive to operate normally.

Air leaks in train revenue service are inevitable and the compressor must cycle to make up for the air loss. An LMOA paper in 2018 showed that a significant amount of the air consumed by the train was due to leaks.[2] In *49 CFR § 232.205 - Class I brake test-initial terminal inspection*, there is a requirement that the air flow (generated by leaks in the air brake system and other air consumption in the locomotive), as measured by a calibrated flow indicator, must not exceed 60 cubic feet per minute (CFM).[3] Additionally, BNSF has requested an exemption from the FRA to allow a maximum of 90 CFM air leak, which matches the limit allowed in Canada.[4]

As part of AAR's update to the RP-589, the Locomotive Committee is considering adding a 30 SCFM compressed air leak to the locomotive fuel consumption test. Without any external compressed air supply, the locomotives compressor would need to cycle normally to make up for the air loss. The compressor operation will have a negative impact on the NTSFC because the power to drive the compressor will not be included in the denominator of the NTSFC equation and the fuel flow rate will increase. However, the 30 SCFM leak will allow the AAR's RP-589 test to more closely represent a real-world accessory load. Note that the 30 SCFM air leak is in addition to any air leaks that already exist on the locomotive.

ACFM vs. SCFM Air Flow

Because air is compressible and the volume, at a constant pressure, is affected by temperature, there are two ways of measuring volume flow. These are:

- Actual Cubic Foot per Minute (ACFM)
    - A common measure method of flow at non-standard pressure and temperature.
- Standard Cubic Foot Per Minute (SCFM)
    - Calculated by measuring ACFM and then correcting it to a standard temperature and pressure.

The SCFM measurement system removes differences in pressure and temperature. As shown in Figure 1, there is a strong effect on a Standard Cubic Foot (SCF) of air as the gauge pressure increases, at a constant temperature and barometer. Figure 2 shows that temperature has a much smaller effect on SCF compared to system pressure.

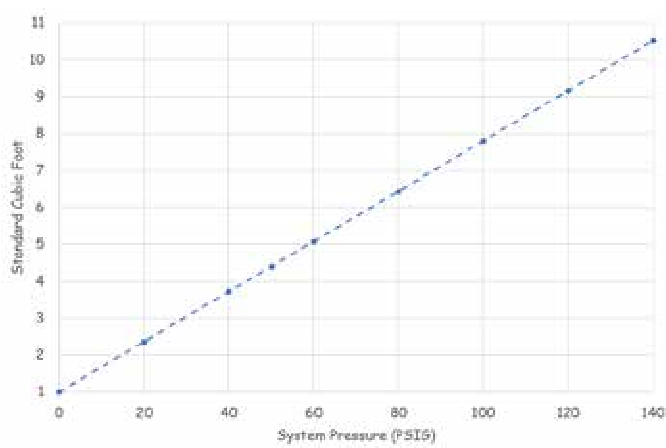
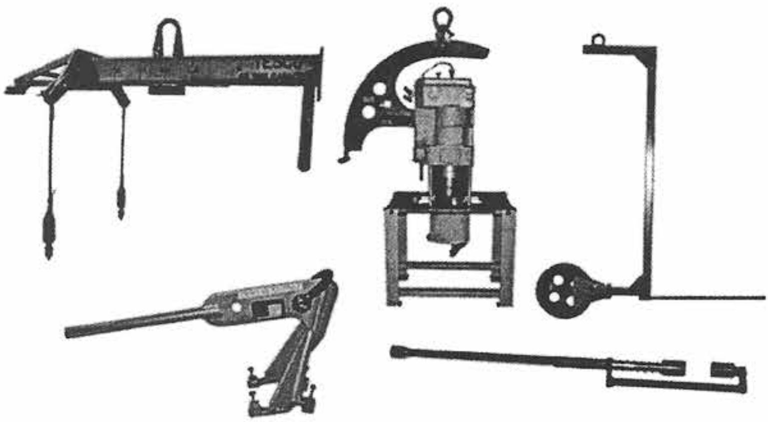
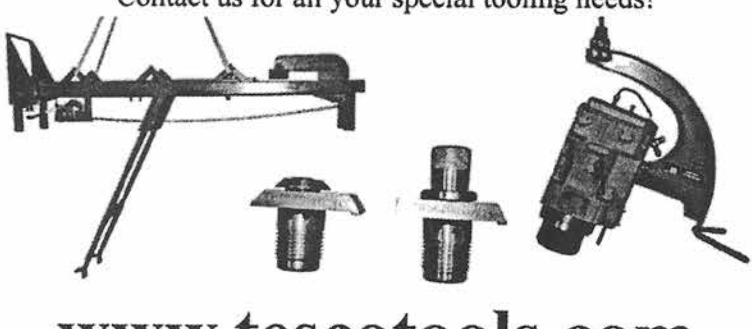


Figure #1 – Pressure Effect on a Standard Cubic Foot at a Constant Temperature and Barometer





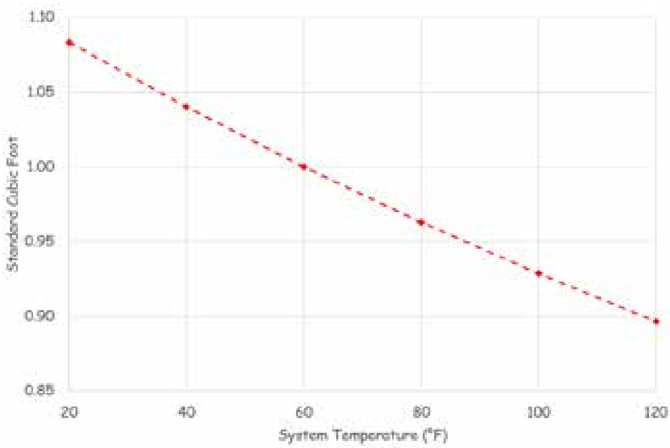


Figure #2 – Temperature Effect on a Standard Cubic Foot at a Constant Gauge Pressure and Barometer

For this paper, SCFM will be corrected to 60°F and 14.696 PSIA (29.921 Inch of Hg) which is the theoretical atmospheric pressure at sea level.[5] The calculation to convert ACFM to SCFM is:

SCFM = ACFM * (Inlet P / Standard P) * (Standard T / Inlet T)

Absolute units (Pounds per Square Inch Absolute [PSIA] and Degree Rankine [°R]) must be used in this calculation. These are:

- Inlet P = Measured PSI (Gauge) + Barometer pressure in PSIA.
- Standard P = 14.696 PSIA
- Standard T = 519.67°R
- Inlet T = Measured (°F) + 459.67

Test Setup

An orifice system was determined the simplest way to maintain the desired 30 SCFM compressed air system leak. Other systems were investigated (i.e.: roots meter, Micromotion, turbine flow meter, …), but the orifice appeared to be the most cost-effective and robust system. All that is required in the system is a good pressure regulator, a laboratory grade pressure transducer upstream of the orifice, and a calibrated orifice of the appropriate size. Figure 3 shows a simplified plumbing schematic of the system.

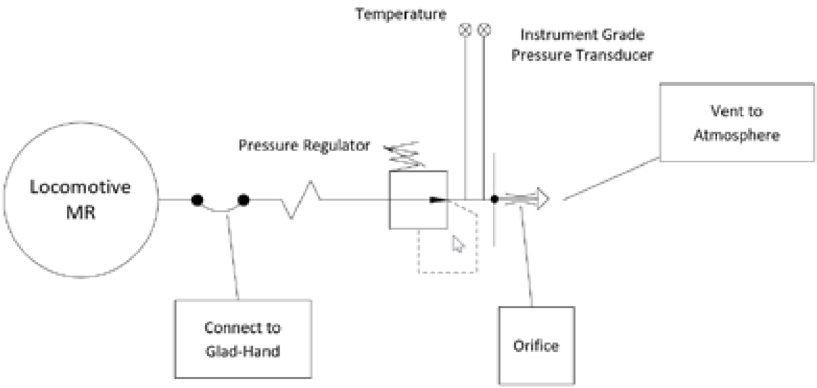


Figure #3 – Simplified Plumbing Schematic

Several orifices were tested to determine the pros and cons of different orifice sizes. For these tests, the compressed air was supplied from the Main Reservoir (MR) glad-hand on the rear of the locomotive. A TESCO T50041 Air Control Kit pressure regulator was used to control supply air pressure at the targeted levels (Figure 4). To calibrate the orifice flow, a roots meter (Figure 5) was installed downstream of the orifice to measure ACFM flow rate. Pressure and temperature were measured at the inlet to the roots meter so that the measured ACFM flow rate (provided by the roots meter) could be corrected to SCFM.

Figure #4 – Pressure Regulator Used for the Orifice Testing [6]

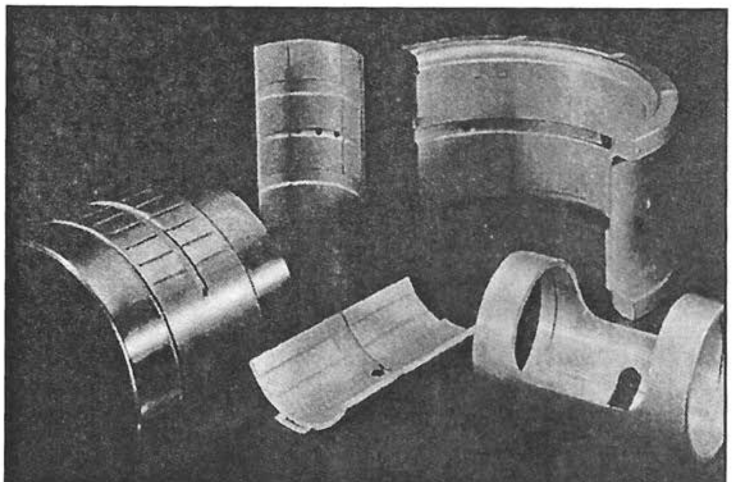
Figure #5 – Roots Meter Used for Orifice Calibration

The use of the TESCO T50041 Air Control Kit pressure regulator was selected because:

- It is sized appropriately for the targeted flow when connected to the locomotive's MR at ~140 PSI.
- This system (or its equivalent) should be available in most railroad shops.
- The pressure regulator has reasonable pressure control.

It was determined that the pressure gauge provided with this TESCO unit, while suitable for the systems original application, is not accurate enough for setting and measuring the air supply pressure to the orifices. It is recommended that an instrument grade pressure transducer be added just upstream of the orifice to measure the supply air pressure, and the gauge only be used as a reference. It is recommended that the pressure transducer output should be an input to the Data Acquisition (DAQ) system and be averaged along with fuel flow and NTHp at each Notch.

The orifices used for these tests were either built in-house or purchased from O'Keefe Controls Co. Regardless of orifice supplier, it is recommended that the orifice be made of stainless steel for maximum durability and have a minimum of ½" pipe inlet / outlet. Additionally, the orifice must be calibrated so that a known supply pressure equates to a known SCFM flow rate through the orifice. Once a calibration has been completed on the orifice, the SCFM can be calculated directly from the measured compressed air supply pressure.



It is critical that the orifice be installed in the correct orientation relative to the flow direction. Many orifices have the desired flow direction etched on the outside of the fitting. If the fitting is installed in the incorrect orientation, then the calibration of the orifice will be invalid.

Orifice Selection & Testing

Several orifices were tested, and the results are shown in Figure 6. The orifice sizes were:

- 9/64" (~0.141")
    - Built in-house and used to check system setup while waiting on supplier to deliver other orifices.
- 0.140" - O'Keefe
    - Initially selected to target ~110 PSI supply press.
- 0.160" - O'Keefe
- 11/64" (~0.172")
    - Made by modifying an O'Keefe 0.125" orifice (not tested in its original 0.125" configuration).

The resultant SCFM flow vs supply pressure was very linear for all orifices, and all orifices tested could provide 30 SCFM at an appropriate pressure. However, during these tests the locomotive compressor cycling on and off caused a variation in the regulator inlet supply pressure, which in turn caused variations in the orifice supply pressure, and this directly translates to variation in air flow through the orifice. The pressure oscillations in the supply pressure while using the 0.140" orifice is shown in Figure 7 and the pressure variations were approximately 7.8 PSI on an average of 114 PSIG, roughly +/- 3.5%. Figure 8 shows the same oscillations while testing with the 0.172" orifice, but the pressure variations were only 1.3 PSI at an average pressure of 68.8 PSIG, roughly +/- 1%. This suggests that the pressure regulator will maintain a more consistent supply pressure and hence a more consistent SCFM flow rate when a larger orifice and a corresponding lower orifice supply air pressure is used.

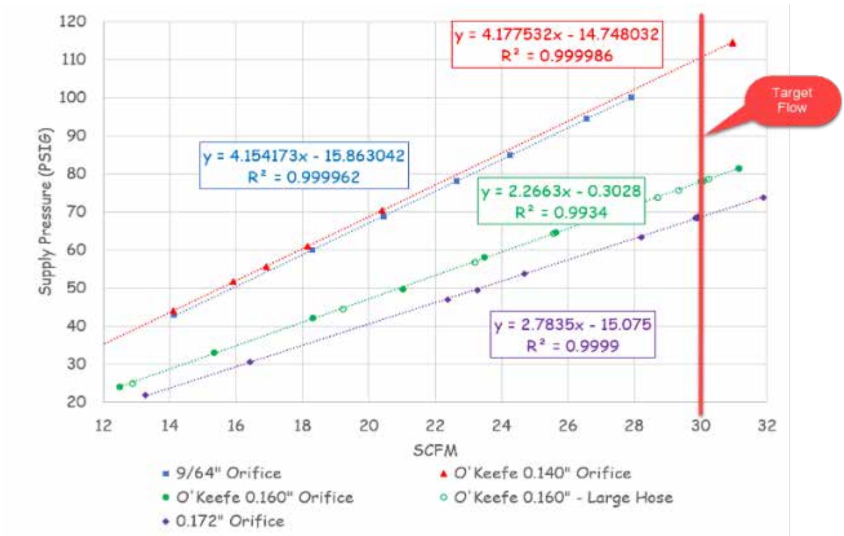


Figure #6 – Calibration Results of Four Different Orifices

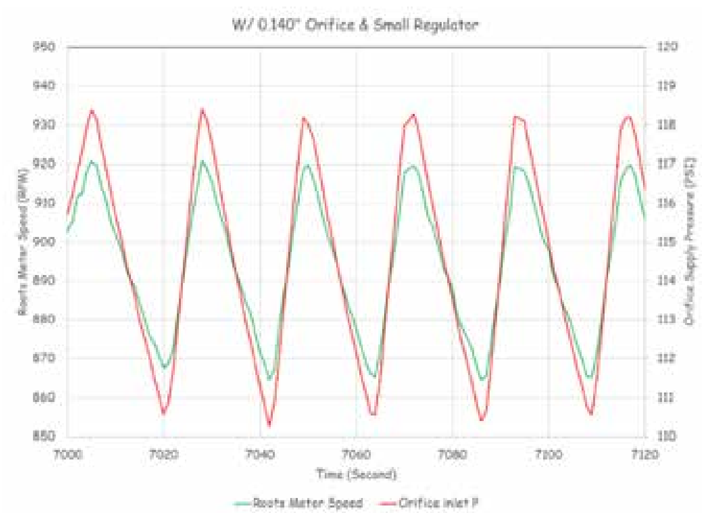


Figure #7 – 0.140" Orifice Supply Pressure and Roots Meter Oscillations

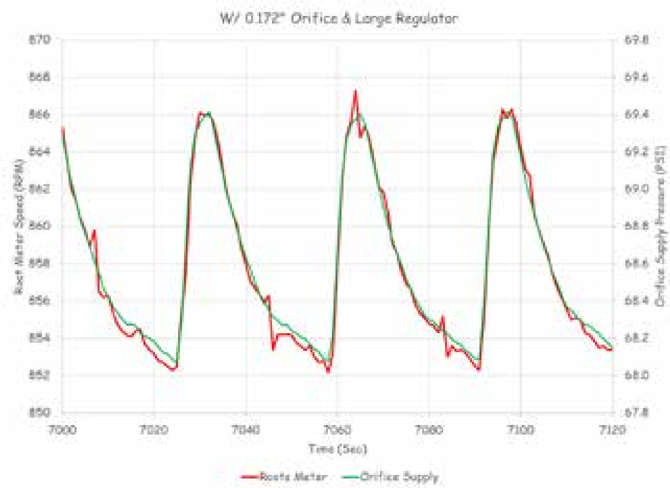


Figure #8 – 0.172" Orifice Supply Pressure and Roots Meter Oscillations

30 SCFM air leak effects on fuel economy

Five different locomotives were tested to investigate changes in NTSFC when a 30 SCFM air leak was introduced to the test. Each locomotive was baseline tested using a modified RP-589 test protocol and then retested with a 30 SCFM compressed air leak (same day and same fuel). The tests were shortened by completing:

- 20-minute N-8 warmup.
- Testing started at N-8 and working down in notches to Idle.
- Each test point was a minimum of:
  - 180 second of stabilization at the notch.
  - Another 180 second data average.

The average TNHp and fuel flow results for each notch were then used to calculate US-EPA Switcher, EPA Line-Haul Duty and the AAR Medium Duty Cycles, for both the baseline test (where shop air provided to the locomotive to keep the air compressor from operating) and a second test with a 30 SCFM air leak (plus existing on-board air leaks) with the locomotive air compressor providing make up air. The weighting factor for each of these tests are shown in Table 1. However, the effect on any specific duty-cycle can be calculated with the data that was collected.

Because all tests were back-to-back on the same day with similar ambient conditions between the tests and used the same on-board diesel fuel, no corrections were made to the NTSFC (ambient or fuel correction). All results are reported as a percent change from the baseline test where the compressor did not operate.

Table 2 provides general information on all 5 locomotives that were tested. There were a wide range of conditions from new, factory rebuilt, three years after new build, and at the end of useful life. One of the five test units had a shaft driven air compressor and the rest were all electrically driven air compressors.

TABLE 1 – weighting Factors Used in Duty cycle Calculations

Notch	EPA Switch	EPA Line-Haul	AAR Medium Duty
Low Idle	29.9%	19.0%	0.0%
Idle	29.9%	19.0%	46.0%
DB	0.0%	12.5%	9.0%
Notch 1	12.4%	6.5%	4.0%
Notch 2	12.3%	6.5%	4.0%
Notch 3	5.8%	5.2%	4.0%
Notch 4	3.6%	4.4%	4.0%
Notch 5	3.6%	3.8%	4.0%
Notch 6	1.5%	3.9%	4.0%
Notch 7	0.2%	3.0%	4.0%
Notch 8	0.8%	16.2%	17.0%

TABLE 2 – Test Locomotives Overview

Locomotive	Tier	Class	Locomotive Condition	Known Air Leaks	Comp Drive
#1	1+	Line Haul	End of Useful Life	Yes	Electric
#2	1+	Line Haul	Freshly Overhauled	No	Electric
#3	4	Line Haul	3 Yrs Old	No	Electric
#4	0	Local Service	End of Useful Life	Yes	Shaft
#5	0	Line Haul	End of Useful Life	Yes	Electric

The results of these five tests are shown in Figure 9. For all locomotives tested, the NTSFC penalty was an average of 4.0% over the switcher duty cycle, 1.9% over the line haul cycle, and 1.8% over the AAR Medium Duty Cycle. These show that the fuel economy penalty from air leaks in the train are expensive and should be minimized. Additionally, this proposed change to the RP-589 will increase the NTSFC significantly and the fuel consumption guarantees that are based on RP-589 need to reflect this new procedure.

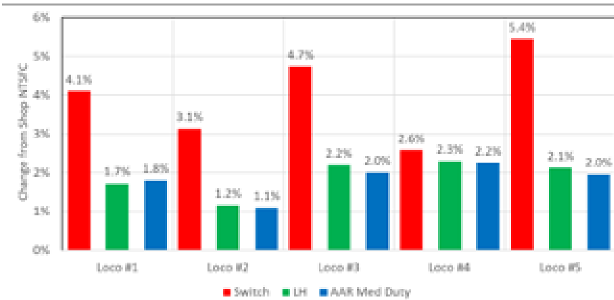


Figure #9 – Percent Change Between Test With \ Without 30 SCFM Air Leak

Conclusions

The use of a good quality air pressure regulator, instrument grade pressure transducer, and an orifice will provide a rugged system to control and measure the air leak. However, care must be taken to minimize the effects of the compressor cycles on the orifice supply pressure. During these tests, it was determined that a larger orifice, with its corresponding lower orifice supply pressure, will minimize air flow variations due to the locomotive air compressor cycling on and off.

It is critical that the orifice be calibrated (supply pressure vs SCFM), and to maintain the calibration the orifice must be installed in the correct orientation. Additionally, the pressure transducer needs to be mounted just upstream of the inlet to the orifice and the transducer must be calibrated.

NTSFC penalty due to air leaks is more significant over Switch cycle. Testing on 5 different locomotives showed that the percent difference in the NTSFC was 4.0% over the switcher cycle, 1.9% over the line haul duty cycle, and 1.8% over the AAR Medium Duty-Cycle.

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Introduction to Variation

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Introduction

This paper will consider how we typically review variation and introduce the distinction between common and special causes. It will show how looking at variation this way can improve the questions that we ask and the likelihood that efforts aimed at improvement are effective.

Explanations

We are exposed on a daily basis to observations of variation with explanations offered or required; for instance:

- May's US trade deficit increased 6.6% over prior month to $54.4B due to weaker than expected soy bean exports
- May's trade deficit was up over the prior year by a whopping 23% as a result of increased vehicle imports and FDI (foreign direct investment)
- Shop count increased this week by 18 locomotives to 76, exceeding the allowed mandated limit of 70. This was justified as being due to increased bad weather failures

Similarly, we see a common format in Figure 1 – A typical management report

- Tables contrasting this month's figures with last month's or annual averages or the same month last year
- Segmented to contrast performance by department or division or shop or brand or market …

Monthly Report for July

uality:	Dept	July Actual Value	Monthly Average Value	% Diff	% Diff from July Last Year	Year-to-Date Values Actual Value	Plan or Average	% Diff	This YTD as % Diff. of Last YTD
n-Time Shipments (%)	20	91.0	91.3	− 0.3	− 0.9	90.8	91.3	− 0.6	− 0.3
irst Time Approval (%)	12	54	70	− 23.0	− 10.0	69.3	70	− 1.0	− 0.4
ounds Scrapped (per 1000 lbs production)	19	124	129	− 3.9	0.0	132	129	+ 2.3	+ 1.5
roduction:	**Dept**	**July Actual Value**	**Monthly Plan Value**	**% Diff**	**% Diff from July Last Year**	**Year-to-Date Values Total or Average**	**Plan**	**% Diff**	**This YTD as % Diff. of Last YTD**
roduction Volume (1000's lbs)	13	34.5	36.	− 4.2	− 2.0	251.5	252	− 0.2	− 8.0
laterial Costs ($/100 lbs)	13	198.29	201.22	− 1.5	− 1.9	198.46	201.22	− 1.4	− 3.6
lanhours per 100 lbs	13	4.45	4.16	+ 7.0	+ 4.5	4.46	4.16	+ 7.2	+ 9.3
nergy & Fixed Costs / 100 lbs	13	11.34	11.27	+ 0.6	+ 11.3	11.02	11.27	− 2.2	+ 9.2
otal Production Costs/100 lbs	13	280.83	278.82	+ 0.7	+ 0.9	280.82	278.82	+ 0.7	+ 0.4
n-Process Inventory (100's lbs)	17	28	19.7	+ 42.0	+ 12.0	21.6	19.7	+ 9.6	+ 5.9

What happened?

Figure 1 – A typical management report

It is commonplace for employees to receive a report like this from their boss with one of the performance comparisons circled, and a request to explain "what happened?" The boss may have been the recipient of a similar report and request and just be passing the request down the line. Similarly, many of us have participated in daily meetings where shop managers are required to justify differences in dwell times or shop counts from goals or prior results.

The motives for doing this are (presumably) learning something that can be used to improve future results and holding people accountable for performance relative to goals/standards/requirements.

Given that we do this all the time, perhaps it's worth taking a step back and examining the nature of variation in measurements with a goal of understanding the variation and how to improve results.

What is variation?

If we look to the dictionary, we see variation defined as "lack of uniformity", "fluctuation" and "difference in things that are supposed to be the same". This ties the concept of variation to other concepts. Since we may each have different ideas of what those concepts mean, this may not help us know that we share a common understanding. There is also no mention of different types of variation, so let's consider a simple example. The series of letters in Figure 2 was produced by asking someone to draw a letter "a" followed by two more that were supposed to look like the first. They then looked at the first 3, decided they liked the third the best, and attempted to draw the next three to match the third. Next, they were asked to change hands before drawing the final "a".

Figure 2

If we examine the first 6 "a's", they are similar to each other, but not the same. The last "a" also varies from the first 6, but seems to do so in a way that differs from the way in which the first 6 "a's" vary from each other.

In 1924, Walter A. Shewhart introduced the concept of chance and assignable causes of variation in a memo to his manager at Bell Labs along with a method for distinguishing between them. These would later be named common and special causes of variation by W. Edwards Deming.

Common (chance) cause [of variation] – a source of variation that is always present, part of the variation inherent in the process (system) itself.

Special (assignable) cause [of variation] – Abnormal or intermittent sources of variation that lead to erratic or unpredictable behavior of the process.

We can imagine that the differences between the first 6 "a's" are due to common causes – for example, changes in the angle of the author's hand, grip, pen condition, paper consistency etc. We can also imagine that the different form of variation from the group exhibited by the last "a" is due to the special cause of having changed hand. Identifying the type of variation in cause that we have enables us to manage variation more effectively, as can be seen in the contrast of how we might improve consistency of "a" production in the two cases:

Common Causes: The first 6 a's are from the same process. Deming called the type of variation exhibited in the differences between the first 6 a's "common cause variation" since it is due to causes that are common to all of the outcomes (inherent in the process). In this case, things like paper and pen used, drawing method and so on likely differ in their effects, but do so in such a manner that the outcomes are stable and predictable (within bounds). Outcomes can be improved by improving the process – acting on common causes by reducing variability in the causes or changing the cause conditions. For instance, reducing variability within the piece of paper or using smoother or rougher paper, changing the angle at which the pen is held or model of pen. Asking "what kinds of things affect all outcomes?" is likely to be a productive direction of inquiry.

Special Cause: Asking "what was different, what was special, what happened?" (implicit special cause thinking) is likely to be productive. Improvement can result from acting on the special cause – often eliminating its ability to affect the process, but sometimes making it standard if the associated outcome is especially good. In the "a" example, we could prevent use of non-dominant hand (eliminate the special cause), work to improve consistency of left- and right-hand performance or adopt non-dominant hand as the standard.

It is commonplace to observe special cause thinking as the default type of thinking for investigation of cause. This is likely to be an autonomic "fight or flight" response that we need to control against as a species, particularly when reacting to bad or catastrophic outcomes. Nature selected the genes that favored quick decisive responses in the presence of a threat – deliberation may have resulted in being eaten!

Figure 3 is an attempt to picture variation produced by common causes. Notice that there are no wild or stray points, just a steady stream of points, staying the same general size with about the same magnitude of fluctuation.

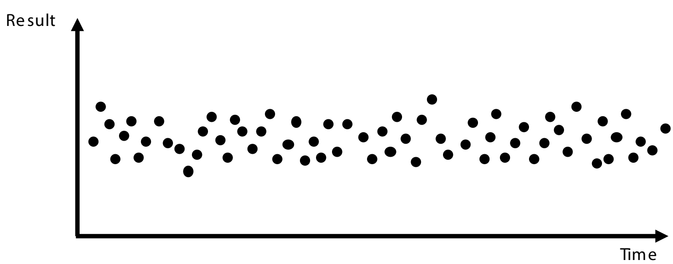

Figure 3

In Figure 4 through Figure 8, the streams of variation are affected by special causes, in addition to common causes. Variation produced by a special cause does not require a point that is different from the pack, but it can include trends, blocks of points different from the pack, increasing variation, etc...

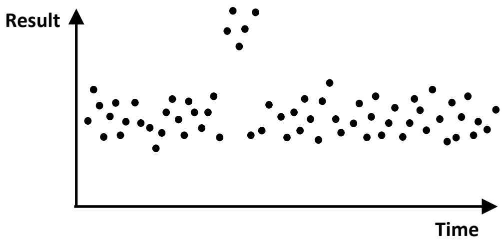

Figure 4

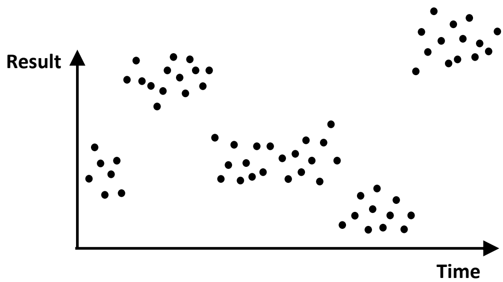

Figure 5

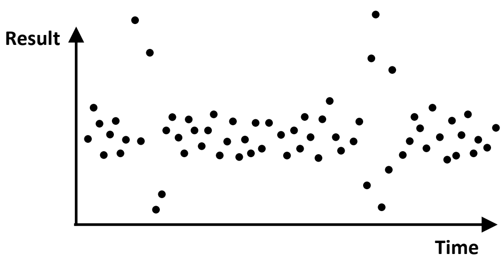

Figure 6

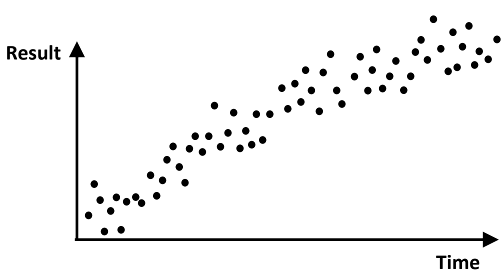

Figure 7

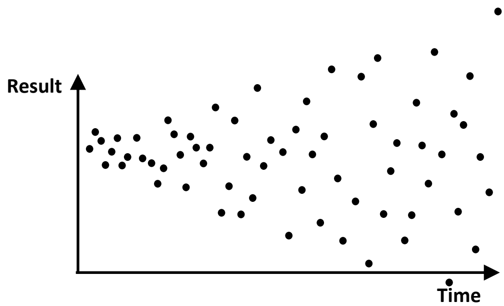

Figure 8

In assigning the type of cause of variation, we can make two types of mistake:

Mistake 1: Conclude that a result is due to a special cause, when in fact it is due to the system (common causes).

Mistake 2: Conclude that a result is due to the system (common causes) when, in fact, it is due to a special cause.

Some possible examples[1] of the two types of mistake are:

Mistake 1

- Wasting time looking for explanations of a perceived trend when nothing has changed.
- Adjust the process when a piece goes out of specification.
- Blaming people for problems that are beyond their control.

Mistake 2

- Spending money for equipment that is not needed.
- Changing company policy based on the latest attitude survey or a bad outcome.
- Worker training worker in succession without aid of a master.
- Matching color to the last batch.

Hopefully that provides a better shared concept of the difference between common and special cause variation, but how do we make sure that the classification of what type of variation we have is made consistently and effectively? Shewhart understood that we would have to make Mistake 1 and Mistake 2 once in a while – the only way to avoid one entirely is to maximize the frequency with which you make the other type of mistake. He therefore set

1. These examples all make assumptions about the actual underlying causes of variation in results, so aren't always mistakes. It is necessary to know what the underlying causes of variation are in order to reduce the likelihood of making mistake 1 and 2.

about developing a method to minimize the economic loss from making the two types of mistake in developing the (statistical process) control chart. The concept of the control chart is illustrated in Figure 9.

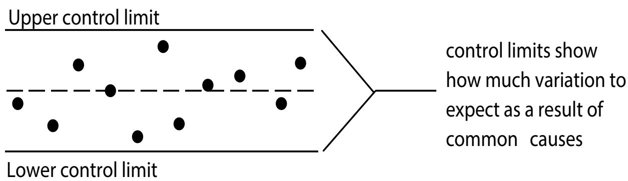

Figure 9

If common causes of variation are the only sources of variation influencing the results, the variation is considered to be *stable* or in a *state of statistical control*. We may consider the Statistical [Shewhart] Control chart which Walter Shewhart developed an *Operational Definition* of when we have a state of statistically controlled variation. An operational definition is an agreed upon method that different people can apply to the same set of data and draw a consistent conclusion of whether the data represents a state of statistical control. As such, it puts communicable, shared meaning into the concept. The Shewhart Control Chart also provides a method by which a state of statistical control may be achieved. Figure 10 is an example of a set of data exhibiting a state of statistical control (stability). The upper and lower [statistical] control limits are a function of the variation in the data, **NOT** specifications or goals. Control refers to statistically controlled variation, not engineering control. In this sense, the use of the term control limits can be confusing. Some have suggested the use of terms like *learning limits* to try and avoid this confusion and to emphasize their role in learning about the nature of the variation as part of taking action for improvement.

If all of the data fall within the statistical control limits (and supplemental rules don't apply – see later), the process producing the data is judged to be in a state of statistical control (stable).

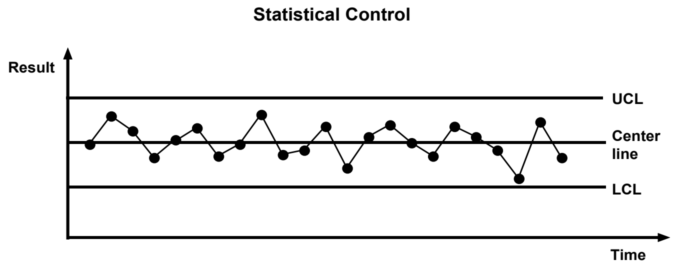

Figure 10

If special causes of variation are present, the variation is considered to be *unstable* or *out of (statistical) control*. A point outside the statistical control limits indicates that the process is NOT in a state of statistical control, as seen in Figure 11

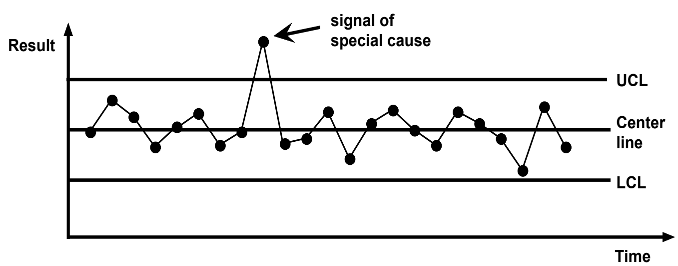

Figure 11

Statistical Control Charts also have supplemental rules for identification of special causes more broadly, such as runs either side of the center line, upward or downward trends, sawtooth patterns and hugging the center line. There are different types of control chart and different supplemental rules apply to each, so specific description is beyond the scope of this paper. They are covered in any standard text on statistical process control, such as Shewhart (1931) or Wheeler (1994).

The data exhibited in the preceding examples is of a sequence of individual data points in succession. This was chosen since it is perhaps the most common way in which data are obtained from processes. The form of control chart appropriate for this form of data is known as the individuals and moving range (IMR) chart. In the following example, we will go through the construction of a statistical control chart for this kind of data. The data set in Table 1 are from lab oil analysis results of Lead (Pb) taken after the locomotive was in service for the number of days indicated in "Service Days".

SERVICE DAYS	Pb	MR (Pb)
28	7	
121	8	1
125	10	2
173	11	1
215	10	1
283	11	1
308	8	3
346	10	2
372	14	4
403	14	0
466	0	14
495	16	16
553	15	1
590	14	1
643	12	2
682	15	3
736	14	1
775	14	0
828	9	5
870	8	1
Average:	11	3.105

Table 1

The first step is to calculate the average of the data for the centerline, $\bar{X} = \frac{7+8+10+\cdots+14+9+8}{20} = 11.$

The next step is to calculate the moving range values – these are the absolute differences between successive values in the sequence, so $MR_1 = |8-7| = 1, MR_2 = |10-8| = 2, MR_3 = |11-10| = 1, MR_4 = |10-11| = 1, \ldots, MR_{19} = |8-9| = 1.$ The average moving range, $\overline{MR}$, is the average of these moving ranges $\overline{MR} = \frac{1+2+1+\cdots+0+5+1}{19} = 3.105$. Note that there is one less *MR* value since the first value doesn't have a prior value to calculate an *MR* from. The Lower and Upper Control Limits may now be calculated:

$$LCL = \bar{X} - 3\,\overline{MR}/_{1.128} = 11 - 3 * \left({}^{3.105}/_{1.128}\right) = 2.74$$

Equation 1

$$UCL = \bar{X} + 3\,\overline{MR}/_{1.128} = 11 + 3 * \left({}^{3.105}/_{1.128}\right) = 19.26$$

Equation 2

The data are displayed in Figure 12. We see that the sample taken after 466 days in service is identified as a special cause since it falls below the lower control limit. It makes sense to ask what was special or unusual about the conditions that gave rise to that data value. In this case, it seems likely that there was an error in measurement or transcription of the data.

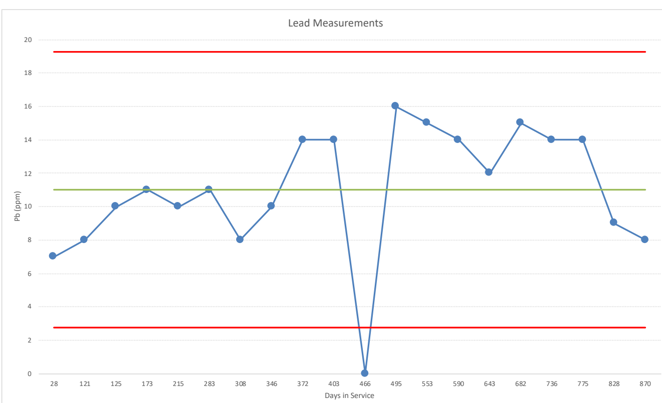

Figure 12

For this type of engine, the OEM warning level for lead is 50ppm and alarm level is 75ppm. The control chart is telling us that we might learn something useful if we ask what was different when a value falls below 2.74 or above 19.26 on this engine. This wouldn't be flagged on a typical oil analysis report.

As described earlier, the control limits are determined from the variation in the data, not specifications or requirements. We can see this in Equation 1 and Equation 2 – the width of the control limits is driven by the average moving range, $\overline{MR}$. You will sometimes hear the control limits referred to as 3σ limits; $\sigma=\overline{MR}/1.128$ for the Individuals chart.

Statistical Control and Prediction

If a process exhibits a state of statistical control (is stable), it is possible to predict future outcomes from the process within limits (and with risk of being wrong) if the process continues to operate the same way.

If a process does not exhibit a state of statistical control (is unstable), one cannot predict its future performance based upon the control chart.

So, bringing a process into a state of statistical control is critical for management of any process. Without doing so, we may not rationally plan since the process output is unpredictable. How does this work in practice? We start by measuring the process outcomes and plotting them on a control chart. Shewhart believed that it was uncommon for the natural state of a process to be a state of statistical control; that this state generally had to be earned. So, most of the time, we will find that the process is unstable. The control chart gives us signals for what kinds of question we should be asking to learn about what's causing variation in process outcomes. When we have special cause signals, we should ask "what changed" or "what was different?" What we learn from doing so can then be applied to the process – this is typically eliminating the ability of the special causes to affect the process. Successive elimination of special causes brings about a state of statistical control. At this point, one can extend the control limits into the future to project the range of expected future outcomes for continuation of the same process. We saw an introduction to the Plan-Do-Study-Act (PDSA) cycle in Standish (2019). In Figure 13, we see the integration of the use of the PDSA cycle as a framework for improvement with the control chart as a method for prompting questions and testing the efficacy of applying what's learned.

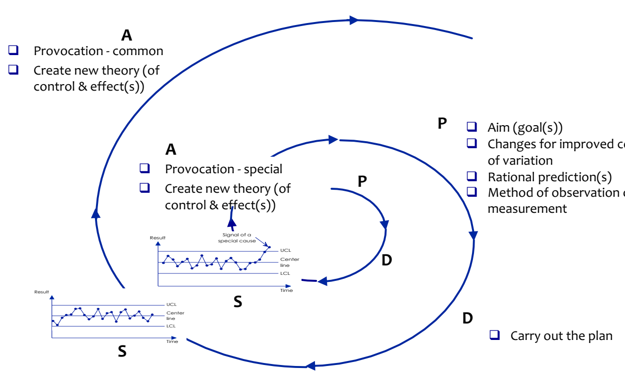

Figure 13

Having achieved a state of statistical control doesn't mean (necessarily) that our efforts at improvement are over. If further improvement is of sufficient value, we can start inquiring after common causes. For instance, if we were looking at reducing locomotive service time, common causes like the way service parts are provided, training, sequence of operations, tooling, ergonomics etc. could be examined. Extending the center line and control limits forward from prior to when a change in common cause(s) is made can be used as a prediction (of no effect) against which the changes can be tested.

Better review meetings

The paper started by suggesting that there might be a better approach to review of performance data than comparisons of current performance relative to goals or past performance. The following illustrates how the control chart can be used to guide different conversations in 6 different scenarios. In all the scenarios, lower is 'better' for results such as for time to complete a locomotive service or failure rates. In the first 3 scenarios, the underlying process is stable so we can predict that future results for continuation of the same process will fall between the control limits. In the last 3, it is unstable.

In Figure 14, we can conclude that we will predictably meet the goal. We might conclude that it is therefore best to focus our improvement efforts elsewhere or, alternatively, that we should set a more aggressive goal if there's comparatively higher value to improvement here than elsewhere.

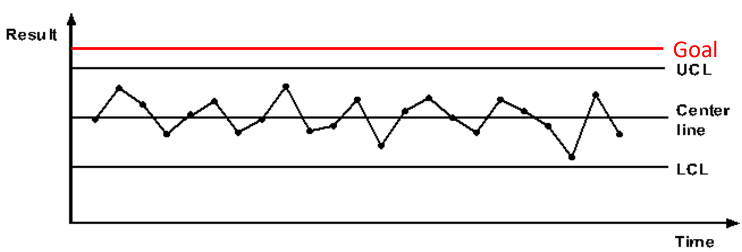

Figure 14

In Figure 15, we will predictably never meet the goal. In order to meet the goal, we would need to act on common causes, i.e. fundamentally change (redesign) the process. Alternatively, the goal could be changed so we know that it can be met. If the goal was established, for instance, based upon the needs of another system, it might be possible to adjust the requirements of the other system to be compatible with the capability of this process.

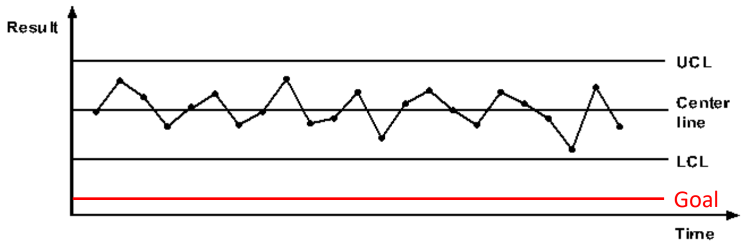

Figure 15

In Figure 16, we will predictably meet the goal most of the time, but not all. It is likely without this kind of a view of the process, that we would ask why the goal wasn't met on the few occasions that it wasn't. However, from a cause perspective, these points are no different than any of the others. We would just be asking for explanations of common cause variation as if it were special. As with Figure 15, we will need to change the process (act on common causes of variation – the process design) if we want to consistently meet the goal or change the goal to be consistent with process capability.

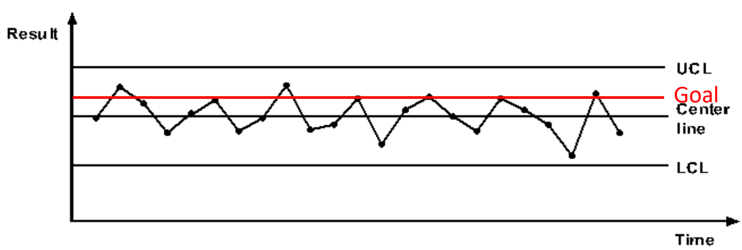

Figure 16

Figure 17 – Figure 19 all show unstable and therefore unpredictable processes. In that respect, it doesn't matter where the goal is set, it will not be dependably met. In the case of Figure 17, it turns out that asking "what happened" when the goal wasn't met also corresponded to the occurrence of a special cause and what's learned as a result is likely to result in improvement when applied. If we learn about and act on the special cause, it looks likely that we can achieve a process that will dependably meet the goal.

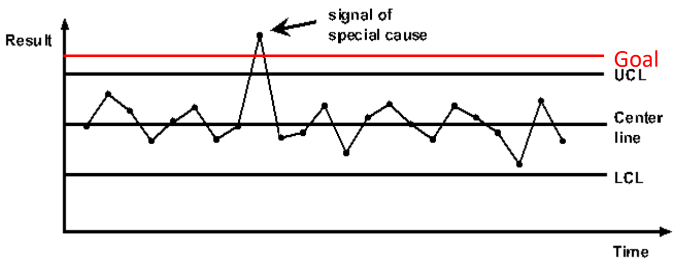

Figure 17

It is tempting in the case of Figure 18 to conclude that we will dependably not meet the goal. However, since the process is unstable, it is not predictable, so we can't even say this. Without understanding the special cause and how it affects the process, we cannot know that a future occurrence wouldn't result in a point below the LCL instead of above the UCL and goal. As with the prior case, the first step is to investigate the special cause and remove its effect on the process. If this results in a stable process, it looks likely that it will dependably not meet the goal and a major system redesign would be required to do so.

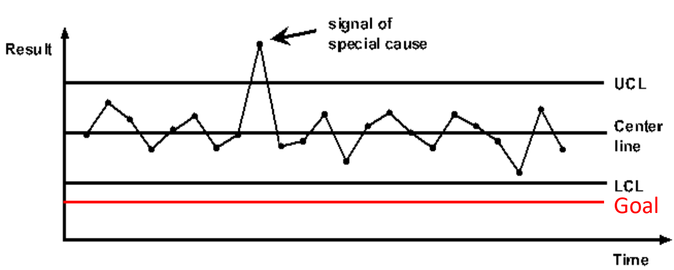

Figure 18

In the situation depicted in Figure 19, asking why the goal wasn't met will sometimes be asking for an explanation of special cause variation and sometimes common cause. That makes sense when it's special cause, but not when common. This at best results in confusion. If action is taken on the basis of the explanations, it can be expected that it will result in increased variation in results – i.e. make things worse. After identifying and removing the special cause, major system redesign would be required to dependably meet the goal.

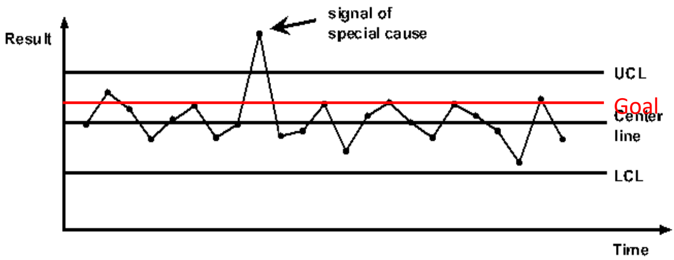

Figure 19

So, if the process is unstable, the sequence is always to first start with understanding and removing special causes from the process to achieve stability. Without this, we don't have predictability and no logical basis to predict that we will meet the requirements for the process (Goal). In this sense, it doesn't matter what the Goal is, step 1 is to get the process stable. Once stable, we can predict whether or not the Goal will be reliably met and move on to improving a different process, change the Goal or start working on common causes of variation depending on the scenario.

Conclusions

We experience variation in results within our work and personal lives on a daily basis. If we are interested in improving these results, understanding whether that variation is due to common or special cause is critical. Effective improvement depends upon taking action that is rational to the cause(s) of variation in results. The statistical process control chart provides a method for distinguishing the type of cause, allowing us to ask better questions. It also provides a method for testing whether the application of knowledge gained really results in improvement. Once a state of statistical control has been achieved, its output becomes predictable within bounds. This allows us to plan, which is why W. Edwards Deming said "Management is Prediction".

Acknowledgments

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Ranney, Gipsie (1993), *Understanding Variation, Process and System Improvement*, GM Powertrain.

Wheeler, Donald (1994), *Understanding Variation The Key to Managing Chaos*, Knoxville: SPC Press.

FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE
(formerly known as Fuel and Lubricants Committee)

2019

1. The Effects of a Hydrogenation-Derived Renewable Diesel (HDRD) Fuel Surrogate on Fuel Consumption and Emissions from a GE Tier 2 Locomotive
2. Used Oil Analysis – Is It Reliable? (2018 Railroad Used Oil Test Laboratory Evaluations)
3. Review of AAR M-963-84 All-Year Journal Box Lubricating Oil Specification
4. Engine Oils for Improved Fuel Economy and Oil Consumption to Railroad Services

2018

1. Diesel Fuel Heating Value Correction for Locomotive Fuel Consumption Calculations
2. SCR for Locomotive NOx Reduction
3. X-Ray CT Scanning of Diesel Locomotive Fuel Injectors

2017

1. One Size Fits All? Clarifying Standards for Locomotive Fueling Infrastructure –Storage Tank Overfill Protection
2. Statistical Evaluation of Lube Oil Analysis as a Potential Predictive Maintenance Tool
3. Failures Resulting from Misunderstanding Used Oil Data, Locomotives, and the Trouble with Trending
4. High Pressure Common Rail Engines in Locomotive Service: Symptoms, Causes and Cures for HPCR Deposits
5. Diesel Fuel Cleanliness- Application of the ISO 4406 Particulate Contamination Codes

2016

1. Defining LMOA Generation 7 Engine Oil Performance Category
2. Natural Gas for Rail Applications: LNG Fuel Quality Considerations
3. Effects of Fuel Composition on In-Service Engine Oil Properties

2015

1. Railroad's Fuel Options, Research and Literature Review
2. Transmix-Derived Fuel for Locomotives

2014

1. Fuel Filtration Considerations in the Changing Landscape of Engines and Fuels in Railroad Applications
2. Diesel Fuel Troubleshooting Guide
3. Locomotive Biodiesel Updates
4. Cold Soak Filter Plugging Test

2013

1. Railroad's Changing Fuel Supply: Diesel No. 2 (high-sulfur, low-sulfur, and ultra-low sulfur), Biodiesel, Fischer-Tropsch, and Blends
2. Locomotive Fuel & Lubricant Oil Filters 101

3. Generation 6 Locomotive Engine Oil Properties

2012
1. Diesel Engine Health Prediction with Integrated Lube Oil Analysis
2. Locomotive Durability Test Protocol for Alternate Fuels and Biodiesel

2011
1. Diesel Exhaust Fluid Properties & Technical Information
2. Locomotive Biodiesel Fuel Update

2010
1. The Clean Water Act and How it Affects Railroad Operations

2009
1. New Generation Oil Additive Technology for Engines Operating on Low & Ultra-Low Sulfur Diesel Fuel
2. The Clean Water Act and How It Affects Railroad Operations
3. Locomotive Testing of an Automatic Self-Cleaning Lube Oil Filter & Centrifuges

2008
1. Prevention of Fuel and Fuel Filter Headaches
2. Locomotive Idle and Start-Up Exhaust Emissions Testing
3. Operational Effects of Low Sulfur Diesel Fuel in Locomotives

2007
1. Automatic Self-Cleaning Lube Oil Filters and Centrifuges
2. Diesel Fuel 2007 and Beyond -What will be in Your Tanks?

2006
1. Fuel Additives-A Possible Method to Reduce Fuel Consumption in Railroad Diesel Locomotives

2005
1. Engine Oil 202 - Refined Base Oils and their Importance in Lubrication
2. Biodiesel - A Potential Fuel Source for Locomotives

2004
1. Discussion of the LMOA Fuels, Lubricants and Environmental Committee Pentane Insolubles Procedures Revision 4
2. Engine Oil 101 - Viscosity and Additives
3. Used Oil Analytical Result: What do they Mean, How to Interpret the Results and How do you Respond?

2003
1. Laboratory Results May Put Your Locomotive at Risk
2. Top of Rail Friction Modification Studies on the BNSF

2002
1. Improved Generation 5 Lubricant Provides Potential for Extended Lube Oil Filter Life
2. Corrosion Protection of Locomotive Cooling Systems

2001
1. On-Board Oil Management System
2. Evaluation of Locomotive Engine Oil Analytical Laboratories
3. Fuel Additives - Friend or Foe

2000

1. Biodegradability and its Relevance to Railroad Lubricants and Fluids
2. Engine Lubricating Oil Evaluation Field Test Procedure
3. Detecting Abnormal Wear of AC Traction Motor, Pinion End, Armature Bearings Through Lubricant Wear Debris Analysis
4. Further Development in Top-of-Rail Lubrication Testing

1999

1. Lube Oil Analysis-Achieving Quality Results
2. Effects of Engine Lubricants on Oil Filtration
3. Recycling and Re-refining of Used Lubricated Oils

1998

1. Safety and Chemical Cleaners
2. Development of a Low Emissions, Dual Fuel Locomotive
3. Fuel Oil Stability Update
4. Ten Questions on EPA's Locomotive Exhaust & Emission Regulations

1997

1. Ferrography-Used Oil Analysis Program
2. 2000 - A New Millennium for Locomotive Maintenance: EPA Exhaust Emissions Regulatory Impacts
3. Standardized Test Procedures - Current Developments
4. Industry Updates and New Developments

1996

1. Standardized Test Procedures-The Annual Subcommittee Update
2. Diesel Fuel Standards and their Applications to Railroad Fuel Quality Issues
3. A Look at Generation 5 Oil Performance and Future Oil Needs
4. LNG as a Railroad Fuel

1995

1. MSDS'S - What do they tell us?
2. Applying Satellite Communications Technology to On-Line Oil Analysis of Crankcase Diesel Engine Lubricants
3. Standardized Test Procedures - Past, Present & Future Developments
4. Locomotive Exhaust Emissions Regulations

1994

1. TBN-A Review of Currently Accepted Methods.
2. GE Multigrade Lubricating Oil Testing and Specification.
3. The Economic Impact of Low Sulfur Diesel Requirements.

1993

1. Used Oil Analysis of Multigrade Oils and Condemning Limits.
2. Insoluble Determination with the Advent of Multigrade Diesel Engine Oils
3. Bioremediation

1992

1. Environmental Issues Relating to Multigrade Railway Issues
2. Readily Biodegradable and Low Toxicity Railroad Track Lubricants
3. Support Bearing Oils
4. Recycling and Re-refining Locomotive Oils

1991

1. Infrared Spectroscopy as an Analytical Tool
2. Diesel Exhaust: Health Effects Research and Regulations
3. Traction Motor Gear Case Seals and Lube Containment (Oil Lubricant)
4. Partnership in Development

1990

1. The Responsibility of Railroads and Facility Managers in the Handling and Disposal of Hazardous Materials
2. Update on Diesel Fuel Regulations
3. Diesel Exhaust and Worker Exposure
4. Field Experiences with Multigrade Railroad Locomotive Oils.
5. Conrail Wheel/Rail Lubrication Update

1989

1. Field Test Data Follow-Up and Description of "Generation 5" Locomotive Crankcase Oil
2. Diesel Emissions: Regulations and Fuel Quality
3. Petroleum Storage Tank Regulations - Guest Speaker - George Kitchen, International Lube & Fuel Consultants

1988

1. Used Oil Analysis and Condemning Limits
2. Review of A.A.R. Procedure RP - 503, "Locomotive Diesel Fuel Additive Evaluation Procedure"
3. Update on Improved Oils - Multigrade
4. Wheel Flange Lubrication Update - Lubricants Being Used
5. Survey of Disposable Practices or Locomotive Engine Lube Oil and Lube Oil Filters
6. Speaker on Overview of Environmental Requirements for The Use of Petroleum Products in The Railroad Industry - Peter Conlon - AAR

1987

1. Common Fuel Additives and their Effectiveness
2. History of LMOA Lubricating Oil Classification System
3. Performance Requirements Needed by the Railroads for a New Generation Lube Oil
4. How do we Provide the Performance Needed for a New Generation Oil

1986

1. Extended Performance Lubricants Through Better Chemistry
2. Fuels and Lubricants Handling Hygiene
3. Fuels Availability and Price Outlook
4. Selection of Lubricants for Wheel Flange and Rail Lubricators

1985

1. Disposal of Lube Oil Drainings
2. Non-ASTM No. 2 - D Fuel
3. Oxidation Analysis
4. Wheel Flange and Rail Lubrication

1984

1. Locomotive Filters
2. Traction Motor Gear Lube Field Test

1983

1. Field Test Update of Multigrade Oils
2. Update of Alternate Fuel Testing
3. A Review of Locomotive Fuels

1982

1. Energy Conserving Lube Oils
2. Alternative Fuels Update
3. Availability of Medium and High Viscosity Index Railroad Oils
4. Journal Box Oil and Aniline Point.
5. Traction Motor Gear Lubricant Update
6. Traction Motor Gear Case Seals

1981

1. Effects of Using Alternate Fuels on Existing Diesel Engines
2. Update on Cold Weather Procedures for Fuels
3. New Techniques in Lube Oil Analysis
4. Traction Motor Gear Lubrication.
5. Multi-Viscosity Oils as an Energy Conservation

NEW TECHNOLOGIES COMMITTEE
(formerly known as the New Developments Committee)

2016
1. ECP Beyond Train-Handling – How ECP System Development Can Enhance Other Locomotive Technologies
2. New Developments in Diesel-Electric Passenger Locomotives
3. Diesel Emissions Control Technologies – A Post-Tier 4 Review

2015
1. Second life for DC locomotives
2. Natural Gas – Dual Fuel Locomotives Developments and Field Demonstrations
3. Hidden Costs of Locomotive Modernization

2014
1. End of the Line for the MU Jumper Multiple Locomotive Unit Control: A Discussion of Past, Present and Future
2. Natural Gas Economics and Fueling for Locomotives
3. What are my Natural Gas Engine Choices?

2013
1. Locomotive Data and Acquisition Reporting Systems (LDARS) and Crash Memory Module (CMM)
2. Natural Gas Locomotives
3. Remote Monitoring of Locomotive Systems
4. Extending Battery Life

2012
1. Tractive Effort and Adhesion: A Review of Yesterday, a Look at Today, Concerns for Tomorrow
2. A New Tier 0+ Solution EFI for EMD 645 Engines
3. Locomotive Repower with a High-Speed Engine and a Reduction Gearbox
4. The A3 Problem Solving Process in Action – a Case Study

2011
1. Positive Train Control
2. EPA Tier 4 Locomotive Development Status Update

2010
1. Tier 4 Diesel Emission Reduction Strategies
2. Testing of the BNSF Fuel-Cell Switch Locomotive: Part 2

2009
1. Ethanol Electric Hybrid Locomotives
2. Testing of the BNSF Fuel Cell Switch Locomotive: Part 1

2008
1. Maintenance Experience with Gen Set Switcher Locomotives to Date
2. Maintenance of the BNSF Fuelcell-Hybrid Switch Locomotive

2007

1. Fuel cell Hybrid Switcher Locomotive: Engineering Design
2. Locomotive Digital Video Recorder
3. CN Distributed Braking Car

2006

1. Variable Hybridity Fuel cell-Battery Road Switcher
2. GE Transportation-Hybrid Freight Locomotive
3. Dynamic Brake Status Reporting

2005

1. PL42AC Locomotive-Overview
2. Fuel Cell Locomotives
3. Locomotive Electric Hand-brake Systems

2004

1. GE Evolution Locomotive – An Overview
2. EMD SD70Ace Locomotive-Reliability for 2005 and Beyond
3. Get Them into Condition: Condition Based Traction Motor Reliability
4. Making the Switch - An Update on the EMD GP20D/GP15D Switcher Locomotive
5. “Fuel Proof Tank Repairs” - A Best Practice for your Locomotives

2003

1. New MPXPRESS Commuter Locomotive Models MP 36PH-3S & MP36PH-3C
2. The Green Goat Hybrid Locomotive
3. Observation on Auto Engine Start/Stop

2002

1. On Board Rider - A Remote Locomotive Condition Monitoring System
2. Cool Your Jets: A Low Cost, High Performance Rooftop Air Conditioner

2001

1. Performance and Economic Aspects of Various Environmentally Friendly Coatings for Rolling Rail Equipment
2. Non-destructive Testing: Crack Detection Technology - EMFaCIS

2000

1. FIRE: EMD Turns up the Heat on Railroad Electronics Integration
2. Put the Chill on Air Conditioning Costs
3. Do Not Get “Steamed” Over Fuel Tank Repairs
4. Industry Responses to Emission Regulations
5. Improved Adhesion Through the Use of Individual Axle Inverters

1999

1. Locomotive Filtration-Where are We Going?
2. EMD Markets a New Line of Switchers

1998

1. Expert Systems
2. EMD SD90MAC 6000 HP Locomotive - Where Are We Today? GE AC6000CW Locomotive - Where Are We Today?

1997

1. An Overview of the Electro-pneumatic Train Brake
2. Locomotive 6724, Where Are You? GPS, Mobile Telemetry and GIS Technologies in a Railroad Environment
3. Runout Measurement Using Non-Contact Sensor Technology
4. Common Rail Fuel Injection

1996

1. Activities Toward New Safety Standards for Passenger Equipment
2. SP-3 Thin Sensor Technology for Variable Force Measurement
3. Top-Of-Rail Lubrication
4. Traction Motor Vibration and its Effects

1995

1. Belt pack Locomotive Control System
2. The MK1200G Switching Locomotive
3. Advanced Traction Motor Testing

1994

1. Electronic Fuel Injection Systems.
2. Status of Distributed Power in Freight Trains.
3. Advances in Distributed Power-Iron Highway.

1993

1. New Technology to Solve Old Problems
2. Developments in Off-Shore Technology
3. Updates on AC Traction Developments

1992

1. Talking to the "Smart' Locomotive
2. Cab Noise Abatement
3. Electronic Management of Locomotive Drawings
4. Update on High Productivity Integral trains
5. AC Traction - A New Development

1991

1. Locomotive Cab Integration and Accessory Management
2. Improvements in Locomotive Adhesion Performance
3. The Role of Duty cycles in Locomotive Fuel Consumption.
4. What's New in Gadgets and Black Boxes: What do our Locomotives Really Need?
5. Failure Analysis

1990

1. Motor Driven Air Compressors for Diesel-Electric Locomotives
2. Locomotive Cab (HVAC) Heating, Ventilation and Air Conditioning Systems
3. Effect of Technology on Standardization of Cab Control Equipment
4. Locomotive Durability, Reliability and Availability Understanding Your Abilities

1989

1. A Rational Approach to Testing Locomotive Components
2. New Developments in Locomotive Cab Design

1988

1. Amtrak F69 PH AC Passenger Locomotives
2. New Component Developments Retrofittable to Older Model Locomotives
3. Locomotive Applications of Caterpillar Engines
4. Wheel slip Control for Individual Axles

1987

1. Electronic Fuel Injection Systems
2. Update on Electronic Governors
3. Recent Advances in Steerable Locomotive Trucks - the EMD. 4 Axle, 4 Motor HT-BB Articulated Truck
4. Converting an F40 Locomotive to AC. Traction

1986

1. Future Train Control Systems
2. Bringing Future Train Control Systems Back to Earth
3. Low Maintenance Locomotive Batteries
4. Electronic Engine Control Systems

1985

1. The Sprague Clutch for EMD Turbocharged Engines
2. AC Traction Locomotives Update
3. Natural Gas Locomotive Update
4. Ceramic Coated Engine Components
5. Locomotive Cab Developments

1984

1. GE Dash 8 Locomotives
2. EMD 50A Series Locomotives
3. Natural Gas Locomotives
4. Appraisal of the AC Traction Locomotive

1983

1. Microprocessors for Locomotive Control and Self Diagnosis.
2. Locomotive Fuel Tank Gauges
3. Locomotive Aerodynamics
4. Bombardier HR 616 Locomotive
5. Missouri Pacific - Phase III Locomotive Heavy Repair Facility, N. Little Rock, Arkansas

ELECTRICAL MAINTENANCE COMMITTEE
(formerly known as the Diesel Electrical Maintenance Committee)

2019
1. Lost In Transition: The Collaborative Effort to Develop a Solution for Generator Transition Circuit Failures
2. What Can the Load Regulator Tell Me?
3. Getting off to a Good Start

2018
1. Slip Rings & Collectors - What Keeps Your Wheels Turning?
2. Still Stuck in the Middle With You: PTC and Short Line Railroads
3. Condition Based Maintenance VIA Rail Canada
4. Troubleshooting a One-Way Serial Link on an EMD SD70M Using EM2000
5. Battery Temperature Performance Study with Strategies to Optimize Charging and AESS Settings

2017
1. We Didn't Start the Fire: Best Practices for Inverter Cooling Management
2. Troubleshooting the Excitation Circuit on an EMD SD40-2
3. AESS (AUTOMATIC ENGINE START STOP
4. A Study of Locomotive Battery Charging and Performance

2016
1. Stuck in the Middle With You: PTC and Short Line Railroads
2. Troubleshooting Multiplexer Faults on EMD Locomotives Using EM2000
3. Battery Technology Within the Diesel Starting Industry
4. Supercapacitor Safety

2015
1. Modular Hardware & Software
2. Idle Reduction on GE Locomotives
3. The Ghost in the Machine: EMI on Your Locomotive

2014
1. FRA Requirements for Headlights, Ditch Lights & Other Lighting
2. Investigating Distributed Power Failures
3. Product Validation and Certification
4. Sensors and Transducers Installation Tips

2013
1. Locomotive Diagnostics
2. Positive Train Control (PTC) - Onboard Segment: An Update and Recommendations
3. Locomotive Battery Storage and Maintenance A Recommended Best Practice

2012
1. Extending Locomotive Maintenance to 184-day Intervals - Part II
2. Design for Reliability: Locomotive Lifecycle Approach

2011

1. Efficiency and Maintenance Aspects of the New Amtrak Electric Locomotive ACS 64
2. Modernizing an Aging Heavy Haul Locomotive Fleet
3. Three Stage Battery Charging for EMD Locomotives

2010

1. Infrared Thermography in Locomotive Electrical Maintenance
2. Electrical Connectors: Standards & Field Service Challenges
3. Locomotive Batteries and Long Term Storage
4. Long Term Storage Electrical Rotating Equipment
5. Long Term Storage Electrical Equipment

2009

1. EMD Slip Rings-Brushes & Wear
2. Using Test Instrumentation Safely on Gen-Set and AC Locomotives
3. Extending Locomotive Maintenance
4. 710 ECO Power

2008

1. Challenges with Retrofitting New Systems to Old Locomotives
2. Locomotive Maintenance Conventional vs Genset
3. Using Test Instrumentation Safely
4. Electric Motor Preventative Maintenance

2007

1. Finding Open and Short Circuits on AC Traction Motors
2. Locomotive Cab Signal Failures and Troubleshooting
3. Maintaining Main Generators - Some Safer Methods
4. Locomotive Software Management

2006

1. Application of 2000 HP Hybrid Yard and Road Switcher Locomotives
2. Portable Troubleshooting Data Logger
3. Adapting a Freight Locomotive into a Passenger Locomotive

2005

1. Wireless Communication Technology Overview
2. Maintenance Benefits of the Green Goat - Part A Hybrid Switcher Update – Green Goat - Part B

2004

1. Electrical Maintenance Benefits of the SD70ACe
2. Remote Monitoring & Diagnostics: Development and Integration with Maintenance Strategies
3. Carbon Brushes Revisited – an Update for 2004

2003

1. Diesel Driven Heating System
2. Trainline - ES TIBS as Applied to CN/IC Locomotives
3. Head End Power (HEP) Safety Issues
4. Fuel Savings Using Locomotive Consist Management

2002
1. Commutator Profiling
2. Basics of an Operations Center
3. Diagnostics for Older Locomotives
4. Traction Motor Protection Panel
5. “Locomotive Auxiliary Power Units” - Lessons Learned

2001
1. Diagnostic and Predictive Maintenance
2. Locomotive Replacement Control System
3. Automatic Shutdown Startup Controls - Fuel Savings through Technology
4. Locomotive Alternative Air Conditioners

2000
1. Custom Electronics and their Applications
2. Locomotive Wire Update
3. Integrated Air Brake & Distributed Power Under EMD Fire System
4. Carbon Brushes - A Fresh Look
5. RM&D - What It Is, What It Does
6. An Alternate Adhesion System

1999
1. Transition Panels for Older Locomotives
2. R.S. A.C. Crash Worthy Event Recorder Update
3. Traction Motor Suspension Bearing Temperature Monitoring System
4. EMD SD90MAC 6000 HP Locomotive-An Update
5. IGBT-What’s New for GE AC6000 Locomotives

1998
1. Locomotive Troubleshooting Assistant
2. Locomotive Electronic Brake Maintenance
3. SD70MAC Capacitor Discharge Procedure
4. Power Savings for Electrical Locomotives
5. Auto Stop/Start and Layover Systems

1997
1. Review of Battery Maintenance and Available Options
2. Battery Charger/Booster
3. Locomotive System Integration
4. Electronic Governors

1996
1. EMD SD80MAC High Voltage Safety
2. GE AC Locomotive Electrical Safety Features
3. Electromagnetic Interference (EMI on AC Locomotives)
4. QTRAC 1000 Adhesion Control System
5. Locomotive Health Monitoring- The Key to Improved Maintenance

1995
1. Canadian National Battery Water Usage
2. Remote Diagnostics-Radio Download
3. Programmed Preventive Maintenance
4. Commutation Monitoring in Locomotive DC Traction Motors
5. The EMD Diesel Engine Control (EMDEC) System

1994
1. Safety First - Video on Electrical Safety
2. Locomotive Health Monitoring Systems
3. Event Recorder Update SD60 Dynamic Brake Improvements

1993

1. Automatic Engine Shutdown and Restart System
2. Layover Systems/Standby Power Systems
3. CN North America – Electronic Temperature Control
4. Speed Sensing Devices Adhesion Alternative
5. Electronic Brake 6. Modern Tooling Update

1992

1. Nickel-Cadmium Batteries as an Alternative
2. Overview of Locomotive Microprocessor Based Controls
3. Locomotive Air Conditioning
4. Testing Traction Alternator Fields on EMD Locomotives
5. Flange Lubricators

1991

1. Locomotive Rebuilding Something Old- Something New. Standardization of Electrical Equipment
2. Locomotive Batteries: a. Storage Handling Procedures; b. Recommended Maintenance Procedures; c. Recommended Repair Procedures
3. Amtrak's AC Traction Locomotives
4. Modern Tooling for Electricians Recorders
5. Why Can't We Have One Central Computer?
6. EPA and Regulation Driven Cleaning

1990

1. Modern Tooling of Electrical Troubleshooting
2. Maintaining Solid State Event Recorders
3. Why Can't We Have One Central Computer?
4. EPA and Regulation Driven Cleaning

1989

1. Modern Tooling for the Troubleshooting Electrician: a) test meters available (single function); b) test meters available (multiple functional); c) analysis and diagnostic tools
2. Sound Electrical Repairs and Practices for: a) traction motors; b) grids and fans; c) wire and cable solderless termination
3. Guidelines for Preparing Electricians for the 1990s

1988

1. Utilizing Magnetic Recorders for Maintenance
2. Solid State Locomotive Recorder
3. Improved Utilization of GE DASH 8 Data Recording Systems
4. Locomotive Health Data and Its Uses to The Railroad
5. Improved Data Acquisition from EMD's 60 Series Display Computer

1987

1. Proper Maintenance of Electrical Fuel Savings Options
2. Preliminary Report on AAR Traction Motor Study

1986

1. Cleaning, Handling & Storage of Electrical Equipment: A. Solid State Components; B. Rotating Equipment
2. Qualification of Locomotive Power Plants through Self load

1985

1. Locomotive Microprocessor Technology in Retrospect
2. Dynamic Brake Protective devices and Troubleshooting EMD-2 and GE-7 Locomotives
3. Indicators and Recorders for Locomotive Retrofit Application - Fuel, Speed, Power and Selected Events

1984

1. Electronic Technology to Improve Performance
2. GE Dash 8 Diagnostic Display
3. "Probe" Locomotive Diagnostic Equipment
4. CATS-Computer Aided Troubleshooting
5. Fuel Conservation Through Electrical Modifications-GE and EMD
6. Performance of Locomotives After Storage

1983

1. Ground Relay Trouble Shooting
2. Specification for remanufactured D87 Traction Motor Frames (Using D-77 Armature Coils)
3. Locomotive Storage (Electrical)
4. Water Cooling and Refrigerating Methods for Locomotive Cab Application

1982

1. Tests on Traction Motors
2. Transition Troubleshooting
3. Onboard Diagnostic Systems
4. Starting Systems

1981

1. Evaluation of Improved Test Methods
2. Teflon Bands
3. New Generation Locomotives
4. Electrical Troubleshooting
5. Batteries and Charging Systems
6. Troubleshooting EMD AC Auxiliary Generator System
7. Selection of Locomotives for Major Locomotive Overhauls

SHOP SAFETY, PROCESSES AND EQUIPMENT COMMITTEE (formerly known as the Shop Equipment and Processes Committee and also the Shop Equipment Committee)

2016

N/A

2015

1. Video Borescope for Locomotive Maintenance Officers
2. Mechanical Department-Three Main Safety Focus Areas

2014

N/A

2013

1. Bolt Torquing / Tensioning Manual Torque Wrenches and Adapters
2. Mechanical Seven Safety Absolutes-BNSF Railway
3. PROPER TRAIN WASHING – More Than Just Brushes and Nozzles

2012

1. Application of Machine Vision Technology in Train Inspection
2. Smart Technologies for Locomotive 92-Day Inspections-Automate or Semi-Automate Wheel Measurement Gauges

2011

*1. New Tooling Development-Level Loading, Extended Reach "C" Frame Lifting Device and Manipulator - Under the Hook Load Limiter Alarm
2. Automatic Wheel Inspection Systems

2010

1. New Tooling Development-Level Loading, Extended Reach "C" Frame Lifting Device and Manipulator - Under the Hook Load Limiter Alarm
2. Ultrasonic Inspection of Railway Wheels
3. Introducing a Portable yet Affordable Solution for Truing your Locomotive Wheels "Without the need to remove the wheels"
4. Automatic Wheel Inspection Systems

2009

1. Going Green in the Maintenace Facility
2. Shop Equipment for Truck Removal, Maintenance and Repair

2008

1. Vehicle Progression Systems

2007

1. Evolution and Improvements in Locomotive Rerailing Cranes

2006

1. Wheel Gauge Technology 2
2. Train Washing
3. Environmental Railroad Containment Products

2005

1. Mobiturn Wheel Truing Services

**This topic appeared in both the 2010 and 2011 LMOA Proceedings Publication*

2004

1. Under the Hook Lifting Devices
2. Sanding in the Railroad Industry- Part III - A Gentle Answer for an Abrasive Situation

2003

1. Locomotive Shop Support Systems and Equipment
2. Hand Tools - An Ergonomic Update
3. Locomotive Lifting Systems

2002

1. Note: Paper on lifting systems was presented by Ron Begier of Portec at the 2002 convention; however it did not appear in publication - will appear in the 2003 proceedings publication.

2001

1. Sanding in Railroad Industries - Part II - How to Specify Reliable and Safe Sanding Systems

2000

1. The Tandem Wheel Truing Machine at Amtrak's Ivy Shop
2. Shop Talk 2000: Fall Protection Technology
3. Sanding in the Railroad Industry

1999

1. Increasing Diesel Shop Capacity
2. Conrail-Cold Asphalt Processing of Environmental Waste Sand and Sludge
3. Dry Ice Cleaning of GE Intake Ports
4. AAR-LFIS No Spill Fueling System

1998

1. Smoke Opacity Testing-Emission Detection Equipment and its Use
2. HydraulicTensioning Tools and its Use
3. High Speed Portable Align Boring Series
4. Locomotive Mobile Servicing

1997

1. Wheel Truing as Preventive Maintenance
2. Conrail-Selkirk Diesel Terminal Wastewater Treatment Facility Recent Environmental Improvements

1996

1. Locomotive Painting Drop Table Tooling for New EMD and GE Locomotives

1995

1. Pre-Maintenance Inspection
2. Railroad Turntable Modification
3. Mobile Locomotive Service Vehicle

1994

1. Electronic Fuel/Unit Injection Tooling.
2. Locomotive Roller Support Bearing Tooling.
3. Fall Protection and Man Lifts.
4. Locomotive Washing Systems.

1993

1. Dynamic Balancing for GE Dash 8 Model Locomotives
2. Air Compressor Automated Station
3. Ergonomics in the Work Place
4. Hydraulic Traction Motor Shimming Table

1992

1. Automated Test and Production Equipment
2. Safety Corrective Action Team
3. Automated Locomotive Wheel Shop

4. Cleaning and Surface Preparation 1, with Sodium Bicarbonate Based Abrasive Blasting
5. Trainline Continuity Tester
6. BN - Railroad Power Assembly Shop of the 1990's

1991

1. Economic Separation of Emulsified Oil from Waste Water Using Ultra Filtration Membranes
2. EMD Cylinder Head Valve Seat Machining
3. Automated Barring Over Machine for EMD Diesel Engines
4. New Equipment for Testing EMD Engine Protectors
5. Compressed Air for Railroad Facilities Issues and Solutions to Achieve Clean, Dry, Oil Free Air

1990

1. EMD Valve Bridge Machine
2. GE Traction Motor Roller Suspension Bearing Replacement Equipment and Procedure.
3. Locomotive Component Replacement Forklift Attachment.
4. Locomotive Sanding, Fueling and Drop Tables
5. Hazardous Waste Disposal

1989

1. Automated Locomotive Wheel Shop
2. Laser Guided Material Handling Vehicles
3. Bulk Rail Lubrication Storage & Fill Systems
4. Pilot Plate Straightening Equipment

1988

1. Fuel Management Control Systems
2. Locomotive Mounted Rail Lubrication Fill Systems.
3. Comparison of Shop Air Compressors
4. Locomotive Toilet Servicing Equipment
5. Innovations in Blue Flag and Derail Protection

1987

1. Modern Servicing Facility for Improved Reliability and Availability
2. New Developments in GE Tools
3. Implementation of a Quality Process
4. A Quality Traction Motor Shop
5. Wheel Truing Machine Technology

1986

1. Robotics Update 1986 – Now What?
2. CNC Machine Tools
3. A New GE Power Assembly Area
4. Locomotive Wash System -1986

1985

1. Computer-Assisted Preventative Maintenance
2. New Tools for Material Handling and Overview of Balancing Technology
3. Effect of Governmental Regulations on Locomotive Finishing

1984

1. Shop Tools: A. New Tools; B. Shop-Made Tools
2. Traction Motor Shop Equipment Up-Date
3. Hazardous Waste Handling and Disposal

1983

1. Locomotive Maintenance Using a Production Line Process
2. Shop Tools to Increase Productivity and Improve Quality
3. Dynamic On-Line Performance of Locomotives Without On-Board Tele-Metering
4. Management in Action
5. New GE Training Center
6. Welding Qualifications

1982

1. Tools
2. Rebuild line for EMD Turbochargers
3. Air Brake Equipment Line
4. Industrial Robots
5. Automated Machines
6. Safety Related Items and Equipment

1981

1. Training Aids
2. Testing Devices Inspired by New FRA Laws
3. Tools and Training for Productivity
4. Changes to Shop Facilities Required by Newly Adopted EPA & OSHA Regulations
5. Tour through Conrail Altoona Shop
6. Supply/Service Facilities
7. GE Assembly Shop

DIESEL MATERIAL CONTROL COMMITTEE

2016
N/A

2015
1. "CORES" Long term assets… What is their value?
2. Innovations in Material Storage/ Management
3. Bar Coding: A 2015 Update and Beyond

2014
1. Examining Lifecycle Costs Part One - Defining the Inputs

2013
2. Recycling of Materials
3. Material Solutions for Implementing PTC

2012
1. Tracking Cores
2. Bar Coding: An Update on Tier Emission Compliance

2011
1. Small/Heavy Component Ergonomics Locomotive Starters
2. Storage, Handling, and Recycling of Locomotive Batteries

2010
1. Green Initiatives
2. Bar Coding, Material Tagging and Identification for Recycle and HAZMAT Controls
3. CN & Sustainable Procurement

2009
1. CSX Supplier Quality "Supplier Rating System"

2008
1. Lean Manufacturing as it Applies to Material Handling

2007
1. Insourcing vs. Outsourcing "The Altoona Story"

2006
1. PDAs for Inventory Control
2. Inventory Management System

2005
1. Centralized Materials Management
2. Centralized Component Core Management-Centralized Warehouse-Locomotive Components -
   Part A: BNSF Rwy.
   Centralized Component Core Management-Rotable Warehouse -
   Part B: Norfolk Southern Corp.

2004
1. Milk Run: Norfolk Southern's Dedicated Locomotive Parts Shipping System

2003
1. Just in Time Delivery - The Juniata - Shop Material Control Program
2. The Continuous Improvement Approach

2002

1. "Mentored Champion Process" - CSX Supply and Service Management

2001

1. RAILMARKETPLACE.COM The Industry's Market Exchange

2000

1. GE Global exchange Services
2. My.SAP.Com

1999

1. Composite Floors and Doors for Locomotives
2. Packaging Standards

1998

1. Tighter is Not Better
2. Are Vending Machines the New Wave for Safety Items?

1997

1. Raising Our Standards for Safety
2. The Rail Industry's Electronic Parts Catalog Exchange Standard (EPCES) - A Better Way

1996

1. Technology Transfer-The Hot Process of the 90's-Condition Based Maintenance
2. Warehouse Automation

1995

1. Warranty and Reliability Management
2. Railroad Industry Group (RIG) Exchange Standard for Parts Catalog Information

1994

1. Material Consignment
2. The Next Step in Electronic Information Management Interactive Technical Manuals.
3. Electronic Catalog Alternatives.

1993

1. Technology Transfer
2. Electronic Cataloging from a Material Perspective
3. Computerized Reordering from the Mechanical Employee's Point of View
4. Electronic Catalogues: OEM/Supplier Point of View

1992

1. Warranty Overview and Issues
2. Recycling-1992
3. Bar Coding
4. Material Packaging

1991

1. The World of Recycling
2. Problems with Solution
3. Problems with Opportunities

1990

1. Waste Minimization.
2. Hazardous Materials End Cost
3. The Role of the Suppliers

1989

1. Packaging and Containerization for Today's Railroad.
2. Innovations in Material Distribution Resulting from Shop Consolidations.
3. Outsourcing! Does Anyone Really Understand the Difference Between UTEX and Repair and Return and the Effect on the Budget?

4. "Stuff" Happens! - A Skit About the Necessity of Feedback from Suppliers - Suppliers to the end User

1988

1. Communication - The Vital Link in Materials Acquisition
2. Quality Assurance Through Communications and Feed-back
3. Paperless Requisitions
4. A Practical Application of Bar Coding in the Railroad Industry

1987

1. Suppliers Selection for Component Failure Analysis
2. Vendor Performance or Service Level
3. Bar Codes
4. Bar Coding - Railroads
5. Material Handling Innovations by the Airline Industry

1986

1. The In-House Electronic Requisition System
2. Electronic Data Interchange.
3. RAILING and Electronic Purchasing
4. Quality Evaluation Sourcing Decisions of Material

1985

1. Evaluating Locomotive Maintenance Projects
2. Reconditioning Material: In-House vs. Vendor
3. Identification and Disposition of Surplus Material
4. Cost of Carrying Surplus
5. Evolution and Future Directions of Material Handling Equipment in Railroad Use

1984

1. The New Language of Bar Codes
2. Forecasting Material Requirements
3. a. Fuel Security - Are You Getting What You Pay For? b. Fuel Oil Is Expensive
4. Pros and Cons of Material Purchasing Contracts (Single Source - Just In Time Inventory)

1983

1. Improved Locomotive Productivity Through Computerized Data
2. Inbound Material Inspection
3. Minimize Maintenance Cost Through Material Management Systems
4. New Ideas in Material Storage Containers

1982

1. Use of kits in locomotive maintenance
2. Cost effective methods of shipping material from vendors
3. Union Pacific's Component Inventory Maintenance System (CIMS)
4. Advantages of using shipping containers

1981

1. Disposal of Unserviceable Component Parts: What is the Most Profitable Method?
2. Innovations in Stores Material Handling, Via Computer Technology
3. Locomotive Held for Material: An Update for the 80's
4. The Best Approach to Procuring Material; New, UTEX, Repair and Return or Shop Repair

MECHANICAL MAINTENANCE COMMITTEE
(formerly known as Diesel Mechanical Maintenance Committee)

2019

1. Locomotive Storage and Return to Service – Update Best Practices
2. Problem Solving Basics
3. Locomotive Emissions Labeling
4. DEF Systems for Locomotives
5. BNSF & GE Pilot Hybrid Locomotive Consist Using a Battery Electric Locomotive

2018

1. New Procedure to Check GE-FDL Cam Timing
2. A Review of Compressed Air Systems
3. Basic Maintenance Practices for High-Pressure Common Rail Fuel Systems
4. Locomotive Shore Connection Heating Systems Update

2017

1. Locomotive Emission Kits
2. DC To AC Locomotive Conversion
3. Water Treatment of Cooling Systems
4. Overview of Locomotive Starter Abutment & Fail-to-Start Issues

2016

1. Locomotive Horsepower
2. Best Practices Locomotive Fuel Spill Prevention
3. LOCOMOTIVE METRICS: Reliability/Availability; Is there a need for a Standard Definition?
4. SD59MX EGR Performance Reports
5. GE Dual Fuel Locomotive Development

2015

1. Measuring the Value of Installing Solid Lube Sticks on Locomotives
2. NS CNG Locomotive Test Program
3. Utilizing Modern Electronics to Assist with Mechanical Maintenance Planning
4. Shore Connection Heating Systems for Locomotives Electric Heating Systems with New Implementation Techniques
5. Locomotive Exhaust Emission Regulations: Is Tier 5 Next?

2014

1. Avoiding Logic Traps in Problem Solving
2. AFM Calibration Absolutes for All Air Brake Systems
3. Locomotive Hand Brake Maintenance, Best Practices
4. Locomotive Cab Securement
5. The Drooping Brake Head – A Perennial Problem

2013

1. Pacific Harbor Line Tier 3+ and Tier 4 Re-Powered Locomotive Emissions After-treatment Experience
2. Locomotive Repower: Why Repower and What to Consider
3. 21st Century Locomotive Truck and Bogie Related Improvements

2012

1. Failure Modes and Effects Analysis
2. Main Generators - AR Type Traction Alternators - Best Practices – II Removal, Installation and Alignment

3. Finding an EPA Certified Emissions Kit for Locomotive Engine Overhaul
4. Locomotive Idle Minimization
5. Manual Torque Wrench Basics

2011

1. Locomotive Storage and Return to Service Best Practices
2. Design for Reliability
3. Main Generators - AR Type Traction Alternators - Best Practices -Identification and Maintenance

2010

1. EMD Turbocharger Change Out Best Practices
2. Effect of Intake Air Filter Restriction on Fuel Consumption and Emissions
3. Locomotive Diesel Exhaust Aftertreatment Demonstrations; Size, Location and Issues

2009

1. Variability and the Toyota Production System
2. The Thorough Bred Maintenance System
3. Air Compressors – Best Practices – Back Shop Maintenance Part II
4. Alignment Control Coupler Requirements

2008

1. Ultra-Low Sulfur Diesel Fuel:Impact on Locomotive Maintenance
2. Exhaust Aftertreatment Technologies: Definitions and Maintenance
3. EPA Emission Requirements for Locomotives
4. Air Compressors-Best Practices-Identification and Maintenance, Part I

2007

1. Training a New Work Force
2. Locomotive Horn Testing
3. Diagnostic Techniques for Predictive/Preventative Maintenance-Exploitation of New Technology
4. Locomotive Particulate Matter Emissions Reduction through Application of Exhaust Aftertreatment Systems

2006

1. Lost Opportunities of Rebuilding Trucks
2. GP/SD38-2S Locomotive-A New Class of Power
3. Heavy Diesel Engine Field Repair
4. Benefits of Mobile Maintenance

2005

1. Crankcase Overpressure Today - Concentrating on EMD and GE Locomotives
2. Cold Weather Locomotive Operations
3. Importance of Cooling System Health, EPA Compliance Impact
4. Overhaul Extension

2004

1. GE Evolution Series-Maintenance and Reliability
2. EMD 70ACe and SD70DC-Tier 2 Locomotive Models-Mechanical Maintenance Enhancements
3. Best Practices Series-For Regional and Shortline Railroads-Managing Locomotive Wheel Wear
4. Maintenance Savings - Mother/Daughter Units

2003
1. Training 60/30 Impact Now Beyond
2. Condition Based Maintenance, Practical Approaches and Techniques

2002
1. Detrimental Effects of Locomotive Engine Idling
2. Emissions Standard Compliance for the GE Dash 8 Locomotives
3. Tier 0 Emissions Compliance for the GE Dash 8 Locomotive
4. Locomotive Inspection Training - A Preview of CFR 229/238
5. Computerized Record Keeping to Improve Performance and Reduce Maintenance Expense for Shortline and Regional Railroads

2001
1. Troubleshooting Electronic Fuel Injection on GE Locomotives
2. Troubleshooting Electronic Fuel Injection-EMDEC ElectroMotive Division Two-Stroke Engine
3. How to Maintain ALCO Locomotives in the 21st Century
4. Catastrophic Engine Failures: Shortlines & Regionals (Best Practices)
5. Are We Ready for Reliability- Centered Maintenance?

2000
1. 2000 Emissions Review - GE Perspective
2. 2000 Emissions Review – EMD Perspective
3. EMD Diesel Engine Crankshaft Main Bearings Edge-Load Condition (Description, Detection and Resolution)
4. 2000 - LMOA Best Practice Series: Locomotive Truck Overhaul Procedures

1999
1. Vibration Analysis
2. EMD Power Assemblies Change Out Practices for Regional and Shortline Railroads
3. Improved Access to GE7FDL Engine Intake Manifold for Cylinder Inlet Port Cleaning
4. What's Ahead in Plastics for Locomotive Applications
5. Cast Iron, Composition Brake Shoe Arrangements vs. Type-J Relay

1998
1. LMOA Best Practices Series: GM Engine Crankcase Pressure Troubleshooting
2. Union Pacific's New EMD Diesel Engine Rebuild Line At Downing B. Jenks Locomotive Facility-No. Little Rock, Arkansas
3. GE Turbo Rebuild Procedures
4. Mechanical Impact of Locomotive Emissions Regulations
5. Locomotive Engine Bearing Developments

1997
1. LMOA Best Practices - GE Water Leaks
2. Locomotive Update - MK 1200G LNG Powered Switcher
3. Proper Use of Gaskets and Seals

1996
1. Air Brake Trouble Shooting-Where We Are Now
2. Best Practices - Internal Water Leaks on EMD Locomotives
3. Best Practices - Oil Out Stack

1995

1. General Electric New 7HDL 6000 HP Diesel Engine
2. LMOA Best Practices Series – Low Oil Pressure Trouble-shooting Procedures for EMD Turbocharged Locomotives
3. How Can a Regional or Shortline Justify a Wheel Truing Machine?
4. EMD SD60M Natural Gas Locomotive Development

1994

1. Electronic Fuel Injection.
2. ICAV - The Physical Affects on Instantaneous Crank Shaft Angular Velocity Technology
3. Maintenance Practices Comparison Between Regionals and Class I Railroads
4. Amtrak Document Management.

1993

1. EMD's Three-Axle Radial Steering Truck
2. The Natural Gas Locomotive at BNRR
3. Locomotive Waste Oil Retention
4. Fragmented Maintenance

1992

1. Mechanical Quality Progress Developing on Major Railroads.
2. Coal Fuelled Diesel Locomotive Development.
3. 18:1 Upgrade for the 645E Engine
4. Automatic Stop and Start Control System
5. Acquiring Locomotives for Regionals and Shortlines

1991

1. Recommended Practices for upgrading 567 to 645 Design.
2. Conversion of SD40 Locomotives to SD 40-2 on CSX
3. Update: Diesel Engine Emission Controls
4. Stationary and Dynamic Test Procedure for Locomotive Fuel Efficiency Measurement
5. Personnel training on New Technology.

1990

1. Caterpillar Power in Remanufactured Locomotives.
2. The EMD 710G3A Engine
3. Improving Performance of Traction Motor Friction Suspension Bearings.
4. Fluid Leaks on GE 7FDL Engine.
5. Rebuild of the EMD F3B Fuel Injector.

1989

1. Wheel Axle Gear Wear/Impact on Traction Motor Life
2. 710 Engine - Operational and Overhaul Update
3. GE Power Assembly Improvements on Welded Head-to-Liner
4. Assembly Rework Procedures.
5. EMD Engine Oil Leaks. Secondary Air Filtration - Barrier vs. Impingement

1988

1. Low-idle Operating Costs vs. Fuel Savings.
2. Rebuilding GE's EB Liner
3. The Extended Maintenance Truck
4. Flange Lubricator Update
5. Permaspray II - Cylinder Liner

1987
1. EMD Water Pump Rebuilding
2. On Board Flange Lubricator
3. Gear Case, Bull Gear and Pinion Gear Longevity in the 1980's - Gear Cases - Canadian National Experience.
4. Maintenance of Locomotive Fueling Systems for a Spill Free Operation

1986
1. Rebuild of Valve Bridge Assemblies
2. Update of New Locomotive Service Problems, EMD and GE Effecting Quality Performance
3. Chromium Plating and Its Uses
4. Development of a New Diesel Engine for Heavy-Duty Locomotive Service

1985
1. Procedures for Storing Serviceable Locomotives for Quality Performance
2. New Locomotive Service Problems, EMD and GE
3. 92 Day Service Requirements: EMD, GE and Bombardier

1984
1. Mechanical Aspects of New Locomotive Designs
2. Maintenance of Locomotive Components

1983
1. Leaks: Cooling Water, Lube Oil, Fuel Oil and Air
2. Torquing Recommendations.
3. Update on Fuel Efficient Locomotives
4. Radiator Screens
5. Alternate Starter Systems

1982
1. Fuel Conservation - Effects on Maintenance
2. Fuel Conservation - What It Costs.
3. Diesel Fuel Receipt and Disbursement
4. Turbochargers

1981
1. Running Gear
2. Filtration
3. FRA Rules
4. Follow-up on Previous Topics

LOCOMOTIVE SOFTWARE AND SYSTEMS
(formed in 2017)

2019

1. IoT – Big Data and Real Time Processing
2. Implementing Predictive Maintenance for Locomotives Using Big Data
3. Analytics through Repairs Integration
4. Locomotive Data Publication Standard S-XXXX.V1.0

2018

1. Best Practices for Locomotive Software Updates
2. Locomotives of The Future as a Mobile Data Center
3. Locomotive Remote-Control Systems

2017

1. Connected Locomotives
2. Sensors and Instrumentations on Locomotives-A Railroad Case Study

FACILITIES, MATERIAL AND SUPPORT COMMITTEE (formed in 2017)

2019

1. Wheel Truing Technology Development and Innovation
2. Reducing Locomotives Held for Material
3. New Coating Technology for Graffiti Prevention

2018

1. The Proper Paint Shop-Current Trend and Best Practices
2. PTC at the Belt Railway of Chicago
3. Designing the Bricks and Mortar for Locomotive Maintenance

Constitution and By-Laws Locomotive Maintenance Officers Association

Revised October 3, 2016

Article I – Title:

The name of this Association shall be the Locomotive Maintenance Officers Association (LMOA).

Article II – Purpose of the Association

The purpose of the Association, a non-profit organization, shall be:

- to improve the interests of its members through education,
- to supply locomotive maintenance and technical information to Association members and their employers,
- to exchange knowledge and information with members of the Association,
- to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad industry.

Article III – Membership

Section 1 – Railroad Membership shall be composed of persons currently or formerly employed by a railroad company and interested in locomotive maintenance. Membership may be subject to approval by the General Executive Committee.

Section 2 – Associate Membership shall be composed of persons currently or formerly employed by a manufacturer of equipment or devices used in connection with the maintenance and repair of motive power. Membership may be subject to approval by the General Executive Committee. Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at the Annual Meeting, serving on Association committees and shall have the privilege of voting and holding elective office.

Section 3 – Life membership shall be conferred on all Past Presidents. Life membership may also be conferred on others for meritorious service to the Association, subject to approval by the General Executive Committee.

Section 4 – Membership dues for individual railroad and associate membership shall be set by the General Executive Committee and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end September 30. Members' whose dues are not paid on or before the opening date of the annual convention are subject to being prohibited from attending the annual meeting, shall not be eligible to vote and may not be entitled to receive a copy of the published Pre-Convention

Report or the Annual Proceedings of the annual meeting. Failure to pay membership dues within a reasonable amount of time will result in loss of membership. Life members will not be required to pay dues, and will be entitled to receive a copy of the Pre-Convention Report and Annual Proceedings.

Article IV – Officers

Section 1 – Elective Officers of the Association shall be President, First Vice President, Second Vice President and Third Vice President. Each officer will hold office for one year or until a successor is elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, continue to serve as an elective officer and be allowed to elevate through the ranks as naturally occurs, to include the office of President.

Section 2 – There shall be one Regional Executive officer assigned to oversee each technical committee. Regional Executives shall be appointed from the membership by the General Executive Committee for an indefinite term, with preference given to those having served as a Technical Committee Chairperson. A Regional Executive who leaves active service may continue to serve as such, and shall be eligible for nomination and election to higher office.

Section 3 – There shall be a General Executive Committee composed of the President, Vice Presidents, Regional Executives, Technical Committee Chairpersons, and all Past Presidents remaining active in the Association.

Section 4 – There shall be a Secretary-Treasurer appointed by and holding office at the pleasure of the General Executive Committee, who will contract for his or her services with appropriate compensation.

Section 5 – All elective officers and Regional Executives must be LMOA members in good standing. (See Article III, Section 4.)

Article V – Officer, Nomination, and Election of

Section 1 – Elective officers shall be chosen from the active membership. A Nominating Committee, composed of the current elective officers and the active Past Presidents, shall submit a slate of candidates for each elective office at the annual convention.

Section 2 – Election of Officers shall be determined by a voice vote, or if challenged, it shall require a show of hands.

Section 3 – Vacancies in any elective office may be filled by presidential appointment, subject to approval by the General Executive Committee.

Section 4 – The immediate Past President shall serve as Chairman of the Nominating Committee. In his absence, this duty shall fall to the current President.

Article VI – Officers- Duties of

Section 1 – The President shall exercise general direction over all affairs of the Association and approve expenditures subject to availability of funds.

Section 2 – The First Vice President shall, in the absence of the President, assume the duties thereof. He shall additionally be responsible for arranging a mid-year joint meeting of the Association, preferably to be held in the early part of May.

Section 3 – The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers required to underwrite the cost of the Annual Proceedings.

Section 4 – The Third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly prepared and distributed, monitoring membership levels and reporting same at appropriate times to the General Executive Committee.

Section 5 – The Vice Presidents shall perform such other duties as are assigned them by the President.

Section 6 – The Secretary-Treasurer shall:

A. Keep all the records of the Association.
B. Be responsible for the finances and accounting thereof under the direction of the General Executive Committee.
C. Perform the duties of Secretary of the Nominating Committee and General Executive Committee, without vote.
D. Furnish surety bond in the amount of $50,000 on behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.
E. Arrange the schedule for presentation of technical reports at the annual convention and coordinate same with the other associations to minimize conflict.
F. Serve as liaison for the LMOA with other associations
G. Arrange for publications of the LMOA Annual Proceedings.

Section 7 – The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.
B. Monitor material to be presented by the technical committees to ensure reports are accurate and pertinent to the goals of the Association.
C. Attend and represent LMOA at meetings of their assigned technical committees.
D. Promote Association activities and monitor membership levels within their assigned areas of responsibility.
E. Promote and solicit support for LMOA by helping to obtain advertisers.
F. Train new Committee Chairpersons on LMOA procedures and bylaws. Mentor and support Chairpersons.

Section 8 – Duties of General Executive Committee:

A. Assist and advise the President in long-range Association planning.
B. Contract for the services

and compensation of a Secretary-Treasurer.

C. Serve as the Auditing and Finance Committee.

D. Determine the number and name of the Technical Committees.

E. Exercise general supervision over all Association activities.

F. Monitor technical reports for material considered unworthy for publication or inaccurate.

G. Approve the tentative schedule and list of topics to be presented at the annual convention and published in the Annual Proceedings.

H. Exercise authority to disapprove, for just cause, any new committee member or other item submitted for its approval. Such member or item will stand approved as submitted if the General Executive Committee declines to act.

I. Handle all matters of Association business not specifically herein assigned.

J. Handle all public relations decisions within LMOA and coordinated associations with confidentiality.

Article VII – Technical Committees

The technical committees will consist of:

Section 1 – A chairperson appointed by the President and approved by the General Executive Committee.

Section 2 – A vice chairperson selected by the chairperson and approved by the President.

Section 3 – Committee members, selected as follows:

A. Representatives of operating railroads and regional transit authorities submitted by their Senior Mechanical and Materials Officers and approved by the President of LMOA.

B. Representatives of locomotive builders designing and manufacturing locomotives in North America submitted by their perspective company and approved by the Committee Chairperson.

C. The Fuel, Lube and Environmental Committee will include members from major oil additive companies or their subsidiaries submitted by their perspective company and approved by the Committee Chairperson.

D. As needed, the Committee Chairperson may invite other non-railroad personnel to participate in committee activities on either a limited time or permanent basis

E. The Chairperson will submit the name of perspective new committee members to the Executive Committee which reserves the right to approve or disapprove membership.

F. Companies are allowed a primary and alternate member on committees at the Chairperson's discretion.

Section 4 – All individuals who are on technical committees must be LMOA members in good standing. (See Article III, Section 4.)

Section 5 – Each technical committee shall prepare one or more technical reports for presentation at the annual meeting and publication in the Annual Proceedings. Oral presentations should include the use of slides, videos, or other media as appropriate to the subject.

Section 6 – Subjects for technical papers will be selected and approved by the General Executive Committee.

Article VIII – Proceedings

Section 1 – The Locomotive Maintenance Officers Association encourages the free interchange of ideas and discussion by all attendees for mutual benefits to the railroad industry. It is understood that the expression of opinion, or statements by attendees in the meeting, and the recording of reports containing the same, shall not be construed as representations or statements ratified by the Association.

Section 2 – Those present at any meeting called on not less than thirty days advance written notice shall constitute a quorum.

Article IX – Rules of Order

The proceedings and business transactions of this Association shall be governed by Robert's Rules of Order, except as otherwise herein provided.

Article X – Amendments

The Constitution and By-Laws may be amended by a two-thirds vote of the active members present at the Annual Meeting.