LMOA

Locomotive Maintenance Officers Association

Proceedings of the 66th Annual Meeting

September 27 - 28, 2004

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2004 ADVERTISERS INDEX

LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION

NOTE: SPECIAL RECOGNITION TO OUR 2ND VP, BRUCE KEHE, WHO SOLICITED NEW ADVERTISERS - THANKS, BRUCE, FOR YOUR EFFORTS

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2003 LMOA MVP RECIPIENTS

The executive board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable People of their respective committees in 2003.

Name	Company	Committee
Charles (Chick) Aday	Metrolink (SCRRA)	Shop Equipment & Processes
Glenn W. Bowen	BNSF Railway	Fuel, Lubricants & Environmental
Richard Dalton	Motive Power, Inc.	New Technologies
Bob Harvilla	Standard Car Loco. Group	Diesel Material Control
Jay Holley	CSX Transportation	Diesel Mechanical Maintenance
Richard Marchese	Electro Motive Divn (GMC)	Diesel Mechanical Maintenance
Bob McCaffrey	National Electrical Carbon Prod.	Diesel Electrical Maintenance

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

A special debt of gratitude to Jay Holley who not only served admirably as a committee person but also as a Chairman and as a Regional Executive of the Diesel Mechanical Maintenance Committee. Thanks Jay.

Also. we wish to extend our sincere appreciation to Bruce Butts who was our past chairman and Regional Executive of the New Developments Committee. Thanks, Bruce, for the energy and direction you gave this committee.

LMOA EXECUTIVE COMMITTEE

THE LMOA EXECUTIVE COMMITTEE
WOULD LIKE TO EXPRESS THEIR
SINCERE APPRECIATION TO
MR. JIM DANIELWICZ
AND
MR. BILL KIRDEIKIS
AND THE ENTIRE STAFF OF THE
CANADIAN NATIONAL RAILROAD FOR
HOSTING THE 7TH ANNUAL
LMOA JOINT TECHNICAL COMMITTEE
MEETINGS IN MEMPHIS, TN
ON MAY 3 AND 4, 2004 AND FOR
THE SHOP TOUR OF MEMPHIS SHOPS.

WE THANK YOU FOR YOUR SUPPORT
OF OUR ORGANIZATION

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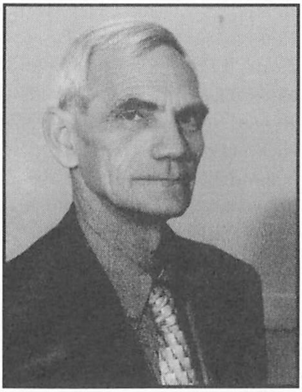

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MR. BRIAN HATHAWAY

Service Area Center/Chief Mechanical Officer

Omnitrax Locomotive Services

Tempe, TX 76504

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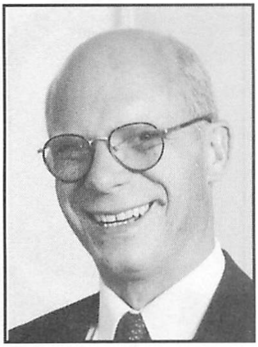

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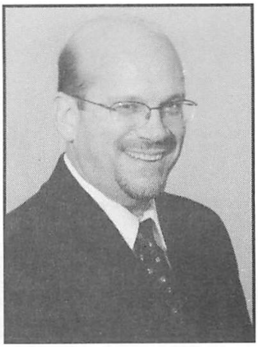

2nd Vice President
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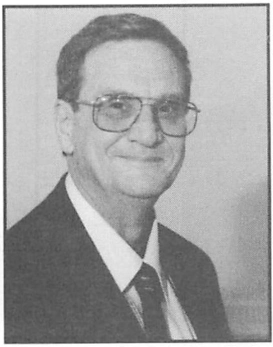
Manager - Mechanical Services
EJ&E Railway Co.
Gary, IN 46402



3rd Vice President
MR. LES WHITE
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RMR (Romic Marc Rail)
Pointe-Claire, Quebec H9R 4Z7

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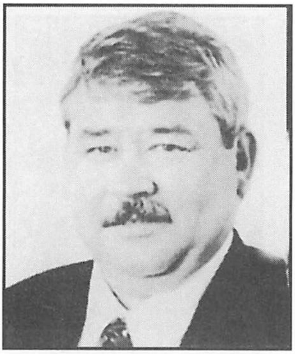

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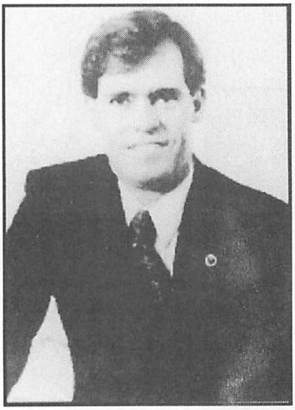
Seattle, WA 98134

MR. MARK COLES
Senior Manager - Loco. Engineering & Quality
Union Pacific Railroad
Omaha, NE 68179



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CSX Transportation
Selkirk, NY 12158

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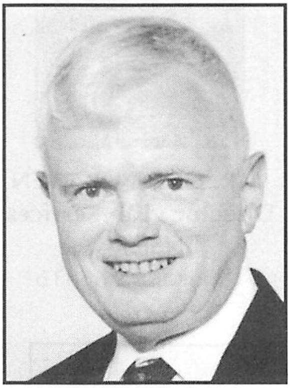
Ellcon National
Keller, TX 76248



MR. ROBERT RUNYON
(Retired Norfolk Southern Corp.)
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Roanoke, VA 24042

MR. DAVID M. WETMORE
General Supt. - Fuel Operations
NJT Rail Opns
Kearny, NJ 07032

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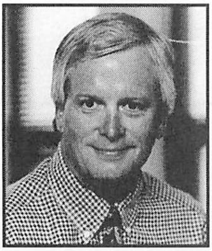

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BNSF Rwy
Topeka, KS 66616

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Amtrak
Beech Grove, IN 46107

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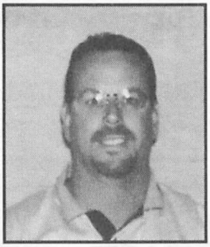
Calgary, Alberta T2P 4Z4



MR. MIKE SCARINGE
Director Warranty Enforcement
Amtrak
Beech Grove, IN 46107

Past President Bob Runyon (left) presents outgoing President Brian Hathaway with the Past President's Pin. The ceremony was witnessed by newly elected President Bill Lechner.

Outgoing President Brian Hathaway (right) presents the LMOA blazer to newly elected 3rd Vice President Les White while Regional Executive Bob Reynolds looks on.

Outgoing President Brian Hathaway (center) presents the gavel to newly elected President Bill Lechner (right). The ceremony was attended by newly elected 2nd Vice President Bruce Kehe.

Regional Executive Glenn Bowen presents the LMOA attache bag to Tom Pyziak who was appointed Chairman of the Fuel, Lubricants and Environmental Committee.

Standing (left to right) - Ron Pondel, Secretary Treasurer, newly elected 3rd Vice President Les White; newly elected 2nd Vice President Bruce Kehe; newly elected President Bill Lechner.
Seated - Past President Bob Runyon (left) and outgoing President Brian Hathaway (right).

REPORT OF THE COMMITTEE ON NEW TECHNOLOGIES

MONDAY, SEPTEMBER 27, 2004
10:15 A.M.

Chairman
TIM BLACK
Manager-Locomotive Scheduling
Union Pacific RR
Omaha, NE

Vice Chairman
R. BRAD QUEEN
Mechanical Supervisor,
BNSF Railway
Topeka, KS

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R. Dalton	Manager-Opns. & Maint.	Motive Power Inc	Conroe, TX
M. Durham		Alstom Transport	Lisle, IL
J. Fedora	Specifications & Std. Engr.	Amtrak	Wilmington, DE
K. Gilbert	Manager-Loco.Parts-Canada	GE Transp. Rail	Montreal, PQ
C. Prudian	Senior Systems Engineer	Electro Motive Divn.	LaGrange, IL
J. Whitmer	Foreman	CN RR	Homewood, IL

NOTE: J. Fedora and J. Whitmer are new committee members.

PERSONAL HISTORY

Tim Black
Manager Locomotive Scheduling
Union Pacific Railroad

Tim was born January 1953 in Manning, Iowa. Upon graduating from Woodbine High School in 1971, he attended Iowa Western Community College in Council Bluffs, Iowa. Tim has a degree in Industrial Electronics and is a 30 year employee of Union Pacific Railroad in Omaha, Nebraska.

His current position is Manager - Locomotive Scheduling in the the Network Operations group.

Tim has two daughters and two sons. Residing in Council Bluffs, Iowa he enjoys traveling, fishing and photography.

THE NEW TECHNOLOGIES COMMITTEE WISHES TO EXPRESS THEIR SINCERE APPRECIATION TO THE FOLLOWING COMPANIES FOR HOSTING AND SPONSORING THEIR MEETINGS IN 2003/2004

MOTIVE POWER – BOISE, ID
NOVEMBER 2003

BNSF RAILWAY – KANSAS CITY, MO
MARCH 2004

UNION PACIFIC RR – OMAHA, NE
JULY 2004

THANK YOU VERY MUCH FOR
YOUR SUPPORT,

NEW TECHNOLOGIES COMMITTEE

I. GE EVOLUTION LOCOMOTIVE - AN OVERVIEW

Presented by:
Keith Gilbert, Manager
Locomotive Parts Sales - Canada,
GE Transportation Rail

Introduction

This paper is intended to be an overview of the new GE Tier II locomotive, the Evolution Series. We will touch on some of the design decisions that were made and will take a brief look at the main systems and sub-systems that were developed to meet the Tier II regulations. Please refer to the Diesel Mechanical Maintenance Committee section of this publication for an article on the engine and cooling systems. Editors note: Attendees at the 2004 convention in Chicago were able to visit the outdoor exhibits to see an Evolution locomotive up close.

Background

The Evolution Series is the result of a six-year research program and an investment of 200 million dollars. In order to gather real-life data and to better validate the new systems under true conditions, a total of 50 pre-production locomotives with a mix of AC and DC units have been in revenue service at all Class 1's. These locomotives have operated under all conditions and over all types of terrain working hard for more than 1.5 million miles of revenue service.

Topics to discuss

The Evolution locomotive was designed specifically to meet the Tier II regulations, so we will start by examining the regulations to better understand what was required. We will then have a look at some of the different drivers behind the decision to develop a new platform, followed by the main components of the new design and what they bring to the table in terms of reliability. Finally we will talk a little about where we are today.

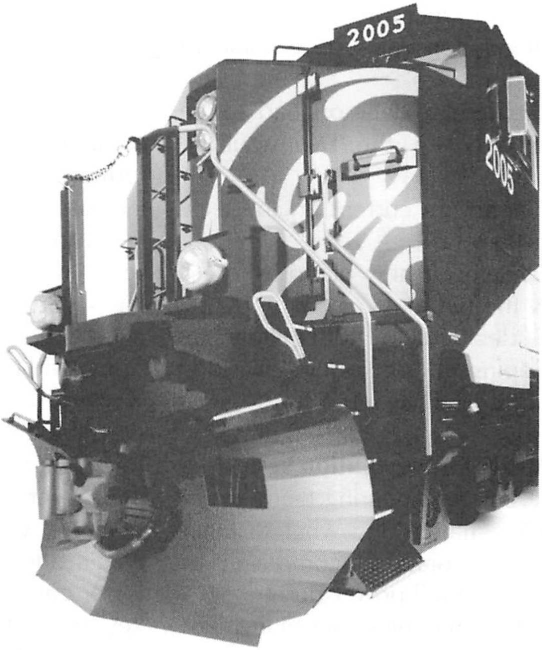
- Regulations
- What is Evolution Series
- Reduced Operating Costs
- Reliability Growth
- Program Plan
- Summary

Why a new locomotive platform?

The EPA has imposed tiered reductions in atmospheric and visible emissions over the 2001-2005 time frame. The most critical atmospheric emissions regulated are Nitrogen Oxides (NOx) and Particulate Matter (PM); however, Hydrocarbon (HC), Carbon Monoxide (CO) and other emissions are regulated as well. Figure 1 details the EPA mandated 56% reduction in NOx and the 67% reduction in PM over that time frame.

In addition to the atmospheric emission, visible emissions are also regulated. The visible emissions regulations require a tiered reduction in steady state opacity (a measure of the ability to see through the stack discharge of a diesel engine). Figure 2 details the 43% reduction in visible emissions over the 2001-2005 time frame.

The EPA regulations were the catalyst that drove the development of the Evolution Series platform, but


2005
2005

what the regulations also did was to provide an opportunity to improve the factors that are key to the success of a locomotive...**Performance, reliability and life cycle cost.**

In simple terms, we can say that the locomotive has to have certain attributes to have a positive impact on the railroad client.

At a high level, those are:

- Create a safe environment for railroad employees
- Maximize asset utilization
- Minimize life cycle cost
- Maximize on time performance

In developing a Tier II locomotive, the new product must also meet the EPA regulations plus drive value to the customer.

Ultimately, a decision had to be made between the two available options:

- Extend the current engine technology, OR
- Develop a new platform for TII & the future

GE decided to concentrate on developing a locomotive platform for Tier II and beyond.

What is the evolution series?

The best engineering team knows what to change and what to maintain. The Evolution locomotive is an evolution in rail power design, not a revolution, meaning that many existing components and systems were retained from the AC 4400. For example, the main traction system components such as the GEB13™ traction motor and the IGBT control system have carried over to the new platform.

The term "Evolution" involves the modification of certain traits to better adapt to one's environment. In this case, that refers to the engine, cooling system and control system (Figure 3).

The GEVO-12, 12 cylinder diesel engine (Figure 4) produces the same horsepower as it's 16 cylinder predecessor. This feat is accomplished using less fuel, with extended service and overhaul intervals.

The GEVO-12 also produces 40% fewer emissions than current locomotives. This engine is the heart of the development potential of the Evolution Series, with growth opportunities designed into the engine in terms of fuel efficiency, horsepower and emission compliance.

Heat is the enemy of all internal combustion engines. It robs performance, reduces reliability and increases maintenance costs. The Evolution Series addresses these issues with the most advanced cooling system GE has ever developed (Figure 5).

In addition to the standard wet/dry radiator and fan combination, the Evolution utilizes dual fans to enhance the intercooler efficiency and lower the combustion air temperature while also reducing the water and oil temperature. The lower combustion air temperature is key to meeting Tier II emissions levels while the lower oil and water temperatures result in longer oil life and longer engine life.

The third system for discussion is the new consolidated control architecture (CCA) control system (Figure 6). The system uses centralized "smart displays" as the central processor and distributor of information. This straightforward, easy-to-understand system delivers the information the operator needs, when it is needed.

Reliability is increased through the use of a redundant wired ArcNet and a significantly reduced number of cards. In addition to reliability the CCA architecture also makes it easier to incorporate third-party devices as well as upgrade software and download data.

Reduced operating costs

As stated earlier, Tier II regulations were the key driver behind the development of the Evolution locomotive. The regulations also provided the opportunity to improve **performance, reliability and life cycle cost.**

Figure 7 highlights the improvements in specific fuel consumption (SFC) and NOx emissions of the GEVO-12 as compared to the 7FDL-16.

Reliability growth

Improved reliability equates to fewer unscheduled shop visits, resulting in better availability. The common theme in the new systems developed for the Evolution is Fewer-As in Fewer Parts.

Figure 8 highlights the areas of improvement.

Program plan

The Evolution Program consists of 50 pre-production locomotives, with a mix of AC and DC units, operating in Class 1 service in excess of 1.5 million miles. The goal is to validate the capabilities of the Evolution Series in real-world testing and to ensure that all systems perform as reliably and efficiently as designed. Figure 9 shows the time-line of the Evolution development program.

Summary

We have discussed here the new GE Tier II locomotive, the Evolution. The highlights of this new locomotive are the engine, cooling system and the CCA control system.

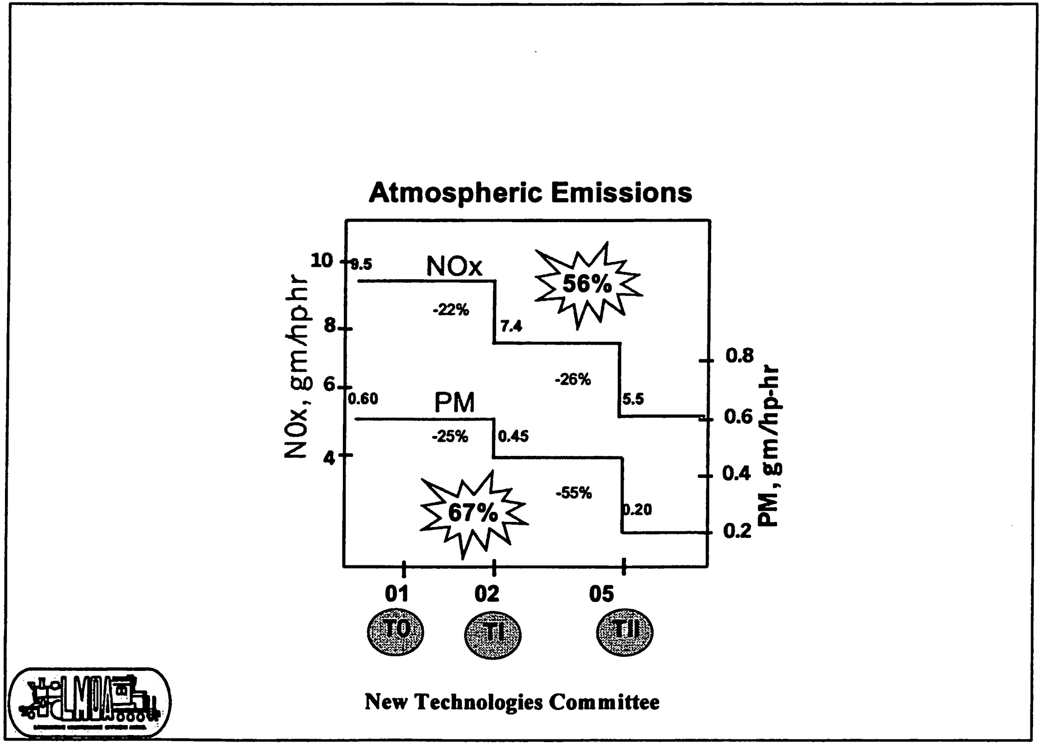
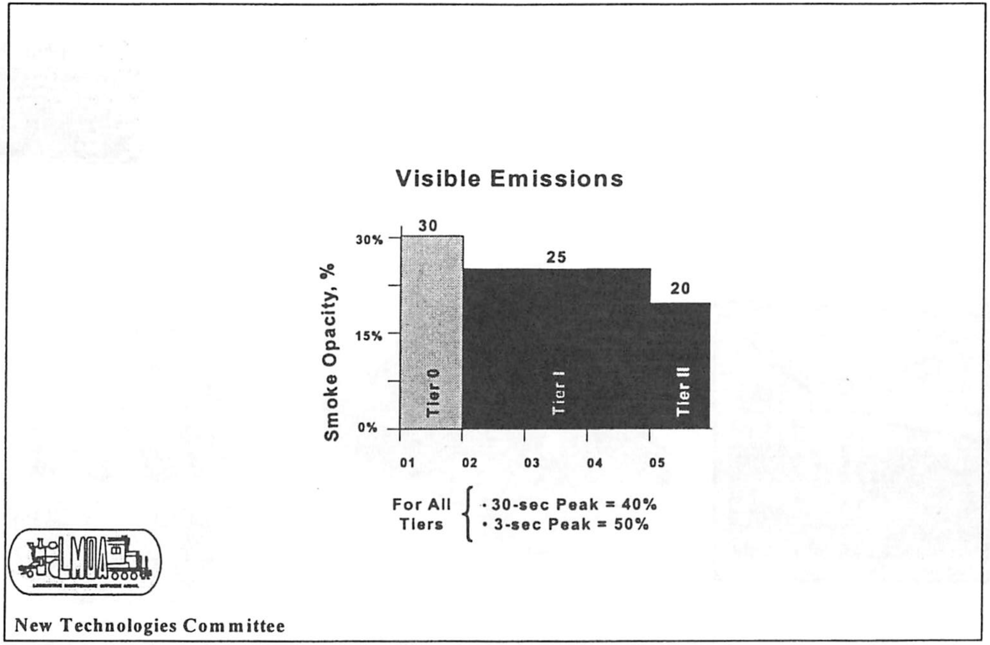

Atmospheric Emissions
NOx, gm/hphr
10
8
6
4
9.5
NOx
-22%
7.4
56%
-26%
5.5
0.60
PM
-25%
0.45
67%
-55%
0.20
PM, gm/hp-hr
0.8
0.6
0.4
0.2
01
02
05
T0
TI
TII
New Technologies Committee

Figure 1



Visible Emissions

For All Tiers
- 30-sec Peak = 40%
- 3-sec Peak = 50%

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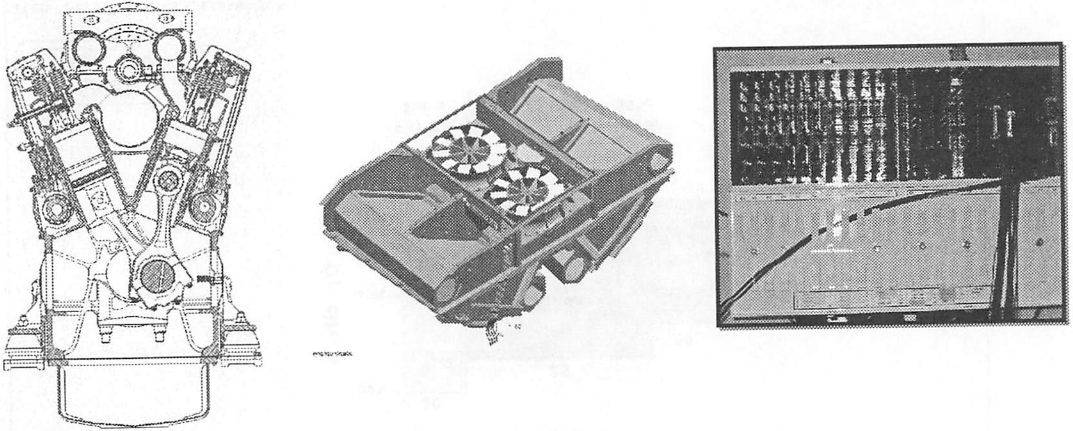
Figure 2



GEVO –12™ Engine Hybrid Cooling System CCA Control

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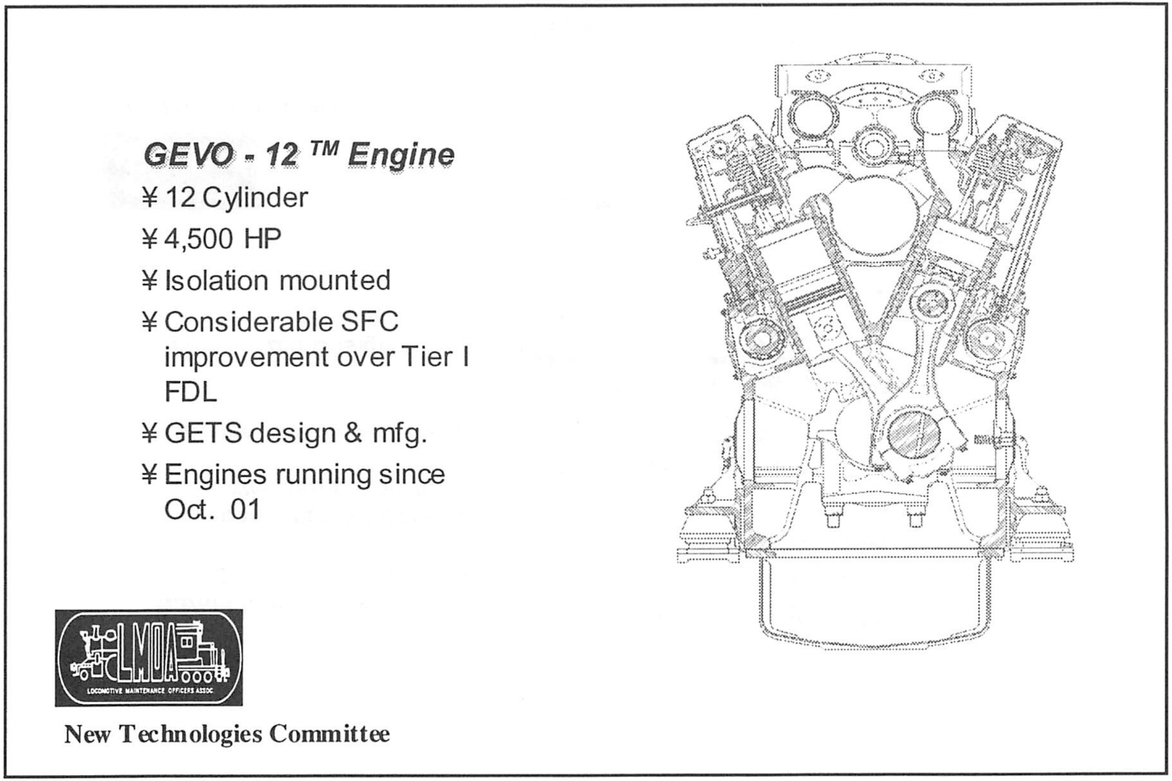
Figure 3



GEVO - 12 ^{TM} Engine

¥ 12 Cylinder

¥ 4,500 HP

¥ Isolation mounted

¥ Considerable SFC improvement over Tier I FDL

¥ GETS design & mfg.

¥ Engines running since Oct. 01

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Figure 4

¥**Lower Manifold Air Temp.**
- Better SFC, Lower Emissions

¥ **Independent MAT Control**
- Lower Temp. Variations

¥**Greater Oil Cooling Capacity**
- Longer Engine Bearing Life

¥**Modularized Design**
- Easier Maintenance

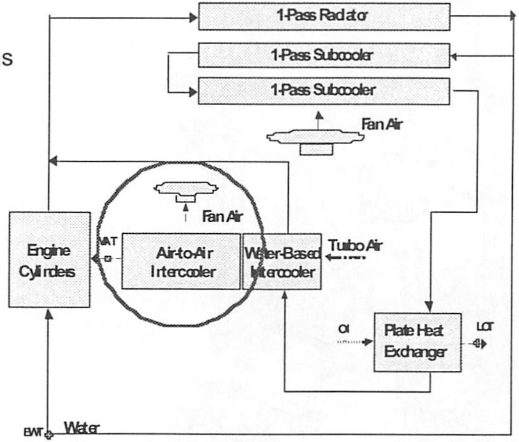

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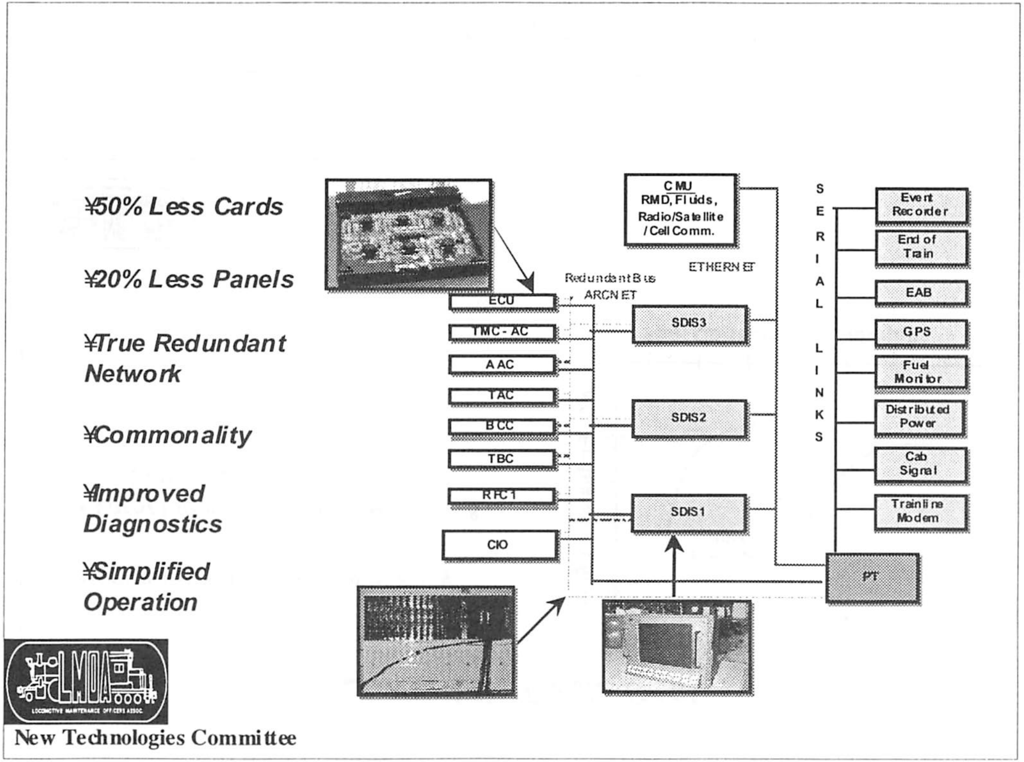
Figure 5



¥50% Less Cards

¥20% Less Panels

¥True Redundant Network

¥Commonality

¥Improved Diagnostics

¥Simplified Operation

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Figure 6

Lower Life Cycle Cost

- Drive Increased fuel efficiency
- Target increased maintenance & O/H interval

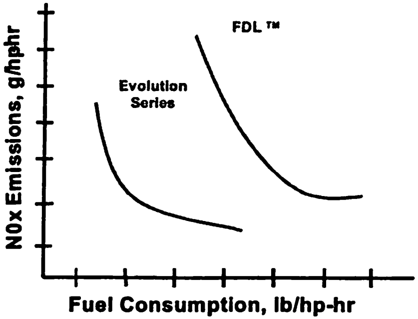

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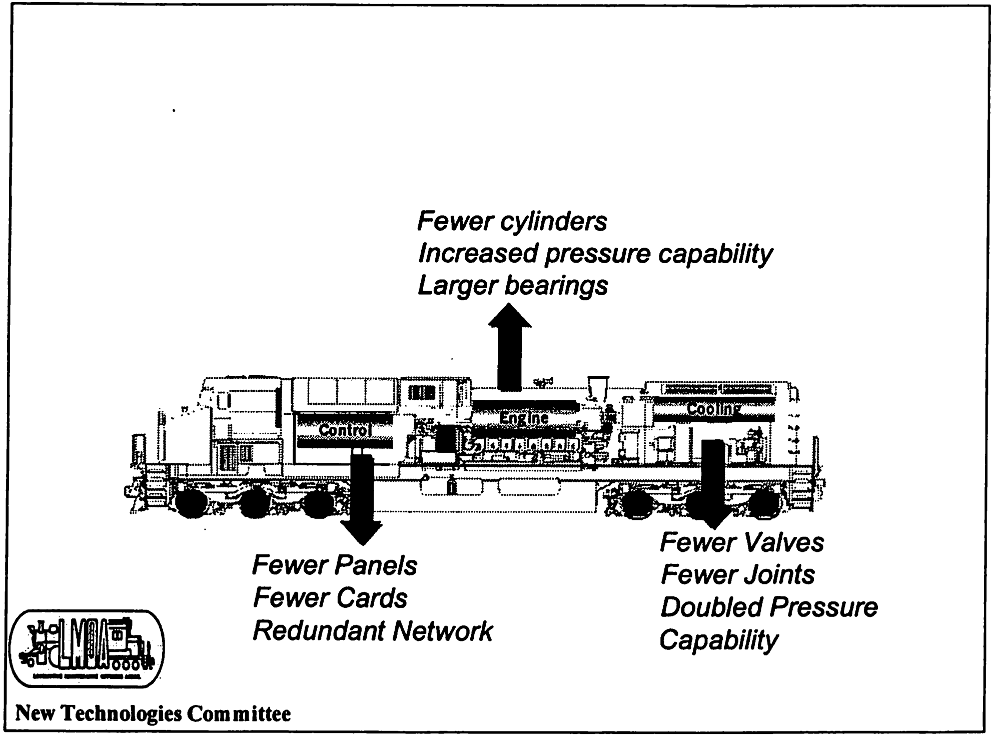
Figure 7



Fewer cylinders
Increased pressure capability
Larger bearings

Fewer Panels
Fewer Cards
Redundant Network

Fewer Valves
Fewer Joints
Doubled Pressure Capability

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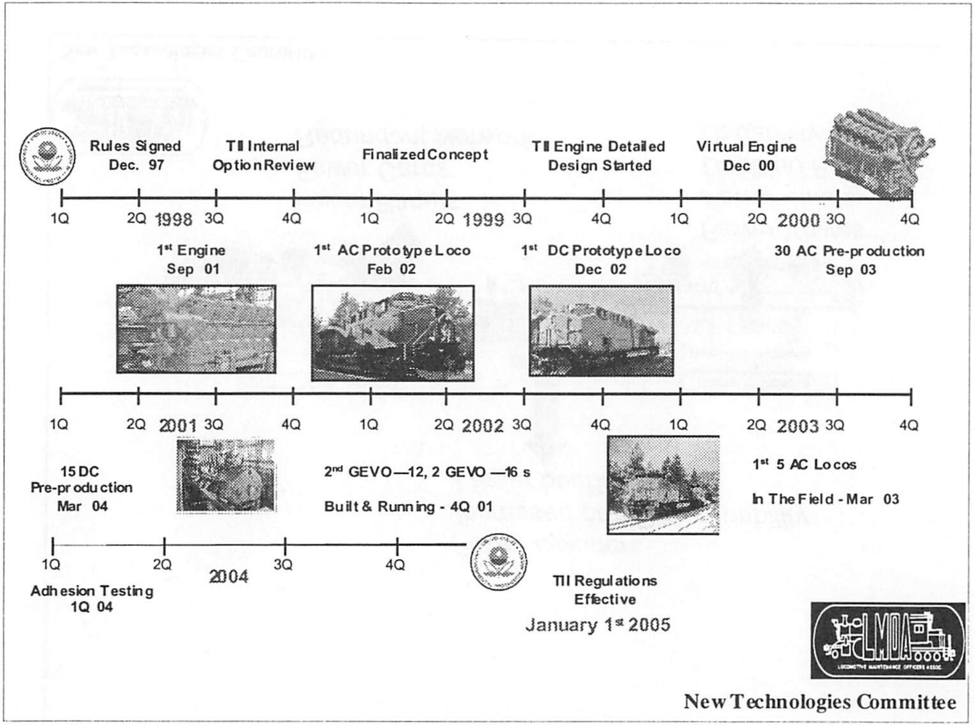
Figure 8



Rules Signed Dec. 97

TII Internal Option Review

Finalized Concept

TII Engine Detailed Design Started

Virtual Engine Dec 00

1Q 2Q 1998 3Q 4Q 1Q 2Q 1999 3Q 4Q 1Q 2Q 2000 3Q 4Q

1st Engine Sep 01

1st AC Prototype Loco Feb 02

1st DC Prototype Loco Dec 02

30 AC Pre-production Sep 03

1Q 2Q 2001 3Q 4Q 1Q 2Q 2002 3Q 4Q 1Q 2Q 2003 3Q 4Q

15 DC Pre-production Mar 04

2nd GEVO—12, 2 GEVO—16 s

Built & Running - 4Q 01

1st 5 AC Locos

In The Field - Mar 03

1Q 2Q 2004 3Q 4Q

Adhesion Testing 1Q 04

TII Regulations Effective

January 1st 2005

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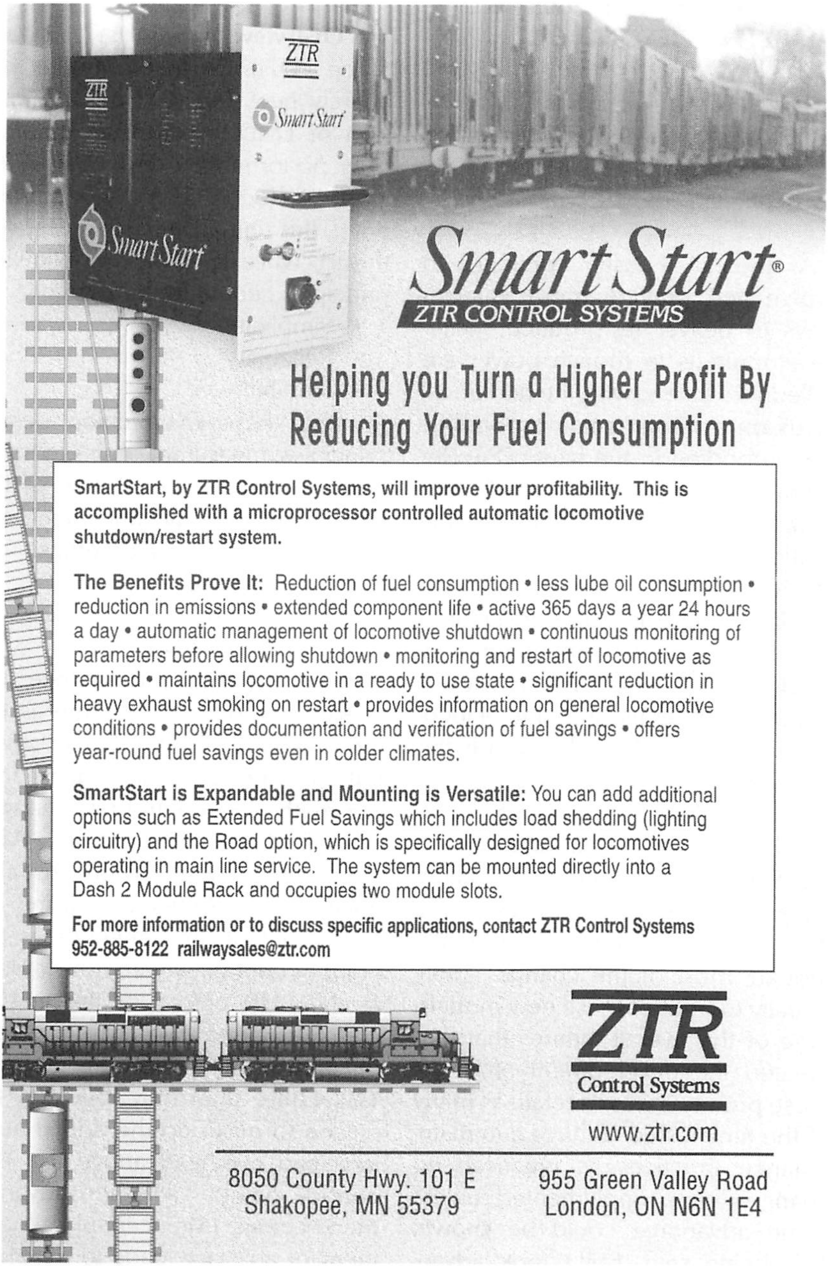
Figure 9



SmartStart®

ZTR CONTROL SYSTEMS

Helping you Turn a Higher Profit By Reducing Your Fuel Consumption

SmartStart, by ZTR Control Systems, will improve your profitability. This is accomplished with a microprocessor controlled automatic locomotive shutdown/restart system.

The Benefits Prove It: Reduction of fuel consumption • less lube oil consumption • reduction in emissions • extended component life • active 365 days a year 24 hours a day • automatic management of locomotive shutdown • continuous monitoring of parameters before allowing shutdown • monitoring and restart of locomotive as required • maintains locomotive in a ready to use state • significant reduction in heavy exhaust smoking on restart • provides information on general locomotive conditions • provides documentation and verification of fuel savings • offers year-round fuel savings even in colder climates.

SmartStart is Expandable and Mounting is Versatile: You can add additional options such as Extended Fuel Savings which includes load shedding (lighting circuitry) and the Road option, which is specifically designed for locomotives operating in main line service. The system can be mounted directly into a Dash 2 Module Rack and occupies two module slots.

For more information or to discuss specific applications, contact ZTR Control Systems
952-885-8122 railwaysales@ztr.com

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955 Green Valley Road
London, ON N6N 1E4

II. EMD SD70ACe LOCOMOTIVE - RELIABILITY FOR 2005 AND BEYOND

Prepared by:
Craig R. Prudian,
Locomotive Systems Engineer
Electro-Motive Division
General Motors Corporation

As the rail industry continues to evolve and provide more efficient ways to deliver its product, similar developments in motive power are called for. Lately, with the additional focus on environmental responsibilities embodied in the latest EPA Tier 2 emission regulations, even further advancements in prime mover utilization are demanded. GM Electro-Motive (EMD) has taken these marketplace inputs as major drivers into the developmental model for new products. As a result, Electro-Motive is proud to offer its latest line of locomotives for 2005 and beyond; the AC traction SD70ACe and the DC version SD70M-2 locomotive.

This paper will focus primarily on the SD70ACe locomotive, to allow for emphasis on the updates to the AC traction system. Generally though, most of the changes apply equally to both of these new models. One of the overall themes that permeated the development phase of these products was to retain as many of the time-tested features and maintenance practices as practical; no changes were implemented unless some advantage could be shown. This being said, EMD took advantage of technological advancements to provide the highest value product possible, both from an initial and a life-cycle cost standpoint.

Overview of major systems

The SD70ACe locomotive is not entirely new, but is a logical extension of EMD's success in locomotives performing today. Using the 70-series locomotive as a starting point, this unit advances the state-of-the-art, while keeping the following principles central to the design:

- Simplicity
- Reliability
- Durability.

Using these overarching design principles, measurable gains in many areas were realized. A few of the more noteworthy advancements are shown in the following metrics:

- Performance
- Crew Comfort
- Maintainability.

Beginning with performance, the rated 4300 THP is the same as the most recent SD70MAC locomotives. But there are some differences: first, our method of control has changed from THP to BHP control. What does this mean? More useable horsepower. Rather than using the NTkW out of the generator as our point of control, we are now looking at the BHP output of the engine. This means that we are now using the engine's full brake horsepower in Th8, rather than only requiring the engine to make up the added auxiliary load overhead above the THP control point. Another advancement comes from careful management of auxiliary loads to minimize parasitic losses due to power needed to run the locomotive itself.

Taken together, these improvements enable the locomotive to provide up to 3% more horsepower at the rail. Similarly, both stall and continuous TE are also positively advantaged.

Crew safety and comfort were also major priorities in development of this model. Over the years, we have continually benefitted from ongoing dialog in the industry that aimed to maximize crew efficiency through ergonomic improvements. With this introduction, we are able to finally implement some of the ideas that were unrealized earlier on-ideas that have been a result of feedback received from customers and other industry experts. Extensive computer modeling of the cab was undertaken (Figure 1), resulting in optimized ergonomics for a full range of operators. EMD focused on a range of operators from the 5th percentile female to the 95th percentile male. Access to controls was maximized, sight lines improved and operating comfort addressed. Taken together, these improvements have been very well received by operators who have had the opportunity to experience this new cab.

Maintainability-wise, this locomotive has been designed to operate for 184 days between periodic inspections. EMD has given special focus to maintainability, using the best design and field experience to provide these exceptionally long maintenance intervals. Maintainability has been improved through implementation of an electrical locker, where most electrical and high voltage equipment is centralized. In addition, there are new on-board tools available that aid in identification of problems, sometimes even prior to a failure. More on these later.

Engine

At the heart of the locomotive is a familiar power plant - the service-proven 16-710 engine, updated specifically to meet the latest emissions regulations. Upgrades of internal components allow for the reduced emissions with no loss of horsepower.

One of the side benefits of the advancements we have made in emission reduction of this engine is a reduction in engine peak firing pressure. Why is this good? There is a demonstrated correlation between peak firing pressure and engine life that shows that, all else remaining equal, the engine with the lower peak firing pressures will last the longest - and EMD has reduced peak firing pressure of this engine 15% compared with pre-tier 0 levels.

In response to the new EPA regulations, lube oil usage has been reduced. This benefit to the environment is a measurable reduction in the total particulate emissions. The only downside is that the lube oil will likely have to be changed somewhat more often than it is today.

What about shop equipment? There should be no need for "EMD shops" to change any of their basic infrastructure. The components are similar, thus the practices will likewise not have to change from those in use in today's EMD shops.

The periodic maintenance interval

goal for this engine is 184 days, in support of our customers' desire to extend maintenance intervals. The major overhaul periods are new to this engine, as well. EMD has designed this engine to operate six years between major overhauls or 28,000 megawatt hours.

Engine support systems

Engine starting differs from the traditional dual electric start motors. An air start system will now be used exclusively. This will eliminate the need to keep the locomotive batteries near a full charge in order to start the unit. A dedicated third air reservoir is purposed solely for air start, so that if main reservoir air is depleting, engine start can still be accomplished.

Automatic engine start stop (AESS) is also part of the new basic package. This EMD designed feature, which complies with AAR Standard S-5502, is a microprocessor-controlled system that will provide automatic shutdown and restart of the locomotive, saving fuel, reducing wear and cutting engine exhaust emissions.

Looking at the long hood, noteworthy is the large radiator bank. The radiator area is greatly increased. Some of the reason for the bigger radiators is not so much cooling, but to reduce engine emissions, as part of this radiator system is devoted to engine aftercooling of the intake air. In addition, the familiar 48" fans have been replaced by larger, more powerful 54" versions. This yields a significant reduction in engine charge-air temperature, and thus lowers emissions to meet the new federal mandates for locomotive engines.

The engine intake air filter is located similarly to older models. Our goal for replacement of this filter was achieved, with a "no tools" method of changeout and easy access.

Brake system

The braking system is a new implementation of microprocessor control: Wabtec FastBrake™. This platform, designed specifically for the rigors of the rail environment, has been developed to be extremely rugged, yet simple to work with, due to the modular nature of its design. The system is designed with a built-in redundancy, which allows for error-free operation even with a local system failure. Functional control has been relocated to the locomotive control computer, obviating the need for a dedicated micro air brake computer. The system has been through a grueling qualification and testing regimen to emerge as EMD's choice for this model line of locomotives. Additional information on Wabtec FastBrake™ is provided by the Diesel Electrical Committee as a separate paper this year. (Editor's Note: Paper not published but presented at convention)

The standard air compressor is a three-cylinder WLN unit, shaft-driven directly from the engine.

Traction systems

One of the biggest changes in the traction system is not a change to the system itself, but a change to its packaging. This model introduces the concept of an electrical locker that houses all electrical control and High Voltage equipment. This locker is designed so that sensitive electrical equipment (including the engine EFI control) is inside a controlled environment, away from the extreme harshness of some of the former locations. This allows for streamlining of maintenance efforts, as all major electrical equipment is in one locker, accessible with enough space for two technicians to work inside.

Most of the AC inverter equipment has been upgraded, compared to previous models. EMD has taken advantage of continually advancing technology to bring one of the simplest and most reliable inverter systems to market. The inverters use the latest IGBT (insulated gate bipolar transistor) design, taking full advantage of the FET-like switching efficiencies of these new semiconductors. The control portion of the former traction converter cabinet (TCC) has been all but eliminated, with all computer control now being resident in the main locomotive control computer, the EM2000. What remains, are the main inverter modules (one per truck) and two interface modules that act as liaison between the brains of the computer and the brawn of the inverters.

The dynamic brake system, now located in the back of the locomotive, has been developed in order to reduce grid blower noise conducted into the cab, and maximize the accessibility of components for ease of maintenance. It has a continuous capacity of 4300 kW.

Electrical systems

The main generator / companion alternator combination used here is designated TA17/CA9. The main generator rectifiers, once mounted in the generator housing, are now located in the electrical locker, where consistent cooling can be ensured. Also, with this change, EMD has been able to eliminate the traction fuses that have traditionally been a maintenance issue.

The companion alternator also has a new twist; it has multiple outputs, each dedicated to specific locomotive auxiliary loads.

The auxiliary generator, long a standard component in EMD locomotives, is now gone. Replacing it is a solid-state auxiliary power converter, located in the electrical locker. This unit is maintenance-free and is driven directly from the companion alternator. It is rated at 30 kW for auxiliary loads, a performance upgrade from earlier 24 kW aux gens.

The EMD standard EM2000 central control computer remains at the heart of the control system. For integration of third-party cab and support electronics, EMD has developed the next generation cab electronics system, known as *Gen 2 FIRE*™ (Functionally Integrated Railroad Electronics). This networked system provides greater processing power, eliminates the reliance on one central computer and accommodates multi-tasking of functions. With the open architecture of *Gen 2 FIRE*™ and the utilization of the AAR LSI standard communications protocol, third party functions can now be integrated **at the software level** into *Gen 2 FIRE™*. This provides all the functionality without the need for separate black boxes, processors and additional connections between systems. This will greatly reduce the repair and maintenance required for these added cab functions.

Trucks

The basic truck arrangement offered for these locomotives is an updated bolsterless design with a minimum number of sliding parts. This serves to minimize routine maintenance and provide long life between overhauls. Of course, a radial truck is still available for those customers who can benefit from the reduction in curving forces and resultant advantage in wheel tracking in tight curves.

Maintainability features

With reference to Figure 2, we consider this latest version of the SD70ACe locomotive a "platform" offering, specifically developed to be the basis for all new high performance mainline models to come. Key to the maintainability of this model is the modular nature of its construction, with removable roof hatches for easy maintenance. In large measure, major maintenance access points for the SD70ACe are much the same as before, with some rather minor variations. Starting from the front of the long hood, we first find the electrical locker, which houses all major electrical equipment. The location of the batteries is now on the engineer's side of the locomotive, next to the electrical locker, directly behind the cab. Behind the electrical locker, are modular compartments with dedicated hatches; the turbo and generator compartments being first. Behind those is the engine area and hatch. The fan and radiator hatch follows, above the equipment rack. The last removable hatch is for the dynamic brake system.

More specific maintenance features for the locomotive are covered in papers prepared by the Diesel Electrical and Diesel Mechanical committees, elsewhere in this book.

Diagnostics and prognostics

One of the features that is now in development, and holds much promise for increasing the life-cycle value of locomotives in service, is the streamlining of the diagnosis of failures, expediting early repairs. Even further enhancements to this concept include the actual anticipation of failures by monitoring selected conditions. In this way, potential failures can be corrected at a time most convenient to the railroad, and in many case will prevent a road failure that would otherwise have impacted operations.

Some examples of prognostic tools are provided below, that are aimed at catching potential failures before they occur. These tools include:

- Fuel filter health monitoring - This system archives fault messages for impending and fully plugged filters,
- Cooling system health monitoring - can provide advance "low water" alert so failures can be

averted with early repairs,
- Power assembly health monitoring - monitors power assembly status individually. Differences in measured output between cylinders can trigger an alert to pending problems.

Testing and validation

The SD70ACe has been extensively tested, and all new components fully validated, prior to introduction. An alpha build of locomotives has been undergoing extensive verification at the TTC in Pueblo since last year. More recently, these units have been on various customers' property demonstrating their capabilities. As well, a pre-production fleet is now delivering and operating in various types of service. By the time these locomotives are officially introduced in 2005, the many gigawatt-hours of qualification will testify to their road-worthiness and suitability for operation.

Conclusion

This information was intended to give the reader a quick overview of the new SD70ACe locomotive, and a new familiarization with an established product line. We have applied our expertise toward making these locomotives the most reliable, most efficient models we have produced to date. EMD's expectations for this model line are high; and we trust that our customers will quickly find that it really does focus on the key success factors that uniquely meet their specific needs. We are looking forward to working with our customers to explore all the possibilities of our latest offerings, as we pull together to keep the rail freight industry a vital part of North American goods transportation.

Cab Arrangement

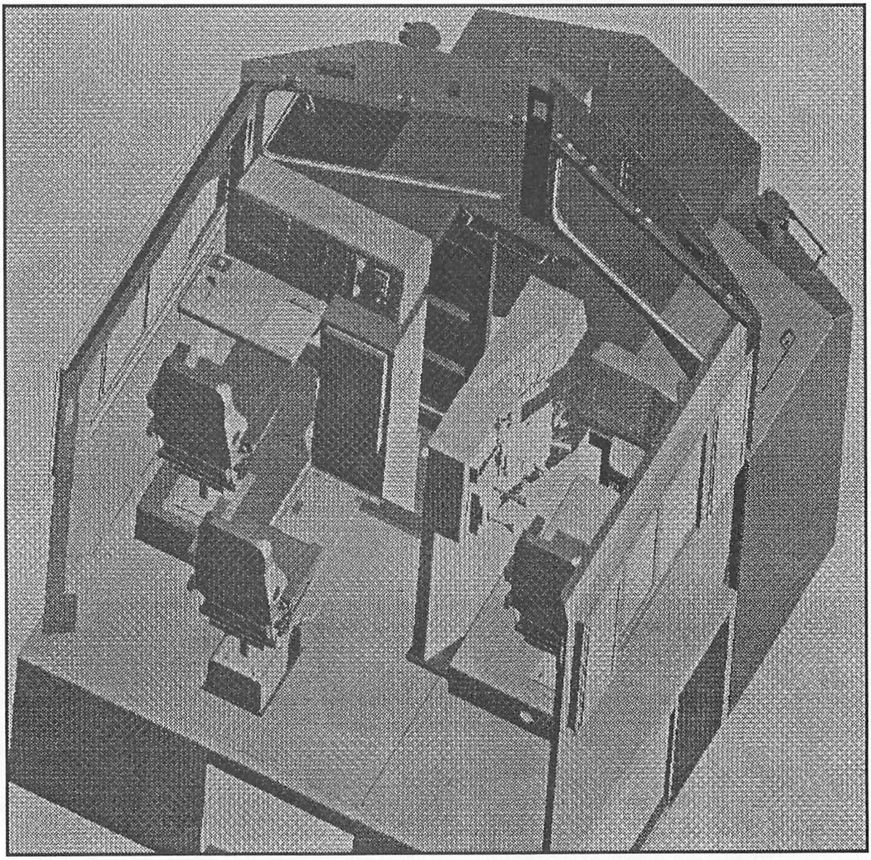
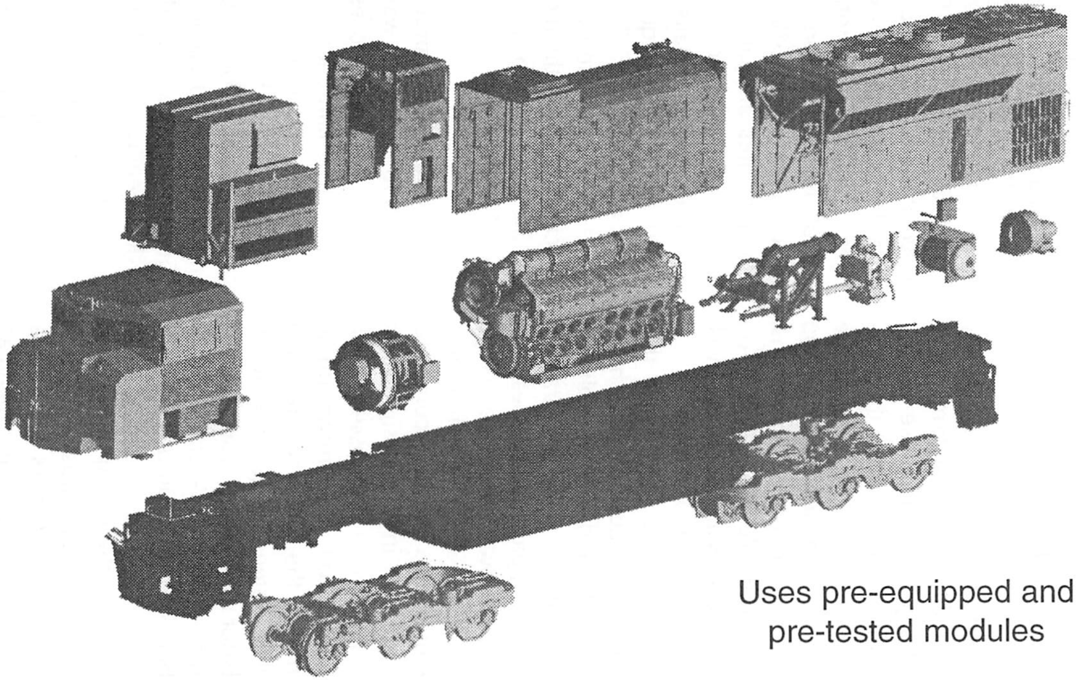


Figure 1

Modular Architecture



Uses pre-equipped and
pre-tested modules

Figure 2

III. GET THEM INTO CONDITION: CONDITION BASED TRACTION MOTOR RELIABILITY

Prepared by:
Jim Christoff / Mike Korf
National Electrical Carbon Products, Inc.

In an effort to improve availability and reliability, many systems have been designed to diagnose operating conditions and predict the likelihood of failure. These systems are being used as the basis for Condition Based Maintenance programs. Some are available as accessories on new locomotives and some are available as retrofits to existing units.

One area of the locomotive that has lagged, because of the harsh environments and the difficulty of implementation, is the DC traction motor. This paper discusses programs, underway, that are aimed directly at the DC traction motor. These programs are not complete. Some are still in the design stage while others have progressed to lab testing and will soon move on to field trials. the DC traction motor reliability system being presented is a collaborative effort, using a components - systems - solution, by members of the locomotive service industry.

To establish the extent of the problem a questionnaire was sent out to a combination of class I railroads, short lines, and equipment manufactures. Eight in all. Based on the results of the questionnaire it was confirmed that traction motor failures are one of the leading costs of failure on locomotive fleets. A running repair will typically cost $1,500 for diagnoses and repair. Shopping the locomotive and replacing the motor will cost an additional $5,500. Add to this $2,400/day for lost availability. What this all adds up to is a failure than can cost a railroad with a fleet of 4000 locomotives, a whopping $7,920,000 annually.

The calculation used (Figure 1) to arrive at the $7,920,00 cost is based on a fleet of 4,000 six axle locomotives. 4,000 locomotives equal 24,000 traction motors. A traction motor failure rate of 5% yields 1,200 motor failures annually. These failures can be further broken down into 180 running repairs (15%) and 1,020 failures that require a motor replacement (85%). The lost availability was calculated at 850 days, anticipating 2/3 of the motors requiring 24 hours to repair and the balance 12 hours.

Maintenance practices

In 1998 a survey was taken by Deloitte and Touch to establish the trend in maintenance practices among US industries. The survey included Steel, Paper, Chemicals, Transportation, Power Generation, and others; 1000 companies in all. The survey was based on work orders generated, and was directed at: What maintenance practice is being used today and where did they expect to be in five years? Maintenance practices were divided into four categories: Reactive, Preventive, Predictive, and Proactive (Figure 2).

As is illustrated in the chart, Figure 3, most of the responders we're using a Reactive Maintenance and moving toward Preventive Maintenance in the next five years. The exception was the benchmark industries that already moved beyond Preventive and onto Predictive and Proactive programs.

The current approach in most industries - preventive, time based, maintenance is not as effective as a fully tailored, predictive, proactive, i.e. condition based, program. Preventive maintenance provides a set of tasks to be completed based on time or schedule. Our research shows that lack of capable maintenance resources coupled with complex tasks and unpredictable asset schedules compounds existing problems. Additionally, the degree of worker skills may introduce other issues during the process. Finally, maintenance and operational procedures are not tailored to the broad range of operating conditions that locomotives experience. The end result is that maintenance is not performed as cost effectively or efficiently as it could be and valuable resources in man hours and materials are not optimized.

Systems exist today that monitor some of the conditions in the DC traction motor. They monitor things like ground relay activity, wheel slip action, and short-time ratings, but they don't tell the whole story.

To better understand and identify the conditions that lead to premature traction motor failures, a diverse group of industry professionals was assembled in Chicago, after last fall's LMOA meeting. The group consisted of railroaders and OEM suppliers with background in the maintenance and design of traction motors. Their task was to break down the traction motor into systems, sub-systems and components and to use the FMEA (Failure Mode and Effect Analysis) process to identify the conditions that, if properly monitored, could be used as the basis for a condition based maintenance program. These experts were asked to break down the traction motor into its sub-systems. Twelve subsystems and four processes/procedures (outside influencers) were flagged as important contributors to overall traction motor health. These subsystems and processes are listed below:

Subsystems-Electrical

- Traction Control
- Commutator
- Brushes/Brush Holders
- Armature Windings
- Main Field/Interpoles
- Cables/Leads/Connectors

Subsystems-Mechanical

- Motor Frame
- Armature Bearings
- Suspension Bearings
- Pinion Gear
- Wheels & Axle
- Forced Air Cooling

Process/Procedures

- Operator Practices
- Track Conditions
- Maintenance Practices
- Lubrication

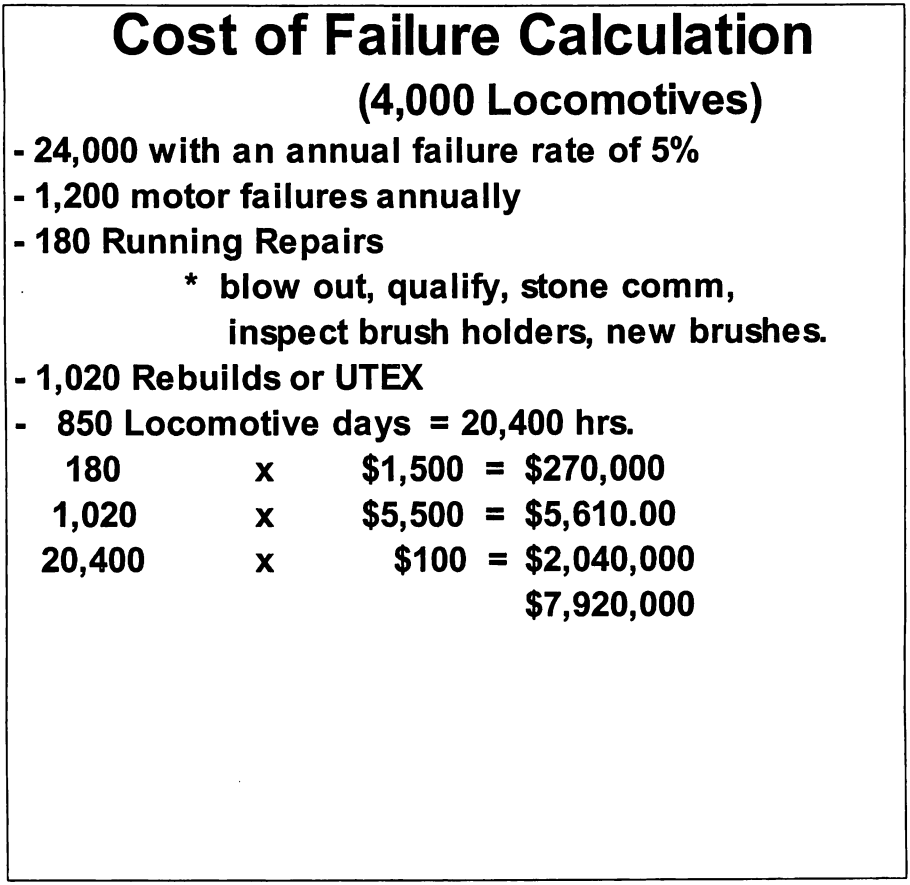
An extensive discussion regarding key critical failures that could occur with each of these subsystems and process/procedures was performed.

At this point in the analysis no concern was given for potential probability or impact of that failure in the subsystem. Every conceivable failure mode was explored. Each expert was then asked individually to rank the specific failure modes for its ability to impact the overall health of the motor. This ranking system ranged from, (5) Severe impact (catastrophic failure) to (1) Low impact (no concern). Additionally, each expert was asked to rank the probability of occurrence. In a similar fashion, (5) indicated a high probability and (1) a low probability. Unlike the overall failure mode discussion that was performed in a group/brainstorming session, the ranking process was performed in an "individual" setting so as to remove any peer influence. The final results were tabulated using a modified delphi probabilistic assessment process. One hundred and nine potential traction motor failure modes were identified. The team identified the top one-third of failure modes as severe and as having high probability of occurrence. An example of these efforts is captured in Figure 4 for the subsystems "brush-brush holders." The failure modes are categorized as Red (severe), Blue (moderate) and Green (low). (Editor's Note: Figure 4 not color coded in publication). For example, (1) commutator out of round was identified as a severe condition while (12) improper brush installation and (7) stall burns were considered moderate. An example of low probability of occurrence would be (8) power mixing or (10) brush holder warpage.

Working toward a solution, the team then focused on identifying non-intrusive predictive maintenance tasks that would identify potential functional failure. A system would be designed to provide the operator/maintenance personnel with credible information that would allow them to pre-empt the functional failure with a potential failure. The non-intrusive tests would have to allow enough time for maintenance personnel or engineers to take corrective action between the 92 day intervals. An example may include the use of a non-contact microwave sensor to monitor brush wear and commutator profile in an on-line fashion, and accelerometers to measure vibration. Acoustics is being explored to predict sparking and preempt potential flashover events. This information, accumulated in a logic box, could be downloaded at the 92 day interval or piped off the locomotive via cellular transmissions.

The data would then be analyzed by engineering departments or outsourced to service providers who would access the motor condition and generate the documentation to support a Condition Based Maintenance Program.

This paper would not have been possible without the technical input from Mike Korf and National Electrical Carbon, who in collaboration with their National Reliability Systems Business Unit, is exploring the identification and potential elimination of over 35 critical failure modes related to a typical traction motor, in its lab in Greenville, SC. A first of its kind monitoring system is being designed in parallel with these efforts. The results of these tests and system are expected in early 2005.



Cost of Failure Calculation

(4,000 Locomotives)

- 24,000 with an annual failure rate of 5%
- 1,200 motor failures annually
- 180 Running Repairs
  - * blow out, qualify, stone comm, inspect brush holders, new brushes.
- 1,020 Rebuilds or UTEX
- 850 Locomotive days = 20,400 hrs.

180 x $1,500 = $270,000
1,020 x $5,500 = $5,610.00
20,400 x $100 = $2,040,000
$7,920,000

Figure 1

Maintenance Categories

- **Reactive**
  - Run to Failure. Allow the component to run until it fails. This approach may be appropriate for low cost items, that do not have a significant impact on operation..
- **Preventive**
  - Interval Based. This approach dictates that maintenance (open and inspects, lubricate, replace seals etc.) is done on some periodic frequency. It is usually based on very conservative MTBF (mean time between failures) rates and can be a costly approach.
- **Predictive**
  - Condition Based. This approach focuses on the conditions (symptoms) that are pre-cursors to functional failure. The approach utilizes non-intrusive techniques (vibration, oil analysis, thermography, ultra-sonics, etc,) to measure and trend parameters that assess the overall health of the equipment. This approach allows the user to pre-empt failure, schedule maintenance, extend the useful life of sub-components and significantly reduce operations and maintenance costs.
- **Proactive**
  - Root Cause Analysis. This approach is an engineering method to logically study various failure modes and understand the root cause for their occurrence. It is a cost saving process that eliminates recurring failures.

Figure 2

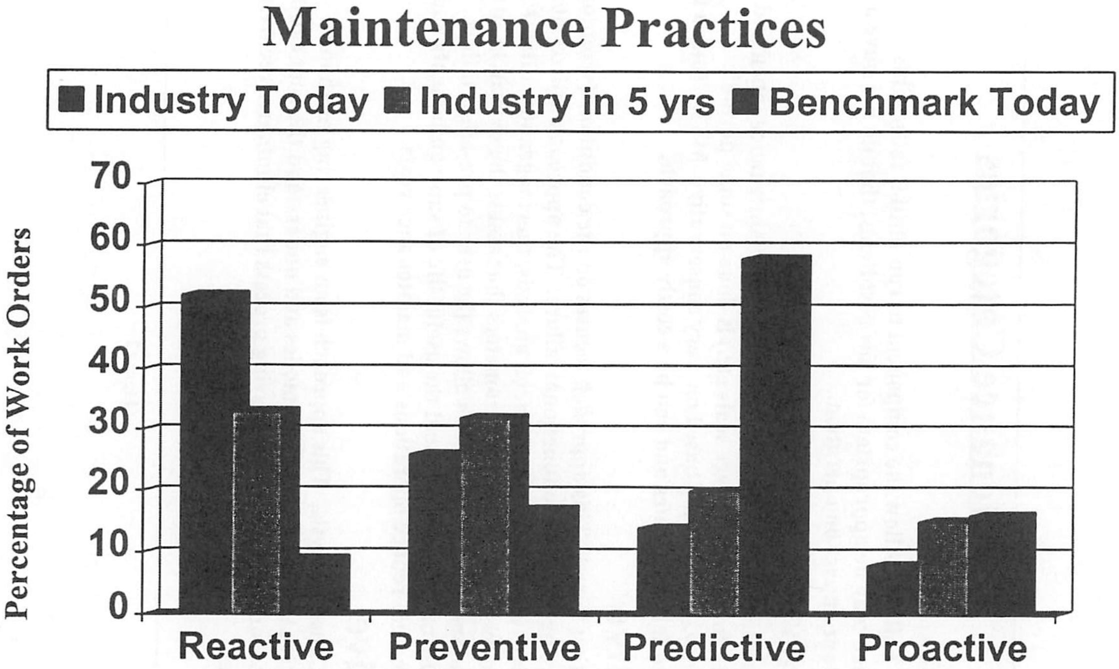
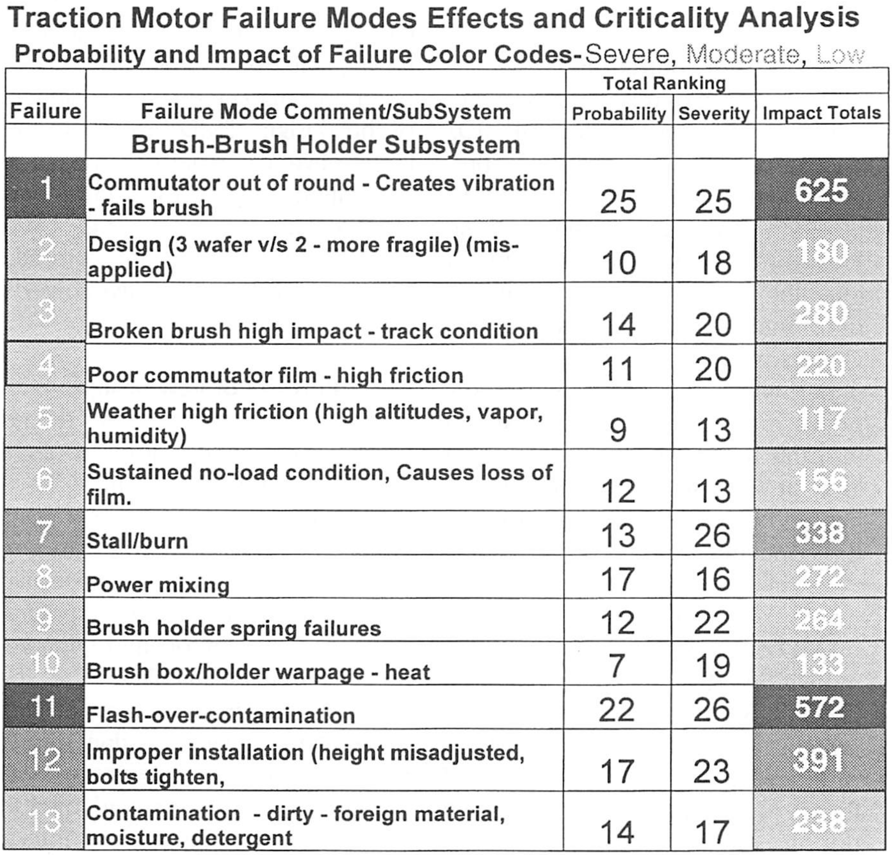

Maintenance Practices
▇ Industry Today
▇ Industry in 5 yrs
▇ Benchmark Today
Percentage of Work Orders
70
60
50
40
30
20
10
0
Reactive
Preventive
Predictive
Proactive

Figure 3



Traction Motor Failure Modes Effects and Criticality Analysis

Probability and Impact of Failure Color Codes- Severe, Moderate, Low

		Total Ranking		
Failure	Failure Mode Comment/SubSystem	Probability	Severity	Impact Totals
	Brush-Brush Holder Subsystem			
1	Commutator out of round - Creates vibration - fails brush	25	25	625
2	Design (3 wafer v/s 2 - more fragile) (mis-applied)	10	18	180
3	Broken brush high impact - track condition	14	20	280
4	Poor commutator film - high friction	11	20	220
5	Weather high friction (high altitudes, vapor, humidity)	9	13	117
6	Sustained no-load condition, Causes loss of film.	12	13	156
7	Stall/burn	13	26	338
8	Power mixing	17	16	272
9	Brush holder spring failures	12	22	264
10	Brush box/holder warpage - heat	7	19	133
11	Flash-over-contamination	22	26	572
12	Improper installation (height misadjusted, bolts tighten,	17	23	391
13	Contamination - dirty - foreign material, moisture, detergent	14	17	238

Figure 4

IV. MAKING THE SWITCH
An Update on the EMD GP20D/GP15D Switcher Locomotive

Prepared by:
Richard A. Dalton, Director,
Operations & Maintenance Projects,
MotivePower Inc.,
A Wabtec Company

Introduction

The purpose of this paper is to provide an update for the EMD GP20D/GP15D switcher locomotive program, first introduced to the LMOA in 1999. The paper given by Craig Prudian, EMD, gave us our first look into the unique design elements, performance expectations and preventive maintenance nuances. This paper will recap some of the key points made previously and expand into the present to include taking a look at whether or not the design has actually met the goals set forth in the conceptual design phase.

History

EMD offered its first switcher locomotive in 1936. Since that time EMD has produced over 8,000 switcher locomotives for the North American market. The majority of these locomotives were delivered during the 1950's through the 1970's. The majority of these locomotives continue to operate today.

Since the early 1980's there have been no substantial deliveries of switcher locomotives in North America. The industry appeared saturated with switcher locomotives. Older road locomotives were cascaded down to hauling and switcher service. Existing switcher locomotives were receiving periodic overhauls to extend their service life giving the impression that switchers have an infinite life.

In the late 1990's EMD collaborated with MotivePower, Inc. (formerly Boise Locomotive) and Caterpillar to jointly develop the EMD GP20D and GP15D model locomotives. Motive Power, Inc. had previously developed and marketed the forerunners of this design. EMD brought to the locomotive its expertise in system integration, locomotive control and mechanical design. The EMD switcher locomotives are currently manufactured at MotivePower's Boise, Idaho facility.

Purpose of new design

The purpose for the new design was to package several of the technological advances that have occurred over the past several years into a common locomotive platform. Microprocessor controls, electronic fuel injection, enhanced structural designs, crew comfort and improvements for maintainability were key concepts that drove the new design. In addition, several existing design features used on previous EMD model locomotives were adapted to this design. Traction motors, trucks, cooling systems and electrical components and their arrangement are common with other EMD model locomotives.

GP20D LOCOMOTIVE SPECIFICATIONS

Item	**Specification**
Model Designation	GP20D
Locomotive Type	
AAR Designation	B-B
Industry Designation	0440
Locomotive Traction Horsepower	2,000
Locomotive Brake Horsepower	2,250
Propulsion Engine	
Model	GM16V170B20
Aspiration	Turbocharged-Aftercooler
Number of Cylinders	16
Cylinder Arrangement	60 degree "V"
Cylinder Bore and Stroke	6.7" x 7.5"
Rated Speed	1,800 RPM
Idle Speed	700 RPM
Rotation (Facing Flywheel End)	Counterclockwise
Fuel System	
Type of Fuel	Diesel
Total Fuel Capacity	2,550 gallons
Traction Alternator	
Model	KATO 8P6.5-2250
Type	Slip Ring
Number of Poles	8
Rating	1,250 VDC
Continuous Current	3,200 Amps
Intermittent Current	4,500 Amps
Excitation	SCR Bridge
Drive	Direct Coupled to Engine
Bearing	Two bearing; ball type
Ventilation	Internal Direct Drive
Companion Alternator (AC)	
Model	KATO 8P5-0875
Type	Slip Ring
Number of Poles	8
Voltage (AC) rating	440/200 VAC, 3-phase
Frequency	46-120 Hz
Power Rating	156 KVA - 220 VAC
Excitation	Main field provided by 74 VDC
Drive	Direct Coupled to Engine
Auxiliary Power Converter	
Model	Lockheed Martin 89954-114E6240G1
Input Power	Variable (72.2 VAC to 244.5 VAC)
Output (Regulated	72 to 78 VDC
Power Rating	31 kw
Excitation	Exciter field controlled by regulator

Traction Motors	
Model	D87
Type	DC, Series Wound
Number	4
Current Rating	Refer to chart below

Continuous and Starting Traction Motor Rating

Rating	Amperes Per Traction Motor	Speed (mph)	Total Locomotive Tractive Effort (lbs.)
Continuous	1,205	9.3	64,700
Starting	1500	Starting	97,000
Maximum Locomotive Speed		70	

Ventilation	External Blower
Bearing	Roller-type armature
Brush holder	Three, brush type
Driving Wheels	
Number	4 pair
Diameter (41″ New)	40″
Speed Limitations with Gear Ration (70:17)	
Maximum Speed	70 mph
Overspeed Set At	72 mph
Curve Negotiation Capability	
Minimum Curve Radius Coupled to Car=>150′ (39 degrees)	
Coupled to Another Locomotive of the Same Type with “E” Coupler=>274′(21 degrees)	
Nominal Dimensions	
Length coupler to coupler	57′ 2″
Length between bolster centers	32′ 0″
Coupler face to truck centerline	12′ 7″
Width over cab sheeting	10′ 1/8″
Height, cab roof to top of rail	15′ 1″
Truck wheel base	9′ 0″
Weights and Capacities	
Loaded nominal weight	260,000 lb.
Sand	41 cu. ft.
Cooling Water	120 gallons
Lubricating Oil	170 gallons
Air Brakes	26L double shoe/wheel

Air Compressor	
Type	2-stage WLN
Number of Cylinders	3
Capacity @ 900 RPM	254 cu. ft./min.
Air Compressor Cooling	Engine Coolant
Lube Oil Capacity	10-1/2 gallons
Reservoir Pressure	140 psi
Air Compressor Motor	KATO 16P2-0900
Type	Induction
Voltage	100 to 400 VAC
Phase	3
Current	Full Load 143 Amperes
Horsepower	55
Frequency	40-120 Hz
RPM	247-900
Storage Battery	
Number of Cells	2 - 32 cell (unitized) batteries
Voltage	64 VDC
Rating (8 Hour)	500 amp. Hr.
Coupler Type	E
Draft Gear	NC390
Toilet	Microphor 94200 LF/510

From paper to reality

Starting in late 1999, a team of engineers and manufacturing specialists from EMD and MotivePower, Inc. integrated the V 170 engine, microprocessor control system, electrical systems, rotating electrical and structural elements into the new locomotive platform. The initial production of fifty switchers (10 GP15D & 40 GP20D) allowed the concept to become reality. Numerous process techniques combined with additional design improvements were developed to further enhance expectations. The major components were built, and the locomotive assembled, utilizing the latest in modular process technology. Once the first locomotives rolled off the production line a series of post production tests and trials took place.

A select number of locomotives went to TTCI in Pueblo, Colorado, for a barrage of tests and trials that included ride quality and general performance testing. In addition, EMD performed emissions testing and certification for both locomotive models. From there the locomotives embarked on a series of application tests where the locomotives were demonstrated on several railroads for periods of 30-60 days in local and switching service. The railroads that took part in this phase of testing and demonstration were:

1) Pacific Harbor Line
2) Union Pacific Railroad in Roseville, CA
3) Canadian Pacific in the Minneapolis/St. Paul area
4) Chicago South Shore
5) CSX: Indianapolis and Atlanta and later in Florida
6) BNSF: Fort Worth-Temple-Houston-Saginaw
7) Vermont Railroad
8) BNSF: Alliance, NE

In June of 2003, ten of the new EMD switcher locomotives made their way onto the Union Pacific Railroad in Houston, Texas. In August of the same year the remaining forty (40) initial production locomotives were placed into service in the Houston area where they continue to operate in local and switching service.

Expectations

The expectations when introducing the new design were primarily to enhance previous models with the integration of new technology. The key expectations for the new design were as follows:

1) Enhance operating safety
2) Meet current emissions requirements and improve fuel consumption rates
3) Improve performance
4) Increase reliability
5) Improve crew comfort
6) Enhance ride quality
7) Improve maintainability - reduce maintenance costs and cycle times

These expectations were partly influenced by customer feedback and new regulatory requirements.

Has the new design met the goal?

To date, several thousand operating hours have been accumulated. Based on the initial list of expectations and initial design criteria this was a good time to get some indication of whether or not the new design has met the goal. A majority of the feedback for this section has come directly from the railroads that tested, demonstrated or are currently utilizing these locomotives.

A. Enhance operating safety:
  a. A full 360 degree view from inside the cab has enabled the operator to improve visual sight with the external work area.
  b. From the engineer's seat, the distance to the front switching step was reduced approximately ten (10) feet from previous locomotive models operated in local haul service. This has improved visual contact with the operator's external work area.
  c. The fuel tank meets the latest AAR recommended practices (RP 506) for fuel tank design and construction for strength. Although the strength of this design has not been tested in normal operation (no catastrophic incidents to date) the strength of the fuel tank provides a heightened level of comfort for operating crews.
  d. Collision posts and anti-climbers are stronger.
  e. Internal and external noise levels are lower as compared to previous generations of


2004
2004

switcher locomotives.

B. Meet current emissions requirements and improved fuel consumption rates:
   a. Certified by EMD to meet latest EPA emissions requirements (currently meets Tier I EPA emissions standards and will meet Tier II for 2005).
   b. Test cell data show improved fuel consumption rates of 10-15% over previous generations of switcher locomotives; reports from the field have indicated reductions in fuel consumption, in some cases, of 17% or better.

C. Improve performance:
   a. The EM2000 microprocessor controls have improved adhesion by 30-40% in most cases. In some cases, this improved adhesion has resulted in such efficiencies as unit reduction.
   b. The dynamic braking system (GP20D models only) has increased versatility and improved locomotive utilization. Some roads have used these locomotives in switching service one day and for local hauling jobs the next.
   c. The GP15D and GP20D are equipped with a dual road or switcher operating mode selector switch. This enables operators to increase engine speed thus enabling locomotive power to develop quicker for "kicking" cars (switch mode) or the operator can choose the normal (road mode) selection for normal hauling jobs. This has enabled roads to maximize utilization of these locomotives by adjusting assignments to varying demand.

D. Improve reliability:
   a. Fewer electrical relays and components due to the integration of the EM2000 microprocessor system has improved reliability (decrease in component failures).
   b. There has been a decrease in the cycle time for repairs (troubleshooting) due to the diagnostic capabilities that come with the microprocessor system.
   c. Familiarization with the EM2000 is seen as a benefit to some railroads...they do not have to retrain their people if they are already familiar with this system, which also decreases the cycle time for maintenance, troubleshooting and repairs.

E. Enhance crew comfort:
   a. Air conditioning appears to be the big winner in comments about improved crew comfort. These locomotives are equipped with an optional heating, ventilation and air conditioning (HVAC) system.
   b. The isolated skid assembly (previously mentioned under the maintenance topic) is also noticed by the operating crews. Crews do not experience engine vibration in the cab and many say this helps reduce crew fatigue.

F. Improve ride quality:
  a. Has met, as tested at TTCI, Chapter 11 ride quality criteria.
  b. Operating crews report improved ride quality over previous generations of switcher locomotives.

G. Improve maintainability - reduce maintenance costs and cycle times:
  a. No special tooling required for periodic maintenance requirements.
  b. No air box cleaning and inspections required. Scheduled oil sampling (S.O.S.) programs are being implemented to determine the internal health of the engine.
  c. No auxiliary generators brushes to maintain/replace due to the integration of the maintenance-free auxiliary power unit (APU).
  d. No fuel pump motor brushes to maintain/replace because the fuel pump is directly coupled to the engine via the lube oil pump.
  e. The engine and main alternator is mounted on a rubber isolated skid assembly. This reduces the vibration resonating from the locomotive frame thus increasing component life.
  f. The cycle time for periodic maintenance has been reduced, in some cases, by 20%.
  g. Traction motor brush life has been extended due to the protection features integrated in the microprocessor system.

Summary

The technological advancements of the past two decades have prompted locomotive builders to design and integrate better and more efficient locomotive systems and subsystems using new or existing locomotive platform designs. Even though the switcher locomotive product line has appeared to lag behind in technological advances in the past, this is not the case in the present and foreseeable future. EMD has integrated the latest in engine, performance controls, structural and rotating electrical technology into its switcher locomotive product line to answer the call for more efficient switching and hauling operations. With the introduction of stricter emissions requirements, the call for safety enhancements, the need for fuel efficient engines and better overall locomotive performance, the EMD switcher product line satisfies this requirement.

Some railroad operations are not ready to make the leap into the newer technology simply because their existing equipment meets their current needs. For those railroad operations experiencing growth and/or can justify the newer technology "to make the switch," the new EMD switcher model appears to be a solid solution. Stay tuned!

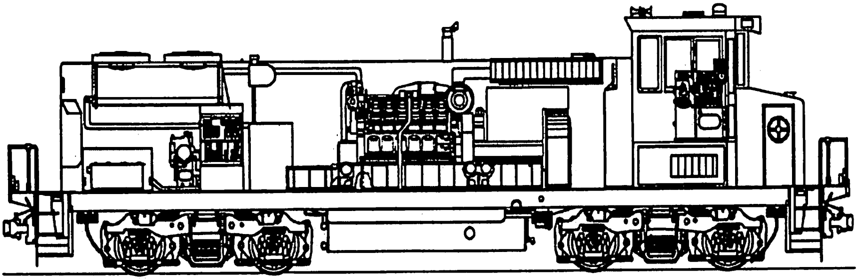
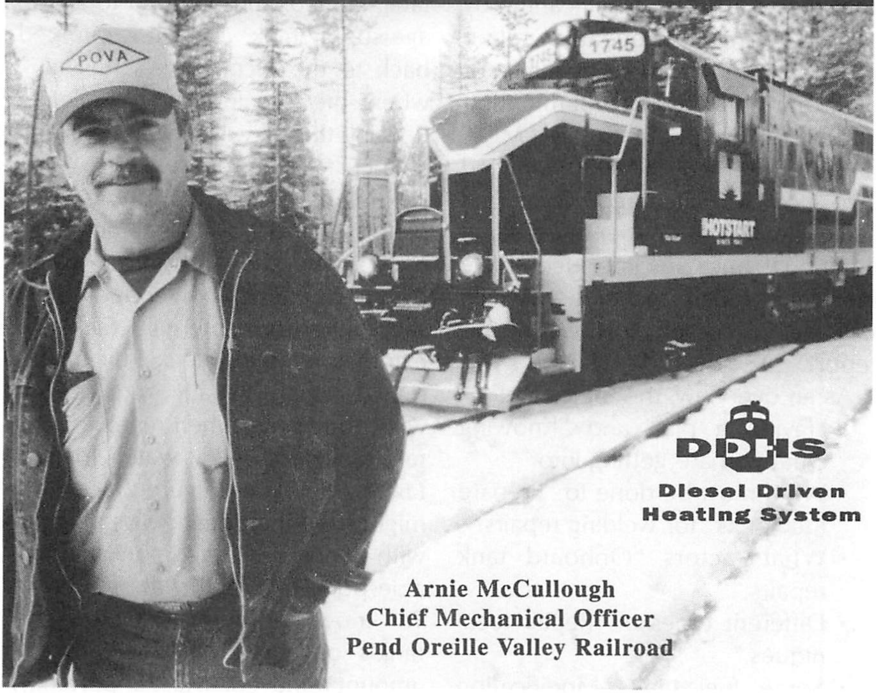


Figure 1: EMD Switcher Side View - GP15D Model



V. "FUEL PROOF TANK REPAIRS" A BEST PRACTICE FOR YOUR LOCOMOTIVES

Prepared by: R. B. Queen,
Mech. Supvr. - BNSF Railway

When performing fuel tank repairs, what is the best way or "Best Practice?" Sometimes other processes may prove to be quicker, however; eliminating a step or two can increase risks significantly by either having to repeat a repair process; or much worse, an injury, or environmental contamination occurs. An update to an LMOA paper presented in 2000, entitled "Do Not Get "$teamed" Over Fuel Tank Repairs," this paper offers some additional best practice locomotive fuel tank repair techniques which will be discussed further in this report.

As an overview, the topics are:

- Having a plan and "Knowing what you are getting into."
- What must be done to "Prepare fuel tanks" for welding repairs?
- What factors "Onboard tank repairs."
- Different types of "Repair techniques."
- Some fuel tank "Modification recommendations."
- A few of those "Simple fixes" that can be made.
- What to look for on "Outsourced tank repairs."

First, know what you are going to accomplish by planning a strategy before the locomotive arrives at the repair facility. Using a digital camera for e-mail pictorial information to the personnel involved with the repairs will allow extra time for fabricating parts, and determining if the fuel tank could be repaired on or off the locomotive.

In addition, a location is needed for de-fueling, capable of spill containment, along with a continuous supply of steam. At the particular station, shown in Figure 1, the fuel is drained from the locomotive's fuel tank, filtered, and pumped to a storage supply tank. Later it is pumped back to the locomotive's fuel tank when the repairs are completed. Reusing this oil will allow a considerable cost saving.

Next, make sure the tank is completely drained. This includes internally mounted retention tanks (Figure 2, middle), which fuel could seep into from internal cracks, or external retention tanks (Figure 2, right), which usually require hot work to remove when removing the fuel tank too. Also, watch for fuel tank baffle plates (Figure 2, left) that might have their drain ways plugged with debris; resulting in an un-drainable pocket of fuel in the fuel tank. To know for sure, compare the tank's original fuel level with the amount removed. Most importantly, pay close attention to exceptionally clean areas on a really dirty fuel tank. This is usually an indication of a leak, which must be marked before the fuel tank is washed. This will allow for further testing during the initial repair process of that area.

When preparing a fuel tank for hot work, using an inert gas to remove oxygen from the combustion fire triangle formula (Figure 3) is an option for small fuel tank repairs.

This paper offers steam as the "Best Practice" for extensive tank repairs. High temperature steam is required to completely remove the explosive elements from the fuel tank, which allows for an absolutely safe welding environment. The key is to ensure that all drain plugs are removed from the fuel tank, which then permits steam to flow freely through the tank and remove the flammable gases. Also, with the tank drains open and by using high temperature steam, the possibility for the fuel tank to rust is considerably reduced. Furthermore, be sure to remember that condensed steam from the fuel tank drains must be directed to some type of water treatment plant operation for processing.

When preparing for fuel tank repairs, ensure that the tank is properly steamed for a minimum of eight hours. Additionally, be sure that a date and time the fuel tank is placed on and off steam is written on the tank. This will allow the person welding, to determine if the tank has been fully steamed. Washing the fuel tank's exterior before removal is recommended, especially on the ends to simplify removal of the mounting bolts (Figure 4) and reducing flying debris.

Upon completion of the previous recommendations, an OHSA certified O_2 (oxygen) meter (or sniffer) is used to determine if the tank is safe to begin hot work. Figure 5 shows an Industrial Scientific model SP402. For a steamed tank, the LEL (lower explosive limit) reading on the meter must not fall below 10% or exceed 20%. Also, notice that even though this tank in Figure 5 is cut wide open, the presence of possible flammable gasses is still continuously monitored as a best practice.

What determines the removal of a fuel tank, or onboard tank repairs, depend mostly the extent of damage and to ease in the hanging of metal while applying patch pieces to lay flat. Figure 6 represents a GE CW-4400 Dash-9 locomotive with an integral fuel tank. The tank is part of the locomotive underframe, eliminating the tank removal option.

Sideswipe damage repairs (Figure 7) can be made on an open inspection pit, although, a draw back to this particular repair resulted in holding up the normal daily pit inspection traffic. Also, do not forget to repair the interior tank baffles.

Baffle plate repairs are time consuming, but as shown in (Figure 8), unforeseen internal damage can exist. Tank baffles not only provide additional tank structural support, but serve an even more important purpose by slowing the pressure of fuel sloshing back and forth inside the tank. A fuel tank with improper or inadequate baffle placement can result in progressively loose fuel tank mounting bolts or tank mounting pads that form stress cracks which lead to fuel leaks.

Corner repairs, such as (Figure 9), can be easily performed on the locomotive. Notice how the fuel tank's bottom skin is replaced first, and then the end plate is tacked on. The next step would be to weld the side skin to the end plate. The end plate is then trimmed leaving an extra 3/4 inch tall edge using a plasma cutter. This will allow additional strength needed in the corner area of the tank. Note this tank was removed from the locomotive for other repairs.

There are many repair techniques for welding locomotive fuel tanks. Though some are not as good as others, such as butt welding (Figure 10, left), mostly because it is not a very strong repair and also it is the hardest to weld without having pin hole leaks. An alternative to the butt weld although still not as desirable, is the scab over patch (Figure 10, right). This repair is done by welding a patch that overlaps the damaged area of the fuel tank by 3/4 of an inch on all sides. Using this technique of fabricating a patch that overlaps the fuel tank's leak allows additional surface area for a stronger weld. Although this technique will resist stress cracks and minimize pinhole leaks, there is a drawback to the unprofessional or unfinished appearance.

A better repair technique or best practice, but the most time consuming, is back plate welding (Figure 11). A 3/16-inch thick by a 1 1/2-inch wide back plate is used behind the hole and the patch (Figure 11 arrow 1). First, the back plate is welded in place on all sides on the tank (Figure 11 arrow 2). Then the patch is applied leaving a 3/8-inch space between the patch and the tank edge. The Patch is then welded to the backing plate (Figure 11 arrow 3). Lastly, the two welds joining the new patch and the tank to the backing plate are welded together (Figure 11 arrow 4). Although time consuming, this repair usually will not have to be re-welded for pin leaks, is very sturdy, and leaves a professional finish that also requires little grinding.

Depending on the location of a crack in a fuel tank (Figure 12), it can be accomplished by simply drilling stress-relieving holes on each end of the crack; then by scarfing, or making a "V", in the crack to run the new weld bead. If cracks are noticed around the tank mounting pads, this repair will not last. In addition, a crack in this area may only leak from the weight of a fully fueled tank, and is almost impossible to detect empty. The key is to cut out the crack and inspect for probable causes such as improper baffle plate placement or inadequate metal thickness, especially if the crack is close to a main structural area of the fuel tank.

The key when testing fuel tanks for leaks is to test and then test again. The best practice for fuel tank leakage testing is to completely seal all holes. Then, using compressed air, a regulator with a shut off valve, and a pressure gauge; apply a minimum of 2 psi to the tank. When the desired pressure is achieved, shut the air supply valve. Now with a spray bottle of soapy water, you can test for leaks. If you cannot find any leaks and the pressure gauge maintains above 1 psi for five minutes, then the fuel tank is ready for use.

A few fuel tank modification recommendations that may be helpful are first, the fuel tank mounting pad reinforcements made on GE Dash-8 locomotives (Figure 13). The only positive repair for this was to increase the thickness of metal on the fuel tank area where the mounting pads are located. Remember that these mounting brackets are supporting an average of 3000-4000 gallons of diesel fuel, which can average to approximately 21,000-28,000 pounds.

Removal of an EMD GP-30's fuel tank is time consuming. Upon closer inspection (Figure 14) it was determined that the long fuel filler necks were rubbing on the locomotive's frame and causing the filler necks to loosen, allowing fuel to leak only when the tank was completely topped off. The fix here was to egg out the locomotive's frame for the fill neck and apply a new fill neck made out of thicker schedule 40 pipe. This repair can be performed in about four hours or less.

A less common fix is fuel tank peening (Figure 15). The criterion for using this repair method is a very small fuel leak that is not associated with a structural area of the fuel tank. Peening is accomplished by peening metal over until it seals using a metal punch or a pneumatic needle gun. This repair does not require draining the fuel tank and can be performed in a few hours at almost any location where the locomotive can be properly blue flagged.

There are many different types of epoxy on the market for small temporary fuel tank leak repairs, but stopping the leak long enough for the epoxy to set up is frustrating. A technique of using a bar of soap to rub into the crack with stop the seepage just long enough to allow the epoxy enough time to cure.

Another simple fix is to have a spare fuel tank for your most common locomotives ready for application. When the tank is needed, just drain the damaged tank; apply the fresh tank and go. The damaged tank can be steamed and repaired at your schedule. The turnaround for this process is from four to eight hours depending on the type of locomotive and shop load.

A fuel tank repair time chart (Figure 16) lists the different repairs discussed in this paper. A break down of time for each respective repair step is given with the total labor hours required for the repair. Since fuel tank material can easily be fabricated, the expense to repair fuel tanks are really not very high except that it usually takes longer to move the locomotive to a repair facility and into the shop than it does to actually make the fuel tank repairs.

Another option for fuel tank repairs is outscoring. When outscoring fuel tank repairs, require standards. Cost savings such as tank mounting pads not properly reinforced will simply not last and you cannot see inside a tank to inspect for proper baffle placement. The effects of these oversights may not be known until months later down the road. As shown in (Figure 17), the fuel tank mounting bracket appears to be fine; but when this tank was applied to a locomotive, it was discovered that all the mounting holes were off by 3/4 of an inch which required additional unplanned rework. The key is to require the vendor to provide documented repair and testing records before accepting delivery.

In summary, look for the "Best Practice." There are many other ways to repair fuel tanks but, the "what if?" question must be asked to ensure a safe and efficient fuel tank repair that will last.

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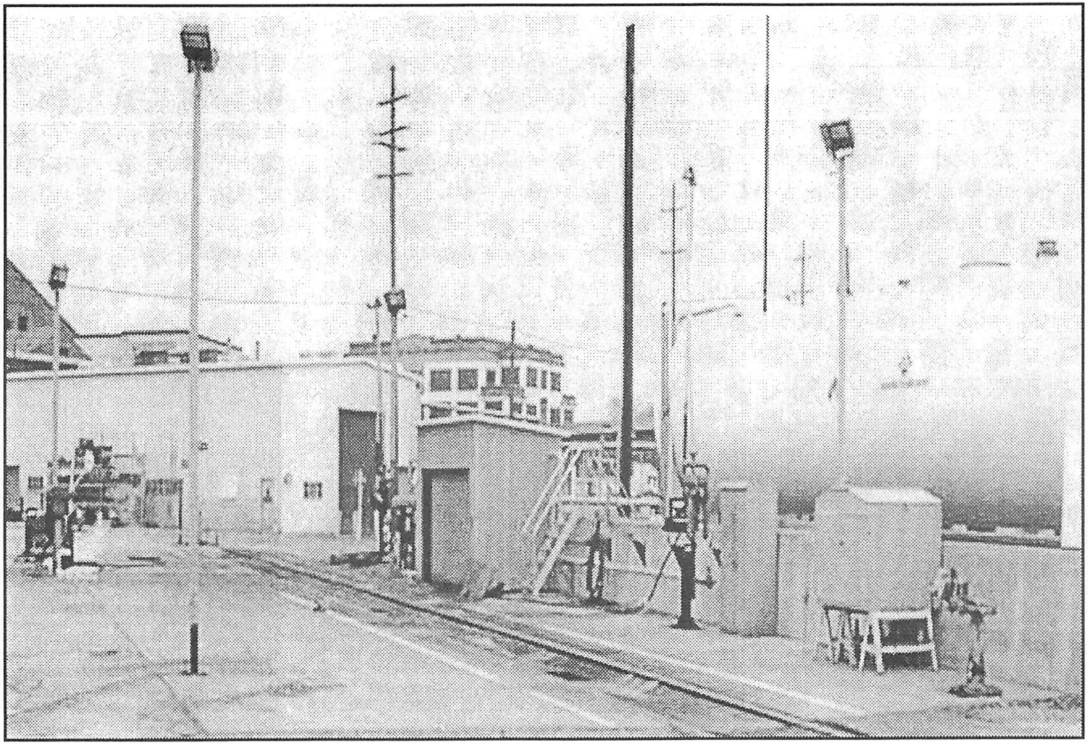


Figure 1

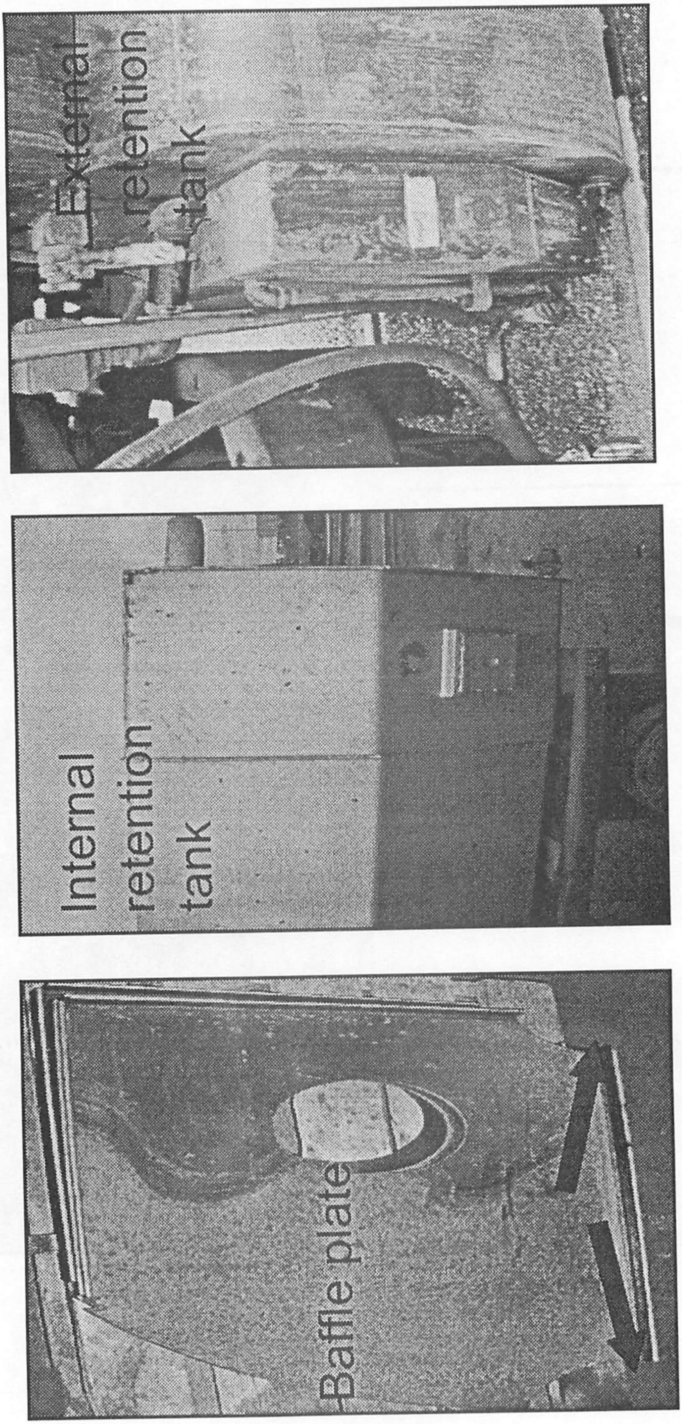
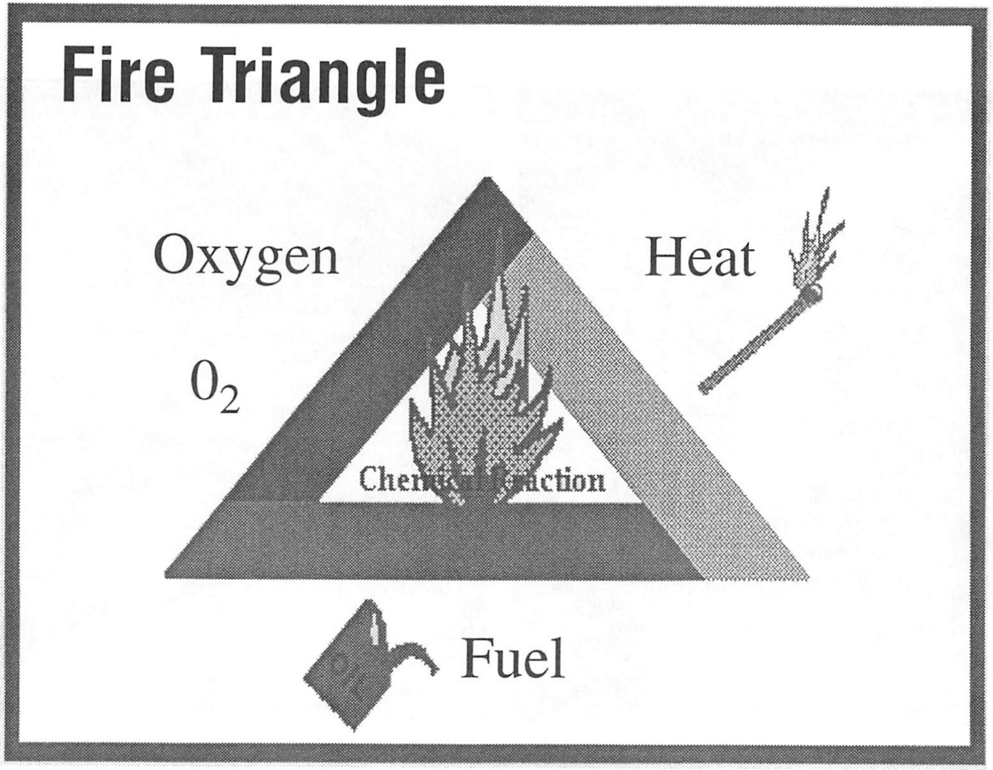

External retention tank
Internal retention tank
Baffle plate

Figure 2



Fire Triangle

Oxygen

0_2

Heat

Chem [illegible] action

Fuel

Figure 3

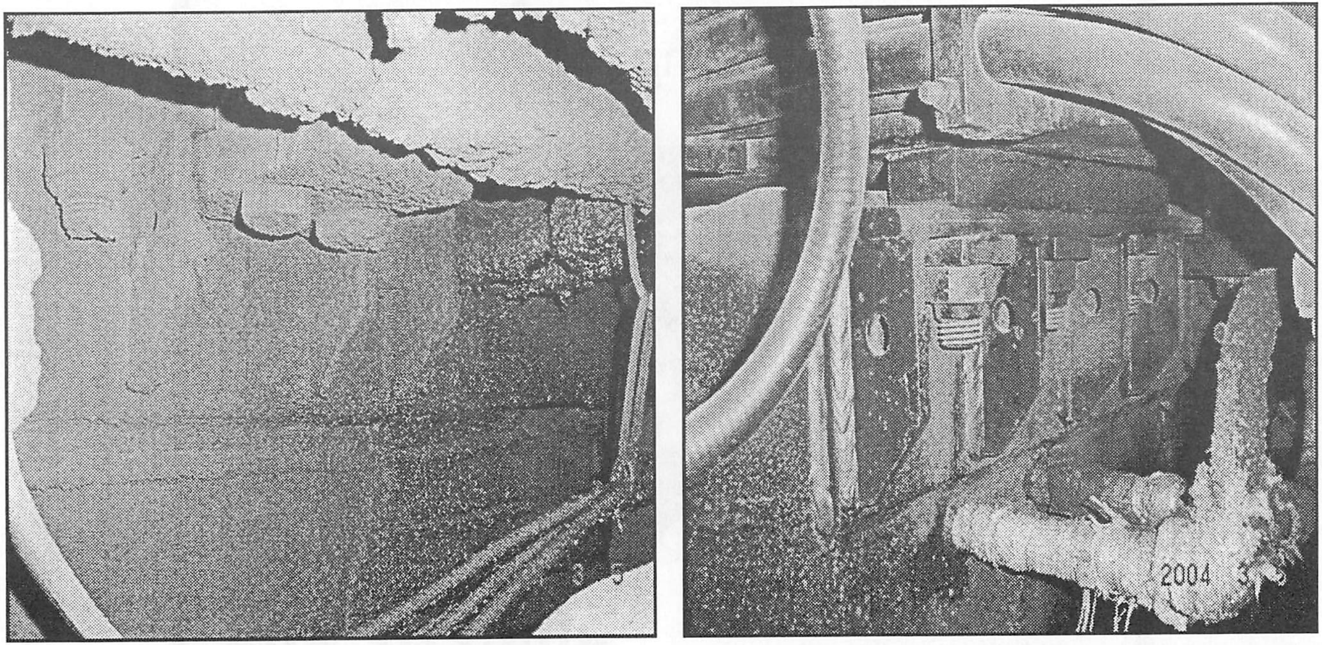


Figure 4

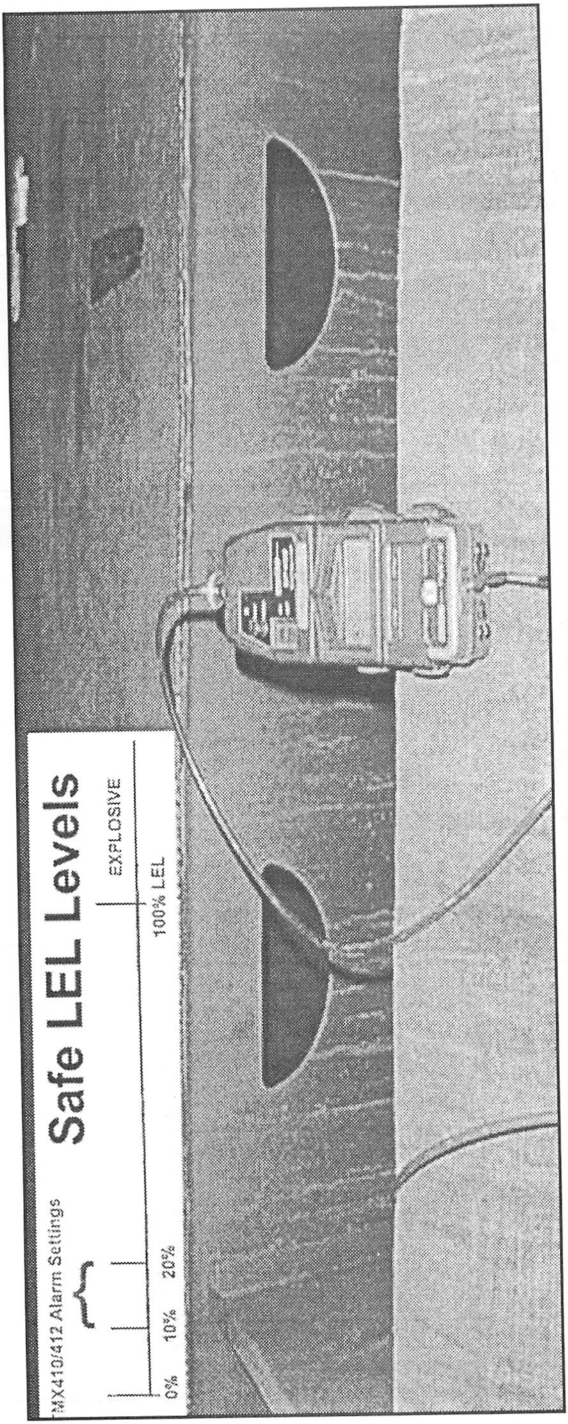

Safe LEL Levels
MX410/412 Alarm Settings
0%
10%
20%
100% LEL
EXPLOSIVE

Figure 5

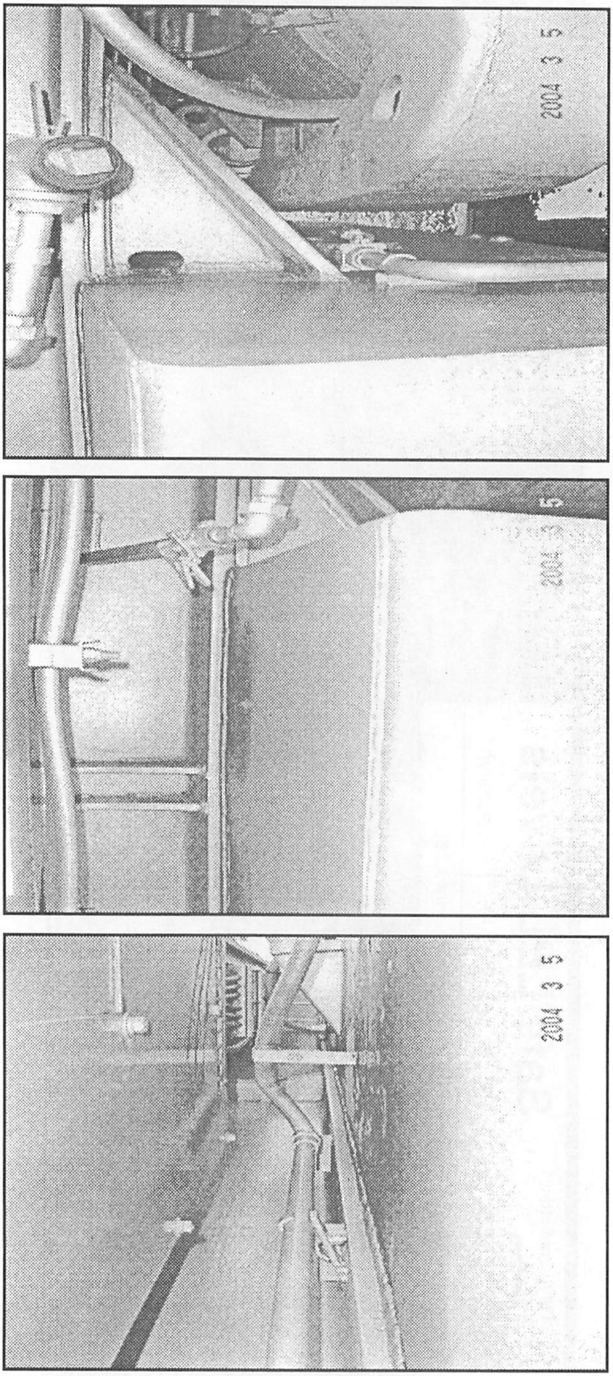


Figure 6

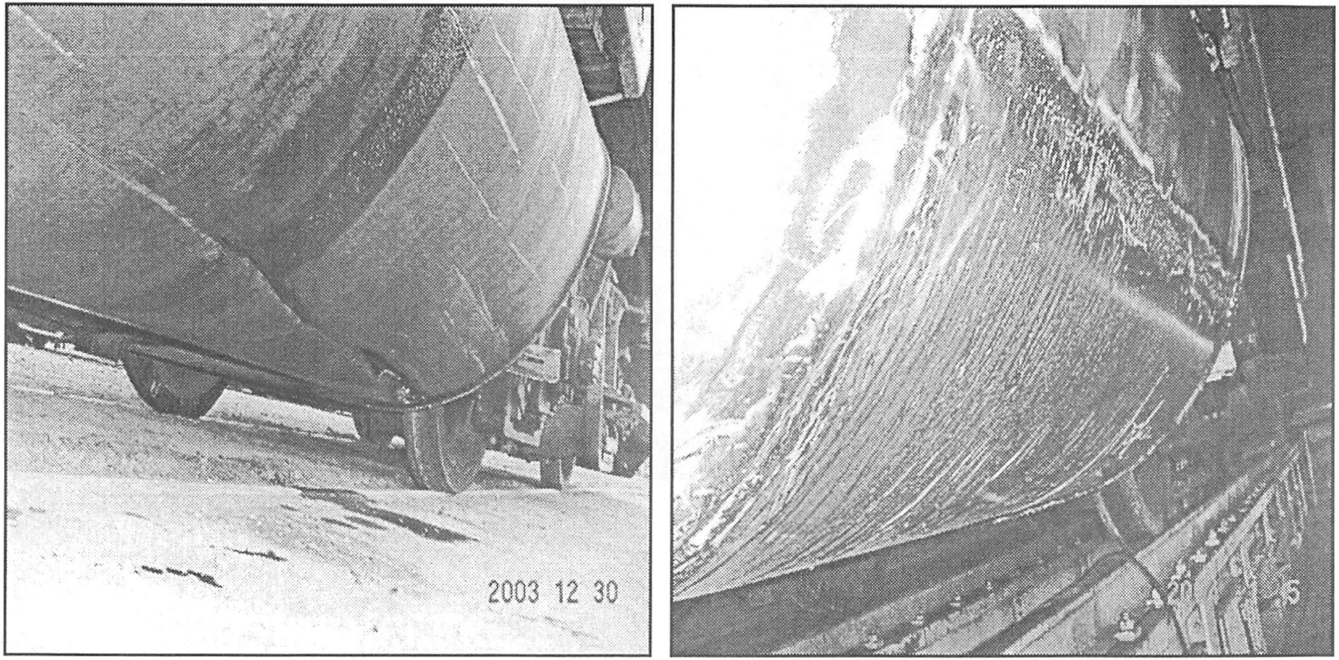


Figure 7

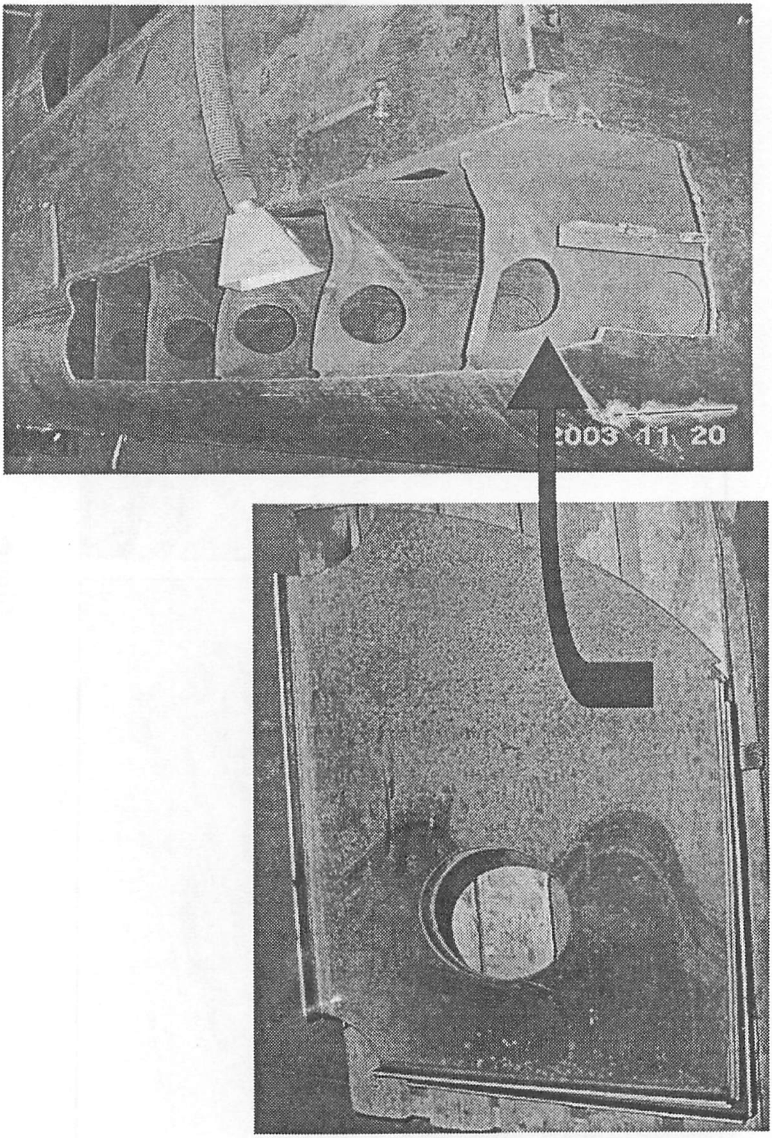


Figure 8

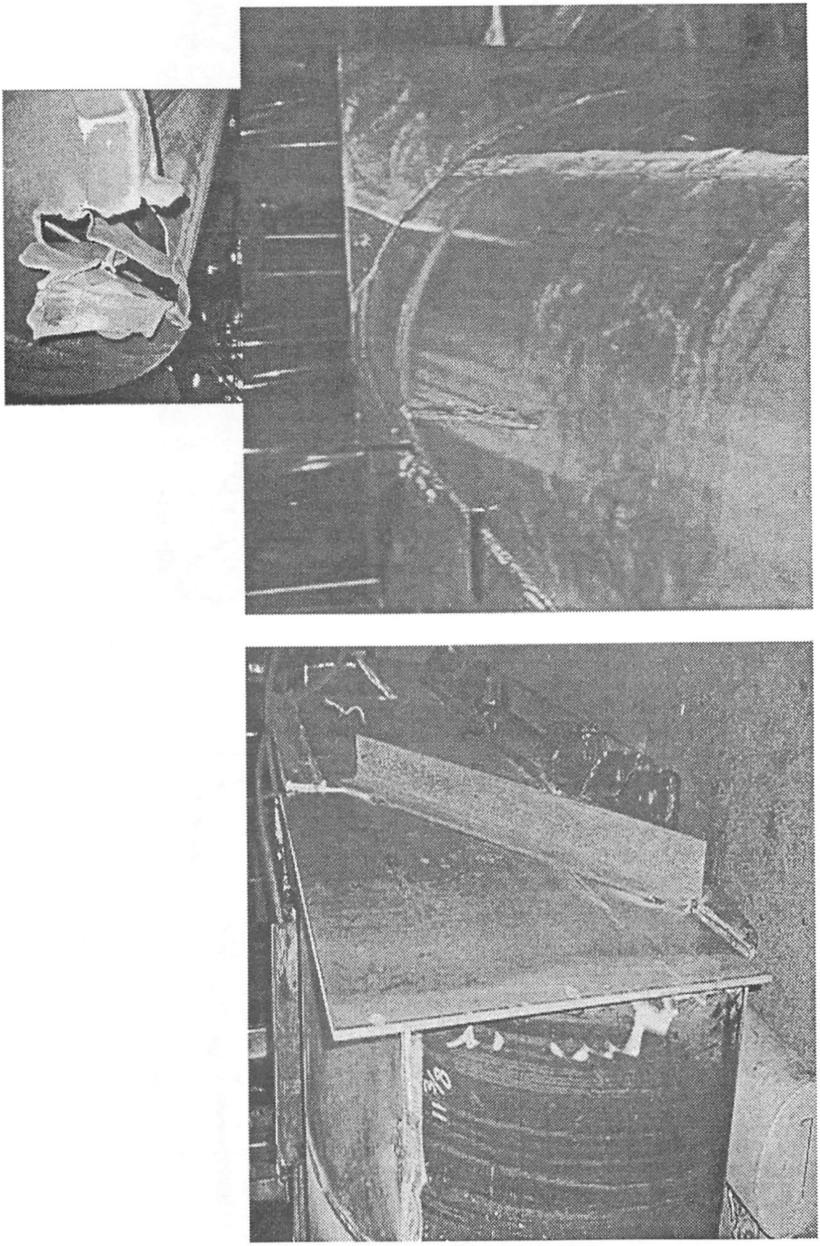


Figure 9

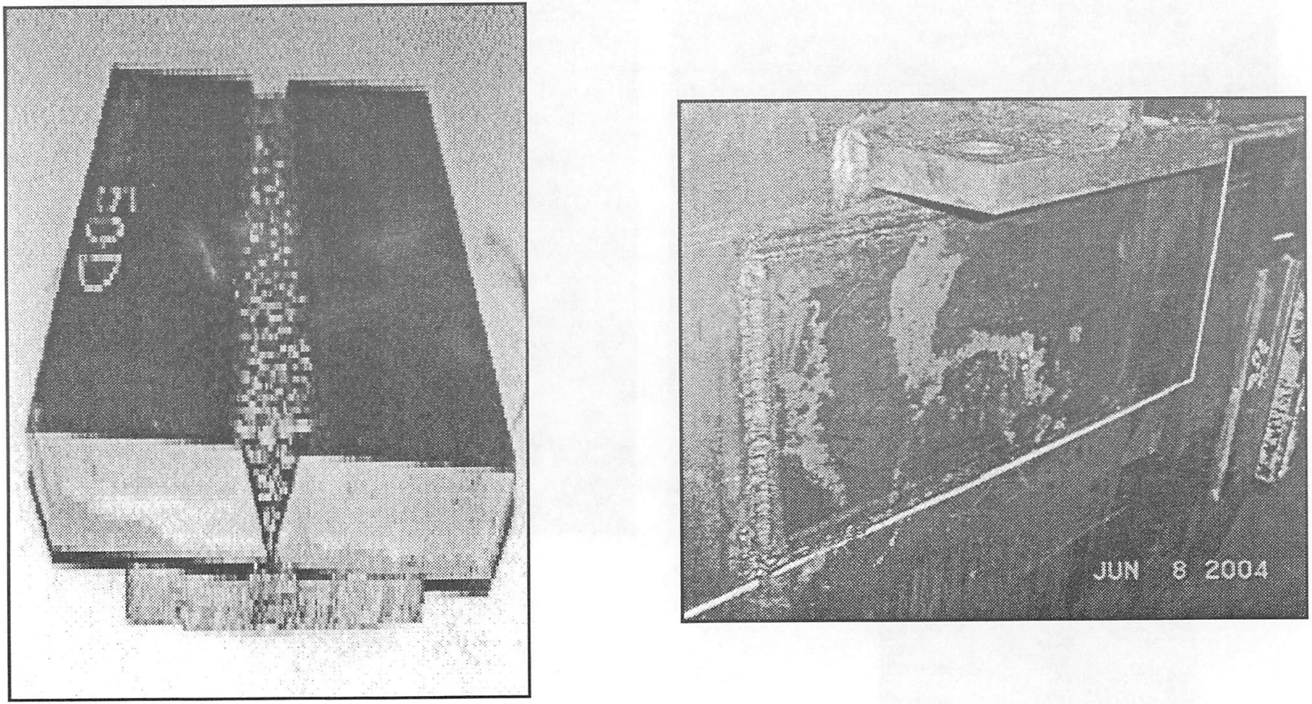


Figure 10

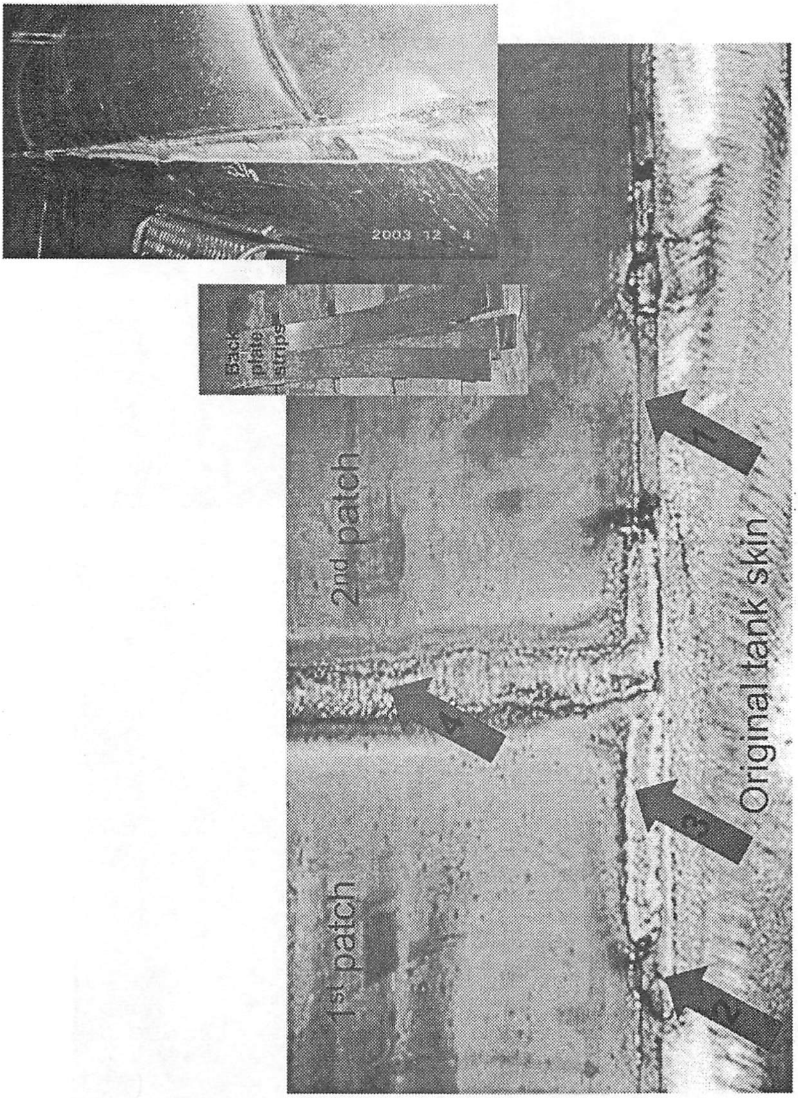

2003 12 4
Back plate strips
1st patch
2nd patch
Original tank skin
2
3
4
4

Figure 11

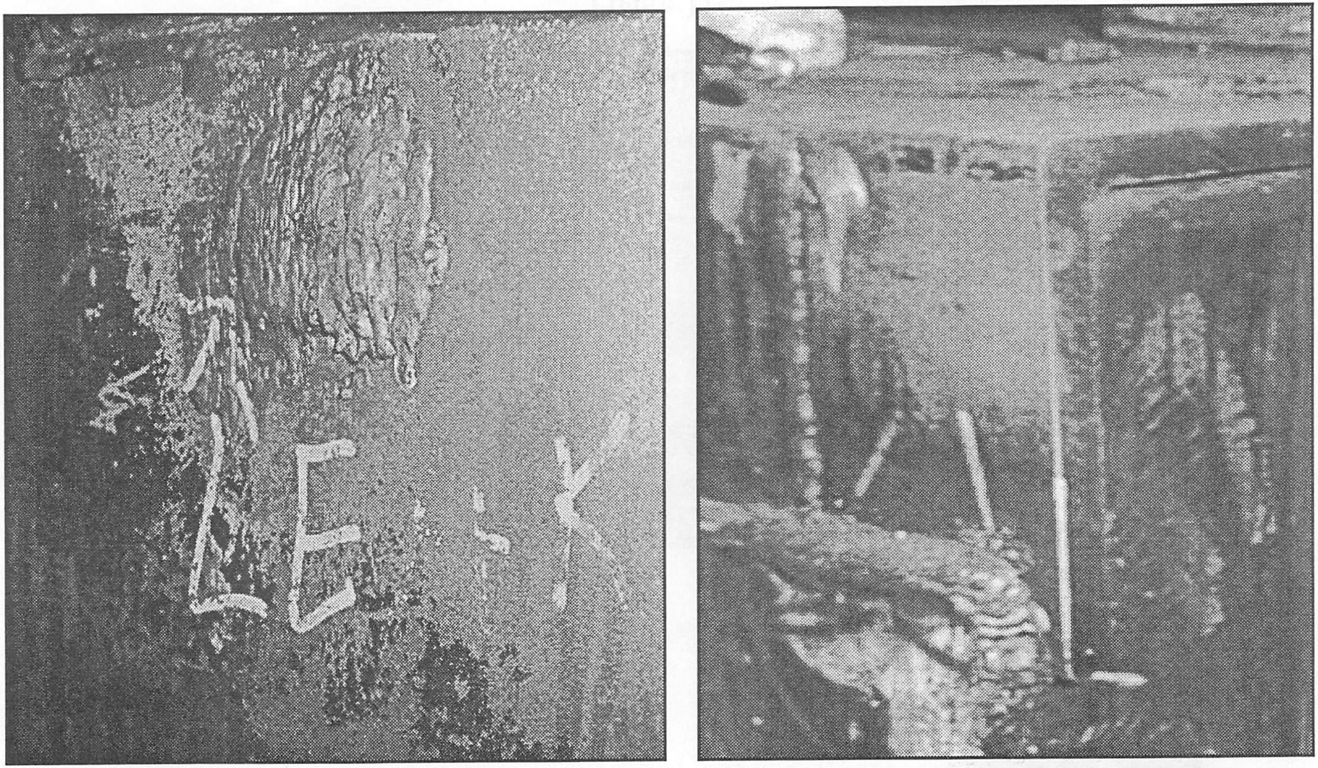


Figure 12

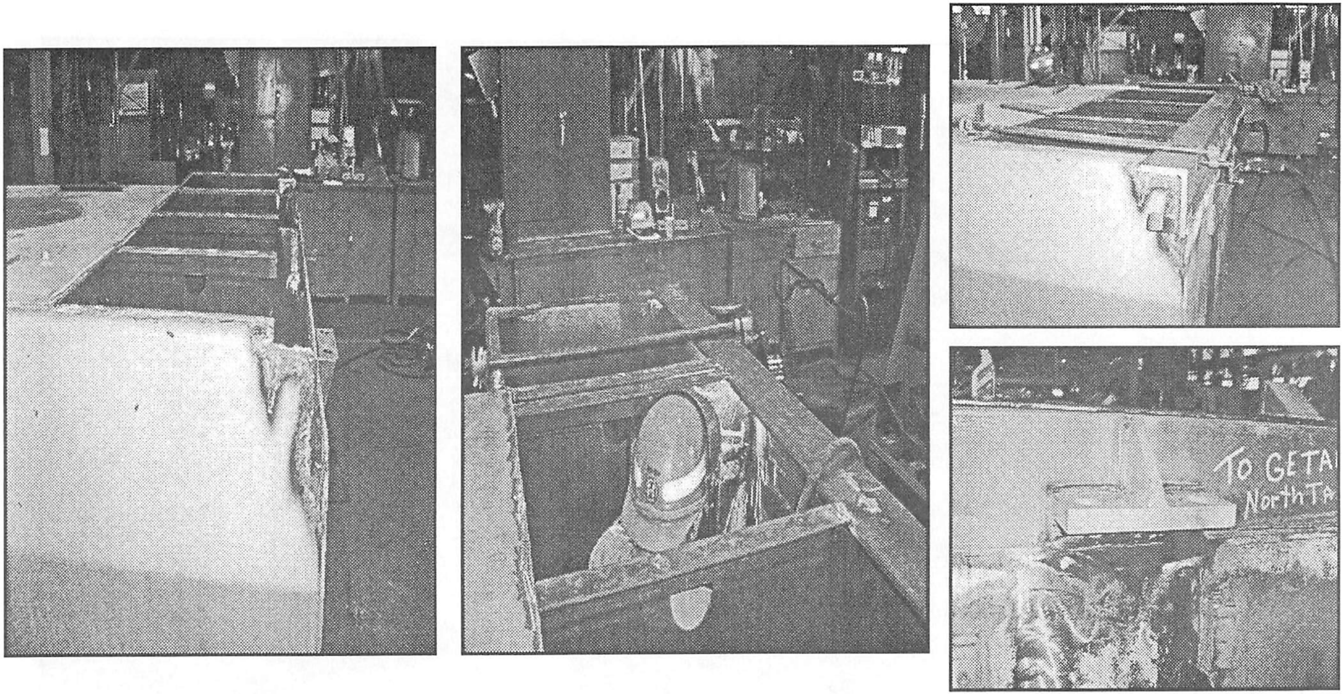


Figure 13

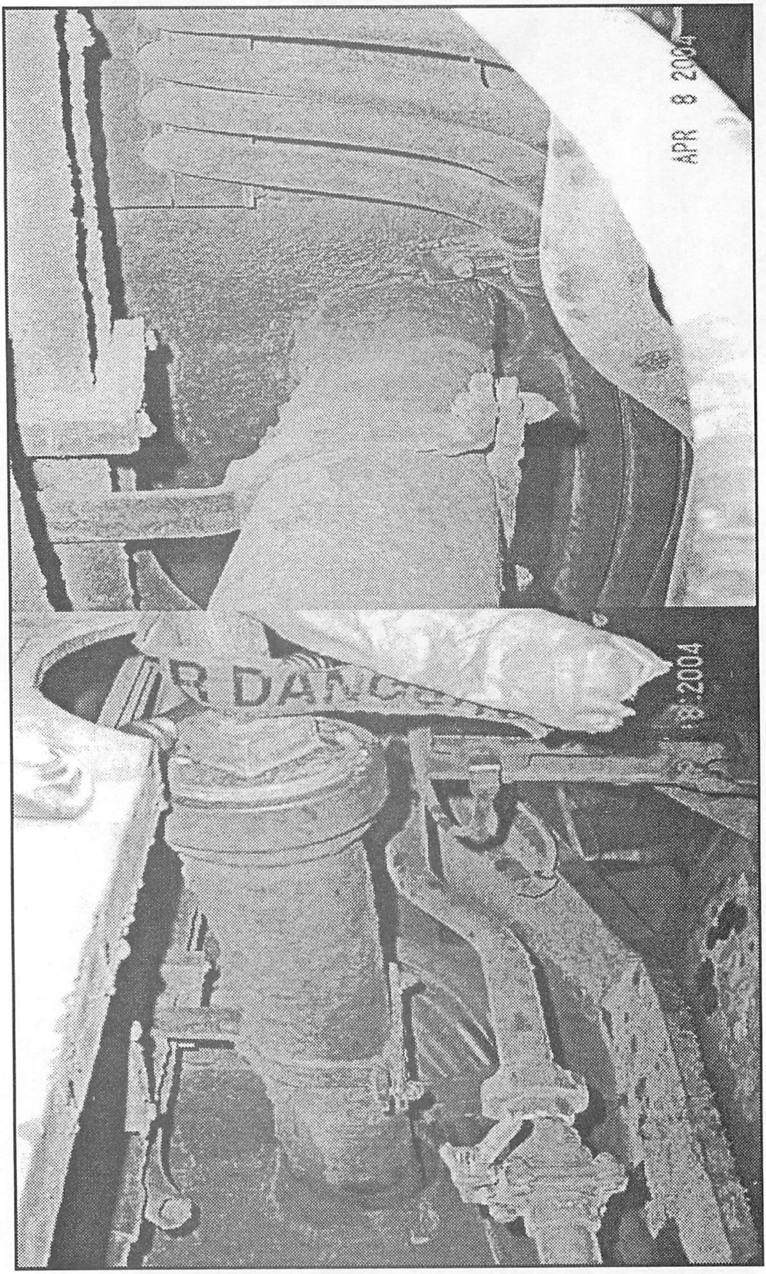


Figure 14

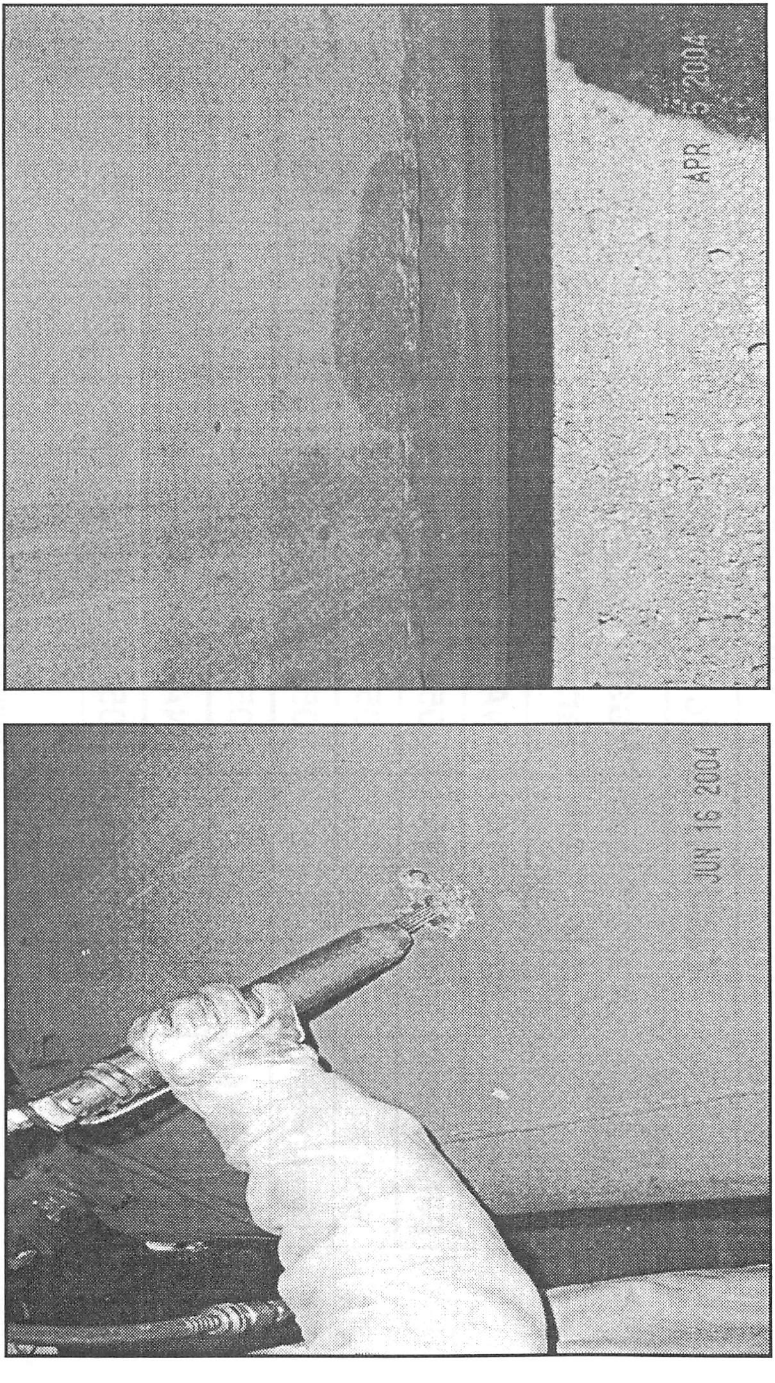


Figure 15

FUEL TANK REPAIR TIME (HOURS) CHART

Type of Repair	EstimatedCycle Time for Each Process						
	Drain Tank	Steam Tank	Wash Tank	Tank Removal	Welding Repairs	Air Test	Total Dwell
Peen	NA	NA	NA	NA	2	NA	2
Filler Neck	15	NA	05	NA	4	05	65
Mounting Pad	2	9	05	4	48	05	64
Corner Repair	15	9	05	4	24	1	40
Side Swipe	15	9	05	NA	24	1	36
Cracks	2	9	NA	NA	4	1	16
Swap & Go	2	NA	05	4	NA	NA	65

Figure 16

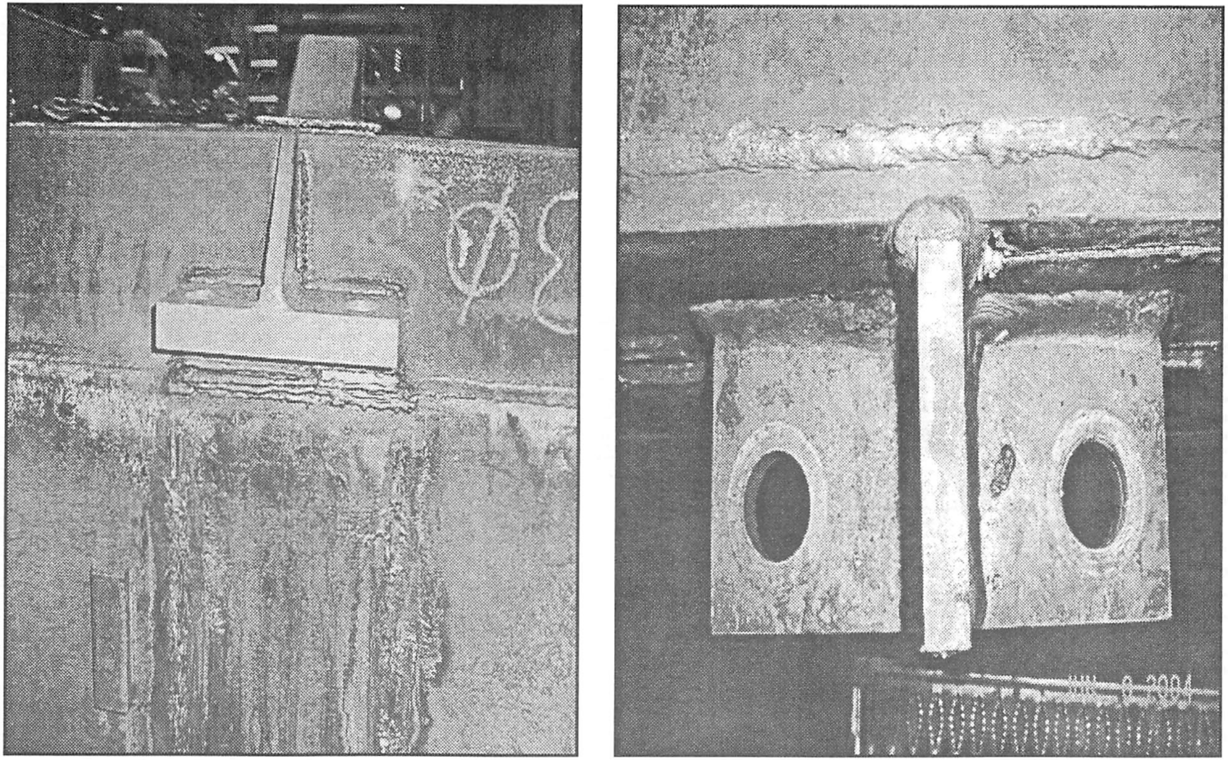
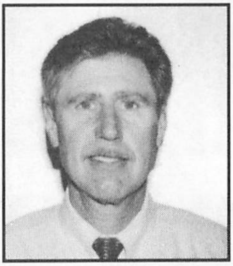


Figure 17

REPORT OF THE COMMITTEE ON DIESEL MECHANICAL MAINTENANCE

MONDAY, SEPTEMBER 27, 2004
2:30 P.M.



Chairman
JACK KUHNS
Vice President-Sales
JMA Railway Supply
Ponte Vedra Beach, FL

Vice Chairman
DAVID RUTKOWSKI
Chief Mechanical Officer
Providence & Worcester
Worcester, MA

COMMITTEE MEMBERS

D. Agler	Supt.-Loco.	KCS Railway	Shreveport, LA
D. Boothe	Manager-Locos.	CN RR	Homewood, IL
E. Burrier	Consultant	Ed Burrier & Assoc.	Roanoke, VA
J. Cutright	Senior Gen. Foreman	Norfolk Southern RR	Roanoke, VA
T. Frederick	General Foreman	Florida East Coast RR	Miami Springs, FL
B. Graham	Gen. Loco. Supvr.	Alaska RR	Anchorage, AK
R. Higuera	Field Engr. Loco-West	Amtrak	Los Angeles, CA
G. King	Chief Mech. Officer	St. Lawrence & Atlantic	Auburn, ME
A. Mallette	Mgr.-Equipment	METROLINK	Los Angeles, CA
R. Marchese	Project Manager	Electro Motive Divn.	LaGrange, IL
D. Miller	Sr. Mgr.-Loco. Engrg.	Union Pacific RR	Omaha, NE
T. Stewart	Mech. Systems-Engr.	CSX Transportation	Jacksonville, FL
D. Taylor	Mgr.-Customer Support	GE Transp. Rail	Erie, PA

NOTE: New Committee Members: D, Agler, D. Boothe, T. Frederick, B. Graham and R. Higuera

PERSONAL HISTORY

Jack Kuhns

In 1978, following a four-year tour of duty in the US Navy, Jack Kuhns began his railroad career with the L&N in Louisville, KY. After completing a machinist apprenticeship and supervisor training Jack transferred to the CSX facility in Corbin, KY, in 1986.

In 1988, Jack joined the supply side of the industry with the Durox Company. For ten years, he studied the industry through the eyes of gaskets and seals. Jack then joined the Hadady Corporation and continued his industry studies focusing on trucks and their components. In 2002, Jack joined JMA as Vice President of Sales. As he continues his studies of the industry he considers himself fortunate to be able to continuously broaden his knowledge in an industry as challenging and as diverse as the rail industry.

Jack and his wife, Patty, have been blessed with three children and five grandchildren and reside in Ponte Vedra Beach, FL.

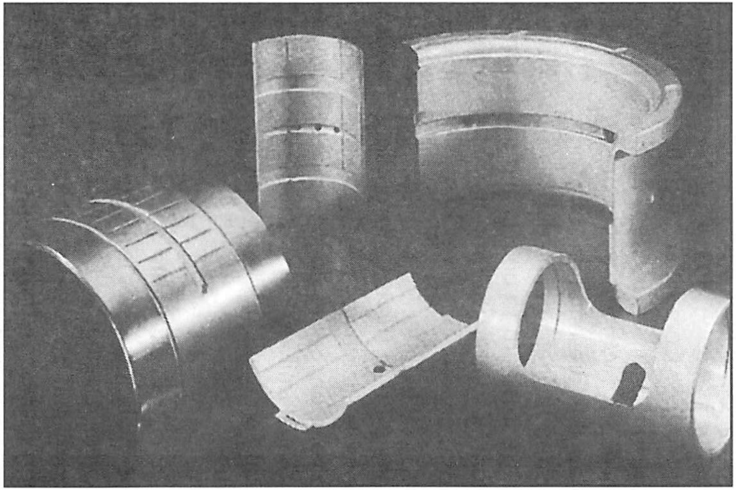
THE DIESEL MECHANICAL COMMITTEE WISHES TO EXPRESS THEIR SINCERE APPRECIATION TO THE FOLLOWING COMPANIES FOR HOSTING AND SPONSORING THEIR MEETINGS IN 2003/2004

ROSEMONT, IL DECEMBER 2003
CHICAGO FREIGHT CAR LEASING

JACKSONVILLE, FLA FEBRUARY 2004
CSX TRANSPORTATION
GRAHAM WHITE CORPORATION
POWERAIL

THANK YOU VERY MUCH FOR YOUR SUPPORT,

DIESEL MECHANICAL MAINTENANCE COMMITTEE



I. GE EVOLUTION SERIES - MAINTENANCE AND RELIABILITY

Presented by
Dennis Taylor,
Manager Customer Support
GE Transportation - Rail

Introduction

This paper is intended to cover the significant Maintenance and Reliability aspects of the new GE Tier II locomotive, the Evolution Series. There is one other paper on the GE Evolution Series which was presented during the Monday morning session of the convention by Keith Gilbert of the New Technologies Committee. Keith's paper is available for review in the New Technologies Committee technical reports in another section of this publication. We are trying not to overlap this presentation, but some information has been duplicated because it is hard to understand the content if you have not had the opportunity to hear or read the other presentation.

Editor's Note: There were outdoor exhibits available for review on the GE Evolution Series locomotive at the annual Railway Show which was held in September, 2004 in Chicago, Illinois.

Background

The Evolution Series is the result of a six-year research and development program and an investment of 200 million dollars. In order to gather In-service data and to better validate the new systems under true conditions, a total of 50 pre-production locomotives with a mix of AC and DC units have been in revenue service on Class I railroads. These locomotives have operated under all conditions and over all types of terrain, working hard for more than 2.0 million miles of revenue service. This experience will be the key to ensuring the performance, reliability and compliance at launch.

Topics to discuss

The Evolution locomotive was designed specifically to meet the Tier II regulations while improving performance and life cycle cost, so we will briefly touch on the regualtions required, why we chose the direction we did, then specifically about the engine and the cooling system and how the Evolution series has performed. (Figure 1)

EPA Regulations

The EPA has imposed tiered reductions in atmospheric and visible emissions over the 2001-2005 time frame. The most critical atmospheric emissions regulated are nitrogen oxides (NOx) and particulate matter (PM). Figure 2 details the EPA mandated 56% reduction in NOx and the 67% reduction in PM over that time frame. Visible emissions are also greatly reduced. The visible emissions regulations require a tiered reduction in steady state opacity (a measure of the ability to see through the stack discharge of a diesel engine). Figure 2 also details the 43% reduction in visible emissions over the 2001-2005 time frame.

The EPA regulations were the catalyst that drove the development of the Evolution Series platform, but what the regulations also did was to provide an opportunity to improve the factors that are key to the success of a locomotive...**performance, reliability and life cycle cost (Figure 3)**

As we looked at our options for meeting the Tier II regulations, we kept our customers' requirements in clear view at all times.

Ultimately, a decision had to be made between the two available options: (Figure 4)

- Extend the current engine technology, OR
- Develop a new platform for TII & the future

GE decided to concentrate on developing a locomotive platform for Tier II and beyond. We enlisted the services of the Class I railroads, our own GETS engineering, and GE Corporate Research and Development, and other other World class engine consultants. (Figure 5)

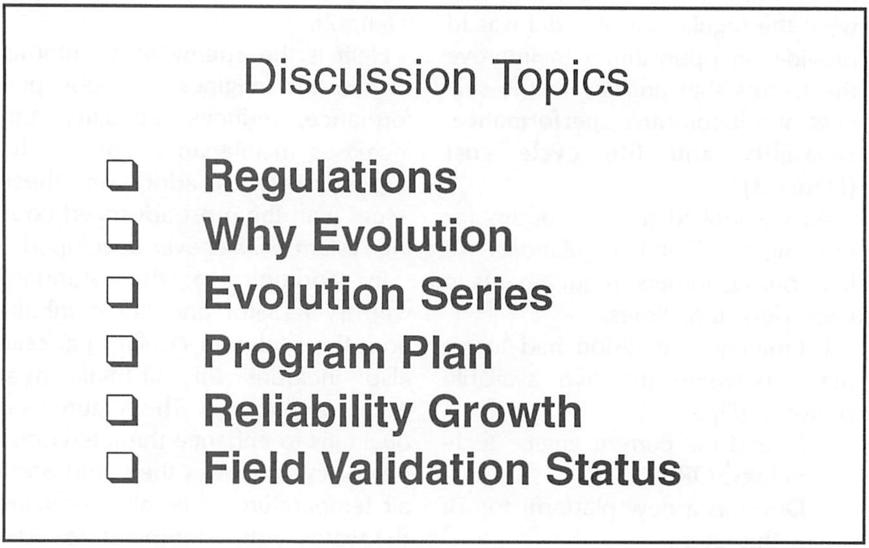
The GEVO-12, 12 cylinder diesel engine produces the same horsepower as it's 16 cylinder predecessor. This feat is accomplished while using less fuel, with extended service and overhaul intervals.

The GEVO-12 also produces 40% fewer emissions than current locomotives. This engine is the heart of the development potential of the Evolution Series, with growth opportunities designed into the engine in terms of fuel efficiency, horsepower and emission compliance (Figures 6, 7, 8, 9).

This complete engine was virtually built before turning the first chip (Figure7).

Heat is the enemy of all internal combustion engines. It robs performance, reduces reliability and increases maintenance costs. The Evolution Series addresses these issues with the most advanced cooling system GE has ever developed.

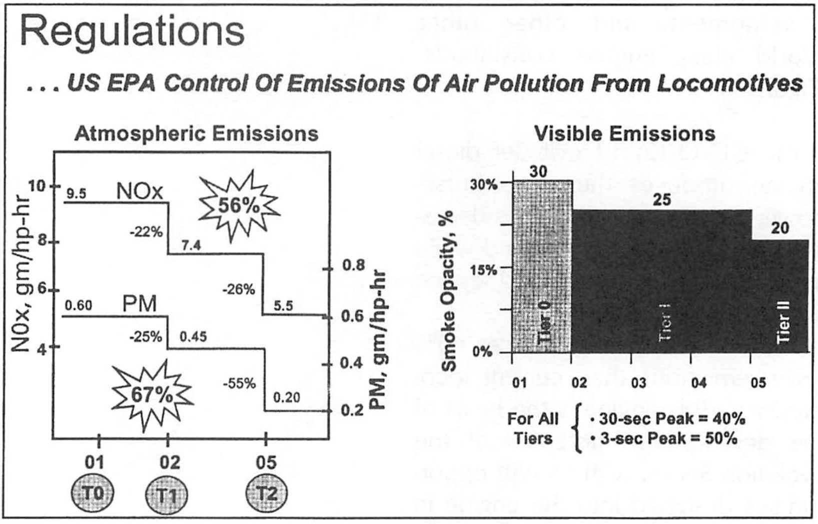
In addition to the standard wet/dry radiator and fan combination, the Evolution cooling package also includes an air-to-air heat exchange package. This feature uses dual fans to enhance the intercooler efficiency and lower the combustion air temperature while also reducing the water and oil temperature. The lower combustion air temperature is key to meeting Tier II emissions levels while the lower oil and water temperatures result in longer oil life and longer engine life and improved reliability (Figures 10, 11, 12, 13, 14, 15).



Discussion Topics

- ☐ **Regulations**
- ☐ **Why Evolution**
- ☐ **Evolution Series**
- ☐ **Program Plan**
- ☐ **Reliability Growth**
- ☐ **Field Validation Status**

Figure 1



Regulations

. . . US EPA Control Of Emissions Of Air Pollution From Locomotives

For All Tiers
- 30-sec Peak = 40%
- 3-sec Peak = 50%

Figure 2

Emissions Challenge

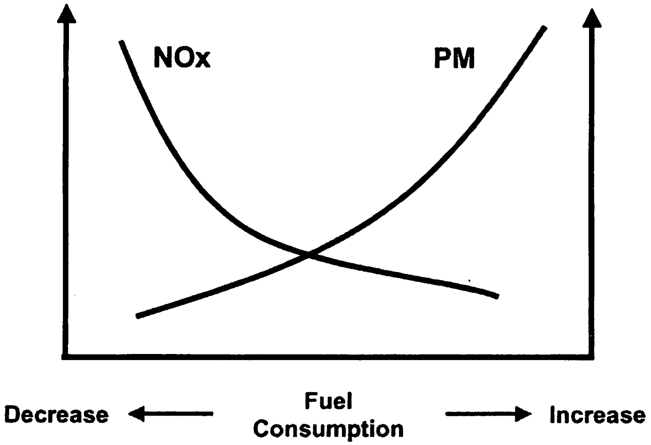
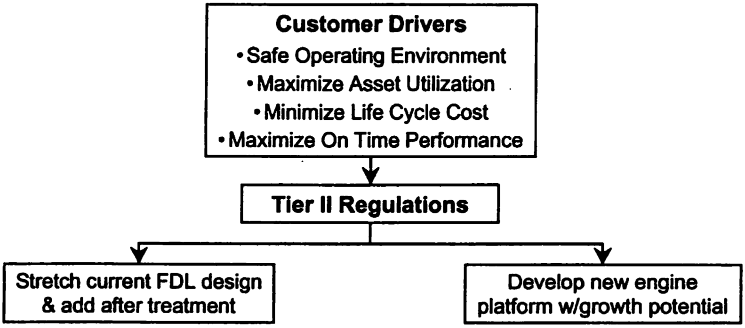


Figure 3

Compliance Options



Customer Drivers

- Safe Operating Environment
- Maximize Asset Utilization
- Minimize Life Cycle Cost
- Maximize On Time Performance

Tier II Regulations

Stretch current FDL design & add after treatment

Develop new engine platform w/growth potential

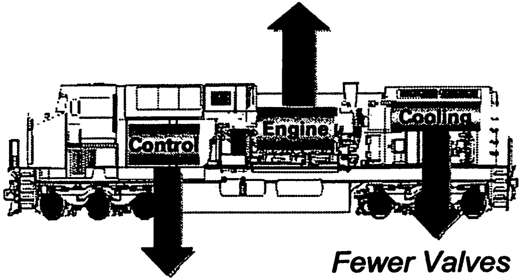
Detailed evaluation of alternative paths:

- *Class I railroads*
- *GETS & GE CR&D*
- *World class engine consultants & manufacturers*

Figure 4

Why Evolution Series?

. . . To Improve Reliability

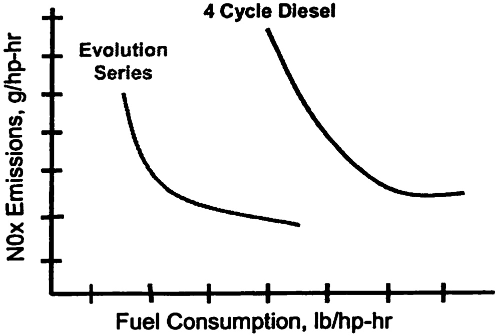


Fewer cylinders
Increased pressure capability
Bigger bearings

Fewer Panels
Fewer Cards
Redundant Network

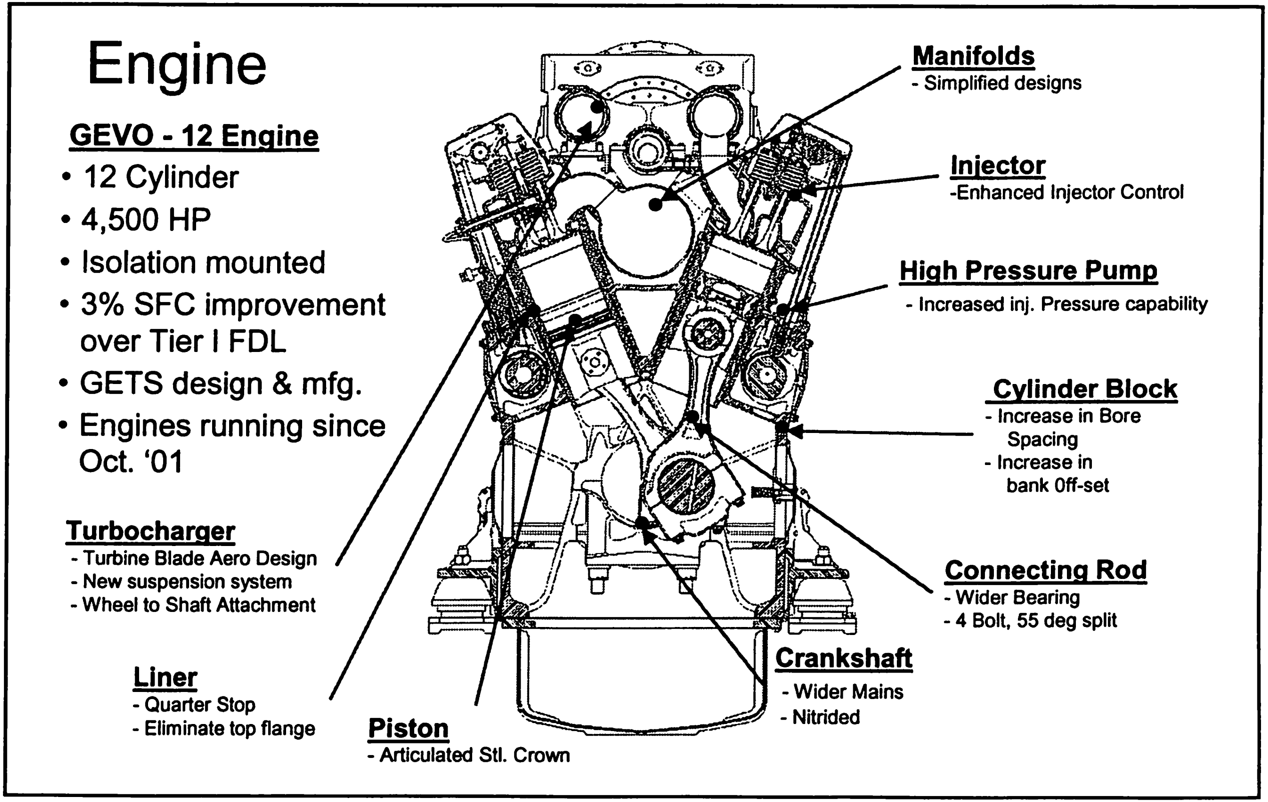
Fewer Valves
Fewer Joints
Doubled Pressure Capability

. . . To Lower Life Cycle Cost



- Drive Increased fuel efficiency
- Target increased maintenance & O/H interval

Figure 5



Engine

GEVO - 12 Engine

- 12 Cylinder
- 4,500 HP
- Isolation mounted
- 3% SFC improvement over Tier I FDL
- GETS design & mfg.
- Engines running since Oct. '01

Turbocharger
- Turbine Blade Aero Design
- New suspension system
- Wheel to Shaft Attachment

Liner
- Quarter Stop
- Eliminate top flange

Piston
- Articulated Stl. Crown

Manifolds
- Simplified designs

Injector
-Enhanced Injector Control

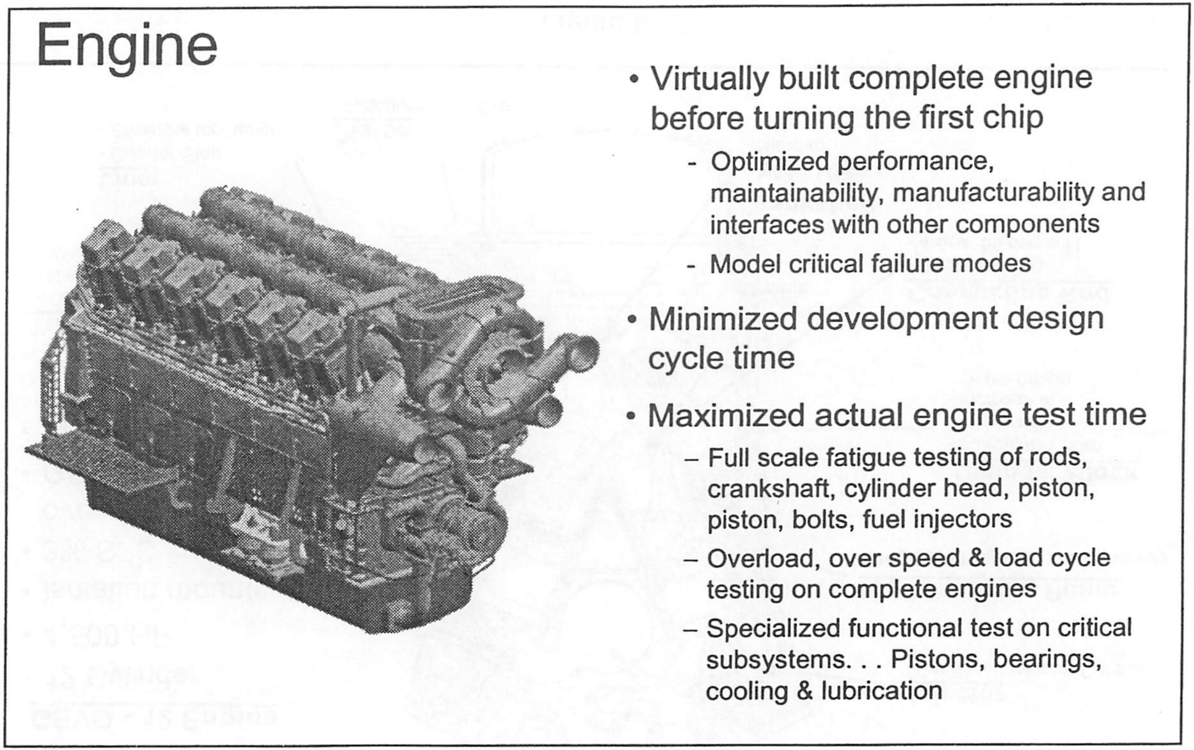
High Pressure Pump
- Increased inj. Pressure capability

Cylinder Block
- Increase in Bore Spacing
- Increase in bank 0ff-set

Connecting Rod
- Wider Bearing
- 4 Bolt, 55 deg split

Crankshaft
- Wider Mains
- Nitrided

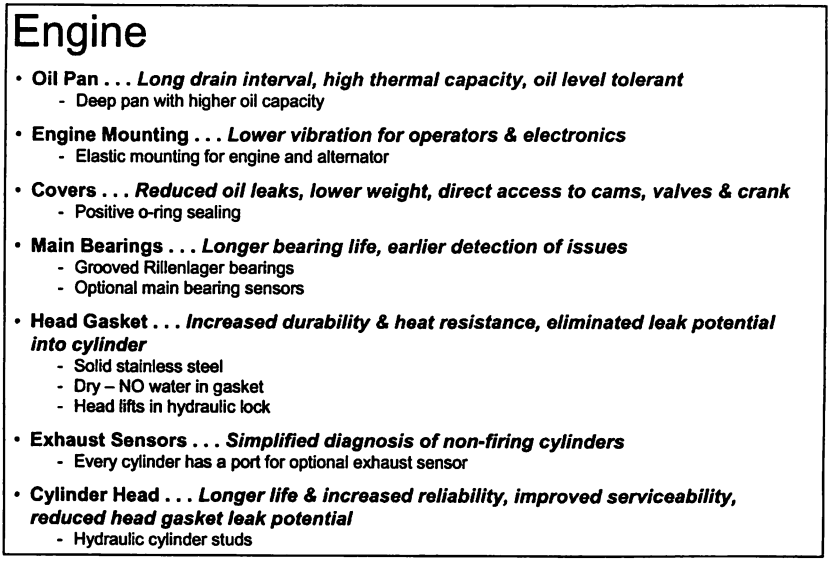
Figure 6



Engine

- Virtually built complete engine before turning the first chip
  - Optimized performance, maintainability, manufacturability and interfaces with other components
  - Model critical failure modes
- Minimized development design cycle time
- Maximized actual engine test time
  - Full scale fatigue testing of rods, crankshaft, cylinder head, piston, piston, bolts, fuel injectors
  - Overload, over speed & load cycle testing on complete engines
  - Specialized functional test on critical subsystems. . . Pistons, bearings, cooling & lubrication

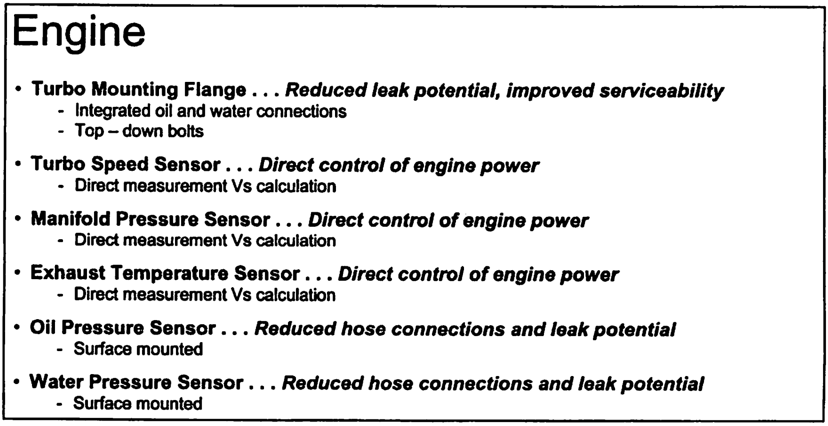
Figure 7



Engine

- **Oil Pan . . .** ***Long drain interval, high thermal capacity, oil level tolerant***
  - Deep pan with higher oil capacity
- **Engine Mounting . . .** ***Lower vibration for operators & electronics***
  - Elastic mounting for engine and alternator
- **Covers . . .** ***Reduced oil leaks, lower weight, direct access to cams, valves & crank***
  - Positive o-ring sealing
- **Main Bearings . . .** ***Longer bearing life, earlier detection of issues***
  - Grooved Rillenlager bearings
  - Optional main bearing sensors
- **Head Gasket . . .** ***Increased durability & heat resistance, eliminated leak potential into cylinder***
  - Solid stainless steel
  - Dry – NO water in gasket
  - Head lifts in hydraulic lock
- **Exhaust Sensors . . .** ***Simplified diagnosis of non-firing cylinders***
  - Every cylinder has a port for optional exhaust sensor
- **Cylinder Head . . .** ***Longer life & increased reliability, improved serviceability, reduced head gasket leak potential***
  - Hydraulic cylinder studs

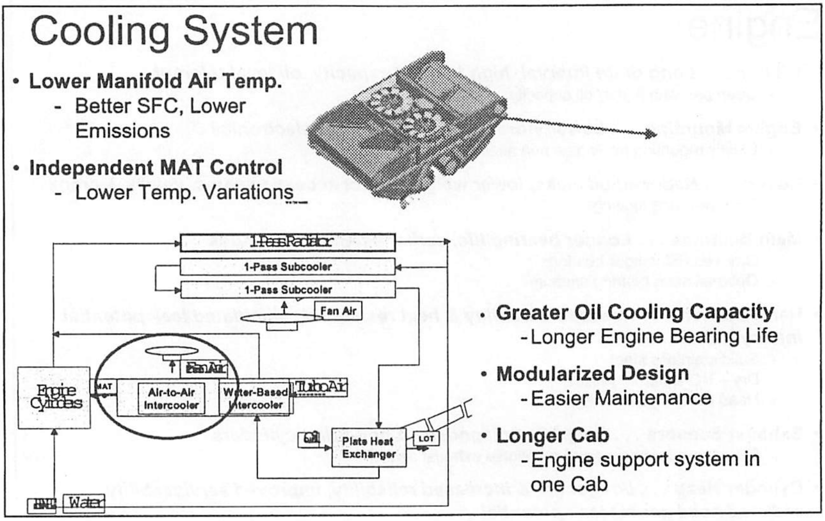
Figure 8



Engine

- **Turbo Mounting Flange . . .** ***Reduced leak potential, improved serviceability***
  - Integrated oil and water connections
  - Top – down bolts
- **Turbo Speed Sensor . . .** ***Direct control of engine power***
  - Direct measurement Vs calculation
- **Manifold Pressure Sensor . . .** ***Direct control of engine power***
  - Direct measurement Vs calculation
- **Exhaust Temperature Sensor . . .** ***Direct control of engine power***
  - Direct measurement Vs calculation
- **Oil Pressure Sensor . . .** ***Reduced hose connections and leak potential***
  - Surface mounted
- **Water Pressure Sensor . . .** ***Reduced hose connections and leak potential***
  - Surface mounted

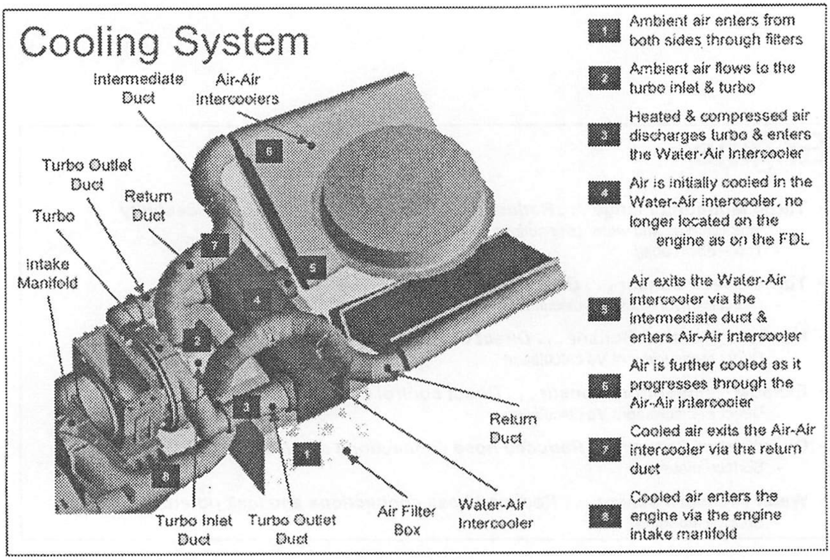
Figure 9



Cooling System

- **Lower Manifold Air Temp.**
  - Better SFC, Lower Emissions
- **Independent MAT Control**
  - Lower Temp. Variations
- **Greater Oil Cooling Capacity**
  - Longer Engine Bearing Life
- **Modularized Design**
  - Easier Maintenance
- **Longer Cab**
  - Engine support system in one Cab

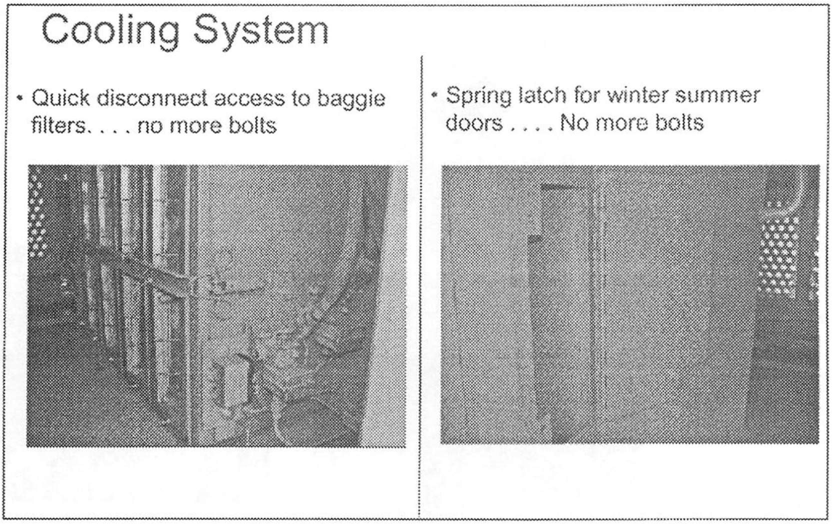
Figure 10



Cooling System

1. Ambient air enters from both sides through filters
2. Ambient air flows to the turbo inlet & turbo
3. Heated & compressed air discharges turbo & enters the Water-Air Intercooler
4. Air is initially cooled in the Water-Air intercooler, no longer located on the engine as on the FDL
5. Air exits the Water-Air intercooler via the intermediate duct & enters Air-Air intercooler
6. Air is further cooled as it progresses through the Air-Air intercooler
7. Cooled air exits the Air-Air intercooler via the return duct
8. Cooled air enters the engine via the engine intake manifold

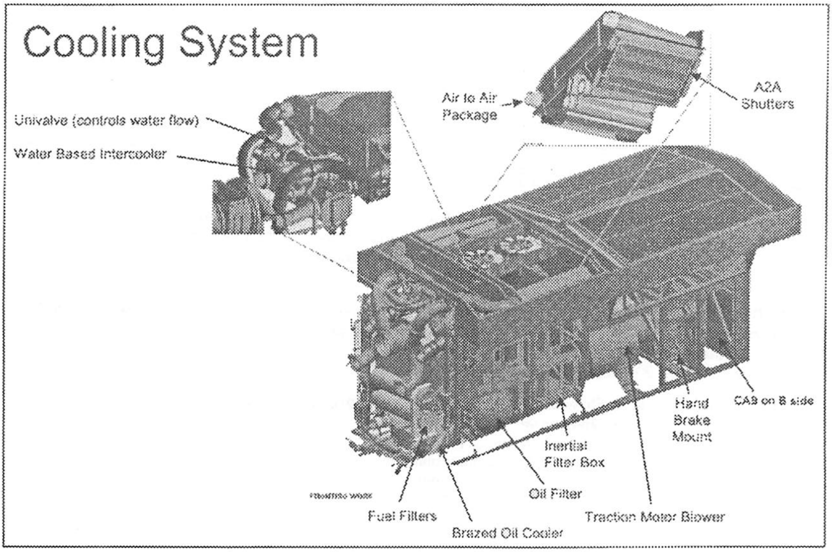
Figure 11



Cooling System

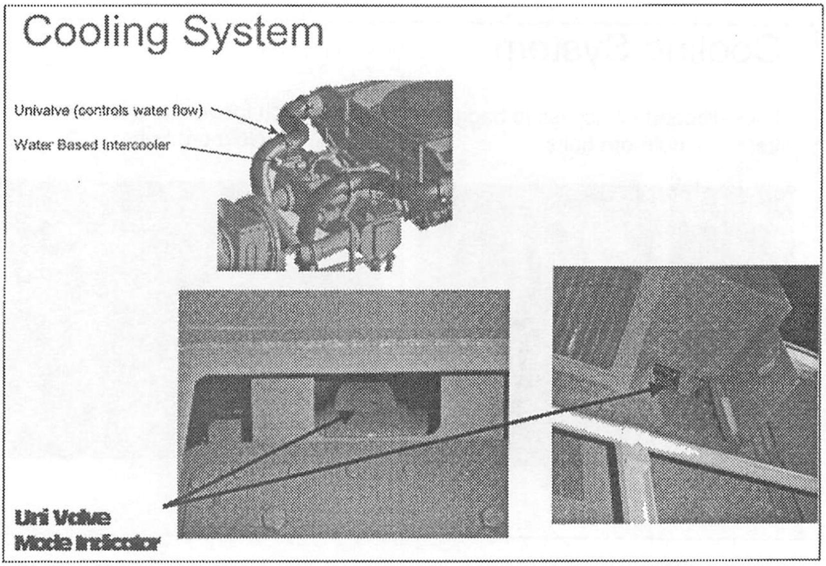
- Quick disconnect access to baggie filters. . . . no more bolts
- Spring latch for winter summer doors . . . . No more bolts

Figure 12



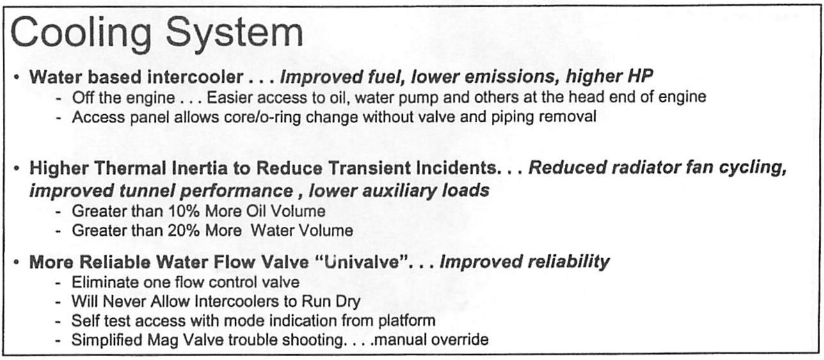
Cooling System

Figure 13



Cooling System

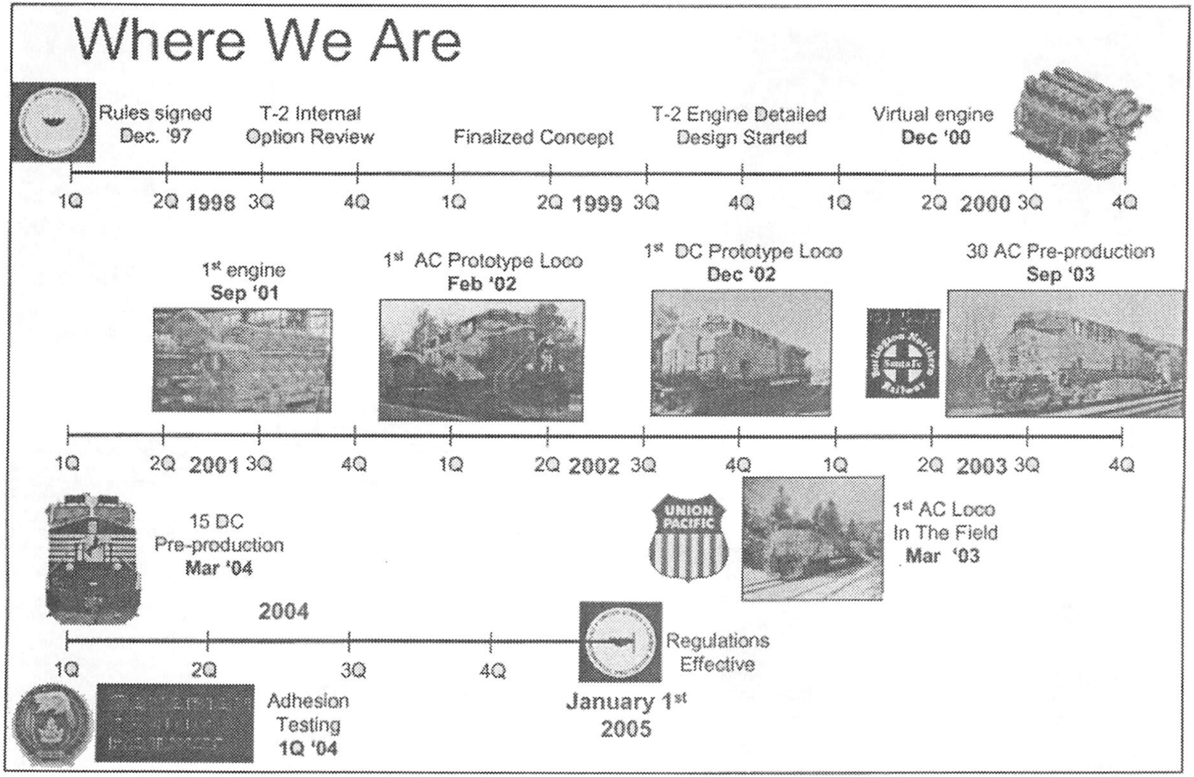
Figure 14



Cooling System

- **Water based intercooler . . .** ***Improved fuel, lower emissions, higher HP***
  - Off the engine . . . Easier access to oil, water pump and others at the head end of engine
  - Access panel allows core/o-ring change without valve and piping removal
- **Higher Thermal Inertia to Reduce Transient Incidents. . .** ***Reduced radiator fan cycling, improved tunnel performance , lower auxiliary loads***
  - Greater than 10% More Oil Volume
  - Greater than 20% More Water Volume
- **More Reliable Water Flow Valve "Univalve". . .** ***Improved reliability***
  - Eliminate one flow control valve
  - Will Never Allow Intercoolers to Run Dry
  - Self test access with mode indication from platform
  - Simplified Mag Valve trouble shooting. . . .manual override

Figure 15



Where We Are

Rules signed
Dec. '97

T-2 Internal
Option Review

Finalized Concept

T-2 Engine Detailed
Design Started

Virtual engine
Dec '00

1Q 2Q **1998** 3Q 4Q 1Q 2Q **1999** 3Q 4Q 1Q 2Q **2000** 3Q 4Q

1st engine
Sep '01

1st AC Prototype Loco
Feb '02

1st DC Prototype Loco
Dec '02

30 AC Pre-production
Sep '03

1Q 2Q **2001** 3Q 4Q 1Q 2Q **2002** 3Q 4Q 1Q 2Q **2003** 3Q 4Q

15 DC
Pre-production
Mar '04

1st AC Loco
In The Field
Mar '03

2004

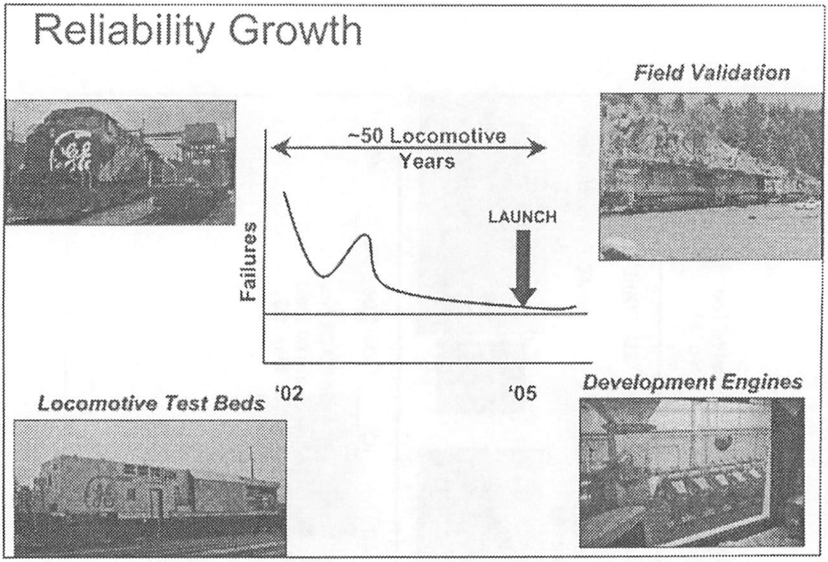
1Q 2Q 3Q 4Q

Regulations
Effective

Adhesion
Testing
1Q '04

**January 1st
2005**

Figure 16



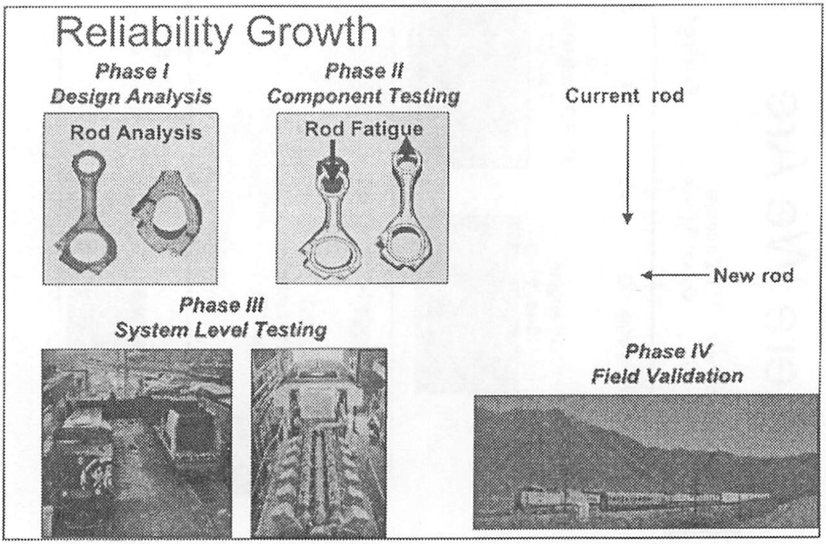
Reliability Growth

Field Validation

Locomotive Test Beds

Development Engines

Figure 17



Reliability Growth

Phase I
Design Analysis

Rod Analysis

Phase II
Component Testing

Rod Fatigue

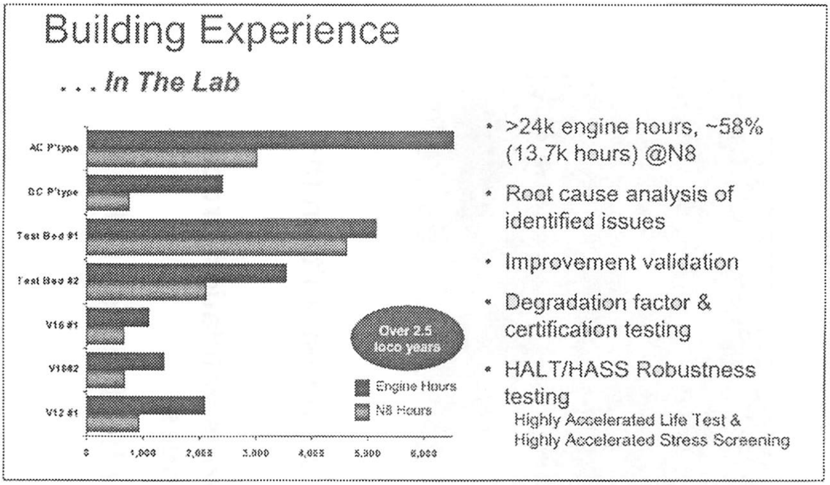
Current rod

New rod

Phase III
System Level Testing

Phase IV
Field Validation

Figure 18

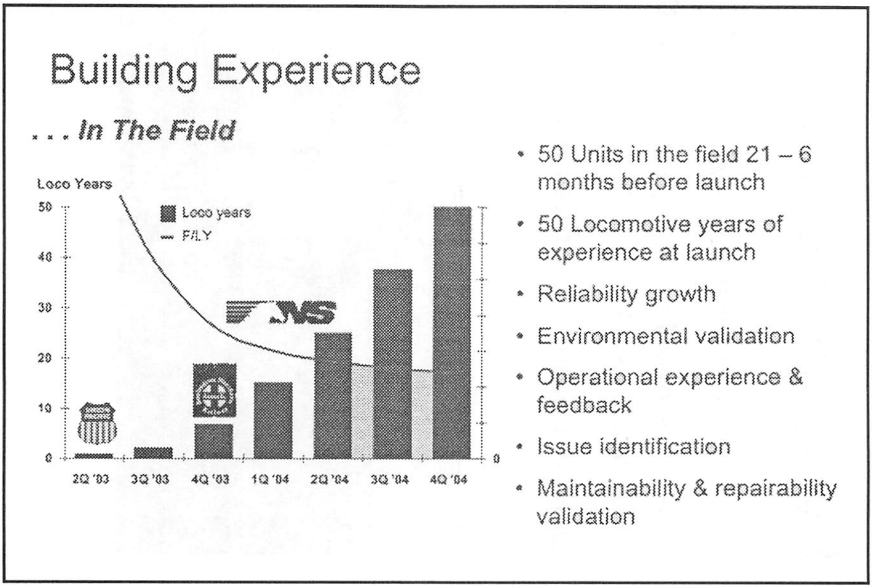


Building Experience

. . . In The Lab

- >24k engine hours, ~58% (13.7k hours) @N8
- Root cause analysis of identified issues
- Improvement validation
- Degradation factor & certification testing
- HALT/HASS Robustness testing
  Highly Accelerated Life Test & Highly Accelerated Stress Screening

Figure 19



Building Experience

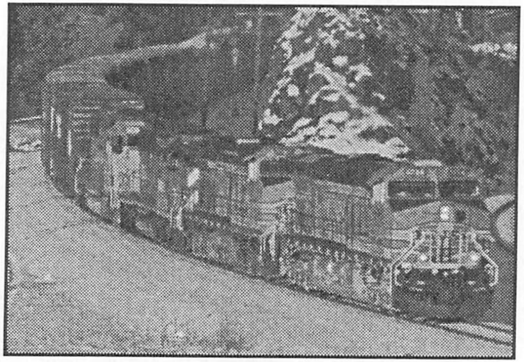
. . . In The Field

- 50 Units in the field 21 – 6 months before launch
- 50 Locomotive years of experience at launch
- Reliability growth
- Environmental validation
- Operational experience & feedback
- Issue identification
- Maintainability & repairability validation

Figure 20

Evolution Summary

- ☐ Tier II compliant 12 cylinder engine
- ☐ Redesigned cooling system with new air to air intercooler
- ☐ New common control architecture



- ☐ Initial field test units in the field
- ☐ Rigorous validation process continues
- ☐ Find what breaks . . . Fix it

Figure 21

II. EMD SD70ACe AND SD70DC - TIER 2 LOCOMOTIVE MODELS - MECHANICAL MAINTENANCE ENHANCEMENTS

Prepared by
Richard A. Marchese, Project Manager - Rebuild Product Lines
Electro-Motive Division,
General Motors Corporation

Electro-Motive Division's answer to the Tier 2 emissions requirement is the SD70ACe locomotive, Figure 1A and the DC traction equivalent, the SD70M-2, Figure 1B.

The SD70ACe and SD70M-2 are EPA Tier 2 compliant locomotives that were developed with multiple goals in mind. Those goals were to deliver an environmentally compliant product that would not only be simple to maintain and operate, but also reliable and durable. In the process, EMD engineers designed a product that is easier to assemble and maintenance friendly.

This paper will focus on maintenance enhancements built into the SD70ACe that pertain to mechanical systems. Although not specifically referenced, similar maintenance enhancements pertain to the SD70M-2 model version.

Keeping extended (184 days) periodic maintenance as a high design priority, every system requiring periodic maintenance was developed with extended maintenance intervals. In addition, several steps were taken to ensure the ease of maintenance of these systems. Input was gathered from internal and external customers and incorporated into locomotive development. Detailed reviews were held to study the removal of major components and assemblies before design concepts were approved. As a result of this research, access to equipment, filters, valves and fittings was improved, resulting in reduced maintenance labor expense. It has been observed that equipment that is easier to work on and maintain, naturally performs better and receives more attention during the maintenance cycle.

Of approximately 160 plus new features/benefits of the SD70ACe locomotive, 94 relate to maintenance enhancement as follows:

- Reliability and durability.........36

- Extension of maintenance intervals.......................................5

- On-board diagnostics.................6

- Ease of maintenance................47

Since the focus of this paper is mechanical maintenance enhancements, we will highlight some of the more significant mechanical improvements.

Reliability and durability

Maintainability begins with reliability and durability. The SD70ACe uses a modular architecture approach to design and assembly, which results in improvement in both reliability and durability. Each module is individually tested when built, then assembled into the final product, and tested again as a system. Further, this modular design results in a locomotive that is easier to assemble and maintain. Figure 2 is a geometric exploded view of the SD70ACe modular architecture.

Reliability and durability cannot be achieved without a proven prime mover. For the Tier 2 models SD70ACe and SD70M-2, EMD selected the well proven 710 diesel engine. With over 5000 of the 710 series engines in service, the engine continues to be incrementally improved based on installed fleet experience and new engineering developments. Of significant note, the basic engine dimensions and structure of the engine have not changed, which allows for:

- No additional workforce training
- No new tooling investment

As component upgrades are developed, they are easily introduced and applied to existing engines with immediate positive results. Most of the improvements introduced to date center on emissions, fuel efficiency, reliability and durability. Engine sensor technology has improved, which also allows for centralized sensor location for ease of maintenance and diagnostics.

The Tier 2 emissions compliant engine used on the SD70ACe is the 16-710G3C-T2, Figure 3.

In addition to being Tier 2 emissions compliant, the 710G3C-T2 features increased durability through on-going component improvements over the past 6 years. The net result of these improvements gives the 710 and its support systems, 600 plus days between failures, for the last three years of delivery.

A significant outcome of Tier 2 compliant development was the substantial lowering, by 15%, of cylinder peak firing pressures. Peak firing pressure generates the cyclical loading, which determines durability of engine components, from the valve train down to the crankshaft. Reducing peak pressure ultimately reduces the amount of stress in all of these parts, resulting in higher reliability due to fewer failures over time.

Ease of maintenance

Should the diesel engine require repairs or maintenance, engine access is significantly improved through the use of gull wing hood roof doors, as shown in Figure 4.

Engine repair and maintenance work can be performed safely and efficiently with improved accessibility. No tools are required to open the gull wing doors and hydraulic cylinders hold them in the open position. In addition to better engine overhead access, the four middle doors on each side are removable, again without tools. If further access is required the middle door supports are easily removable with a wrench. This arrangement affords the maintenance specialist the most access to the engine, short of complete hood removal. Engine accessibility improvements will translate to labor hour savings as well as the fostering of a safer work environment for maintenance personnel.

Should hood removal become a necessity, the SD70ACe modular build architecture, allows for the safe and efficient removal of the engine hood structure. As shown in Figure

5, the hood can be easily unbolted and removed using built in lifting eyes.

Main generator and engine removal becomes safe and efficient with this modular arrangement. No welding is required and several man-hours can be trimmed from this formerly labor-intensive task. Similar bolt-on removable structures house the cooling system, and other locomotive support equipment.

SD70ACe electrical equipment has been incorporated into a centralized electrical locker located directly behind the locomotive cab, Figures 6A and 6B.

Centralization of the electrical hardware allows for the relocation of environmentally sensitive components from a harsh to a controlled environment. This arrangement improves not only the equipment environment but also the accessibility to the EM2000 traction control and EMDEC injection computers for troubleshooting, diagnostics and repair. The traction inverters, traction generator diodes, contactors and switchgear, and feedback devices have also been designed into the centralized locker. As shown in Figure 7, the electrical locker allows technicians to work comfortably inside the locker.

Additional maintainability highlights

In addition to the maintenance highlights previously discussed, there are many enhancements to all of the sub-systems that also contribute to improve maintainability and performance of the SD70ACe locomotive model:

- The inverter control system has been simplified. Previous design utilized two non-EMD traction inverter computers with over 50 modules. With the addition of just three additional computer modules, the existing EM2000 computer has replaced the two inverter control computers.
- The traction rectifier fuses have been eliminated and replaced with a solid-state protection system. At the same time the traction rectifiers themselves have been relocated from the traction alternator air box to the electrical locker. This significantly improves access and climate for the rectifiers and as a side note improves access to the traction alternator slip rings and brushes.
- Easier isolation of traction motors for insulation testing. The technician no longer needs to break the leads under the locomotive to Megger the motor. This procedure can now be conducted from the side of the locomotive.
- Introduction of a battery saver system allows the locomotive electrical system to automatically shed non-essential battery loads in standby mode by disconnecting high load devices after a time delay.
- The traction inverters utilize IGBT (insulated bi-polar biased transistors) for traction control. Previous systems were GTO (gate turn-on) devices. The IGBT technology allows for less wiring and equipment to main-

tain.

- Air starting allows higher cranking speeds, which ensures more reliable starting. Discharged batteries no longer affect starting. Locomotives with air starters can be easily jump started from any air source including another locomotive or shop air source.
- The engineer controls have been simplified. An AAR style control stand and standard AAR controller mechanism replaces the desktop controller.
- A HTSC-2 (high traction and speed, Co-Co) bolsterless truck is basic equipment on the SD70ACe and SD70M-2 locomotive models. The HTSC-2 truck is derived from the highly successful HTRC self-steering truck assembly. The HTSC-2 truck is designed with reduced components, minimal wear surfaces and hydraulic damping.
- Removable side sill section to facilitate easier air compressor removal. This feature allows the air compressor to be safely and efficiently off loaded with a forklift.

Summary

The goals were set; build an environmentally compliant, simple, reliable, durable and maintainable locomotive product. The SD70ACe and SD70M-2 model locomotives have met all of these goals in a cost effective, easy to maintain package. Electro-Motive Division is proud of these environmentally friendly locomotive models and wishes you too will soon have the pleasure of experiencing their performance first hand.

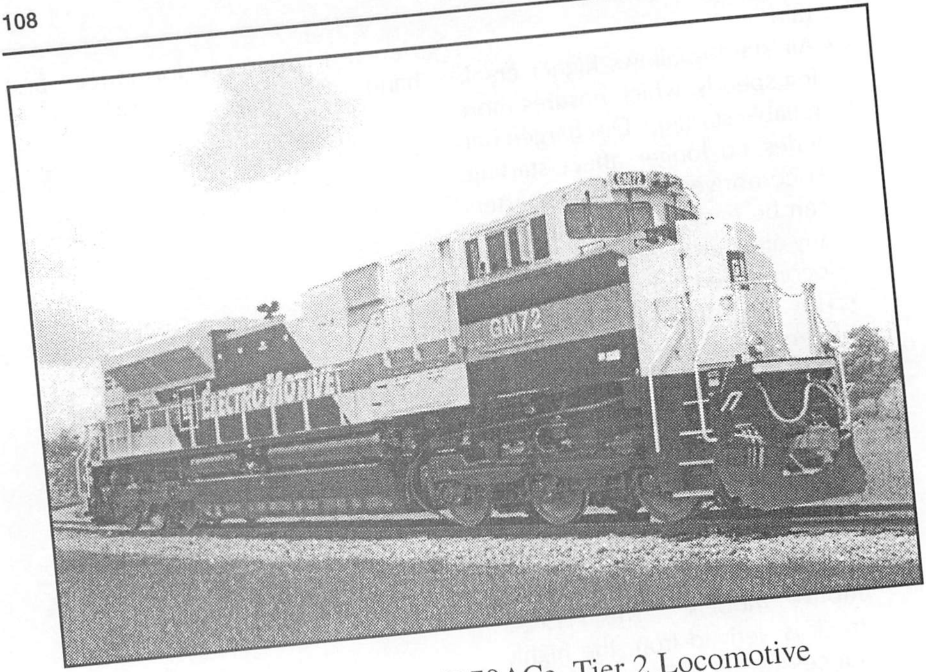


Figure 1A - EMD SD70ACe, Tier 2 Locomotive

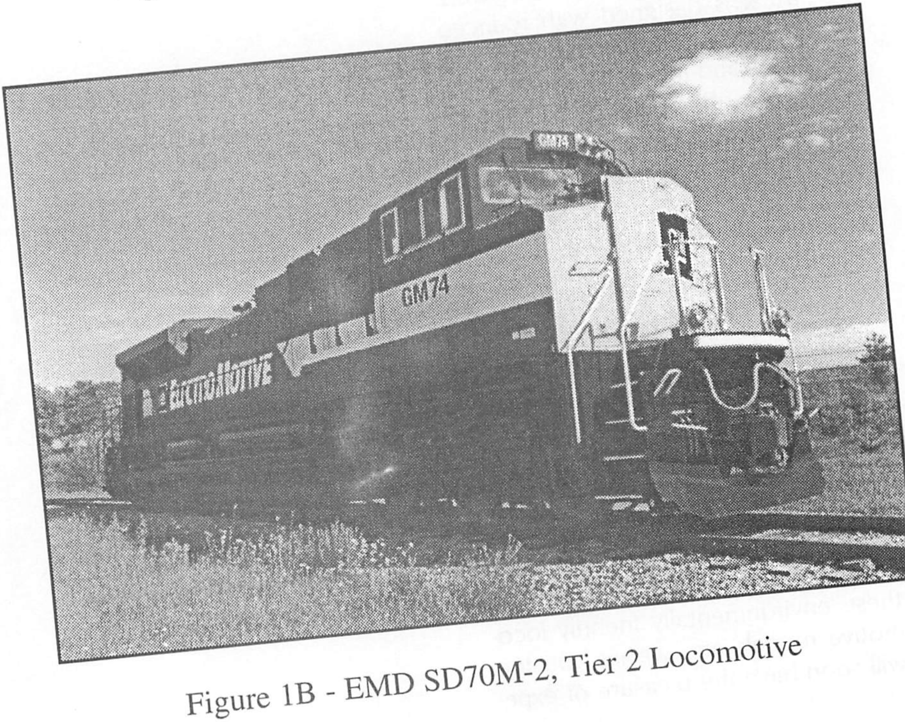


Figure 1B - EMD SD70M-2, Tier 2 Locomotive

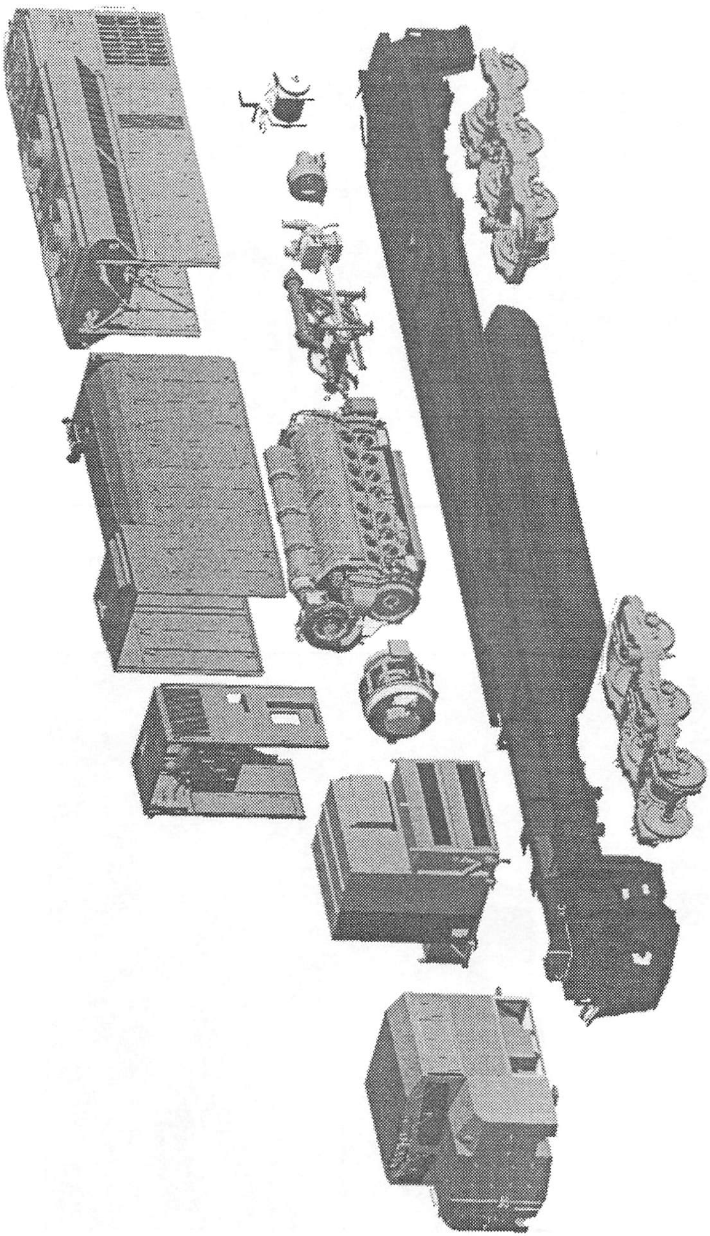


Figure 2 - SD70ACe Modular Architecture

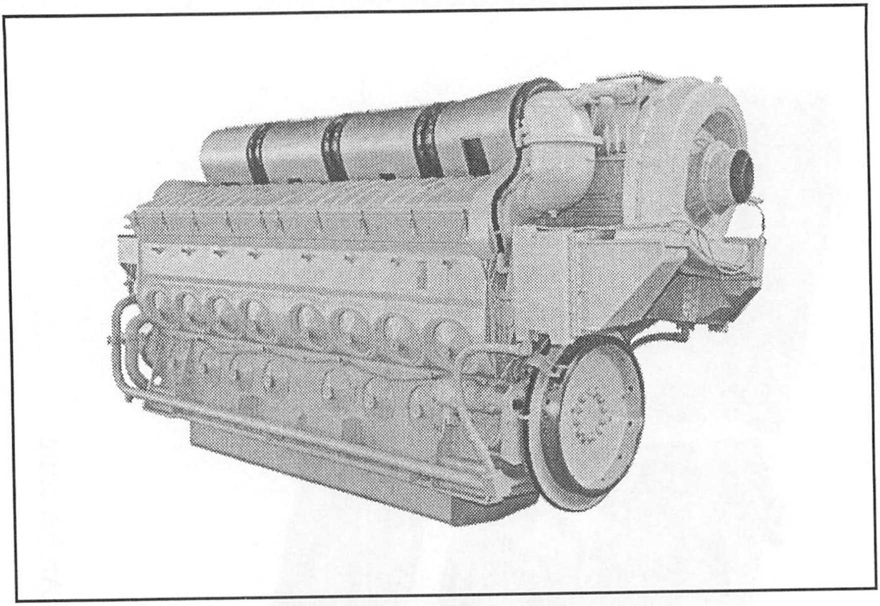


Figure 3 - 16-710G3C-T2 SD70ACe Diesel Engine

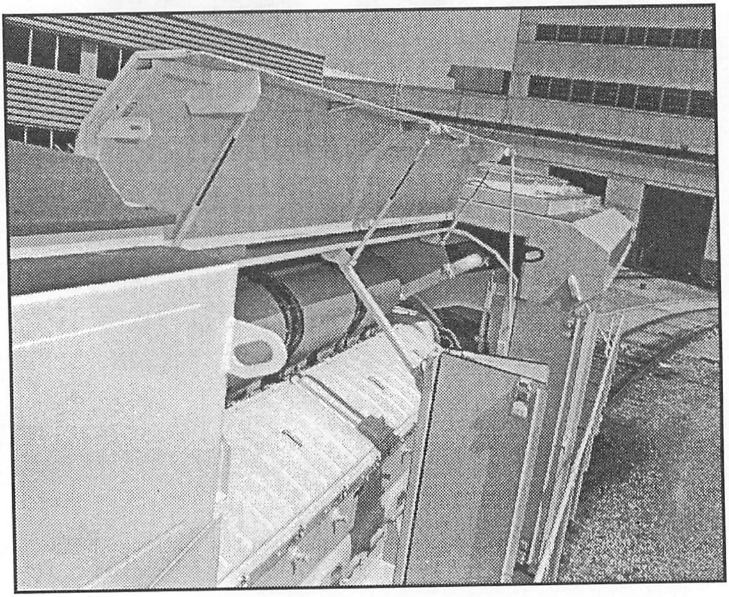


Figure 4 - Improved SD70ACe Engine Access

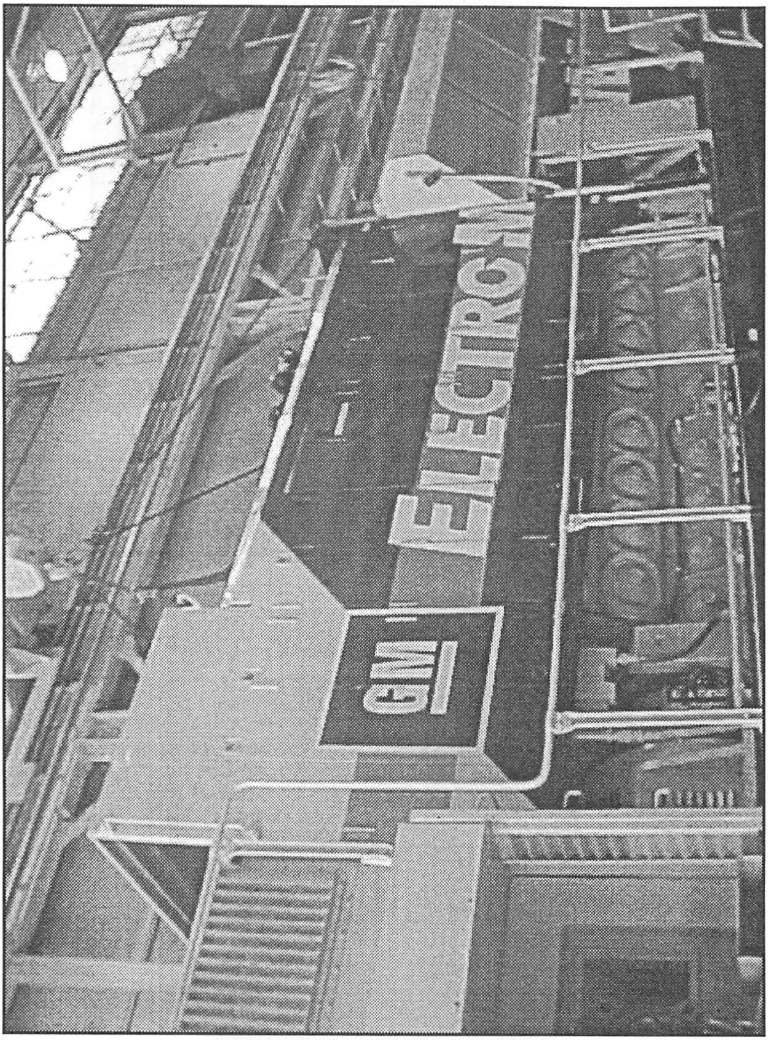


Figure 5 - SD70ACe Engine/Generator Hood Structure Removal

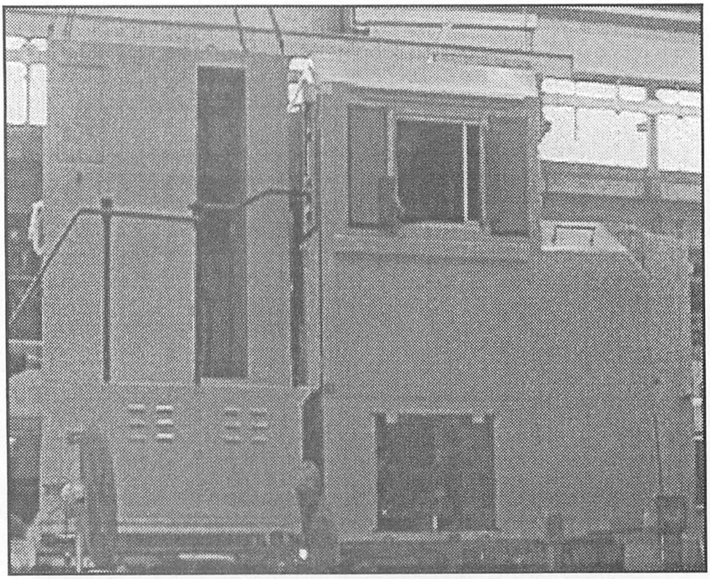


Figure 6A - SD70ACe Cab and Electrical Locker Modules

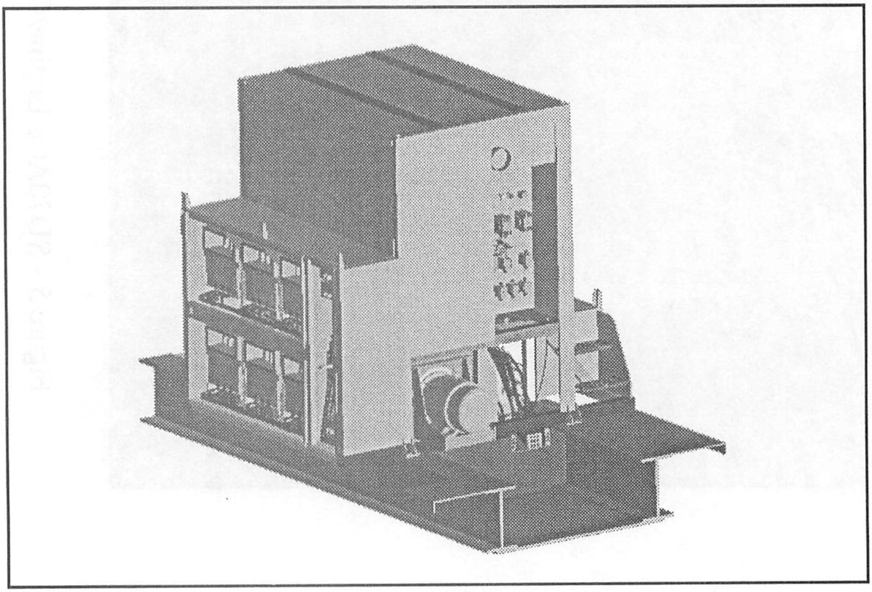


Figure 6B - Geometric Rear View of Electrical Locker

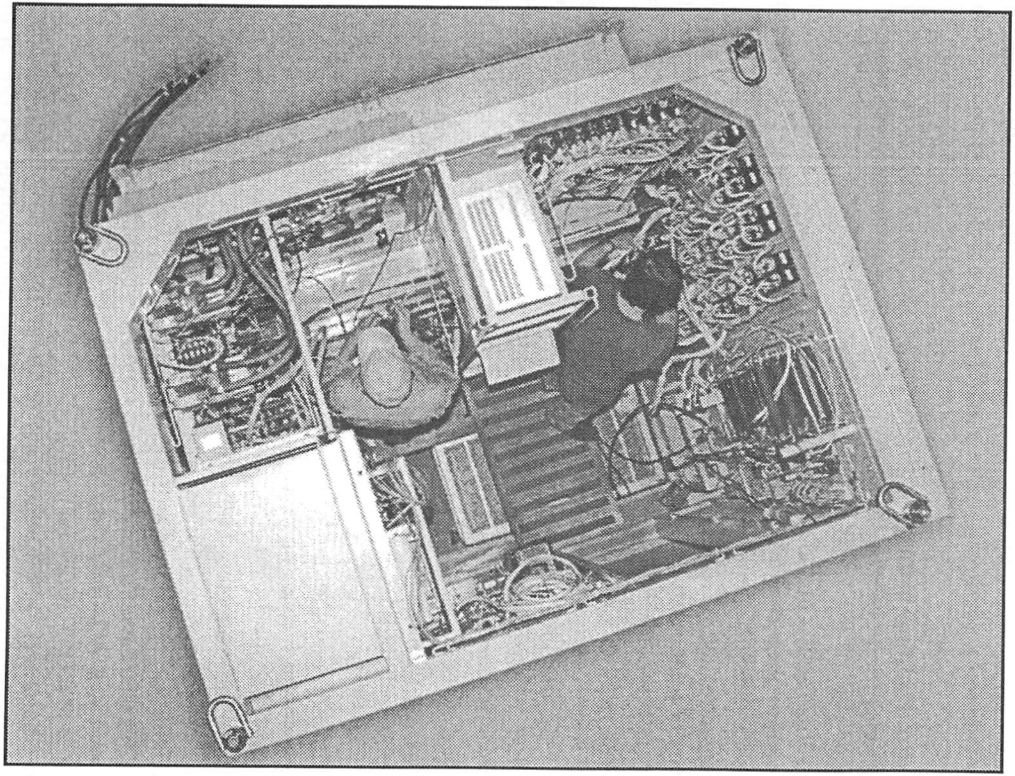


Figure 7 - Top View Electrical Locker

III. BEST PRACTICE SERIES FOR REGIONAL & SHORTLINE RAILROADS

MANAGING LOCOMOTIVE WHEEL WEAR

Written by
David Rutkowski, CMO
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Introduction/History

The development of the flanged wheel was one of the most significant advancements in railroading. At first, wood strips or strips of iron rail were attached to planks to keep the wheels tracked. This style of wheel was not flanged. This created a flange for the plank instead of the wheel. Soon after, various forms of bearings were used to keep wheels tracked. By the time it was determined that the steam engine was more efficient than horses and oxen, the flanged wheel riding on wooden or iron rails on planks had developed into the basic flanged form we use today.

There have been other innovations in wheel design. The tread went from being flat to being tapered. The wheels are beveled with the smaller diameter towards the outside of the wheel and curved towards the flange. This is known as a hyperbole (one wheel will ride up its rail and the other will ride down its rail). The different diameters of the wheel in contact with the rail compensate for the distance of travel, necessary to negotiate the curves. This is the same effect in an automobile that is compensated by a differential rather than a solid axle. When wheel flanges bump the rail head, the resulting metal on metal contact wears the wheels.

Regulations

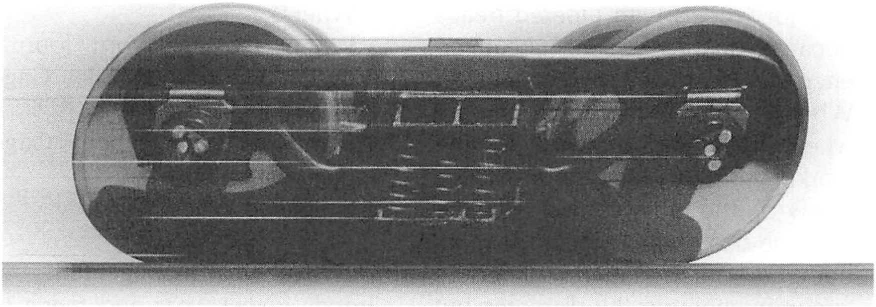
The Code of Federal Regulations (CFR) 40 Appendix To Part 229-Schedule of Civil Penalties Subpart C - Safety Requirements 229.75 wheel and tire defects clearly states that the following defects are in violation.

- On slid flat or shelled spot(s) 2 1/2″ or more but less than 3″ in length.
- Two adjoining spots each of which is 2″ or more in length but less than 2 1/2″ in length.
- Two adjoining spots each of which is at least 2″ in length, if either spot is 2 1/2″ or more in length.
- A gouge or chip in a flange more than 1 1/2″ in length but less than 1 5/8″ in length and more than 1/2″ in width but less than 5/8″.
- A gouge or chipped wheel flange 1 5/8″ or more in length and 5/8″ or more in width.
- A broken rim or a seam in the tread and any crack is condemnable.

All of these defects can be measured by using the wheel gauges illustrated in Figure 1-D.

Wheel measurements

When truing a wheel by means of a wheel lathe (wheel set out of the locomotive) rather than a wheel-truing machine (under slung machine that trues the wheels while they are installed in the locomotive truck), the circumference of the wheel must be measured using a wheel tape or



by using newly innovated electronic measuring devices. A wheel tape is a tool that is specially calibrated and is made from spring steel. One end of the tape is fastened to a brass casting. The tape has four legs, which fit against the wheel flange to ensure that the tape is properly placed on the tread for accurate measurement at the correct point on the tread. This is particularly necessary for wheels with tapered treads because of their varying circumference due to their tapered contour. When the tape is placed around the wheel tread and drawn tight, the marking on the tape opposite the arrow on the brass casting indicates the tape size of the wheel. The number read from the tape is neither the circumference nor the diameter, but may be converted to either by using the tables in the back of the AAR's Manual of Standards and Recommended Practices, Section G, Wheel and Axle Manual. For example, the tape number 333 indicates a diameter of 40 inches. Tape used for freight car wheels are 10 1/2 feet long and accommodate wheels sizes up to 38 43/64. A longer wheel tape capable of measuring wheels up to 45 inches is required for locomotive wheels.

The wheel defect gauge is used as a *go-no-go* measuring device. Cut outs on this tool will enable the inspector to determine whether or not the wheel has a thin flange. This tool also has detailed notches representing measurements for the determination of flat spots.

The Standard Wheel Gage and the Simplified Wheel Gage are designed so that when they are applied to a shell with acceptable flange height there will be clearance between the gage and the apex of the wheel flange. If there is no clearance, the flange is too high and must be trued or changed.

Wheel measurement gages that are typically used are:

- Circumference Measure for 38 in. to 52 in. Steel and Steel-Tired Wheels
- Wheel Defect, Worn Journal Collar and Journal Fillet Gage (Figure 1-D-F)
- Standard Steel Wheel Gage (Figure 1A)
- Simplified Wheel Gage

Wheel wear management

Trendy wheel wear and trying to predict when wheels will wear out can help predict and control costs associated with wheel change outs. To forecast costs and change outs, measure wheels when new to start a history. Measure wheels every 92-day FRA inspection. Be sure to measure and record the tread thickness, flange height, flange thickness and tread wear.

When measuring a wheel flange, the measurement is in 16th's of an inch. For every 16th of an inch flange wear, a 16th of an inch must be taken off of the tread to true the wheel. For example, when using the steel wheel gage to measure a flange thickness, if measuring point reads "7", that corresponds to 7/16 of an inch which needs to be removed from the tread. The Federal Railroad Administration (FRA) regulations dictate that a wheel with a tread size of one inch is condemnable; if the wheel in the example above was 1 $^1/_2$", then the wheel can be trued. If the wheel tread size was 1 $^7/_{16}$", then truing the wheel tread would result in a tread thickness of 1", which is condemnable. Proper wheel wear management means using the wheel until the tread size is 1", at which point it is condemned. This maximizes the life of the wheel and stretches your costs over a longer period of time.

Typically a wheel set should be trued (i.e., remove material from a wheel to bring a wheel into AAR/FRA profile compliance) after achieving a flange thickness of a 5 on the standard wheel gage, as shown on Figure 1A. Every 1/16" of wear adds costs. A few years ago, interchange rules provided for a credit or charge for the difference in rim thickness going in versus coming out of a freight car. Costs per 1/16" at that time were, $16 per 1/16" for one wear and $34 per 1/16" for two wear wheels. Locomotives wheel truing could easily cost $50 per 1/16" with all of the added hardware that must be removed to change a wheel and to true a wheel on a wheel truing machine.

When wear is observed, identify the causes. Captive locomotives always headed in the same direction will cause uneven wheel wear. You must monitor your locomotive fleet and periodically wye your locomotives.

There could be a possibility that the rail on your railroad is worn. Rail grinding not only enhances rail life but provides other benefits as well. Rail grinding is a rail maintenance procedure whose primary objective is to extend the rail life. This procedure uses on-track machinery. The rail head is ground using rotating abrasive grinding stones acting on various angles and various pressures. This process removes surface defects, corrugations, burrs, spalling, shelling, etc. from the rail head. The grinding of the rail head re-shapes the rail head to a desired cross section profile which optimizes the rail-wheel interaction for maximum all round advantage. It will reduce wheel shelling and wheel spalling, reduce noise and wheel squealing, reduce wheel wear, and reduce derailment potential just to mention a few of its benefits.

Utilizing wheel flange lubricating systems can reduce general wheel wear. Lubricating systems are usually self contained and service requires adding lubricating fluid or lubricating sticks. These systems have been around for years and some in the industry have had great results in using them.

Ride the rails to troubleshoot potential human errors during locomotive operations. Excessive independent braking in some conditions could lead to spalling. Leaving hand brakes applied can lead to flat spots. While riding the rails observe the rail conditions at the same time.

Wheel shelling and spalling have been misdiagnosed for many years. Shelling is caused by fatigue failure of the wheel tread due to mechanical overloading. The chance of a wheel shelling is very remote since the wheels are designed for the locomotive weight range. Wheel slipping or sliding and the resulting brief intense heating of the wheel tread causes spalling. Spalling transforms the wheel material from pearlite to austenite. When the wheel is quenched against the rail, the wheel material becomes martinsite which leads to small thermal cracks and subsequent loss of tread material due to repeated mechanical loading as the wheel rotate. Spalling and mild shelling may look very similar, but the key distinction is the heat input involved in spalling.

Best practice reasons to true wheels

- Condemnable flange wear
- Preventative wheel loss by truing ahead of condemnable wear limits
- Flat spots
- Shelling
- Spalling
- Overheat and thermal cracks
- Built up tread
- Wheel diameter mismatched on the same axle
- Hollow tread

Other reasons to true wheels

- Reduces derailments
- Reduces rail wear
- Improves ride

What do I need to know about truing locomotive wheels?

- What is your wheel profile? (AAR Manual of Standards Section G). Depending on the profile that the locomotive has in comparison to the vendor could mean more material would need to be removed from the wheel to be AAR, FRA complaint.
- Have a contingency plan in case the wheel needs to be scrapped.
- Get a detailed quote before sending the locomotive. Some vendors may turn a wheel in the traction motor. This would eliminate the freight charges associated with moving the entire locomotive.
- If the locomotive is equipped with EMD or Hyatt journal boxes, this would be an excellent time to have the vendor check and or adjust the lateral movement of the axle (EMD Maintenance Instruction 1522) since the journal box caps are removed in the wheel truing process.
- When wheels are turned to return them to an acceptable AAR tread profile they often show what is called a *witness groove.* Such grooves are allowed by AAR to prevent a user from being required to remove more service metal then is necessary to return a wheel to satisfactory service. If enough tread surface is removed each time to eliminate a witness groove then usable service metal is removed and the life of the wheel is considerably shorter than would be the case if a witness groove were left. AAR has limiting criteria for witness grooves which are used to determine the maximum acceptable size. Limiting criteria are listed in AAR Manual of Standards and

Recommended Practices Section G - Part II, Rules 1.5.2, paragraph 2.4.3. and figures 4.47, 4.48, 4.49, & 4.50.

Conclusion

The type of service that locomotives are used in will vary. Considering the variations, locomotive wheel sets should last 5 to 6 years. Managing wheel wear by monitoring the rate of wear will extend the life of the wheel. Be familiar with tell tale signs of conditions causing wheel wear. Be able to identify spalling condemnable limits by visual inspections. Make sure that price quotes for truing wheels are accurate. Have a contingency plan in place if the wheel set you are having trued or turned is scrapped.

Many wonder how railroads came to the standardization of the current rail gage. Below are comical but informative reasons why our railroads tracks are 56.5" wide.

American railroad tracks are 56.5" wide (the "gauge") because the English built the first railroad in America and they used that width. Why did they use that width? Because the first rail lines were built by the same people who built the pre-railroad tramways, and that's the gauge they used. Why did "they" use that gauge then? Because the people who built the tramways used the same jigs and tools that were used for building wagons which used that wheel spacing.

Why did wagons have that particular odd wheel spacing? Because older wagon ruts throughout England used that spacing, and if they changed it, wagon wheels would break falling into or being forced out of the old ruts, which were 56.5" wide.

The old ruts were that size because the roads were built by Romans, who arrived in England in 54 B.C. and left about 400 A.D. Their wagons, and their chariots before their wagons, used that spacing, and that spacing was used all over Europe and wherever Rome conquered, because their wagons used the identical wheel base everywhere. So the modern railroad track width derives from the Roman chariot.

Why was the Roman chariot track width 56.5"? Because that was the width of a chariot that would equal the width of two "standard" Roman horses. Specifications and bureaucracies live forever!

Such curious dimensions continue today. A space shuttle sitting on its launch pad has two big booster rockets attached to the sides of the main fuel tank. These are solid rocket boosters, or SRBs, made by Thiokol at their factory in Utah. The engineers who designed the SRBs might have preferred to make them a bit fatter, but the SRBs had to be shipped by train from the factory to the launch site. The railroad line from the factory had to run through a tunnel in the mountains. The SRBs had to fit through that tunnel. The tunnel is just wide enough to accommodate a railroad car, and the railroad track is about as wide as two horses' behinds, (and we now know why) so the booster rockets were made to fit.

The major design feature of what is arguably the world's most advanced transportation system was determined over two thousand years ago by the width of a horse's ass! *(Truth or Fiction.com).*

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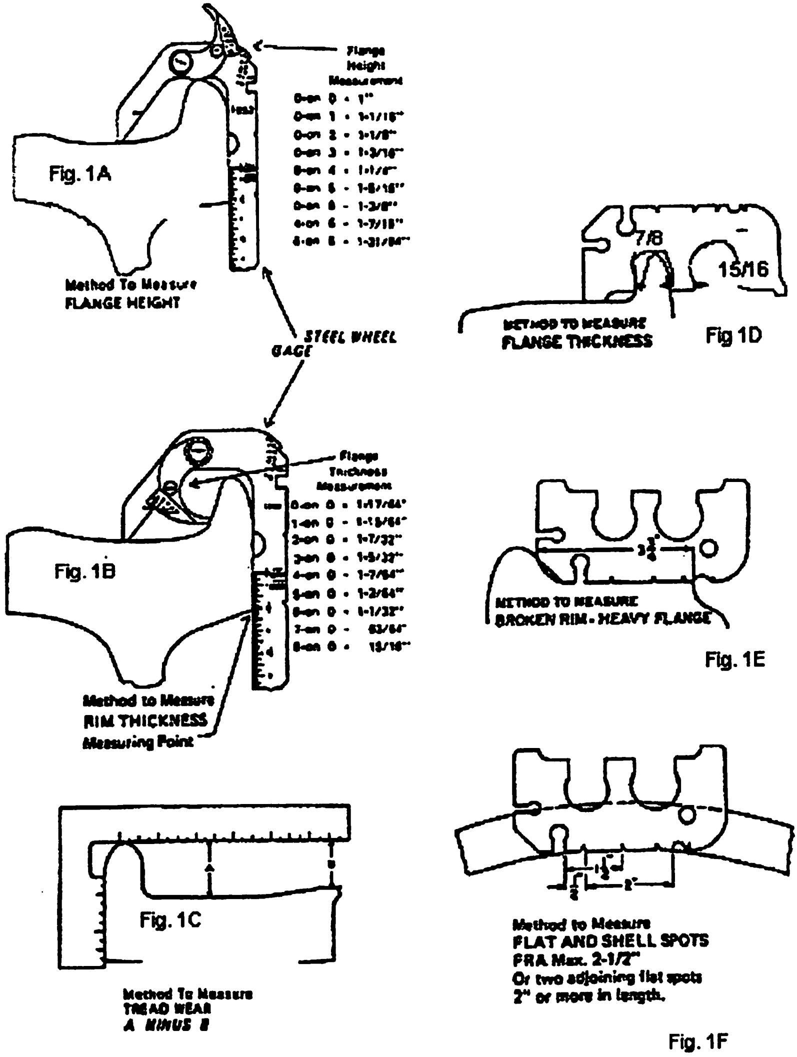
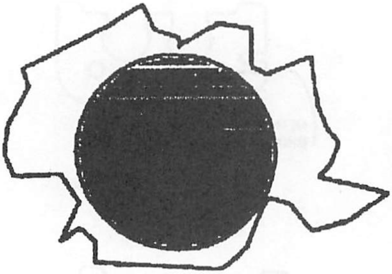


Figure 1

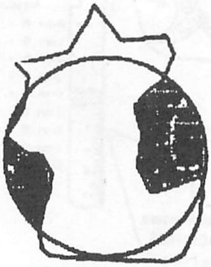
Standard Wheel Gage
Wheel Defect, Worn Journal Collar and
Fillet Gage

Shelled tread: Whenever any shell or spall is 1 inch or more in diameter, the wheel must be removed from service. “Islands” of original tread surface metal contained in the shell or spall will not be considered as part of the area of the shell or spall.

See illustration below:



CONDEMNABLE



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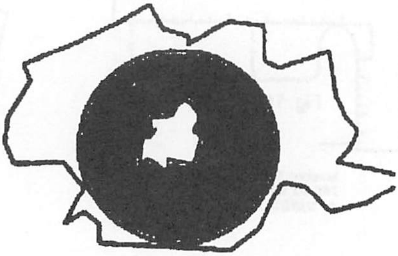

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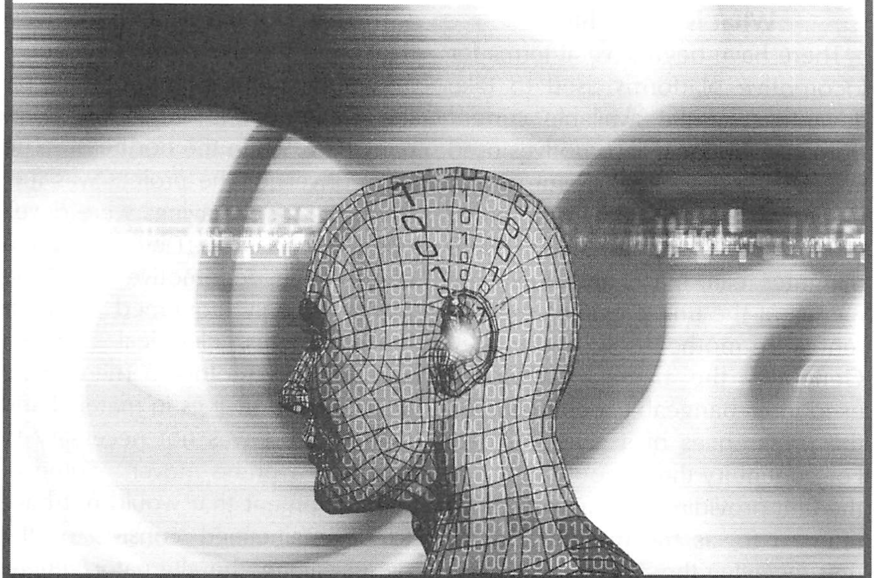

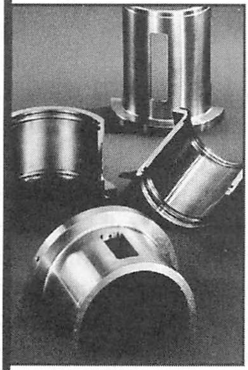

IV. MAINTENANCE SAVINGS - MOTHER/DAUGHTER UNITS

Prepared by
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&
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What is a daughter?

There have been several terms for locomotive platforms used to take advantage of the available current from conventional locomotives used in low speed service. Some of the names of the unit taking advantage of available electrical current were daughter, calf, mate, and slug. The names of the unit providing the current were mother, cow, and master. Generally, the names have been used interchangeably, depending on the preferences of a given railroad. For continuity throughout the paper, the unit providing the current will be referred to, as the mother and the unit receiving the current will be the daughter.

Conventional locomotives have excess generator/alternator capacity at low speeds that cannot be utilized. The mother-daughter combination is able to utilize this low speed capacity in yard/shifter/transfer service or in the application of this paper, in a service where speed is not the highest priority. Generally, the current available to the daughter has been turned off at transition, somewhere between 30-35 MPH. This has been the limit of a conventional locomotive to generate enough current to power 8 or 12 motors at speeds above 35 MPH.

There is a population of daughters in use by several railroads in a variety of service today. CSXT has some 193 slug sets in yard, local and branch service. UPRR has 14 sets primarily in yard service with three sets in road service. BNSF and CPR also use slug sets in several applications.

The basis for this paper is an investigation of the use of mother-daughter combinations built to operate on the Genesee and Wyoming Company (G & W) in the northeast. The main driver for the project was fuel savings. Added savings were developed for this project by replacing a conventional locomotive with one that was only equipped with air brake systems, electrical controls, and traction motors. There were considerable savings in material and time when it was not necessary to maintain a prime mover. Some of the equipment that would not have to be maintained consists of the diesel engine, the alternator/generator, the batteries, the air compressor and possibly the operator's cab.

The definition of a daughter would be a locomotive platform that could receive current from the conventional locomotive used to power the extra traction motors, increasing the tractive effort of the mother-daughter combination. Generally, daughters were built on older locomotive frames, utilizing varying degrees of the original car-body. Daughters needed to have ballast to replace the weight of the prime mover, alternator/generator and air compressor. One of the bonuses of the mother-daughter combination is the added braking of both the air and dynamic systems.

Daughters have been equipped in many combinations of equipment. Naturally, the first choice would be the number of axles used. Most daughters were of the four-axle configuration. Daughters started out as a way to add braking force for moving cars in yards without having the air systems operable in the cars. The fully equipped daughter would have an operator's control cab, air brakes, dynamic brakes, and traction motors. Historically, most mother-daughter combinations have been used in yard, local, or transfer service. A few Class I railroads have used mother-daughter combinations, but today, with the move towards high-speed, high-density traffic lanes this practice has just about been eliminated. The potential for this type locomotive service primarily lies with short line operators with specific applications and territories.

The Genesee & Wyoming project

In 2000, the Genesee & Wyoming Company started investigating the possible use of mother-daughter combinations on specific properties in over-the-road freight operations. The project was to investigate whether or not a mother-daughter set could take the place of two conventional units in dedicated service. The major benefit for this substitution of power was to save fuel. The service was limited to a section of railroad that was a low volume line that did not handle time sensitive freight. Several fuel saving options were tried prior to the development of the mother-daughter concept.

After the conceptual plan was agreed upon, the specific design was developed and contracted to build seven sets of mother-daughters. The units were to be utilized in the G & W Canadian region. Four sets were sent to the St. Lawrence and Atlantic Railroad and three sets were sent to the Quebec and Gatineau Railroad.

The project has shown excellent results so far in fuel savings. The specific savings is in Figure B. The savings in fuel so far have been about 38.3% or 1576 gallons per day. And, there are other savings for maintenance and overhaul costs that will be discussed later in this paper.

The Genesee & Wyoming locomotives

The G & W locomotives selected for this project were GP40 for the mothers and either GP38 or GP 40 for the daughters. The mother-daughter locomotive candidates were completely rebuilt both from the frame up and frame down. The mother and daughters were both equipped with motorized switchgear and 62-15 traction motor gearing.

The daughters were ballasted for a total weight of 273,000 pounds each. The daughters were equipped with a fully operational control cab, full car-body, fuel tank that has operator initiated transfer, 26L brake equipment, extended range dynamic braking, and D77 traction motors. Being control cab equipped, switchgear, air brake, control stands and traction motors were all re-built to specific requirements for trouble free life and easy maintenance.

The mothers were re-built with 645E3 prime movers, AR10/D14 main alternators, 19 KW auxiliary generators, WBO air compressors, and 26L air brake, extended range dynamic brake and D77 traction motors. The mothers were equipped with microprocessors; allowing for optimum control of each mother-daughter set.

Overview of St. Lawrence and Atlantic Railroad

The test section of the St. Lawrence and Atlantic Railroad is made up of 180 miles of mainline from Aubrun, Maine to Richmond, Quebec. The Western Portion of the mainline resides in Quebec. Starting in Auburn, the terrain consists of rolling hills west bound through the United States with forty miles of down grade when crossing into Quebec. The eastbound terrain is undulating in Canada with a constant rise in elevation for forty miles back to the United States. The grade is about 1.3% with numerous curves prior to reaching the summit.

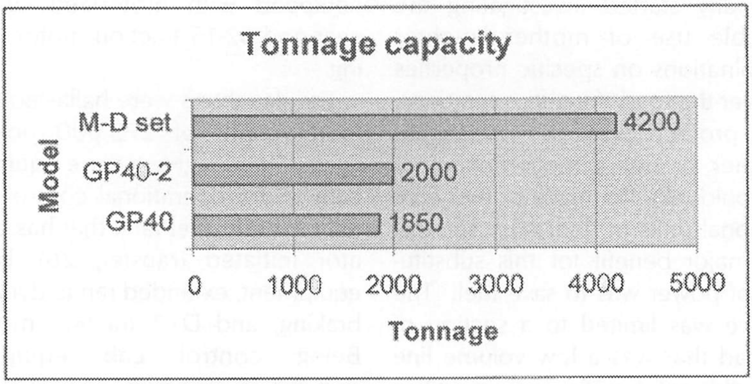
Track speed averages 30 MPH, with a tonnage restriction of 7500 in both directions to minimize roadbed stress. Average train length is held to 5200 ft. east bound and 7000 ft. westbound.

Annualized cost comparison

Scheduled maintenance items on an annual basis for cost review do not include brake shoes, TM lubricant or oil. Comparing two GP40 or GP40-2 to a mother-daughter set allows for a 30% reduction in material use. See Figure A.

Overhaul cost projections for major components

Cost analysis of two GP40/GP40-2 locomotives versus a mother-daughter set allowed for reducing future expenditures by $146,000 during a seven year overhaul cycle. The savings come from the fact that the daughter is not equipped with a prime mover, AR10, auxiliary generator and air compressor.



Tonnage comparisons

Mother-daughter set vs. GP 40 / GP40-2 single units. (See chart on previous page)

Gross ton miles comparison

Year 2003, GTM using GP40 and GP40-2 locomotives.

Year 2004, GTM after mother daughters were being used.
(Figure B).

Fuel efficiency increase
2004 vs. 2003

Using Figure B, we see that the gross ton-miles moved by a gallon of fuel increased between 20% and 48%. The dip in fuel efficiency that occurred in April 2004 is directly related to the equipment out of service time to allow for additional upgrades to be performed.

- January 20.2%
- February 34.9%
- March 47.9%
- April 37.8%
- May 43.3%

Conclusion

Although only a few months of testing have been completed, the mother-daughter implementation on the St. Lawrence & Atlantic Railroad has been a success. The G & W has experienced about 40% reduction in fuel use for comparable tonnage hauled per train. Other positive results have been reduced cycle times for scheduled Federal inspections, and lower material and labor costs with the mother-daughter combinations when compared to two conventional locomotives. Increased crew comfort and a cab-equipped daughter have mitigated stress issues with T & E employees.

The mother-daughter implementation has reduced future capital expenditures by 50% for the set when compared to two standard locomotives.

If there is an operating scenario where the mother-daughter concept might work on your railroad, given the benefits realized with this project, it would be well worth investigating the feasibility of applying this concept.

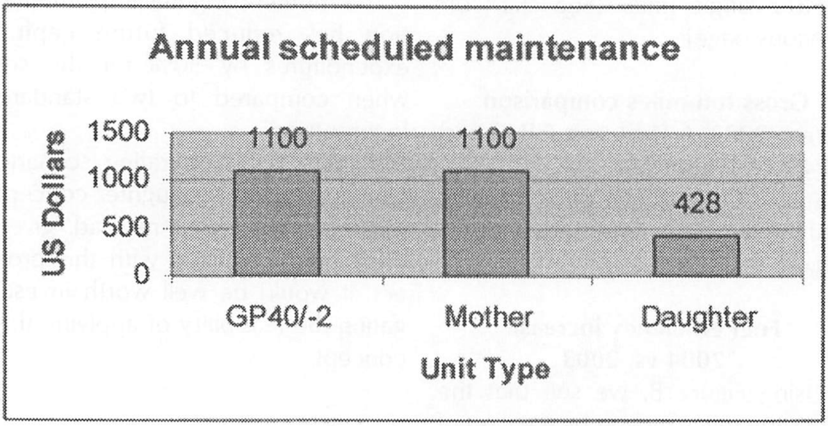
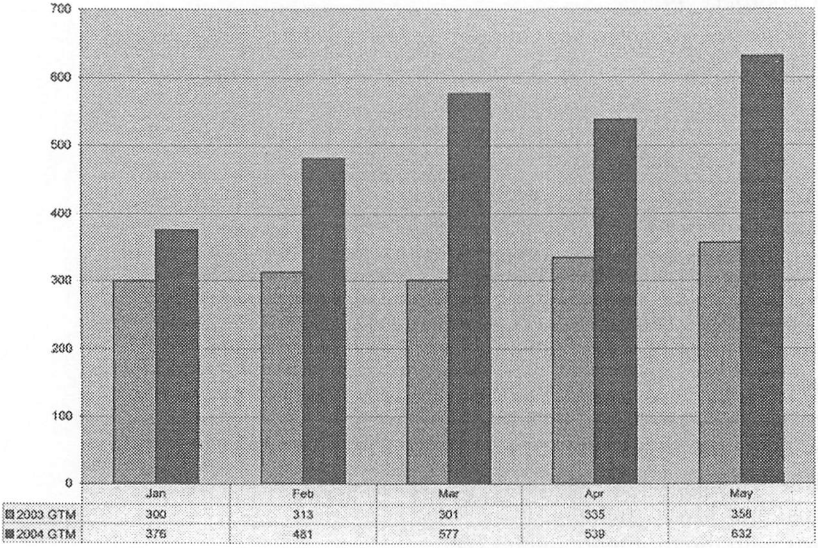
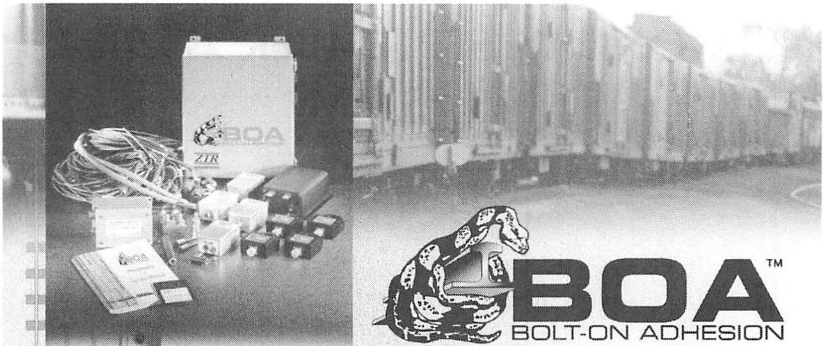


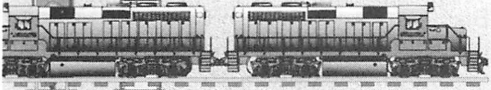
Figure A



	Jan	Feb	Mar	Apr	May
▨ 2003 GTM	300	313	301	335	358
▩ 2004 GTM	376	481	577	539	632

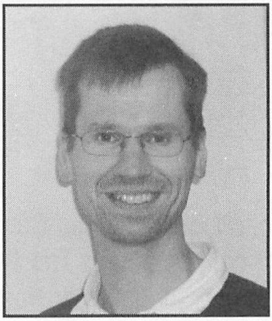
Figure B





REPORT OF THE COMMITTEE ON DIESEL ELECTRICAL MAINTENANCE

MONDAY, SEPTEMBER 27,2004
3:45 P.M.



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NOTE: Mike Cross, Andy Fonville and Brad Steffel are new committee members

PERSONAL HISTORY

Ron Bartels,
Manager Electrical & Engine Systems Group
VIA Rail Canada

Ron has always lived in Montreal, Quebec. He was born there in 1965. He attended McGill University and graduated in 1988, receiving a Bachelor of Engineering degree in Electrical Engineering.

He began his career at CN Rail, working for five years in the Motive Power and Car Equipment department. In 1993, he left CN for AMF Technotransport. As Senior/Principal Electrical Engineer, and later, manager of testing at AMF, Ron headed the Electrical Engineering and Test Departments, supporting various locomotive and passenger car refurbishment programs.

In January, 1988, Ron took the position of Manager, Electrical Systems at VIA Rail Canada. Now at VIA, Ron manages the Electrical and Engine Systems Group, which is responsible for the maintenance program and configuration of all electrical and engine systems on VIA's locomotives and passenger cars.

Ron has been a member of the LMOA Diesel Electrical Maintenance Committee since 1998.

A recreational badminton player, Ron also enjoys camping, cycling and cross-country skiing with his wife Karen and daughters Kaitlin and Hannah.

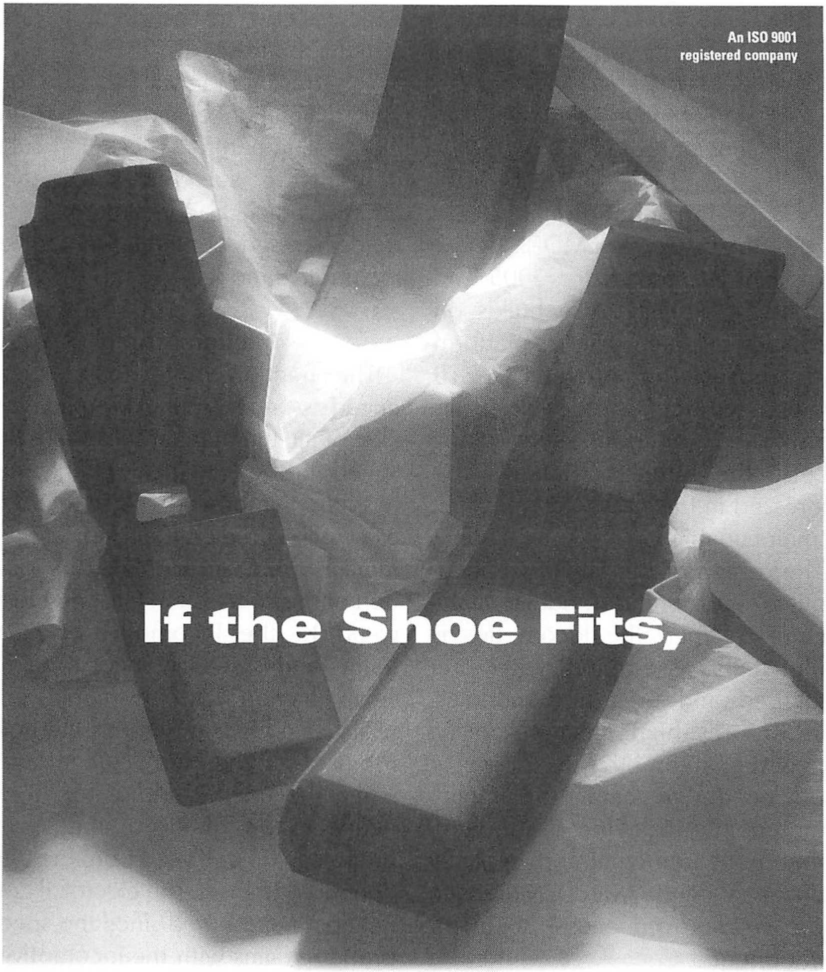
THE DIESEL ELECTRICAL MAINTENANCE COMMITTEE WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO THE FOLLOWING COMPANIES FOR HOSTING AND SUPPORTING THE COMMITTEE MEETINGS IN 2004

NATIONAL ELECTRICAL CARBON
GREENVILLE, SC – FEBRUARY 2004

VIA RAIL-CANADA
MONTREAL, QUEBEC – JULY 2004

THANK YOU,

DIESEL ELECTRICAL MAINTENANCE COMMITTEE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I. ELECTRICAL MAINTENANCE BENEFITS OF THE SD70ACe

Written by
Dean Becker, Design Engineer - Electro Motive Division, General Motors Corp.

Introduction

The SD70ACe is EMD's Tier 2 compliant AC model for 2005 and beyond. The SD70ACe builds on the highly reliable 70 Series platform and utilizes the proven 16-710 engine. Although the design of this locomotive encompassed many facets, the subject that will be addressed in this presentation is that of maintainability.

The design of the SD70ACe locomotive incorporates modular architecture. When the locomotive is built, it is assembled with pre-equipped and pre-tested modules. This ensures high initial reliability. Once the locomotive is in use, a modular design helps to simplify maintenance activities. Indeed, component removal and replacement is straightforward. Moreover, there is improved access to major components.

Figure 1 illustrates the modular design of the locomotive. Figure 2 shows a layout for the removal of the main generator. Once the generator hood is removed, the generator can be lifted out without having to remove the engine or the turbocharger.

There is access to smaller components, too. Figure 3 shows the engineer's workstation. Note that access to the display screen is not inhibited by a desktop controller. Also, a rear panel provides improved maintenance access to the control stand terminal boards.

This presentation will describe specific maintenance features that are electrical in nature. These particular items were selected since they address practical concerns that railroads have encountered with earlier locomotive models.

Traction Motor

The traction motor has experienced several significant changes. First of all, the manner in making the speed probe electrical connection has been improved. Instead of a twist-lock connector, a solid ring terminal is used. Additionally, the location of the connection has been relocated to the locomotive's underframe, and is actually made within a small junction box. This application provides a cleaner, less hostile environment for the interface. At times when the traction motor (or truck) needs to be removed, the speed probe can be unbolted from the traction motor frame. The electrical connection is preserved since the speed probe remains with the locomotive.

Secondly, improvements have been made to the motor's insulation. On the outside of the traction motor, thicker insulation is used on the traction motor cables. The new insulation is 60% thicker, which provides a greater degree of armoring. Inside the traction motor, Teflon insulation has been added to the stator windings to improve its robustness.

Finally, the manner of connecting traction cables has been simplified. Instead of traction motor leads terminating in a remote, combination splice (which is protected by heat shrink tubing), cables are routed directly to the traction inverters. Since individual traction motor circuits are preserved, the process of tracking down a grounded traction motor is simplified.

Locomotive wiring

Wiring provides a critical function on today's locomotives; it serves as the electrical interface between components. A significant example of this is the hundreds of wires that provide the input and output signals to the control system's computer. Locomo-tives use a large number of wires and cables that traverse the entire unit. This vast network has led to some field problems with the wires or with their interconnections. With this in mind, the subject of locomotive wiring was considered during the development of the SD70ACe.

First of all, an electrical locker was designed as the repository for the majority of the electrical components. Hardware previously located in various places throughout the locomotive now resides in the locker. This includes the items formerly within the AC cabinet, the inverter cabinet, and the auxiliary power converter cabinet, as well as the EMDEC computers and the traction rectifiers. The close proximity of the electrical hardware makes the wiring quite straightforward.

Secondly, the locker provides a controlled environment for the electrical hardware and the associated wiring. These items are shielded from the harsh environment of the outdoors. Also, filtered air is used to maintain a small positive pressure to help keep dirt from entering the locker.

Third, fewer wires are used, which is due to integrating the components within the electrical locker. The number of wires and cables has dropped about 14% from a previous model. Furthermore, many splices and connectors have been eliminated since direct wiring connections are made within the locker. And, many of the connections that go to the cab or elsewhere on the locomotive are made within the protective walls of the electrical locker.

Batteries

Maintaining locomotive batteries has been an ongoing task with locomotives. When batteries failed to perform in the past, a road failure was likely. Accordingly, several steps have been taken to lessen the impact that the batteries have on SD70ACe reliability.

Electric starting motors - the largest and most demanding load on the batteries - have been eliminated. Instead, an air powered starting motor is used. In addition, features such as Battery Saver and Automotive Engine Start/Stop, which further manage battery loading, are included within the EM2000 control system.

With regard to maintainability, access to batteries has been made convenient. The batteries are integrated within the electrical locker - located under the walkway. Top, hinged doors are provided for battery inspection and filling. Side doors are provided for battery removal. Figure 4 depicts the battery box layout.

Main generator slip ring brushes

Inspecting and changing the brushes associated with the traction alternator and the companion alternator has been an undesirable maintenance task. Typically, access to the generator airbox was inconvenient. And once entry was gained, visibility of some brushes was obscured. Instances of road failure may occur when brushes wear out. In a few cases, some obscured brushes had worn out since they had been overlooked during a previous brush replacement activity.

For the SD70ACe, several changes were made to simplify the routine tasks of brush inspection and replacement. First of all, accessibility has been simplified. A single cover is used, along with four wing bolts. No tools are required to remove the cover. Secondly, once the cover is removed, there is plenty of room to view and handle all of the brushes. Figure 5 shows two views of the brush compartment.

Electronic air brake

The air brake system is mentioned in this presentation since it uses electrical hardware. On the SD70ACe, FastBrake™ is an integrated air brake system that uses Wabtec hardware in conjunction with the locomotive's FIRE computer. Some of the FastBrake™ system is shown in Figure 6.

Major braking hardware is easily removable. Items are held in place with four bolts and have a single electrical connector.

When an electro-pneumatic module is replaced, the FIRE computer checks that the correct software is installed on the module. If necessary, FIRE will reprogram the module automatically - without any intervention by the maintenance worker. This assures that the system software is at the correct revision level. Also, it simplifies stocking of spare modules since one module will work in all applications.

"No Defect Found" (NDF)

Electrical systems and their hardware have some familiar modes that are difficult to find. Sometimes a failure mode may be intermittent. (This is in contrast to a mechanical system where components may have broken or worn out). These types of failures are likely to cause a locomotive failure, yet not be discovered during troubleshooting activities. When this occurs, it is typically listed as NDF, which indicates that no defect was found. An objective of the SD70ACe design process was to reduce the number of NDFs.

One method to reduce NDFs is to reduce the number of components. This philosophy has been used throughout the SD70ACe. The output of the traction alternator has fewer components: The number of traction rectifiers has been reduced from sixty diodes to twelve diodes, and generator fuses have been eliminated altogether. (Generator fault protection is provided by the generator excitation chopper). Fewer auxiliary motors and blowers are used throughout the locomotive. The SD70ACe uses five blowers driven by four motors whereas a previous model had six blowers driven by six motors. Within the inverter system, two modules replace dozens of previous modules. Finally, as mentioned above, the total number of wires in the electrical system has been reduced by 14%.

Another method to reduce NDFs is to provide expert help during troubleshooting activities. EMD offers TechPro SD70ACe, which is an optional interactive diagnostic tool that assists a maintenance worker in troubleshooting a locomotive. The tool begins by evaluating the initial symptoms - typically error messages, crew reports, or possibly the results of a lube oil analysis. This leads to a list of components that are most likely to have failed. Next, the tool recommends related tests and specific troubleshooting activities. When work is done, and the results entered in, the tool will re-process the information to re-rank potentially failed components and then update the list of recommended tests. This is an interactive process that quickly converges to finding a defect.

Finally, keeping a constant watch on the locomotive can reduce NDFs. EMD's Intellitrain is an optional remote monitoring system that enables the systematic collection of important locomotive data. Critical events are visible when they occur, which enables maintenance work to be done before the situation escalates into a major problem.

Conclusion

The SD70ACe locomotive was designed with maintenance and serviceability in mind. Specific instances of this were described, particularly ones that are electrical in nature. Furthermore, some of the maintenance issues encountered on past locomotive models have been reduced or eliminated on the SD70ACe locomotive.

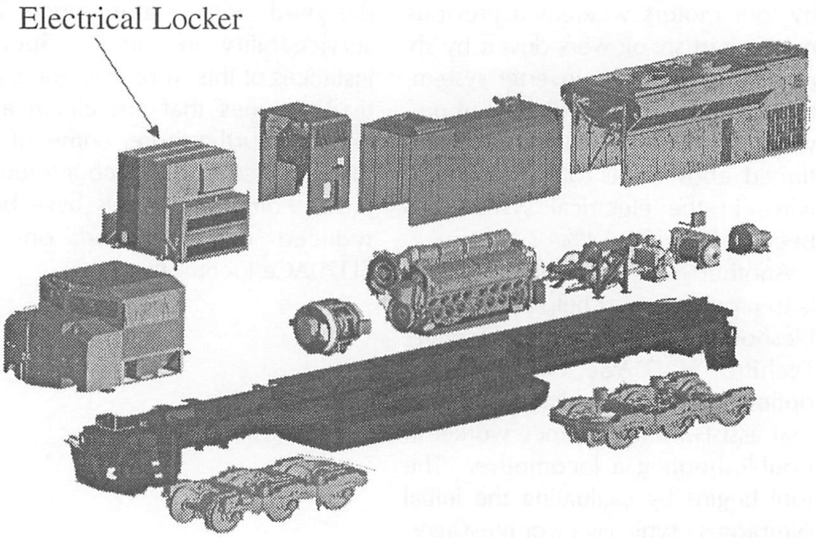


Figure 1 Modular Layout of Locomotive

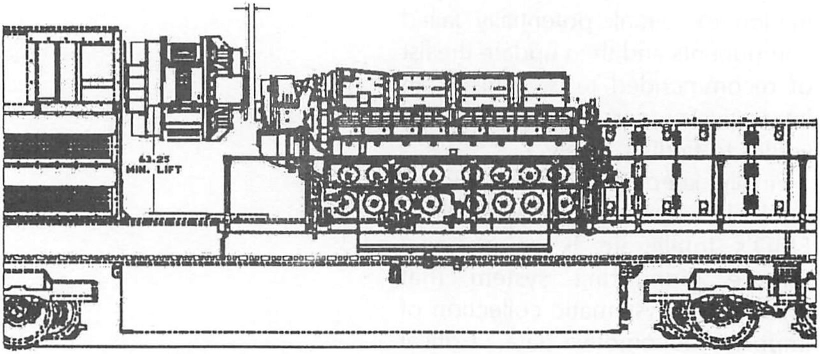


Figure 2 Generator Removal

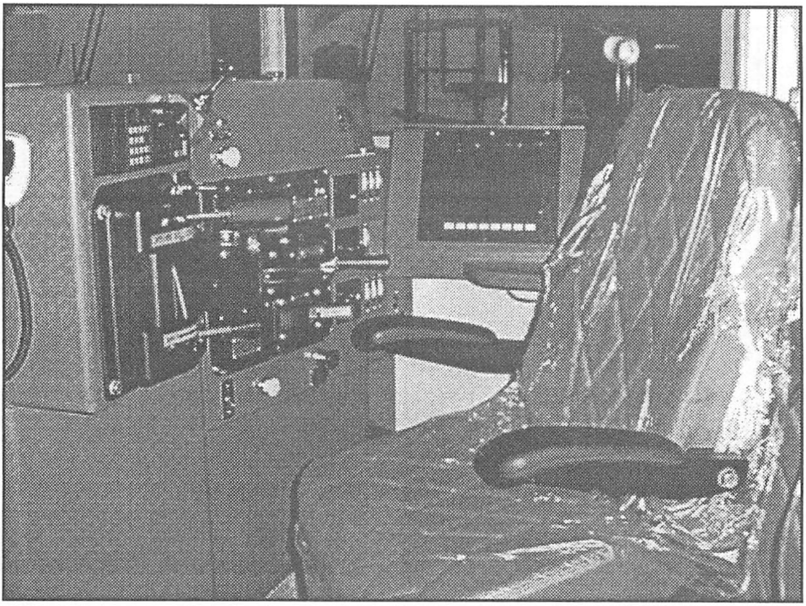


Figure 3 Engineer's Workstation

Figure 4 Battery Box

Figure 5 Main Generator Slip Ring Brush Compartment

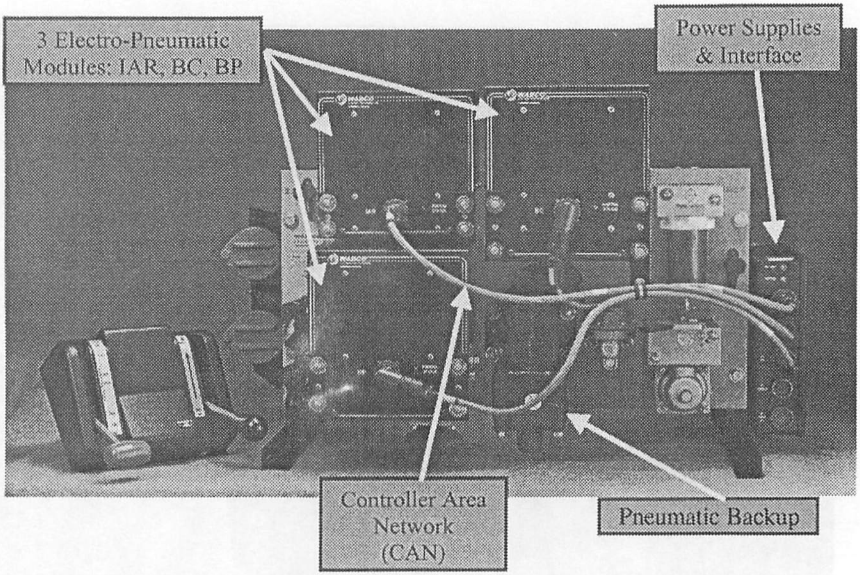
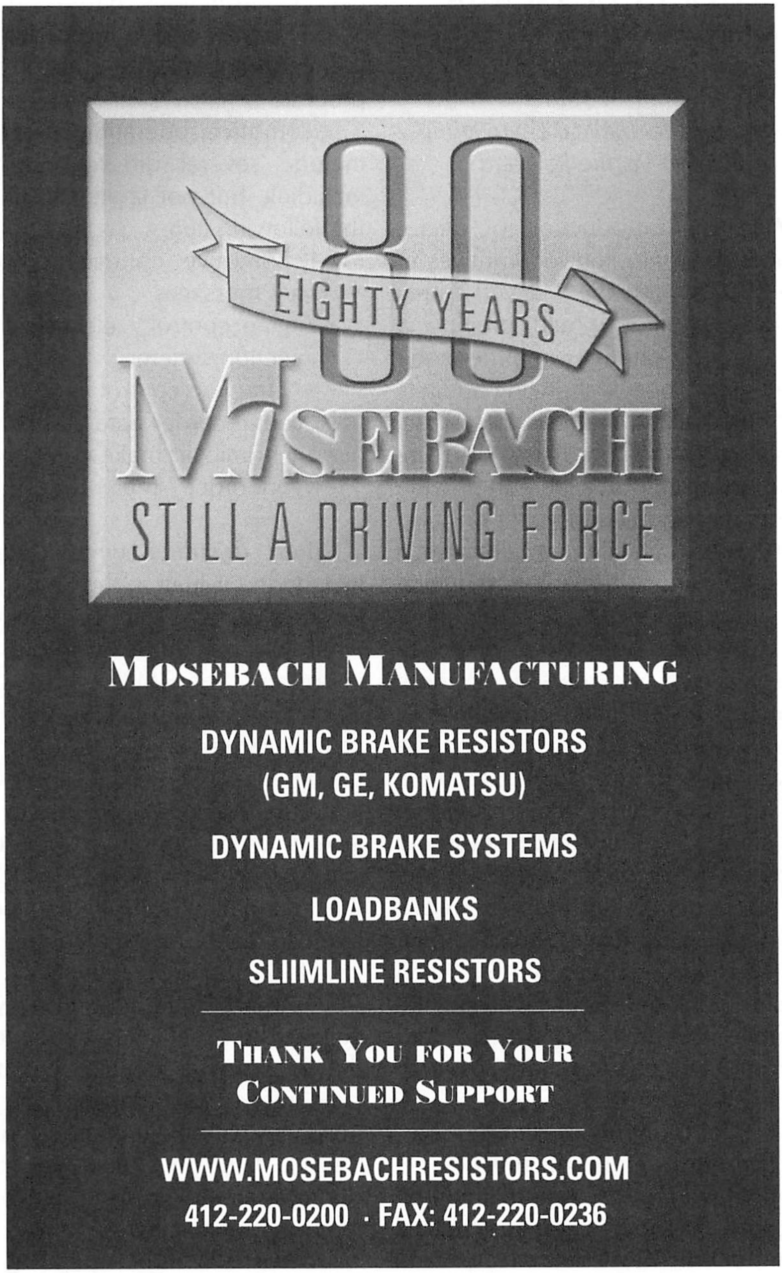


Figure 6 FastBrake™ System



II. REMOTE MONITORING & DIAGNOSTICS: DEVELOPMENT AND INTEGRATION WITH MAINTENANCE STRATEGIES

Prepared by
Brad A. Steffel
Manager Mechanical Engineering
Union Pacific Railroad

With the introduction of microprocessor controlled locomotives in the 1980's, railroads received a new technology that would provide a means to change maintenance strategies. Today's shrinking budgets and increasing maintenance costs challenge railroads to use the technology currently available to provide the biggest possible impact on reliability and availability. Maintenance strategies must focus on reducing expenses and increasing component life whenever possible to minimize the total cost of ownership. Remote monitoring and diagnostics (RM&D) allows railroads to capitalize on the advantages of microprocessor controlled locomotives by providing assistance in the troubleshooting process. This paper will cover the components behind remote monitoring and diagnostics, outline some of the issues encountered by Union Pacific Railroad and highlight the benefits of integrating RM&D into current maintenance strategies.

Components of remote monitoring and diagnostics

To implement a remote monitoring and diagnostics strategy, several components must be collected and developed. These components include locomotive operating data, a method of retrieving the data, a system to analyze the data, a way to deliver instructions based on the RM&D data, and a procedure to gather feedback for the RM&D process.

Locomotive operating data can include several different sources including, but not limited to any of the following items:

- Locomotive control computer fault messages
- Engine control / electronic fuel injection system
- AC traction control computer
- Event recorder data
- Electronic air brake computer
- Work order / repair history

When deciding what data to include in evaluating the health of a locomotive, take into consideration what information is available and important. The RM&D process can begin with any one of the data sources listed above. As more data becomes available, they can be integrated in the RM&D process to provide a more complete picture of locomotive performance. Much of the information will need to be filtered so decisions are made on only valid locomotive operating data. For example, when the ground relay circuit is tested, messages are logged in the locomotive control computer fault archive. By combining the fault messages with the locomotive repair history, fault messages generated during a shopping event can be filtered before analysis.

Once a locomotive operating data source is identified, a process must be developed to retrieve and store the data. The data can be retrieved manually through a download with a personal computer. If appropriate, an automated data collection system can be developed to use tools such as satellite or cellular communication packages to transmit data to a central database. Data must be retrieved frequently enough to be able to identify potential failure modes before failure occurs. When deciding how data will be retrieved, ask the following questions:

- How important is the data?
- What will it cost to retrieve the data?
- Will anything be done with the data collected?

For example, if a component is identified to have intermittent problems, repairs may not be made until the locomotive reaches its final destination or is available for its next scheduled maintenance interval. As a result of this business decision, it does not make sense to pay communication fees to collect data that will not be used immediately. Instead, the information could be collected as the locomotive approaches a repair facility.

After the locomotive operating data is collected and stored, the data needs to be analyzed to determine if component failure is imminent. Data analysis can be completed manually by an employee after every download or automatically by a computer program once the data is committed to a database. When deciding how data will be analyzed, consider the following questions:

- What training will be required to understand the data?
- Will bias in manual analysis defeat the purpose?
- Can the cost of a program to analyze the data be justified?
- When and where should repairs be completed?

While developing a remote monitoring and diagnostics strategy, Union Pacific created a program to automatically analyze data and generate recommendations. This program is referred to as the locomotive diagnostic module or LDM. The LDM monitors several data sources and receives triggers to start a complete analysis of a specific locomotive, as new data is available. The data was compared against thousands of rules to see if an exception exists. If an exception is identified, a remote diagnostics case is generated for the specific locomotive which provides detailed instructions to troubleshoot the problem. The instructions in the remote diagnostics cases use specific maintenance and operating knowledge from several employees to provide clear, consistent steps to employees at any maintenance location when a problem is identified. Each remote diagnostic case is coded to identify the severity of the situation - such as already failed, failure probable within 48 hours or address at next shopping event - and the location where the repair should take place - specifically a shop, service track or run-through facility.

When the data is analyzed and an exception is identified, instructions need to be delivered to maintenance personnel so repairs can be completed. If this information is not communicated effectively, all the efforts leading up to this point have been wasted. Union Pacific has discovered that remote diagnostics cases are most effective when they are inserted directly in the work order with all other maintenance activities. This provides one central location where employees can receive a list of all maintenance required for a specific locomotive.

After repairs have been completed, feedback must be gathered to help measure how effective the repair recommendations were during the troubleshooting process. This feedback can come from the repair history and repeat failures of the locomotive. Data fields can also be included in the work order to ask for feedback related to the tasks completed during the troubleshooting process. These data sources can be used to identify how the troubleshooting process can be improved. The feedback data can also be used with the fault messages and parameters to develop additional methods to identify the root cause of the failure.

The components of remote monitoring and diagnostics can be put together to provide a process that can be used to identify problems and lead to a successful repair. Figure 1 shows how this process takes place at Union Pacific.

1. Data is generated relative to locomotive performance.
2. The data is retrieved and sent to a centralized database.
3. The data is analyzed and problems are identified.
4. Tasks are generated in the work order identifying specific items to be addressed.
5. Repairs are completed and recorded to provide feedback.
6. The locomotive is released to pull freight and the process is repeated.

Matching remote monitoring & diagnostics and general maintenance strategies

As David K. Miller covered in his paper, "Condition Based Maintenance, Practical Approaches and Techniques," maintenance strategies can be categorized into three approaches: reactive, preventative and reliability centered. A reactive maintenance strategy employs the principle of performing maintenance activity when the asset can no longer perform its desired function. Preventative maintenance utilizes the execution of periodic maintenance events to decrease the likelihood of failure. Reliability centered maintenance is quantifying and understanding the risk of failure and using this knowledge on an asset by asset basis to tailor the maintenance activity appropriately.

When developing a remote monitoring and diagnostics strategy, the instructions provided as a result of the data analysis should match the appropriate maintenance strategy. Remote diagnostics cases could then be classified as being reactive, preventative or reliability centered.

A reactive RM&D rule uses data to identify a component that has already failed. The resulting remote diagnostics case provides a notification to the employee with appropri-

ate instructions so a repair can be completed. This strategy is most effective when used to identify when non-critical components fail. However, it can also be used to signal when any component has failed and repairs need to be completed. This will lead to faster and more reliable troubleshooting by identifying the root cause of the failure correctly the first time. Figure 2 illustrates a remote diagnostics case that can be categorized as reactive.

As mentioned earlier, a preventative maintenance strategy utilizes the execution of periodic maintenance events to decrease the likelihood of failure. Many of these activities are scheduled lubrication, filter replacements and visual inspections. Often, locomotive performance data is not collected when performing preventative maintenance activities so the risk of failure is not evaluated during these scheduled events. However, if observed conditions are recorded and trended over time, data from preventative maintenance events can be used to gauge locomotive performance and generate appropriate work order tasks.

A reliability centered RM&D rule uses data to identify components that are drifting out of acceptable ranges and adjusts the periodic maintenance activity accordingly. The resulting remote diagnostics case provides a warning to the employee with appropriate instructions so a failure can be prevented. Asset availability is also increased by identifying the failure component and making repairs during a scheduled servicing event instead of an unscheduled shopping event. Figure 3 illustrates a remote diagnostics case that can be categorized as condition based.

Benefits of remote monitoring & diagnostics

There are several benefits to implementing a remote monitoring and diagnostics strategy. The first benefit that will be realized is the prevention of road failures. Catastrophic failures of major components can be prevented with RM&D while non-critical components can be identified and repaired upon failure. RM&D can also shorten troubleshooting time and reduce the possibility of repeat failures when the correct component is repaired the first time.

Overall maintenance costs can be minimized by using RM&D to move towards a condition based maintenance strategy. Identifying components before they fail and eliminating scheduled replacements can increase the life of components. By keeping the asset operating in optimum condition, the period between overhauls can be extended. Using RM&D in a condition based maintenance strategy eliminates the need for a complete locomotive overhaul. Instead, individual components can be continuously evaluated. If an engine or a main generator overhaul were necessary, only the major components that show performance issues at the time of the overhaul would have to be addressed.

Asset availability will also increase if remote monitoring and diagnostics is implemented properly. Maintenance planning can take place because the failure reason can be identified before a locomotive reaches a repair facility. This introduces the possibility of eliminating shopping events. An opportunity to move maintenance closer to the train exists when light repairs can be identified and successfully completed on run-through facilities or service tracks.

When data is stored and analyzed collectively on a fleet of locomotives, trends can be identified. If the input parameters are known for a particular fault message, the parameters can be analyzed for each occurrence of the fault message to confirm its validity. The data can then be used to identify hardware reliability issues or software bugs. This data can be used to provide feedback to the OEMs regarding locomotive performance. An example where fault data was used to identify an OEM design flaw can be seen in Figure 4.

The graph shows two speed inputs that were compared to verify the correct operation of the axle alternator. If the speeds were significantly different, a fault message would be generated. By analyzing fault messages from hundreds of locomotives, it was found 90% of the time this particular fault message was generated, it was invalid. The OEM reviewed the software and found an error in the logic used to generate the fault message. As a result, an updated software version was released and failures were eliminated because the invalid fault messages were eliminated.

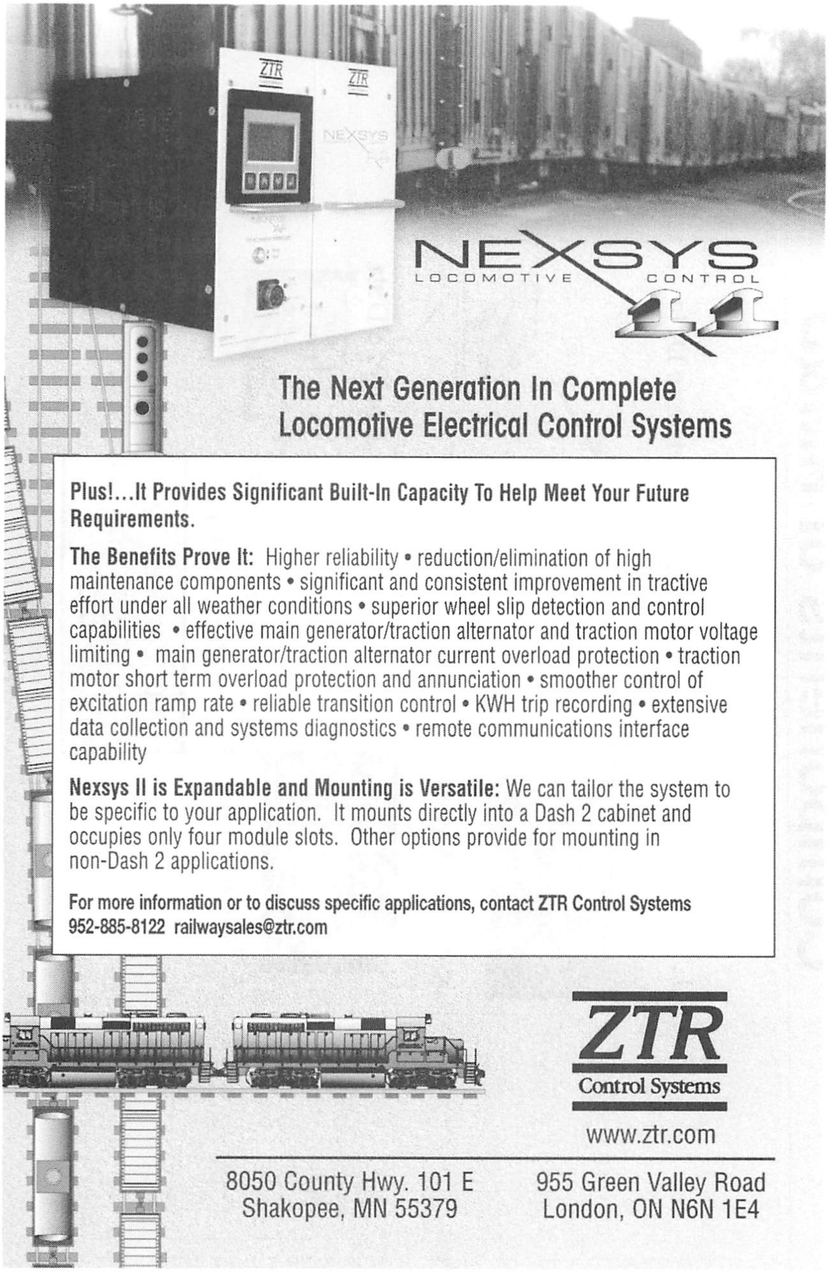
Remote monitoring & diagnostic alternatives

The creation and implementation of a remote monitoring and diagnostics system will take years to fully develop. The process of collecting, storing and analyzing data is initially very labor intensive. Benefits can be realized almost immediately by using some of the available data to get started and integrating additional data sources as they become available.

However, if it is not feasible to develop a remote monitoring and diagnostics system, the service can be purchased directly from OEM. For example, General Motors' Electro-Motive Division (EMD) has developed IntelliTrain® to monitor and diagnose EMD locomotives. General Electric (GE) has developed their Expert-on-Alert® (EOA) system to monitor and diagnose GE locomotives. These RM&D services can be purchased through the OEMs and may be more effective when compared to the cost of developing an internal RM&D system or the cost of not doing anything at all. This may particularly be true for smaller railroads that may not have the available resources to develop a remote monitoring and diagnostics system internally.

Summary

Remote monitoring and diagnostics is a relatively new concept for the railroad industry. Several organizations have attempted to integrate RM&D into their maintenance strategy with varying levels of success. This field will evolve over time based on the various improvements in control systems, sensor equipment, communication systems and other technologies as they are integrated with locomotives. Perhaps in the future, instead of writing programs to parse fault data, a standardized industry format can be established so locomotive operating information can be shared between computer systems at different organizations more easily. As RM&D becomes integrated with maintenance strategies, it will become an invaluable tool in improving locomotive reliability and availability while simplifying the troubleshooting process and minimizing maintenance costs.



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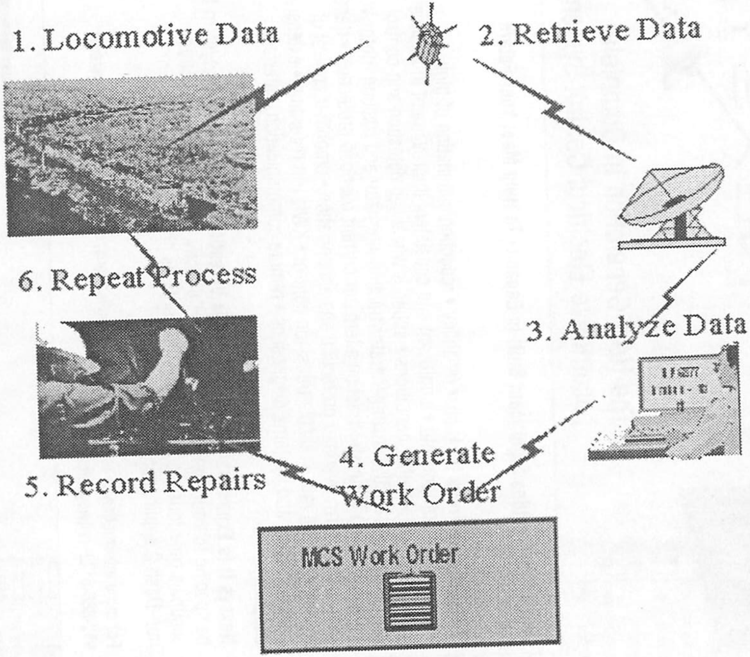
Components of RM&D



1. Locomotive Data

2. Retrieve Data

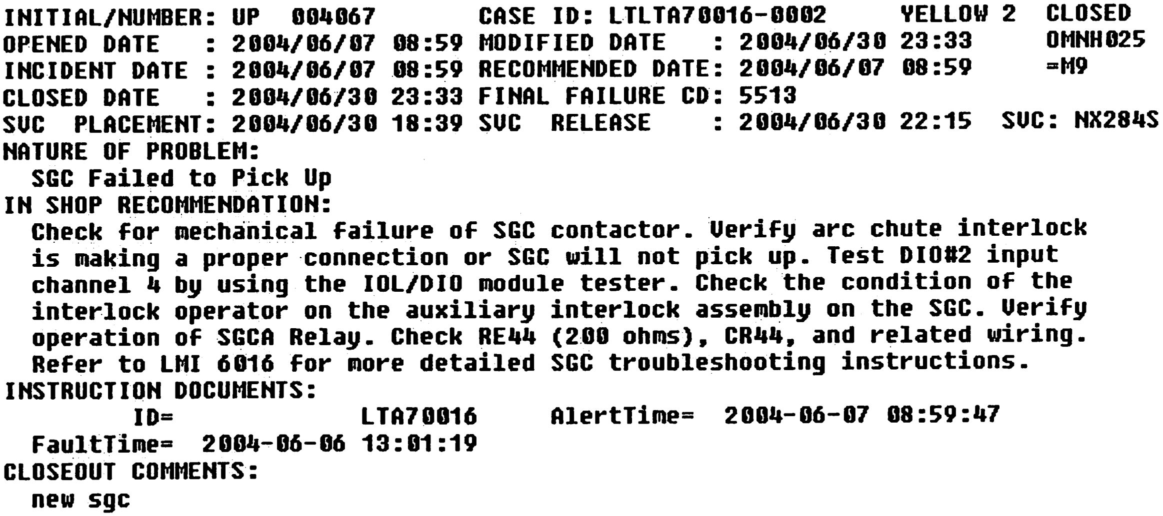
3. Analyze Data

4. Generate Work Order

5. Record Repairs

6. Repeat Process

Figure 1



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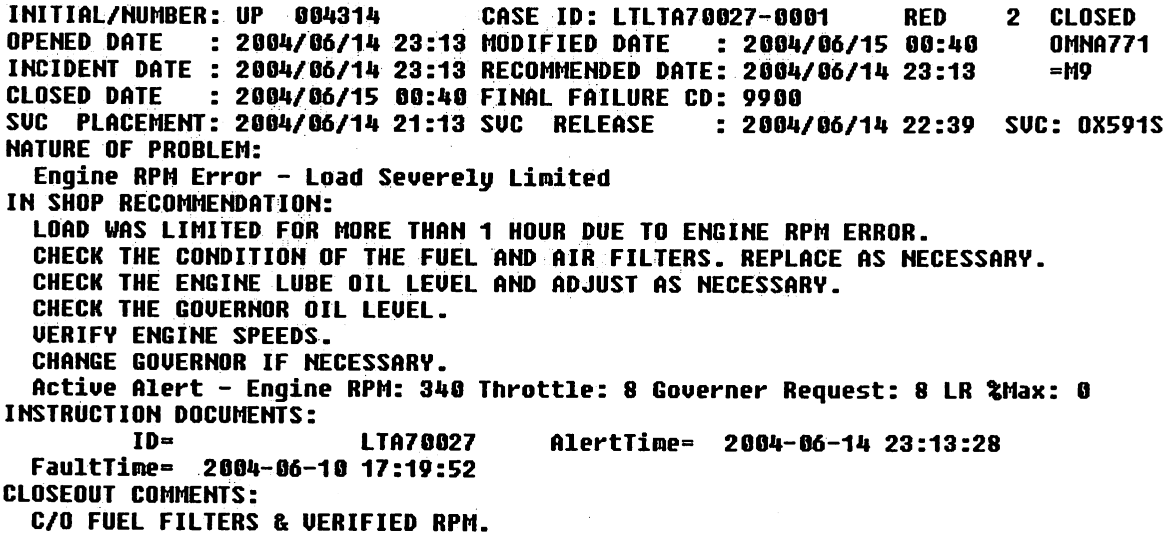
INCIDENT DATE : 2004/06/07 08:59 RECOMMENDED DATE: 2004/06/07 08:59     =M9
CLOSED DATE   : 2004/06/30 23:33 FINAL FAILURE CD: 5513
SVC  PLACEMENT: 2004/06/30 18:39 SVC  RELEASE    : 2004/06/30 22:15  SVC: NX284S
NATURE OF PROBLEM:
  SGC Failed to Pick Up
IN SHOP RECOMMENDATION:
  Check for mechanical failure of SGC contactor. Verify arc chute interlock
  is making a proper connection or SGC will not pick up. Test DIO#2 input
  channel 4 by using the IOL/DIO module tester. Check the condition of the
  interlock operator on the auxiliary interlock assembly on the SGC. Verify
  operation of SGCA Relay. Check RE44 (200 ohms), CR44, and related wiring.
  Refer to LMI 6016 for more detailed SGC troubleshooting instructions.
INSTRUCTION DOCUMENTS:
         ID=             LTA70016     AlertTime=  2004-06-07 08:59:47
  FaultTime=  2004-06-06 13:01:19
CLOSEOUT COMMENTS:
  new sgc
```

Figure 2. – Reactive Remote Monitoring and Diagnostics Case

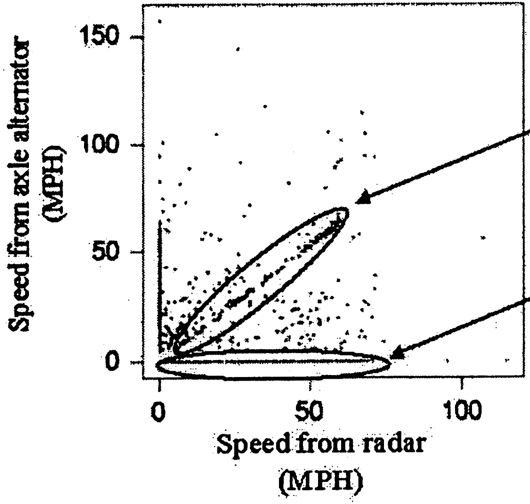


```
INITIAL/NUMBER: UP  004314        CASE ID: LTLTA70027-0001     RED    2  CLOSED
OPENED DATE    : 2004/06/14 23:13 MODIFIED DATE    : 2004/06/15 00:40     OMNA771
INCIDENT DATE  : 2004/06/14 23:13 RECOMMENDED DATE: 2004/06/14 23:13     =M9
CLOSED DATE    : 2004/06/15 00:40 FINAL FAILURE CD: 9900
SVC  PLACEMENT: 2004/06/14 21:13 SVC  RELEASE    : 2004/06/14 22:39  SVC: OX591S
NATURE OF PROBLEM:
  Engine RPM Error - Load Severely Limited
IN SHOP RECOMMENDATION:
  LOAD WAS LIMITED FOR MORE THAN 1 HOUR DUE TO ENGINE RPM ERROR.
  CHECK THE CONDITION OF THE FUEL AND AIR FILTERS. REPLACE AS NECESSARY.
  CHECK THE ENGINE LUBE OIL LEVEL AND ADJUST AS NECESSARY.
  CHECK THE GOVERNOR OIL LEVEL.
  VERIFY ENGINE SPEEDS.
  CHANGE GOVERNOR IF NECESSARY.
  Active Alert - Engine RPM: 340 Throttle: 8 Governer Request: 8 LR %Max: 0
INSTRUCTION DOCUMENTS:
          ID=             LTA70027     AlertTime=  2004-06-14 23:13:28
  FaultTime=  2004-06-10 17:19:52
CLOSEOUT COMMENTS:
  C/O FUEL FILTERS & VERIFIED RPM.
```

Figure 3. – Condition Based Remote Monitoring and Diagnostics Case

Example Of Corrected Software Bug

- **FEEDBACK ERROR - AXLE ALT FEEDBACK INCONSISTENT WITH OTHER SPEED SIGNALS**



90% of the time, this fault was invalid

74% of faults show axle alternator matches radar within two mph

16% of faults occur when axle alternator was at zero mph and unit is at idle.

Figure 4 – Example of Corrected Software Bug

III. CARBON BRUSHES REVISITED - AN UPDATE FOR 2004

Prepared by
Robert P. McCaffrey
Manager Transportation Products
National Electrical
Carbon Products, Inc.

Although locomotives with AC traction motors and other systems have made significant inroads, carbon brush usage on railroads remains at a high level. Of course, there are still a very large number of conventional DC locomotives in operation, and will continue to be for many years to come. At least 50% of the new locomotives being built today are equipped with DC traction motors. Present design AC locomotives use carbon brushes both on the collector rings of the alternator, and in the grid blower motors. Consequently, performance of the commutation and current collection systems remains a very high priority for locomotive maintenance personnel.

The primary goals of maximizeing brush life while maintaining optimum commutator or collector ring condition remain. A more recent consideration is extending maintenance periods beyond the current 92 days, to 184 days or more. Brush life may be a limiting factor for extending maintenance periods. This is especially true for high horsepower locomotives in high speed service.

What are the factors that affect brush life in a DC motor?

- Design of the commutation system
- Brush, brush holder, commutator
- Electrical adjustment of the motor
- Carbon material
- Commutator condition
- Brush Holder condition
- Spring Force
- Dirt, dust, contamination
- Amount of useable carbon
- Type of service

For traction motors, brush life is measured in miles, not time. This is less true for other brushes whose wear depends on other factors, such as engine hours, time in dynamic braking, etc. However, traction motor brushes are usually the limiting factor with regard to maintenance interval. Let us look at each of the above factors, with the goal of achieving maximum life.

Design of commutation system:

This is generally a fixed characteristic, determined by the locomotive builder. However, some components can be modified for longer life.

Electrical adjustment of the motor:

Electrical adjustment consists of such things as the neutral point of the brushes, the correct application of field and commutating poles including air gap, proper alignment of the brushes, etc. These characteristics are fixed when the motor is originally built, or remanufactured.

Carbon Material:

Several different carbon grades are offered by the brush manufacturers. These materials are specifically

designed for locomotive service. Often one grade will provide superior performance in a particular application.

Commutator condition:

Over time, all commutators deteriorate. This occurs through mechanical wear, from sparking, contamination, etc. As a commutator becomes rough, sparking increases, leading to more rapid brush wear; mechanical wear also increases.

Brush holder condition:

Like commutators, brush holders also deteriorate. They also become warped from excessive heat and flash over. The moving parts in the spring assembly can become stiff or frozen; springs can lose tension or break. All of these can lead to the brush not contacting the commutator properly - again leading to sparking and more rapid wear.

Spring force:

The correct spring force is critical to good brush performance. If it is too light brush bouncing, with resulting sparking, occurs. This is highly detrimental to the commutator. Excessive spring force leads to mechanical wear of the carbon, as well as the commutator.

Dirt, dust, contamination:

Any foreign material in the motor can affect brush wear. Obviously, excessive amounts of dirt - particulate matter - can cause wear. Other contaminants such as cleaning solutions, oil and grease also have detrimental effects on commutator condition and brush wear.

Amount of usable carbon:

The amount of usable carbon is fixed by the brush length, the location of the shunts that are tamped within the carbon, and the limits of spring finger travel. It is possible to use longer brushes. This will be discussed in more detail.

Types of service:

It is obvious that locomotives that accumulate more miles, will wear out brushes faster (over time) than those that accumulate less miles. Traction motor brushes in switching locomotives will last a very long time, while those in locomotives used in high speed container train service will require replacement far more frequently.

With an understanding of the factors determining brush life, what can be done by maintenance forces to maximize, or even extend, brush life?

One of the most important tasks is to ensure that good commutator conditions are maintained. A key factor is training maintenance personnel to recognize detrimental commutator conditions, and knowing how to minimize their effects, or to change out a motor when necessary.

Probably the most common commutator condition leading to increased brush wear is high TIR, or out of roundness. This can occur for a variety of reasons, but most commonly it is from wear over time. In most motors, commutators do not wear uniformly. This then leads to the commutator becoming out of round, although it is usually not egg-shaped, but wavy. This causes vibration of the brushes that then move up and down in the holder as the irregularities of the commutator pass underneath the brushes. The most obvious symptoms of this vibration are "shunt fray" and heavy wear patterns on the surfaces of the brush. Less obvious is the excess sparking that occurs as the brush loses contact with the commutator. This, of course, causes even more rapid brush wear. A motor with a commutator that has degenerated to this point should be removed from the locomotive. Figure 1 shows a commutator with significant wear and high TIR. Figure 2 shows shunts that have frayed from high vibration due to an out of round commutator.

When a motor is removed from a locomotive for reasons other than motor failure, it is recommended the commutator TIR and BTB (bar to bar height) be checked with a commutator profiler or other instrument. This procedure can identify commutators that are near, or beyond, condemning limits, and prevent their being reapplied to a locomotive, only to cause problems in a short period of time. It is important that strict guidelines be established for motors to be reapplied to locomotives. Figure 3 shows the commutator profiler unit. Figure 4 illustrates the profiler sensor inserted in an EMD brush holder ready to record a profile.

Brush holders can also affect brush life. Holders must be properly installed, with particular attention to the clearance between the brush holder and the commutator and alignment (parallel with the commutator - not cocked or angled). If the clearance is too small, sparking between the commutator and brush holder can occur. If it is too large, brush stability is affected. Brush holders may become warped or bent from a variety of reasons. In this case the brush may not move freely in the holder; this is another cause of sparking. Holders should be examined for free brush travel at each inspection. It is also important that maintenance personnel be trained in the proper placement of spring fingers on the pad of the brush. Figure 5 shows an EMD three pocket brush holder with the spring fingers correctly applied to a brush.

Spring tension is a very important factor in brush wear. If spring tension is low, brush bounce can occur, again causing excessive sparking. If spring tension is too high, mechanical wear increases. The recommended spring tension has been determined by the manufacturers to provide optimum brush performance and life. In a traction motor it is higher than for other applications due to the extreme shocks a traction motor is subjected to from the rail. In traction motors and most other locomotive applications, spring tension is not adjustable; however maintenance forces must pay attention to spring condition when changing brushes. An experienced electrician can usually tell if a spring is far from the normal tension. Spring force should be measured during motor overhauls and corrected if necessary. Dirt build up in the spring mechanism can affect the smooth operation of the spring assembly, causing binding of the fingers. Figure 6 is a graph showing the relationship of spring tension to brush wear. Note the high wear at low spring pressures, resulting from high levels of sparking when the brush does not maintain good contact with the commutator.

It is important to keep foreign material from entering the motor. Obviously, particulate matter can cause abrasive wear of the brush and commutator. Liquid contaminants, such as oil, cleaning solutions, and even water, also have a deleterious effect on the commutator film, and can be absorbed by the carbon of the brushes. Proper maintenance of locomotive air filtration systems, fixed ductwork, and the flexible ducts into the traction motors will keep solid and liquid contaminants to a minimum. Care should be taken when cleaning locomotives not to spray cleaning solution directly into the motors. Figure 7 shows a motor with evidence that liquid contamination has been on the brushes and brush holders. Note the streaks on the brushes left by dripping liquid.

Commutator condition, motor electrical adjustment, brush holder and spring condition, use of the proper brush material, cleanliness, are all items controlled by maintenance forces, either in the running shop or in the back shop. It is vital to have good programs in place to monitor and maintain these characteristics. Equally important is the knowledge and training of personnel who will be performing the actual maintenance tasks. They must be knowledgeable with regard to the equipment, and to the procedures and standards mandated by the mechanical department.

When it comes to the amount of usable carbon, this is fixed by the length of the brush, and the depth of the shunt wires within the carbon, as well as the maximum travel of the spring fingers. Extended length brushes for EMD motors have been available for some time. These are 1/8" longer than the "standard brush," and will provide from 10,000-20,000 additional miles between brush changes. Figure 8 illustrates both regular and extended length EMD brushes.

Recently, a brush for GE motors that is 1/4" longer than standard has been tested. While the tests were successful, concern remains regarding reduced spring force when the brush is longer than the standard brush. This additional length can be expected to provide up to 30,000 additional miles. Figure 9 compares the extended length GE brush with the standard length brush.

Both locomotive OEM's are actively pursuing new commutation system designs to reliably extend life to a minimum of 184 days, and possibly beyond. Additionally, longer life alternator current collection systems are also under consideration.

The type of service seen by a locomotive is governed by the nature of traffic on the railroad, and the assigning of power by the Operating department. It is not within control of the Mechanical department; therefore, maintenance practices must be tailored to match whatever type of service locomotives undergo.

Conclusion

It is more important than ever to ensure that brush life is maximized due to extended maintenance periods and the need to keep locomotives operating without road failures. Proper attention to the condition of the commutation system, consisting of the commutator, brush and brush holder is vital to assuring maximum brush life.

Maintenance programs and practices must reflect this need, and maintenance personnel must be well trained to carry out the details of the program.

In the future, commutation systems will be designed to provide better brush life, but in the meantime, good maintenance will insure trouble free operation.

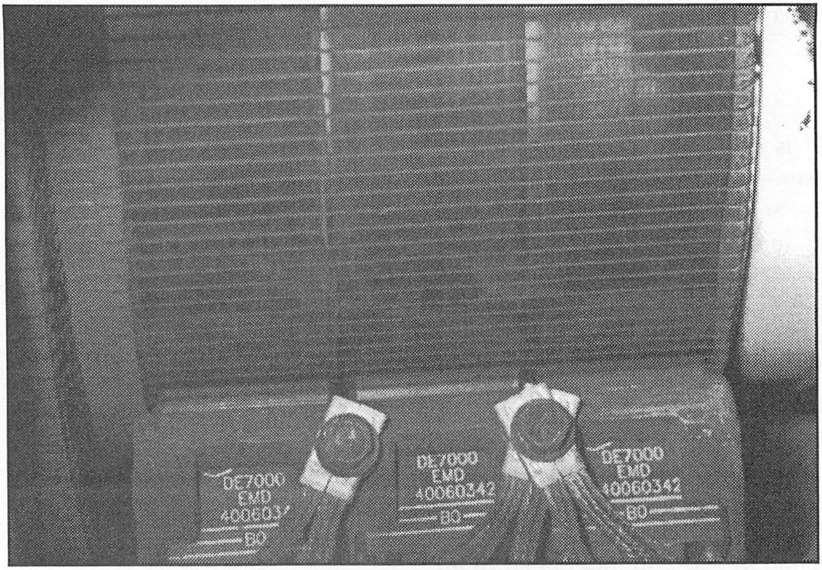


Figure 1: Commutator with high wear and TIR

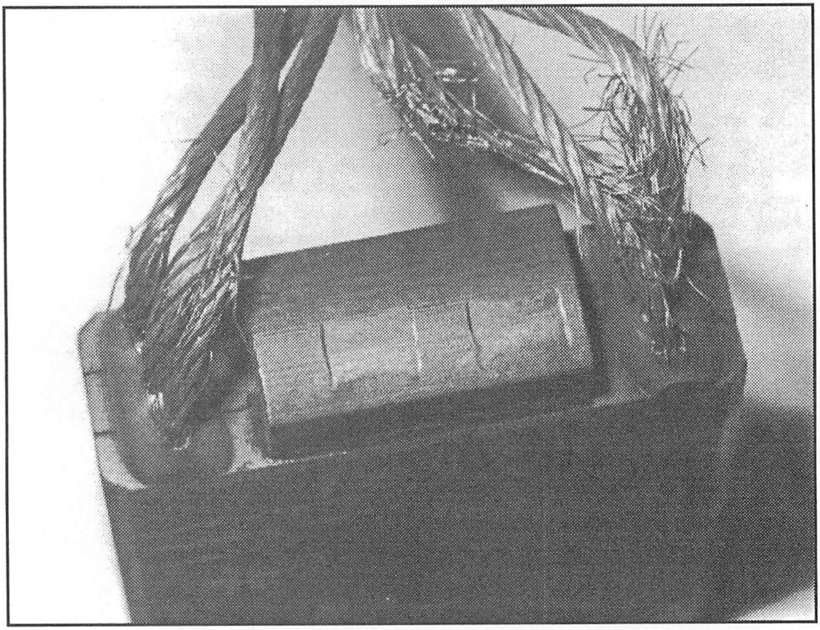


Figure 2: Brush with shunt fray from rough commutator

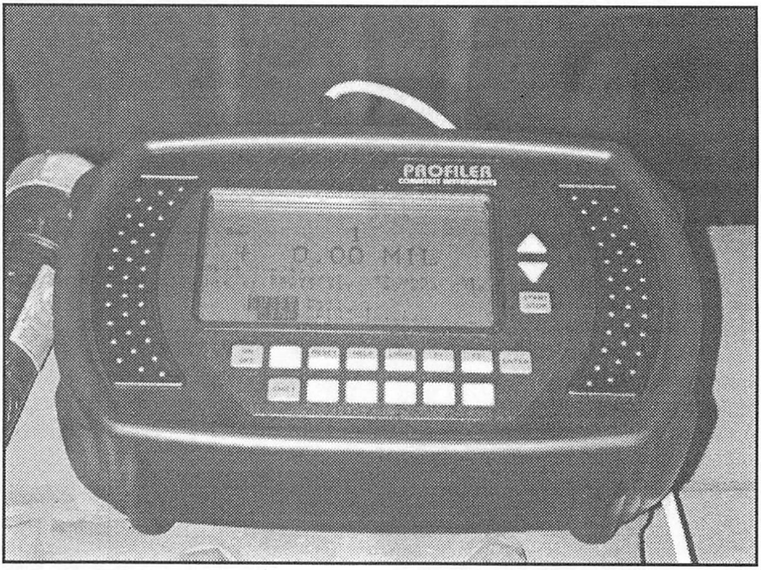


Figure 3: Commutator Profiler

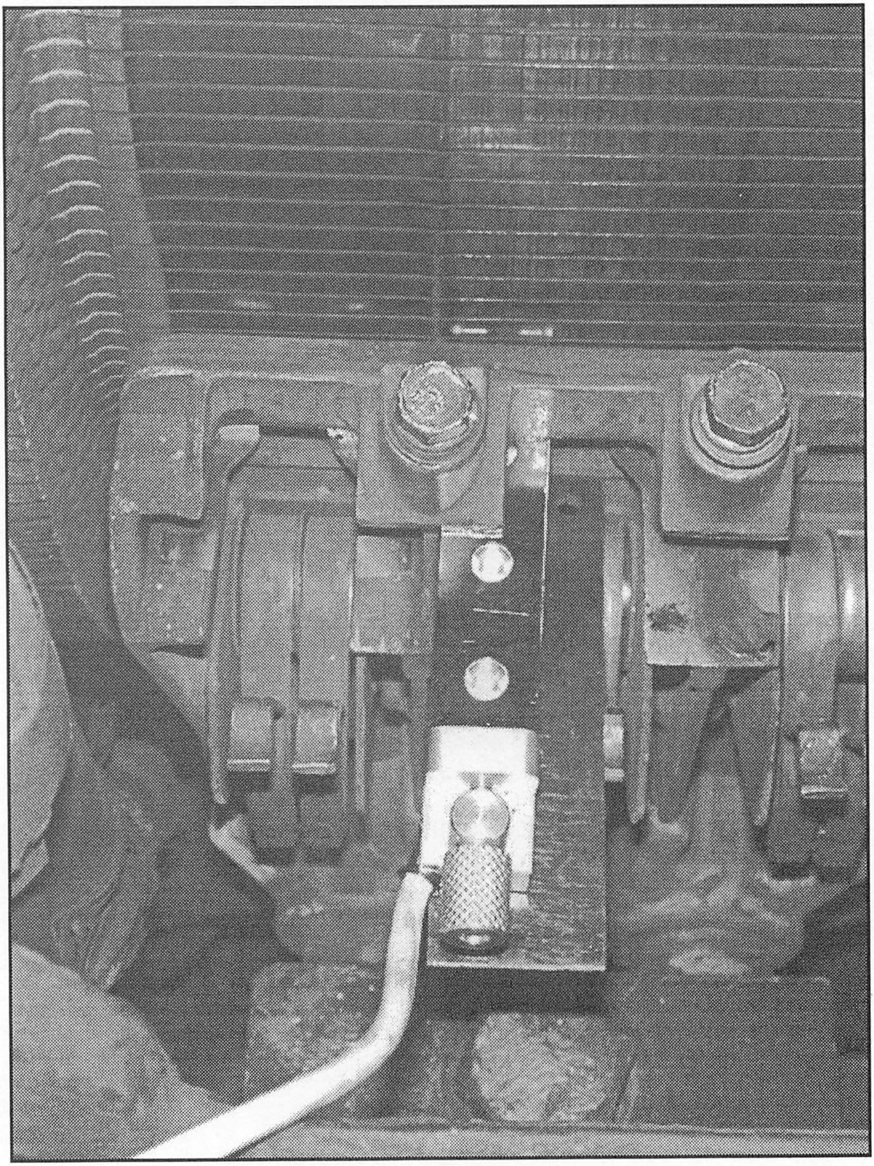


Figure 4: Profiler Sensor mounted in traction motor

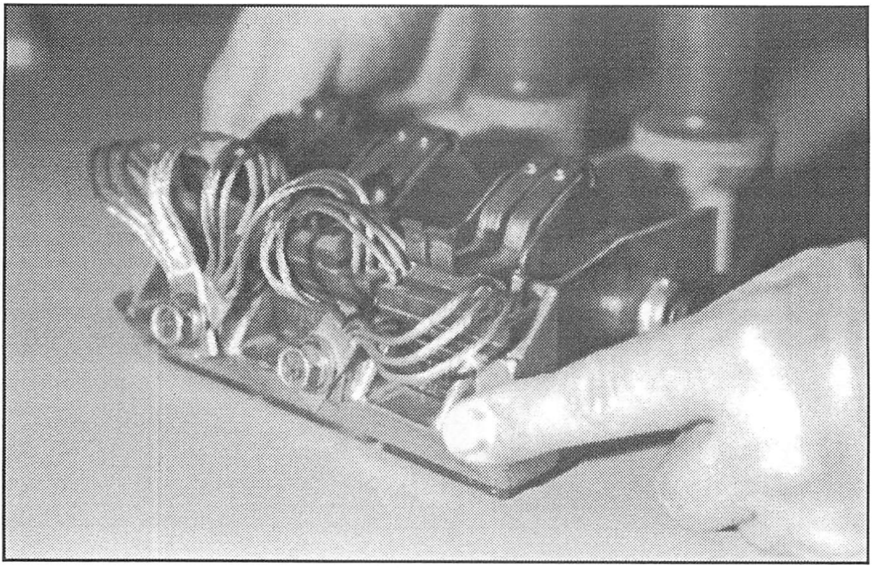


Figure 5: EMD brush holder showing proper placement of spring fingers and shunt wires

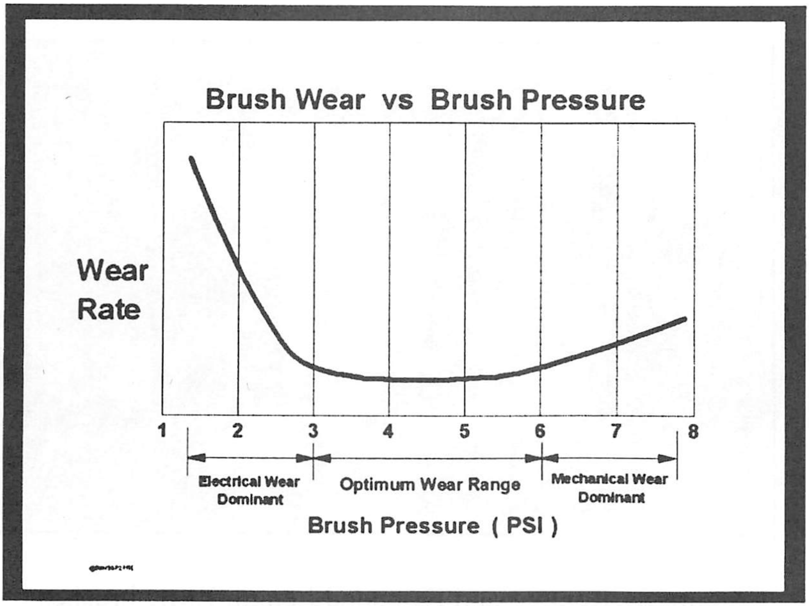


Figure 6: Wear vs. Spring Force graph

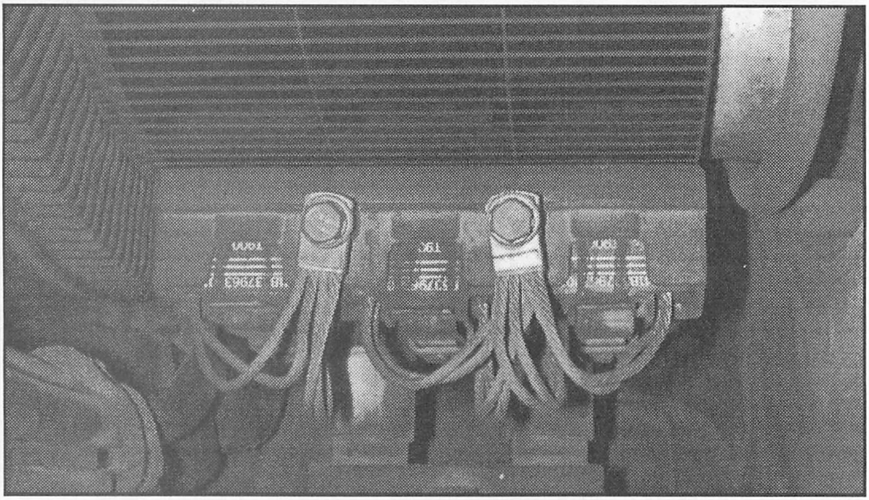


Figure 7: Evidence of Liquid Contamination in motor

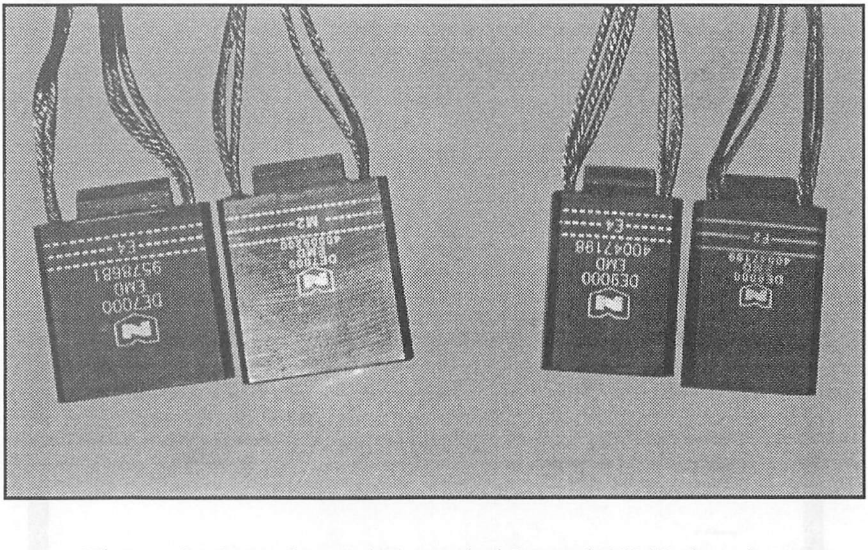
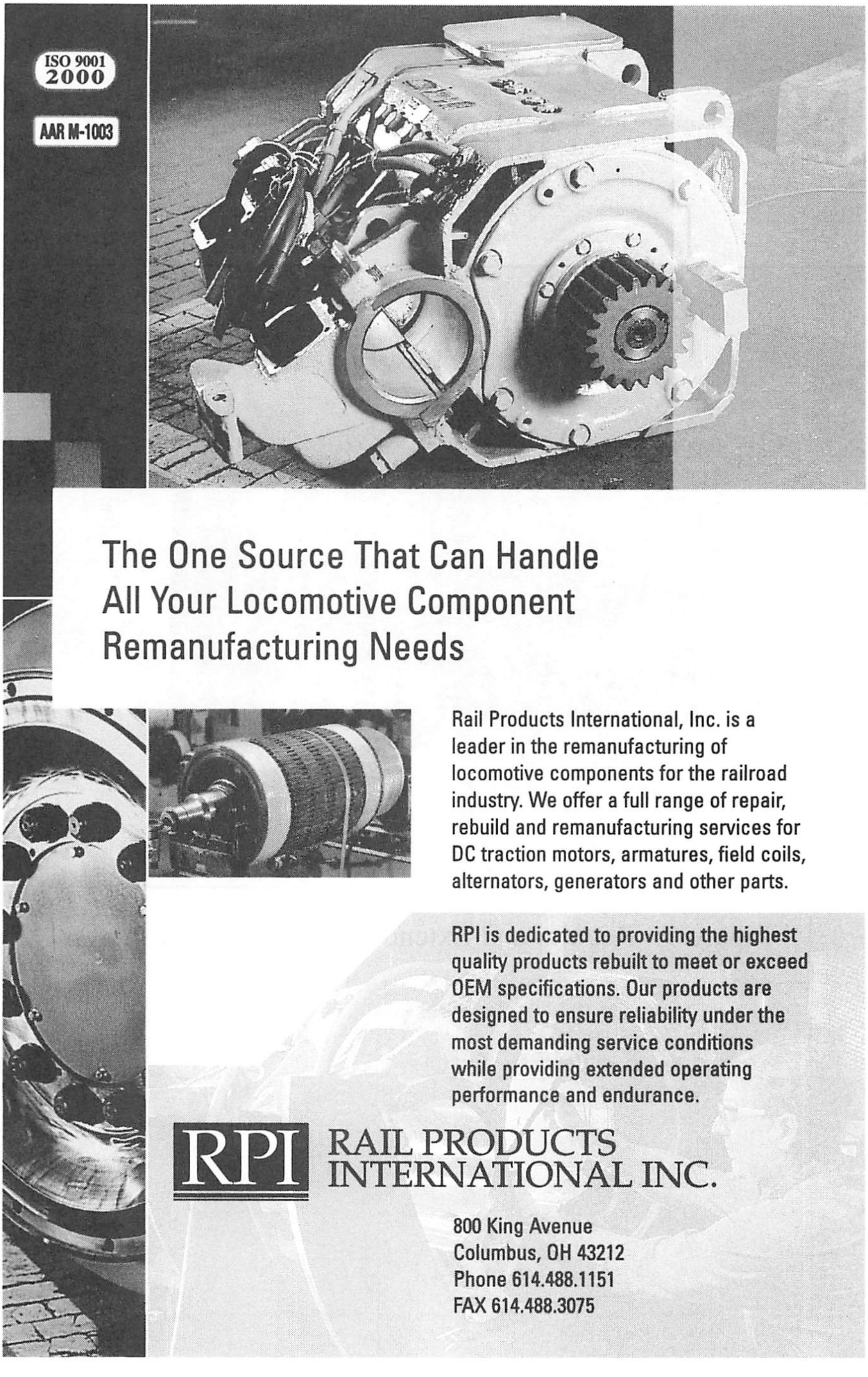


Figure 8: Regular and Extended Length EMD brushes



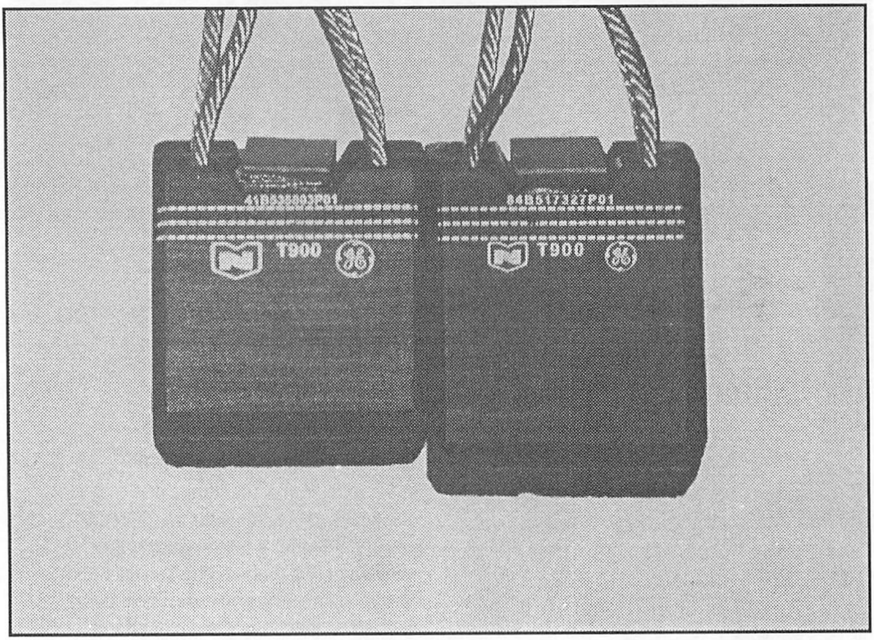


Figure 9: Regular and Extended Length GE brushes

REPORT OF THE COMMITTEE ON FUEL, LUBRICANTS AND ENVIRONMENTAL

TUESDAY, SEPTEMBER 28, 2004
9:00 A.M.

Chairman
TOM PYZIAK
Senior Account Executive - Safety-Kleen Systems, Inc.
Palatine, IL

Vice Chairman
ROBERT DITTMEIER
Customer Tech. Service - Afton Chemical Corp.
Richmond, VA

COMMITTEE MEMBERS

G. Bills	Vice President	Searle Petroleum Co.	Council Bluffs, IA
G. Bowen	Dir.-Lab Services	BNSF Railway	Topeka, KS
K. Davis	Mgr.-Test & Lab Services	CSX Transportation	Waycross, GA
J. Dinklage	Engine Oil Formulator	Shell Global Sol (US) Inc.	Houston, TX
F. Eberhardt	Purchasing Manager	Belt Railway of Chicago	Bedfork Pk., IL
T. Eitzen	Staff Engineer	Chevron Lubricants	Richmond, CA
S. Fritz, P.E.	Principal Engineer	Southwest Research	San Antonio, TX
F. Girshick	Lube Specialist	Infineum USA, L.P.	Linden, NJ
A. Haas	Production Mgr-RREO	Lubrizol Corp	Wickliffe, OH
L. Haley, Jr.	Chief Chemist	Norfolk Southern	Chattanooga, TN
J. Jackson	Principal Systems Engr.	Amtrak	Wilmington, DE
B. Kehe	Mgr-Mech. Services	Elgin, Joliet & Eastern Rwy	Gary, IN
D. Koehler		Predict	Cleveland, OH
C. Kunkel	Sr Manager-R&D	Union Pacific RR	Omaha, NE
G. Lau	Sr. Rel. Specialist	CN RR	Edmonton, Alberta
R. Lodowski	Asst. Shift Superintendent	CSX Transportation	Selkirk, NY
M. Maddox	Technical Support	Industrial Specialty Chemicals	Harvey, IL
D. McAndrew	Fuel & Lube Specialist	GE Transp. Rail	Erie, PA
W. Middleton	Engineer	Oronite Additives	Richmond,CA
K. Myles	Mech. Engineer	Amtrak	Wilmington, DE
J. Pantos	Sr. Customer Engineer	GM-Electro Motive Divn	LaGrange, IL
D. Tuttle	Supvr-RR & Marine Sls	American Refining	Marietta, GA
K. Wazney	Chem/Testing Specialists	Canadian Pacific Railway	Winnipeg MB
P. Whallon	Mgr.-Eastern Region Sales	Clark Filters	Lancaster, PA

NOTE: G. Lau, D. Koehler and K. Myles are new committee members

PERSONAL HISTORY

Thomas Pyziak

Thomas J. Pyziak, Chairman of Fuel, Lubricants and Environmental Committee, was born in Chicago on August 10, 1954. Tom is a graduate of Gordon Technical High School in Chicago. He attended and graduated from St. Norbert in DePere, Wisconsin in 1976 with a Bachelor of Science degree.

Tom began his career as a lab technician with Motor Oils Refining Company in McCook, Illinois which is a re-refiner of petroleum lubricants. He learned all aspects of manufacturing from plant operation to quality control and research and development.

Tom transferred to marketing as a Technical Sales Representative and subsequently became an Industrial Sales Rep. He was given railroad/sales responsibility in 1984, handling product development, marketing/sales and oil waste removal sales. In 1989, this portion of the operation was sold to Breslube which two years later was acquired by Safety-Kleen Corp. Tom's current position is Senior Account Executive, handling all aspects of railroad engine oil development, sales/marketing with added technical responsibilities to the OEM's, GM, Ford and Chrysler.

Tom's hobbies include gardening, Chicago softball and auto racing. He is married. His wife's name is Katie and they reside in Palatine, Illinois.

THE FUEL, LUBRICANTS AND
ENVIRONMENTAL COMMITTEE
WOULD LIKE TO EXPRESS THEIR
SINCERE APPRECIATION TO
ORONITE ADDITIVES COMPANY
FOR SUPPORTING THE COMMITTEE'S
MEETING IN NEW ORLEANS, LA
IN
FEBRUARY 2004

THANK YOU,

FUEL, LUBRICANTS AND
ENVIRONMENTAL
COMMITTEE

I. DISCUSSION OF THE LMOA FUELS, LUBRICANTS & ENVIRONMENTAL COMMITTEE PENTANE INSOLUBLES PROCEDURE

REVISION 4

Prepared by Bob Dittmeier,
Afton Chemical Corp.

This fourth revision to the LMOA Pentane Insolubles Method was developed because of some concerns about inconsistency when comparing results between various analytical labs. This lack of consistency can become problematic considering that many of the North American railroads are moving to longer drain intervals, which inevitably will cause higher levels of insolubles in the engine oil. Since the level of insolubles in the engine oil is a primary condemning limit for one locomotive manufacturer, accurate and repeatable determinations are a needed requirement.

One railroad analytical lab reviewed the procedure and investigated what possibilities there were for improvement to the method. These included:

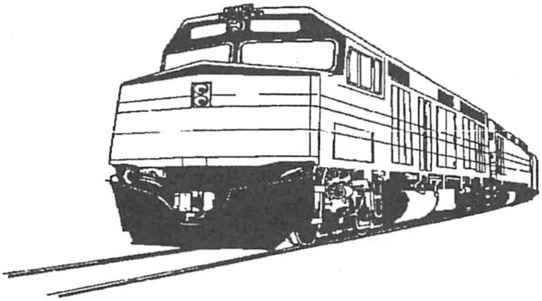
- Post filtering filter conditioning
- Coagulant age
- Minimum vacuum requirement
- Length of time for filtration
- Monitor relative humidity
- Stopwatch requirement

From discussion within the FL&E committee, it was decided that the first two of the above list were in need for further adjustment.

The original time chosen for the filter conditioning was set at 15 hours. In an analytical lab that analyzes very large numbers of used oil samples a day, this timeframe would not be sustainable on a continuing basis so a shorter timeframe is required. The conditioning length of time came from letting the filters sit over night but actually that timeframe can be as short as one hour. The one hour conditioning time was agreed to and is included as part of Revision 4.

The other procedural step that needed further review was the fresh or daily manufacture of the coagulant solution. What was needed was the determination of the life of the coagulant solution and from that set a timeframe for addressing the manufacture of fresh solution. After discussion within the committee, it was determined that coagulant solution could be made on a weekly basis, not daily, and that the maximum lifetime for a batch of coagulant should be one month. This also is included in the Revision 4.

In addition to the aforementioned changes there were also a number of other minor changes/additions to the protocol that addressed suspected causes for the variability seen in the results. These included: minimum vacuum requirements, filtration time, relative humidity and stopwatch use. These additional requirements should help remove the opportunities for additional variability and by adding this needed detail to the procedure, they



should better standardize it and limit the possibility of alternate methods becoming included within the procedure.

Included with these latest revisions it was also suggested to the FL&E committee that the LMOA Insolubles Procedure be proposed for addition into the ASTM as a recognized ASTM method. The committee is currently investigating this proposal for inclusion as a recognized ASTM method.

Also, the committee would like to thank Dennis McAndrew - GE Transportation Systems, Glenn Bowen - BNSF Railroad and their respective analytical labs for all the work that was done that allowed us to develop this 4th revision.

STANDARD INSOLUBLES TEST METHOD

Revision 4

(Revisions in ***bold italics***)

Scope: A filtration procedure for the determination of coagulated pentane insolubles in used diesel engine oils.

Equipment:

(1)Smooth tip forceps Millipore catalog, # XX6200006 Graduated cylinders, 50 mL with stopper

(2)Filtering flask, 1-litre capacity

(3)Pyrex filter holders Millipore catalog, # XX10047 ***02***

(4)Filter membrane 0.45 um Millipore catalog, #HAW PO47 00

(5)Aluminum weighing dish

(6)Balance capable of weighing to the nearest 0.0001 grams with a range of 160 grams.

(7)Vacuum capable of maintaining 15 inches Hg minimum.

(8)***Stopwatch***

Reagents: Coagulant - n-butyldiethanolamine 98% ***(J.T. Baker, catalog #JTD933-07)***

n-pentane 98% If industrial grade pentane is used, filter using 0.45 um filter prior to use.

Pentane coagulant solution, 1.0% by volume

(5 ml n-butyldiethanolamine to 500 ml pentane, if possible made fresh weekly and used no longer than 1 month after making solution)

Procedure:

1. Prepare oils to be tested by warming in an oven @ ***50° C (122° F)*** for 1/2 hour prior to use.
2. Use dry filters. Store filters in desiccator for 15 minutes prior to use.
3. Place 0.45 um filter into identified aluminum dish or other suitable container, weigh several times or until weight stabilizes and record to the nearest 0.1 mg.
4. Place 50 ml graduated cylinder on balance and tare.
5. Remove oil from oven. NOTE: Since some settling should occur during storage, vigorously shake the sample by hand for a minimum of 30 seconds before use.
6. Using a medicine dropper, weigh ***0.25*** grams into a graduated cylinder. Record weight to the nearest 0.1 mg. ***(If filtering time exceeds 5 minutes, rerun filtertion using 0.1 gram - see Troubleshooting note 1)***
7. Add 10 mL pentane and agitate gently until oil sample is fully dissolved in pentane.
8. Bring volume in the graduate up to the 50 mL mark with ***fresh*** 1% coagulant solution. Stopper and shake gently, ***inverting the graduate 4 times in 5 seconds.*** Allow to stand for ***30 minutes.*** Shake the solution gently every ***10 minutes of the 30 minutes.***
9. Mount the filter on ***a dry*** holder and apply vacuum. Mount and securely clamp the filter funnel to the filter holder. Ensure that a

minimum vacuum of 15 inches of Hg is attained and held.

10. Shake sample ***gently*** one last time, ***pour into funnel and using a stopwatch, immediately start timing the flow rate.***
11. Rinse the graduate twice using ***a minimum of 35 mL*** pentane and pour into the funnel. ***Stop timing when the last of the free liquid on the filter disappears. Record the flow rate to the nearest second.*** Rinse the funnel wall with pentane from a squirt bottle.
12. Remove the funnel from the filter holder and rinse the filter membrane with a stream of pentane from the squirt bottle. Ensure that the edges are rinsed well to remove any oil trapped beneath the funnel. ***See Troubleshooting Note 2.***
13. Release the vacuum, and using a smooth tip forceps transfer the filter to its original weighing dish.
14. Dry at 100°C ***for 1 hour.***
15. Cool to room temperature in a desiccator ***for a minimum of 1 hour.***
16. Weigh and record stabilized weight to the nearest 0.1 mg.

Calculation for determination of Mass% of insolubles (Wt. of filter & deposit)-(Wt. of filter) / (Sample wt.) x 100

Troubleshooting:

During the development of this test, a number of observations were made that helped operators recognize problems: These are described below:

1. Repeatability was found to be best if the samples filtered in less than ***five minutes.*** With extended filter times, the weight tends to be high, since the insolubles on the blocked filters cannot be rinsed well enough to remove all the oil and coagulant residue.
2. The following were found to indicate the presence of residual coagulant:
    a. Curling of the filter edges with drying, a yellow ring around the edge of the insolubles, or a blotchy surface appearance that is tacky. Residual coagulant will give high results. ***You cannot use too much pentane to insure a complete rinsing.***
3. In humid climates ***(>65% Relative Humidity)*** the cooling caused by the pentane evaporation may cause frost to form on ***both*** the filter ***and inside the funnel*** while rinsing. If this happens, ***remove the filter after rinsing and dry for at least 1 hour in a 100°C oven. An oven or compressed air may be used to thoroughly dry out the funnel. Warm the dried funnels on top of oven until ready for use. Avoid using any funnel that is still hot or damp.***

II. ENGINE OIL 101: VISCOSITY AND ADDITIVES

Prepared by Fred W. Girshick,
Infineum USA, L.P.

Abstract

This paper reviews the functions and compositions of engine lubricating oils, how viscosity is measured and classified, some basic concepts of additive chemistry, the destructive chemical and physical processes that take place in engines, the chemical additives used to minimize those destructive processes and impart required beneficial properties, and the special requirements of locomotive engine oils.

ENGINE OILS BASICS

Functions of Engine Oil

An analogy is often made between engine oil and blood. Both are fluids that circulate through systems, deliver "nutrients" to the required places, and remove contaminants. And just as animals cannot function without blood, engines cannot function without lubricating oil.

The primary function of engine oil is to separate moving parts that would otherwise rub against each other and wear out. This is essentially what we mean by lubrication. The key oil property that provides this function is viscosity, which will be formally defined and discussed shortly. Much effort on the part of engine designers is devoted to matching the expected engine operating conditions to the recommended oil viscosity. Likewise, manufacturers and suppliers of lubricating oils pay strict attention to ensuring that oil is the correct viscosity demanded by the engine design and operating conditions.

In addition to the correct viscosity, a lubricant should have a property called "lubricity." This is a vague term commonly called "slipperiness" and formally defined as the ability to wet a metal surface. Lubricity is the reason, apart from viscosity, that oil is a better lubricant than water. Lubricity can be felt by noting that olive oil feels more slippery than water when rubbed between your fingers. Water placed on a metal surface will bead up and form a drop; oil will spread out and form a film coating. Several types of additives are used to enhance the natural lubricity of oil.

Another important, but often overlooked, function of engine lubricating oil is cooling. In addition to the cooling water, lubricating oil is responsible for removing heat from engine pistons, rings, bearings and other parts. This heat is absorbed by the oil and released in the sump, in the case of small passenger car engines, or *via* heat exchange with cooling water in an oil cooler, in the case of a locomotive engine. The heat absorbed by the oil can do damage to the oil itself, in the form of thermal breakdown or oxidation. Additives are used to prevent oxidation and thermal degradation, as will be addressed in detail later. The cooling function is largely controlled by engine design. However, the lubricating oil can help prevent the buildup of engine deposits on critical surfaces. These deposits would act as insulators and impede cooling. Piston undercrowns are particularly sensitive.

The lubricating oil is required to prevent destructive processes that occur in an engine. To a large degree, an engine is in its best condition the day it is delivered and the best the lubricant can do is reduce the rate of deterioration. Typically, lubricants do not improve an engine with time, only extend its usable life and delay the inevitable. The specific destructive processes of oxidation, wear, friction, rust, corrosion, and shear will each be addressed in more detail later.

A properly formulated engine lubricating oil can help maintain the engine's designed operating condition, increase longevity, and reduce maintenance costs.

Composition of Engine Oil

This section gives an overview of engine oil composition. Each component will be discussed in more detail in a later section.

Engine oil can contain many components, which are classified in four categories: base stock, pour point depressant, viscosity modifier, and performance additives.

Base Stocks

Base stocks are the distilled and refined mineral oil streams derived from crude oil. A detailed discussion of base stocks is beyond the scope of this paper, and only a few points will be noted. Base stocks commonly have names such as "Solvent 150 Neutral," "Solvent 600 Neutral," or "Solvent 150 Bright Stock." These are abbreviated as S150N, S600N, and 150BS. The numbers refer to the viscosity of the base stock in historical units called Saybolt Universal Seconds. Some base stock manufacturers have different nomenclature and/or brand names. Engine oils usually use a mixture of base stocks to achieve the correct viscosity at engine operating temperatures. For railroad service, S500N, S600N, or S700N is usually the major base stock in the mixture. Lighter or heavier base stocks are used to fine-tune the viscosity.

Base stocks are often categorized as paraffinic, naphthenic, or aromatic. These terms refer to the majority type of hydrocarbon in the base stock. Parafinns are straight or branched saturated (all bond positions filled) structures without any rings, and are relatively stable towards oxidation. Naphthenes - not to be confused with naphthalene (moth balls) - are saturated structures with rings. The presence of ring structures makes them less stable towards oxidation. Aromatics are unsaturated ring structures. Unsaturated means that some of the possible locations of a chemical bond are empty, and therefore the molecule wants to react to fill the missing space. This makes these structures the least stable towards oxidation. Simple paraffinic, naphthenic, and aromatic molecular structures are shown in Figure 1. The molecules in base stocks used for railroad oil contains, on average, about 30 carbon atoms, but there is a wide distribution of molecular size in the mixture.

The heaviest base stocks, called bright stocks, contain a relatively high proportion of aromatic molecules, and therefore their content in railroad engines is limited to 10 mass percent maximum.

One engine manufacturer found, in searching and analyzing the database of all lubricating oil approval data, that oxidation stability deteriorated sharply when oils contained more than 10 mass percent bright stock. The previous maximum allowable content of 15 mass percent was reduced to 10 mass percent (General Electric 1991).

Base stocks by themselves do not have all the necessary properties to protect modern engines. Additives are used to enhance the desired properties and minimize the unwanted properties.

Pour Point Depressants

As hydrocarbons, most base stocks contain parafinns, or wax molecules. These wax molecules can crystallize at low temperatures, plug filters, and impede flow in engine passages. Waxy crystals can also interfere with lubricant storage and delivery, independent of engine operation. Pour point depressants (PPD), also called lube oil flow improvers (LOFI), help improve flow properties at low temperatures. Oils that are not expected to experience low temperatures, or those made from base stocks with very little wax (e.g., naphthenics), may not require a PPD.

The mechanism of pour point depressants is illustrated in Figure 2. Waxes are very regular molecules that can easily crystallize to form large sheets, like spoons fitting together in a drawer. PPD's are molecules designed to look like wax at one end and have bulky groups at the other end. The wax-like end gets incorporated into the wax crystals as it forms, and the bulky groups prevent the "fitting together" of more wax molecules. Additives commonly used to perform this function are polymethacrylates and fumarate vinyl acetates, shown in Figure 3. They are effective at concentrations as low as 0.05% to 0.2%. In closing PPD, the wax-like end must be matched to "fit" the wax in the specific base stock being used.

The same additives used in fuel are called Wax Crystal Modifiers (WCM) or mid-distillate flow improvers (MDFI).

Viscosity Modifiers

Viscosity depends very strongly on temperature. Oils are much thinner at engine operating temperatures than at room temperature. Similarly, oils are much thicker at outdoor winter temperatures. For oils that might experience temperature extremes, a reduction in the viscosity-temperature dependence is desired. Additives called viscosity modifiers (VM), or viscosity index improvers (VII), or VI improvers are used for this purpose, and will be discussed in more detail below.

Performance Additives

Finally, we categorize all other additives as performance additives. These are also known as the detergent-inhibitor (DI) package. This paper will discuss the function, composition, structure, and mechanism of the following types of additives: detergents, dispersants, anti-oxidants, anti-wear, rust and corrosion inhibitors, friction modifiers, and anti-foamants. These are the additives commonly used in railroad oils. There are other types of additives, such as extreme pressure, seal compatibility agents (seal swell agents), demulsifiers and emulsifiers, ant-mist, tackifiers, and dyes, which can be used in other types of lubricants, such as automatic transmission fluid, gear oils, or industrial oils. These will not be addressed in this paper.

It is important to keep in mind that not every oil contains every type of additive. It is the job of the oil formulator to achieve all the required properties with the minimum amount of additive. Some additives can perform two or more functions. It is the engine design, its intended service, the fuel quality, and the base stock quality that determine how much and which additives are needed.

The total additive content in engine oils varies considerably. There are some industrial oils that are only base stock, with no supplemental additives or only a few parts per million. There are marine diesel cylinder lubricants (MDCL), designed for diesel engines burning high sulfur (>3.5%) residual fuel that contain twice as much additives as a typical railroad engine oil.

A typical railroad oil probably contains between 12 and 16 percent performance additives, between zero and 0.2 percent PPD, and between zero and eight percent viscosity modifiers. As mentioned above, not all oils require PPD, and as we will see later, not all oils contain viscosity modifier. Railroad oils typically contain about 50-100% more performance additive than passenger car engine oils, and about the same amount as heavy duty truck engine oils. The specific mixture of additives for railroad is very different from the mixture for on-highway HD engine oils.

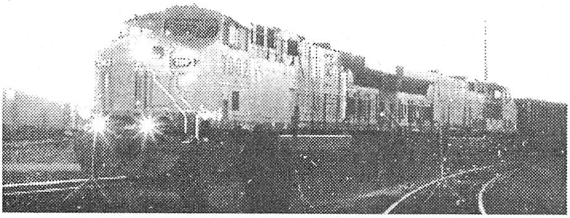
Additive Packages

The performance additives are typically delivered to an oil company or compounder-blender pre-blended into a Detergent-Inhibitor package, or DI pack. The oil formulator must ensure compatibility of the additives with each other and stability of the resultant DI package. Additive packages and oil approved by the engine manufacturers for railroad service are required to be compatible with each other, even those from different manufacturers. This is to add a measure of safety if a railroad uses more than one system oil, changes technologies, or if locomotives are used for power-sharing.

Although present in seemingly small amounts, these additives are critical to the successful performance of engine oils, just as small amounts of vitamins and minerals are essential to our own health.

Viscosity

Viscosity is defined as resistance to flow, and is analogous to friction and electrical resistance. Viscosity is a common, everyday concept - we



recognize that honey and molasses are "thicker" than water and flow (pour) more slowly. We notice that some fluids have more "weight" or more "body" than others. For most common household products, viscosity is not only a performance feature, but a marketing and sensory feature as well. A thin shampoo might clean hair just as well as a thick shampoo, but might not provide a luxurious tactile experience. Toothpaste that is too thin would drip past the toothbrush bristles. Paint needs to be thick enough not to drip but thin enough to spread easily. Catsup is advertised according to how slowly it pours. For engine oils, the correct viscosity is determined primarily by engine design and intended service temperatures; appearance or tactile experience should not be factors in engine lubricant selection.

The formal definition of viscosity is: shear stress divided by shear rate. In this sense, the word "shear" is used as an adjective, to mean "sliding." Shear stress is the sliding stress, or sliding force. Shear rate is the sliding rate or sliding speed. Viscosity is then (sliding) force divided by (sliding) speed. Or, as we sometimes say, "how hard you push it divided by how fast it moves." The SI unit of viscosity is the millipascal-second (mPa-s).

There are many different methods to measure viscosity. The most convenient, and most common, is to let the fluids flow under its own weight through a narrow tube, called a capillary. The time for a known volume of fluid to drain is measured, and multiplied by a factor supplied by the capillary manufacturer. In this case, the driving force is gravity, and the shear stress is determined by the weight of the fluid, which in turn depends on the mass of the known volume. Mass per unit volume is density, and the quantity measured is viscosity divided by density, which is called kinematic viscosity. The most common method to measure kinematic viscosity is ASTM D 445.

The SI unit of kinematic viscosity is the millimeter-squared per second (mm^2/s). An older unit, the centistoke (cSt) is still commonly used, and is equal to one mm^2/s. The unit Saybolt universal second (SUS) is uniquely used to describe base stocks, usually at 40°C. Kinematic viscosity in SUS is approximately equal to 4.6 times the kinematic viscosity in mm^2/s. For example, a S600N base stock has a kinematic viscosity of approximately 130 (=600/4.6) mm^2/s at 40°C. The 150 designation of 150 Bright Stock is the kinematic viscosity in SUS at 100°C, rather than 40°C.

Viscosity depends very strongly on temperature. Again, this is a common experience: cooking oil in a frying pan will slosh more as it is heated and thins. Liquids pour more slowly when cold.

The system to measure viscosity-temperature dependence of engine lubricating oils is viscosity index, VI. The key concept is that higher VI means less temperature effect on viscosity. VI was an historical development. In 1936, the best and worst available base stocks, in terms of viscosity-temperature dependence were chosen and assigned the values 100 and 0, respectively. An unknown oil is compared to these and interpolated to derive its VI. Very soon thereafter, base stocks with worse performance than the zero VI reference were found, and the scale was extended downwards. Similarly, oils better than the 100 VI reference were found, and the scale was extended upwards. Later, the definition of VI was revised to use the SI units of viscosity (mm^2/s) and temperature (Celsius). Viscosity Index is calculated by using the kinematic viscosities at 100°C and 40°C and referring to a table of standard values. VI can also be calculated from equations using the viscosity values; this is now the more common practice. Viscosity index is defined in ASTM Standard Practice D 2270.

Paraffinic base stocks, with straight or branched structures, have VI's around 95. This is because the open structure allows flexibility to change configuration with temperature. Naphthenic base stocks, with ring structures, have VI's around 60. This is because the tight rings structures don't allow any molecular flexibility. Multigrade oils, as will be discussed later, typically have VI's above 110.

For oils that may experience temperature extremes, it is desirable to reduce the dependence of viscosity with temperature. Otherwise, oil selected for correct viscosity at engine operating temperatures may be too viscous to allow cold starting. Likewise, oil selected for good low temperature fluidity may be too thin to adequately protect the engine at operating temperatures. Ideally, lubricating oil should combine the best of both properties; good low temperature fluidity and good high temperature protection.

Viscosity Modifiers

Additives called viscosity index improvers (VI improvers or VII) were developed to improve the viscosity index. Later, these additives were called Viscosity Modifiers (VM), because they can do more than just improve the VI. VM's are very long polymer molecules that have the ability to coil and uncoil in reaction to temperature. VM polymer chains can contain between 1,500 and 15,000 carbons. Just as the paraffinic base stocks have higher VI's than the naphthenic base stock due to molecular flexibility, the VM molecules take this to another level. At high temperatures, the long VM molecules stretch out and occupy a large volume, which impedes flow. Since resistance to flow is the definition of viscosity, this thickens the oil and creates a higher viscosity at the high temperature. At low temperatures, the long VM molecules coil up and occupy a smaller volume, which impedes flow to a lesser degree. This thickens the oil less at low temperature than at high temperature. The relative changes in volume with temperature are illustrated in Figure 4.

Viscosity Modifiers are polymers. "Poly-" means "many" and -mer" means "unit." A polymer is a molecule made up of many repeating units. The single unit is called a monomer. A co-polymer is made from two types of monomers, which can combine with each other. Common polymers used as Viscosity Modifiers are polymethacrylates, ethylene-propylene copolymers, and styrene-isoprene copolymers.

Engine Oil Viscosity Classification

Engine oils are classified according to their viscosity using the Society of Automotive Engineers document SAE J300, Engine Oil Viscosity Classification, which is summarized in Table 1 and illustrated in Figure 5. The latest version of SAE J300 is May 2004. SAE J300 was developed for oils intended for passenger car and heavy duty truck engines. Certain modifications and additions are required for railroad locomotive engine oils, as will be pointed out.

The so-called "summer" grade, which is indicative of high temperature performance, is derived by measuring kinematic viscosity at 100°C. Each summer grade has minimum and maximum limits, and all are measured at 100°C. For example, the SAE 40 grade is defined as greater than 12.5 mm²/s and less than 16.3 mm²/s at 100°C, as measured using test method ASTM D 445. SAE J300 also imposes on each summer grade a minimum viscosity measured under high shear (high speed) conditions at 150°C. For SAE 40 grade, the minimum is 3.7 mPa-s, as measured by one of three test methods, ASTM D 4683, D 4741, or D 5481.

For railroad service, a minimum kinematic viscosity of 13.9 mm²/s at 100°C is required by the engine manufacturers, which is still within the SAE 40 grade. Many Class I and other railroads have their own internal specifications for lubricating oils, which often have a more narrow range of acceptable viscosities than those allowed by the engine manufacturers. It is common to find viscosity ranges between approximately 15.0 and 15.8 mm²/s.

The so-called "winter" grade, appended by a "W" to indicate "winter," is indicative of cold starting ability at low temperatures, and is derived by measuring viscosity at a temperature representative of the expected use of that grade. Each winter grade has a maximum viscosity limit at a different temperature. For example, the SAE 20W grade is defined as less than 9500 mPa-s at -15°C. The instrument used for this measurement is the Cold Cranking Simulator, ASTM D 5293, which uses relatively high shear stress (high force) to mimic a starting motor.

In addition, SAE J300 requires winter grades to demonstrate good low temperature fluidity under low shear rate (low speed) conditions, as measured in the mini-rotary viscometer, ASTM D 4684. Each winter grade is measured at a different temperature, but all grades have the same maximum limit, 60,000 mPa-s. The pumpability for each grade is measured 5°C lower than the cranking temperature, to ensure a safety margin. The pumpability of an SAE 20W oil is measured at -20°C.

Winter grades must meet minimum kinematic viscosity limits at

100°C. In the case of SAE 20W, this limit in effect requires the oil to be a minimum of SAE 20.

As shown schematically in Figure 5, an oil that meets the summer grade requirements for SAE 40 only will be labeled as SAE 40. An oil that meets the winter grade requirements of SAE 20W only will be labeled as SAE 20W. Each of these is called a monograde, since it meets only one viscosity grade. Since the oil shown meeting both SAE 20W and SAE 40 meets multiple viscosity grades it is called a multi-grade oil. It would be labeled as SAE 20W-40. (Note: The SAE 20W oil could be labeled as SAE 20W-20, since it is also required to meet SAE 20.)

For railroad service, it has been determined that SAE 40 and SAE 20W-40 are the only suitable viscosity grades. A slight variation of SAE 20W-40, called "railroad multigrade," with a slightly relaxed CCS limit is also known. Railroad multigrade has a maximum of 5000 mPa-s at -10°C, as measured by ASTM D 5392.

The introduction of very high molecular weight polymer as viscosity modifiers improves the temperature dependence of viscosity and creates multigrade oils. A side effect of these additives is viscosity shear loss, also called "shear" or "shearing." In this sense, "shear" comes from the same root word as "shears" meaning scissors. Some of the larger molecules in the oil are literally cut in half by the action of the moving engine parts. This is illustrated in Figure 6, where the flow of fluid "pulls" on the long polymer molecule and stretches it out. In extreme circumstances, this can break the molecule in half. Two shorter molecules don't thicken oil as much as one long molecule, resulting in a lower viscosity. The extent of this thinning depends on engine operating conditions and VM molecular strength. Test method ASTM D 6278 has been shown to be representative of, or more severe than, engine operating conditions.

To protect locomotive engines, the LMOA Fuels, Lubricants, and Environmental Committee recommends all oils have a minimum viscosity at high shear rate (high speed) at 100°C <u>after</u> being degraded by ASTM D 6278 (McAndrew 1994). These conditions are more representative of the engine environment during service than the fresh oil limits imposed by SAE J300. Railroad engine oils must have a viscosity no less than 10.8 mPa-s by ASTM D 6616 following ASTM D 6278.

The full viscosity requirements and typical values for railroad engine oils are listed in Table 2.

Additives and Engine Chemistry

This section will discuss fundamental concepts in lubrication, and then introduce chemically destructive processes in engines and the additives that are used to minimize those destructive effects. Typical compositions of such additives and the mechanism of their action are presented.

Polarity

The main problem facing an engine oil formulation chemist is that oil and water do not mix. Although a common and familiar phenomenon, it is worth examining exactly why this is true. The answer lies in the fundamental nature of carbon, hydrogen, and oxygen atoms and the structure of chemical bonds.

Atoms are composed of positive protons and neutral neutrons in the nucleus (center) surrounded by negative electrons orbiting around the nucleus. The number of protons and the number of electrons are the same, to maintain electrical neutrality. The number of protons determines which element the atom is: hydrogen is one, helium is two, lithium is three, *etc.* The electron orbitals or shells have certain preferred numbers of electrons which are more stable, for example two or ten. Atoms seek to "complete their shells" to achieve the stable configurations. Hydrogen has one electron and seeks to gain another. Carbon has six and seeks four more. Oxygen has eight and seeks two more. The way atoms complete their electron shells is by sharing electrons. Two hydrogen atoms, each with one electron, get together, "pool" their two electrons and share both. Then, each hydrogen atom seems to have two and is more stable. This sharing of electrons is a chemical bond.

The two hydrogen atoms are now a hydrogen molecule, H_2. Since each hydrogen atom is identical to the other, the electrons are shared exactly equally; each hydrogen atom has the electrons 50% of the time. (This sharing of electrons, with each hydrogen atom counting both, has sometimes been called "faulty accounting" by non-chemists.)

Carbon needs four extra electrons to complete its shell. it can combine with four hydrogen atoms, each of which contributes one. This forms the molecule CH_4, which is methane. A carbon atom can bond to many other types of atoms, as long as it shares four electron pairs. The element carbon has a unique ability to form chains with itself, as long as each carbon has four bonds. Commonly in carbon chains, the places carbon is not bonded to another carbon are filled with hydrogen atoms. Molecules containing only carbon and hydrogen are called hydrocarbons. A hydrocarbon molecule is shown schematically in Figure 7a. Carbon and hydrogen have approximately the same affinity for electrons, and the sharing is nearly equal.

In contrast, when an oxygen atom (which needs two electrons to complete its shell) combines with two hydrogen atoms (each contributing one electron) to form H_2O (water), the sharing of electrons is not equal. Oxygen has a greater affinity for electrons than hydrogen. Therefore the electrons spend more time near the oxygen atom and less time near the hydrogen atoms. As a result, the oxygen atom becomes partially negative and the hydrogen atoms become partially positive. The overall molecule is still electrically neutral.

This separation of charge, shown in Figure 7b, makes two poles, similar to the north and south poles on a magnet. For that reason, this type of molecule is called a polar molecule. By contrast, the hydrocarbon molecules are non-polar. Polar molecules prefer to mix with other polar molecules because the north poles attract the south poles, *etc.* Polar molecules cannot attract non-polar molecules, which have no north or south poles. This is the reason oil and water do not mix. Oil, which has the right viscosity and lubricity characteristics to make good lubricants, is non-polar. Almost everything else in the engine environment is polar, including the metal surfaces of the engine, the byproducts of fuel combustion, soot, oxidation products, acids, sludge, and varnish. To control these polar contaminants, it is necessary to make them soluble in the non-polar lubricating oil.

Surfactants, Micelles, Emulsions, and Colloids

Surfactants are molecules that are polar at one end and non-polar at the other end, as shown in Figure 8. The polar end is called the "head" because it is usually smaller and more compact; the non-polar end is called the "tail" because it is usually a long hydrocarbon chain.

A molecule with both polar and non-polar sections can interact or mix with both polar and non-polar species. For example, the polar end can attract water and the non-polar end can attract oil, resulting in oil mixing with water. this is the operating principle of hand soap, shampoo, laundry detergent, paint, toothpaste, mayonnaise (a mixture of non-polar oil and polar vinegar using egg yolk as the surfactant), and thousands of more products.

Surfactant molecules can be self-organizing. If placed in water (or other polar medium), the polar ends of the surfactant will preferentially want to face outwards, and the non-polar ends will want to be shielded. This results in a three-dimensional spherical object called a micelle, shown in Figure 9a. If placed in oil (or other non-polar medium), the non-polar ends will want to be on the outside and the polar ends in the middle, as shown in Figure 9b. This is sometimes called a reverse micelle, but commonly also called a micelle.

Depending on the relative sizes of the surfactant's polar and non-polar ends, the micelle can have a space in the middle. If that space is filled with a liquid, the whole unit is called an emulsion (for example, mayonnaise). If filled with a solid, the whole unit is called a colloid (for example, water-based paint carrying pigment particles - in England water based paint is called "emulsion").

This is the answer to the basic lubrication problem - how to get oil and water to mix. As we will see in the next sections, most lubricant additives are surfactants and form micelles, emulsions, or colloids.

Detergents

Detergents are arguably the most important additives for railroad engine oils, and can comprise more than 50% of the total additive content. The functions of detergents are to neutralize combustion and oxidation acids, reduce carbon, varnish, and lacquer deposits particularly on the higher temperature engine surfaces, such as pistons and liners, and prevent piston ring sticking. To neutralize acids, detergents must be bases (alkaline). To control high temperature deposits, detergents must be surfactants with relatively large and strong polar ends and relatively small and weak non-polar ends. These are essentially two unrelated requirements, but can be combined into one additive making lubricant detergent multifunctional. In addition, many detergents also act as anti-rust additives.

Like any surfactants, detergents have a polar head and a non-polar tail. The commonly used (strong) polar heads are calcium sulphonate, calcium salicylate, and calcium phenate. These are all made by reacting weak organic acids (e.g., sulfonic acid) with strong inorganic bases (e.g., calcium hydroxide), which makes the resulting salt basic or alkaline and allows them to neutralize acids. The non-polar tail is relatively short, perhaps 12 to 20 or 30 carbons, and can be straight or branched. This combination of a strong polar head and a weak non-polar tail give the detergent an affinity for highly polar materials, such as lacquer, varnish, and metal surfaces. This allows detergents to keep lacquer and varnish pre-cursors in solution in the oil instead of dropping out and forming deposits on the engine. The ability to bond to metal surfaces allows the detergent to form a coating or film that further protects the metal surface from deposit formation or rust. Some examples of detergents are shown schematically in Figure 10.

Calcium is the preferred metal for railroad service. Other metals, such as magnesium, lithium, and barium, have been used for other types of lubricating oils. Calcium is a divalent metal, meaning it prefers to form two bonds. In the reaction between the strong base calcium hydroxide and the weak acid "tail," if two "tails" are used to fill both of these places, the detergent is called a neutral detergent. If only one "tail" is used, and the other place is left with a hydroxide group, the detergent is more basic, and is called a basic detergent. Either of these is called "soap." The old-fashioned way to make soap is to boil animal fats (organic acids) with lye (sodium hydroxide), in a similar chemical reaction now used to make lubricating oil soaps.

Basic soaps have a higher capacity to neutralize acids, which is a primary function of the detergent. To get even more acid neutralizing capacity, detergents can be made "overbased." An inorganic metal base (calcium hydroxide or calcium carbonate) is even stronger than the reacted soap, but is not soluble in oil. However, the calcium soap is a surfactant that can form a colloid to make the calcium hydroxide or carbonate soluble in oil. The inorganic metal base (hydroxide or carbonate) is called the "core." Figure 11 shows schematic examples of neutral, basic, and overbased detergents.

The amount of base oil is measured as base number (BN). Total base number (TBN) is the older and more common term. BN is measured using one of two test methods: ASTM D 2896 or D 4739. The former is commonly used for fresh oils because it measures all basic species. The latter is recommended for used oils, or oils in service, because it only measures strong bases, which will be effective to neutralize acids. The demands of railroad service led to two commonly recognized levels of basicity: 13 TBN and 17 TBN. By contrast, passenger car engine oils are typically 6 - 8 TBN, and heavy duty truck engine oils have about 8 - 10 TBN, and are now approaching 12 TBN. These values only refer to the amount of base in the oil, and not other performance parameters.

In lubricants terminology, detergent explicitly refers to surfactants containing a metal, such as calcium. In fuels terminology, a detergent is what lubricants call a dispersant. The metal in the detergent, when burned, will leave a residue called ash. A common laboratory test for this, ASTM D 874, reacts the oil with sulfuric acid, to mimic acid combustion products, and then heats it until burned. The residue from this test is called sulfated ash (SASH) and is a measure of metal content.

In formulating engine oils, choices can be made about the metal (calcium, magnesium, etc.), the type of "tail" (sulphonate, salicylate, phenate, etc.), the length of the "tail," the straightness or branching in the tail, the degree of overbasing, and the total concentration of detergent. Mixtures of different kinds can be used to achieve a better overall balance of performance.

Dispersants

Dispersants, also called ashless dispersants, are also surfactants that act to keep the engine clean. In lubricants terminology, dispersant explicitly means a surfactant that does not contain a metal, such as calcium. Dispersants are made from carbon, hydrogen, oxygen, and nitrogen, do not leave any residue when burned, and are therefore called ashless. In fuels, dispersants are called detergents; detergent gasoline does not contain any metals.

Dispersants, as their name implies, are used to disperse or suspend soot, sludge, and deposit precursors. Dispersants are the primary additives used to keep the engine clean in the relatively low temperature areas (crankcase, valve train), but have also been shown to be effective in higher temperature areas (ring zone). Dispersants also play a role in stabilizing detergent colloids, dissolving organic acids from combustion and oxidation and helping the detergent to neutralize the acids.

Dispersants are surfactants designed to have a relatively small and weak polar head and relatively large non-polar tail, held together by a bridging group. The non-polar tail is typically made from polyisobutylene (PIB) from 60 to 200 carbons. The bridging group is commonly succinic anhydride (SA). The polar head is often polyamine (PAM). This type of dispersant is called PIBSA/PAM. Other tails, bridging groups, and heads can be used. A schematic diagram of a PIBSA/PAM is in Figure 12.

Dispersants can be made with one head and one tail (as is commonly drawn), or with one head and two tails, two heads and one tail, two heads and three tails, etc., etc., etc. The exact length of the tail can be chosen, and there is some degree of control over the amount of branching in the tail. The size and strength of the polyamine in the head group can be controlled. Of course, mixtures of different dispersants can be used.

Table 3 compares detergents and dispersants.

Oxidation

Oxidation is one of the main mechanisms to degrade lubricating oil. Oxidation is deterioration caused by combination with oxygen from the air. There has been a great deal of publicity recently about the effects of oxidation on the aging process in humans, and the benefits of incorporating anti-oxidants, such as Vitamin E, into diet and various anti-aging creams. Lubricating oils, like humans, are hydrocarbons which are subject to oxidation and benefit from anti-oxidants.

For lubricating oils, oxidation is a necessary and inevitable byproduct of fuel combustion. As long as engines burn fuels, there will be oxidation. The results of oxidation are viscosity increase, acid buildup, corrosion, bearing wear, and insolubles.

Oxidation is a chain reaction caused by radicals. Radicals are molecular fragments with an unpaired electron. As discussed above, atoms make electrons pairs to complete their shells, resulting in chemical bonds. If such a bond is broken, for example by ripping a hydrogen away from a hydrocarbon, the hydrogen takes its one electron, leaving the rest of the original molecule with an unpaired, single electron. This is a very high energy and relative species, called a radical or free radical. Most cosmetic advertisements warn about the dangers of free radicals.

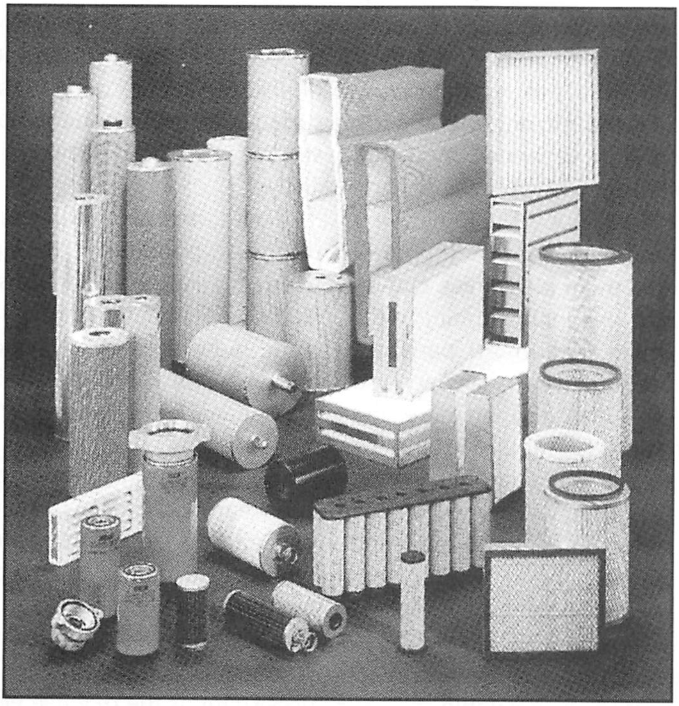
A chemical radical is similiar to a political radical, in having lots of energy and going around making trouble. The easiest way a radical can get another electron to complete its shell is to steal it from another molecule. This propagates the chain reaction, which can also branch to increase the number of radicals.

Oxidation increases at higher temperatures. A rough rule of thumb is that the rate of oxidation doubles of every 10°C increase. Oxidation can be catalyzed by the presence of metals or acids; catalyzed in this sense means accelerated. Engines are made of metal, and the wear process puts metals into the oil, so such catalysis is inevitable.

Anti-oxidants are additives that interfere with the radical chain reaction process. They do this by combining with the radicals to form relatively harmless products, or by decomposing the radicals. Additives commonly used to do this are hindered phenols and diphenyl amines, shown in Figure 13.

Wear and Friction

Wear and friction are similar, but different phenomena. Both are caused by the relative motion of sur-



faces (rubbing). Wear is a loss of material and friction is a loss of energy. The preferred way to minimize both wear and friction is to keep engine parts from rubbing. As mentioned above, the primary function of lubricating oil is to separate moving parts. If the moving metal parts cannot be kept separated by a thin film of oil, they will rub against each other and wear out. A fluid film of a few millionths of a meter (hundred thousandths of an inch) thick can be sufficient to eliminate rubbing wear and minimize friction. If parts are allowed to rub, wear will decrease the engine's life and increase the concentration of metals in the oil which can then catalyze further oxidation. Friction will waste engine power, reduce fuel economy, and cause further heat which will increase oil and engine degradation. Correct viscosity selection is the key to achieving this; however, contact of moving parts is inevitable.

When moving parts are forced into contact, anti-wear additives can reduce the damaging effects. Anti-wear additives chemically react to form a film on the metal surface. This film is weaker than the underlying metal and sacrificially wears away to protect the engine. In welding or soldering, flux is used to clean the parts to be joined because clean parts make a good join. In some senses, anti-wear additives act in the opposite way - they make the surfaces chemically dirty, so that they will not weld together under the heat and pressure of engine operation.

In commercial passenger car and heavy duty truck engine oils, the anti-wear additive type universally used in zinc dialkyldithio phosphate, or ZDDP. This additive contains zinc, sulfur, and phosphorous, and decomposes at the temperatures typical of sliding contacts to form a surface film as described above. The structure of ZDDP is shown in Figure 14.

There are also non-zinc, phosphorous containing compounds, used in Automatic Transmission Fluids (ATF), aviation engine oils, and some industrial oils. A typical additive of this class is TriCresyl Phosphate (TCP), shown in Figure 15.

Some non-zinc, non-phosphorus anti-wear additives use chlorine as the reactive element to form a film on metal surfaces. Due to concerns about the environment and used oil disposal, the use of chlorine is discouraged. An alternate chemistry uses sulfur as the reactive element to form the protective film.

Locomotive engines manufactured by Electro-Motive Division used to use silver bearings, which are corroded by typical zinc and phosphorus anti-wear additives. Railroad engine oils therefore required zinc-free anti-wear additives, which were initially chlorine-based, and are now chlorine-free for environmental reasons. Even though EMD has replaced the silver bearings in their current engines, there are many engines in the installed fleet with silver bearings, and railroad engine oils will continue to require zinc-free lubricants. Also, as will be mentioned in the section on evolution of railroad oil quality levels, modern locomotive engines were designed in conjunction with these special zinc-free railroad lubricants and there is no desire to change the balance in a system that has worked so well.

Rust and Corrosion

Most engine parts are made of iron, steel, or similar alloys. These iron-containing metals have been refined from ores primarily containing iron oxide. Iron in the oxide form is sometimes called its native state. Chemically, iron would prefer to return to this native state. The same iron oxide, when formed from machined metal alloys, is called rust. The formation of rust can accelerated by the presence of water or acids, both of which are byproducts of oxidation. In addition, water can be introduced through condensation, water leaks, or from the environment. Certain additives can create a film on the metal surface to prevent rust from forming, in the same way that a paint coating prevents rust.

Corrosion is a similar process to rust, but usually refers to non-iron containing metals or alloys. Some engine parts, such as bearing and bushings, are made from copper, lead, tin, or other similar elements. Combination of these elements with oxygen, sulfur, or acids is called corrosion. Corrosion inhibitor additives act on these metals in the same manner that rust inhibitors act on iron alloys; the difference is designing the additive to bond preferentially to the appropriate metal. Common rust and corrosion inhibitors are shown in Figure 16.

Friction Modifiers

All chemicals, when added to lubricating oil, have the potential to modify friction. The term friction modifier specifically refers to those additives that, when added in small concentrations (less than 1%) can significantly lower the friction of metal-to-metal rubbing. Friction modifiers come in two broad classes: soluble and non-soluble. Non-soluble friction modifiers, such as graphite and molybdenum disulphide, are perhaps more familiar from everyday shop and home use. These additives can be made soluble in oil by use of surfactants (see above). They work because their chemical structure has the architecture of flat sheets that can slide over each other, as shown in Figure 17.

The soluble friction modifiers are organic molecules designed to form a film on metal surfaces with tails extending into the oil, analogous to a pile carpet. The polar head group is specifically designed to bind to metal surfaces, rather than engine deposits or soot, for example. The hydrocarbon tails are approximately as long as the base stock molecules, for good solubility and compatibility in the bulk liquid which will help them stand up straight. The tails are designed to be somewhat more rigid than the tails of detergents or dispersants, and ideally to have interacting forces whereby each molecule helps its neighbors stand up straight. Some common friction modifiers are shown in Figure 18.

Anti-Foamants

Foam and air entrainment are both the incorporation of gas (vapor) into the liquid lubricant. Air is a much worse lubricant than oil, and its presence in the engine oil can lead to severe engine damage, as well as damaging the oil pump. Foam refers to situation when air mixed into the oil rises to the surface and forms a "head," as in beer. Air entrainment refers to the situation where air is mixed into the oil and remains as bubbles in the liquid, as in champagne.

Both foam and air entrainment are controlled by using anti-foamants, additives designed to act at the oil-air interface, similar to the way detergents and dispersants can act at an oil-water interface. High molecular weight silicones perfom this function.

Special Requirements for Railroad Service

Zinc-free and chlorine-free

Railroad engine oils must be zinc-free. This precludes the use of zinc dialkyldithio phosphate (ZDDP) which is a potent and cost-effective anti-wear and anti-oxidant. Railroad oils must contain other types of anti-wear and anti-oxidants. Anti-wear additives using chlorine chemistry were used previously, but are now discouraged due to environmental concerns. Modern railroad oils are therefore zinc-free and chlorine-free.

Total Base Number (TBN) Requirements

Railroad engine oils are typically 13 or 17 TBN. This indirectly measures the amount of basic detergent in the oil, but is unrelated to other additives or performance parameters. The primary function of these basic detergents is to neutralize acids produced by fuel combustion (Haley 1994). As the acid is neutralized the basicity, or base number, of the oil decreases. Eventually, the base number reduces to the point where it may be insufficient to protect engine parts, particularly bearings from acidic attack. This point is the condemning limit when the oil should be changed. Often, base number decrease is the limiting factor in establishing oil drain intervals for four-stroke engines. In two-stroke engines, the base number retention must be sufficient to maintain the equilibrium level of base number above the manufacturer's condemning limit; otherwise an oil change will be required. Although some 13 TBN oils are capable of meeting the formal engine manufacturer performance specifications, railroads may select a 17 TBN oil to achieve extended oil drain intervals or increased safety margin. This strategy works if base number retention is the limiting factor and all other parameters (insolubles, oxidation, wear metals, etc.) are in control. Whatever the oil quality level, extension of oil drain interval should only be done in conjunction with a proper oil monitoring program and in consultation with the engine manufacturer.

Viscosity

The viscosity grades for railroad

engine oils are SAE 40, SAE 20W-40, or "Railroad Multigrade," which is a slight variation of SAE 20W-40. Other viscosity limitations, more restrictive than the SAE classification, are required for railroad service.

Evolution of Quality Levels and the "Generations"

The LMOA has issued a set of quality definitions, called generations, which are summarized in Table 4 (Hoffman 1979). Generation 4 and earlier are obsolete. The only quality levels now recognized and approved are General Electric Generation 4 Long Life and LMOA Generation 5. These are the only quality levels recommended for use in railroad service.

The LMOA "Generations" of oil quality evolved in parallel with engine design improvements. As new engine designs were introduced, the increased severity would strain the current quality of oil commercially available, which in turn led to the marketplace changing to higher quality oil. Engine designers could then take advantage of the higher quality oil to increase further the severity of new engine designs. By this interactive process of "push-and-pull" the quality of both engines and lubricating oils increased.

The LMOA "Generations" represent major increments in engine oil quality level. The word "Generation" was specifically chosen to denote a significant advance in lubricant technology. These major changes do not happen frequently, as indicated by only five generations being defined since about 1940.

Within each generation, there have been more minor increments, not formally designated with nomenclature, but recognized by the engine manufacturers, railroads, and oil and additive marketers. It can be seen in Table 4 that LMOA Generation 3 changed from a minimum of 7 TBN, the same as LMOA Generation 2, to minimum of 10 TBN shortly after formal introduction of the generation. This could be considered a "mid-course correction."

Within each generation, engine oils evolved to incorporate improvements in lubricant technology. For example, railroad oils changed from predominantly naphthenic to paraffinic base stocks independently of a specific generation definition. Similarly, the introduction, gradual acceptance, and eventual domination of multigrade railroad oils took place within the LMOA Generation 5 and GE Generation 4 Long Life categories. The shift from 13 to 17 Base Number as the majority volume used by Class I railroads was independent of a generation definition, as both may be capable of meeting LMOA Generation 5 and GE Generation 4 Long Life requirements.

The Generations are often associated with their minimum base number requirement, as listed in Table 4, and it may falsely be assumed base number is the only difference between the generations. it is generally agreed the main areas of improvement between successive generations are oxidation resistance, detergency, dispersancy, alkalinity, and lubricity (Hoffman 1979).

The first diesel engines for railroad motive power were introduced before 1930. The transition from steam to diesel engines occurred for the most part between 1940 and 1960, as seen in Figure 19 (Progressive Railroading 2000). Presumably, at first, railroads used whatever quality engine oil was available. As engine designs stabilized and the specific needs of locomotive engines became apparent, the first LMOA Generation was defined, around 1940. It comprised straight mineral oil (base stock) with minimal additives - perhaps some detergents and/or anti-oxidants (General Electric 2000).

The first areas identified for improvement were extended oil and filter life, reduced sludge, and better low temperature properties. Oil formulations began to incorporate ashless dispersants and pour point depressants, and detergent levels increased modestly. This new performance level was recognized as LMOA Generation 2 in 1964, just as the steam to diesel transition was almost complete (ibid.).

Shortly thereafter, in 1968, LMOA Generation 3 was introduced to improve piston ring sticking. Although the initial definition of Generation 3 maintained the same minimum TBN as Generation 2 (7 TBN), the level and effectiveness of detergents increased, which was recognized by a modification of the Generation 3 definition in 1970 to be a minimum of 10 TBN. Concurrent formulation changes, most notably dispersants and lubricity agents, improved insolubles and corrosive wear control, and bronze lubricity (ibid).

The introduction of LMOA Generation 4 in 1976-77 was a response to the further need for better alkalinity retention, as denoted by the increase in minimum TBN to 13. Improved dispersant technology was also incorporated in these oils. Later, a sub-set of Generation 4, with minimum TBN of 20, would be defined for service using high sulfur (1%) fuels.

The Fuels, Lubricants and Environmental Committee of LMOA developed a Field Test Evaluation protocol to standardize the demonstration of lubricant performance (LMOA 1987). This field test protocol would be updated several times as engine service and lubricating oil composition changed (LMOA 1983, 1989, 1990; Tincher 1993, McAndrew 1994, Dittmeier 2000).

Field experience with Generation 4 engine oils eventually led to oils with improved performance in all areas - viscosity and alkalinity control, oxidation and wear control, and cleanliness. This led to the definition of LMOA Generation 5 and GE Generation 4 Long Life in 1984. Field experience and the introduction of more sophisticated data analysis tools have revealed that initial oil TBN is not the best method to designate oil quality. The important factor is the ability of the base (detergent) to neutralize acids while maintaining a sufficient reserve to allow a comfortable safety margin. LMOA Generation 5 and GE Generation 4 Long Life do not specify initial oil TBN (n.b., For "backwards compatibility" with older engines, the oil is expected to also meet LMOA Generation 4, so 13 TBN minimum is implied). The most significant parameter is the oil's ability to maintain TBN above the engine manufacturer's condemning limit under operating conditions of prescribed severity.

The difference between LMOA Generation 5 and GE Generation 4 Long Life is that the description of LMOA Generation 5 implies these oils can achieve 184-day oil drain intervals, while GE Generation 4 Long Life formally approves oil drain intervals based on service severity (megawatt-hours per month, MW-hr/month). Approval for extended oil drain intervals in General Electric engines is considered by GE upon submission of satisfactory used oil analysis and operational data (D.W. McAndrew, personal communication).

During the 1980's, multigrade railroad oils were introduced within the LMOA Generation 5 and GE Generation 4 Long Life categories (LMOA 1981, 1983, 1988, 1990; Tincher 1993; McAndrew 1994).

LMOA Generation 5 (GE Generation 4 Long Life) oils are continually improving. The most recent trends increase oil filter life and deposit control (Middleton 2002).

Lubricant Approval Procedures

Oils meeting LMOA Generation 5 or GE Generation 4 Long Life or both must meet several chemical and physical limits, such as minimum Base Number and viscosity specifications, etc. They must then pass laboratory bench tests for oxidation, silver corrosion, friction, and wear. They are then tested in three stationary laboratory engines, a Caterpillar 1M-PC, an EMD 2-567, and a GE 16-FDL, and compared to reference and absolute standards. Oil with a new DI package must then pass a rigorous field test for a minimum of one year in railroad or marine service, at high power utilization (Dittmeier 2000). Oil with a new viscosity modifier must be tested in the field for two years. It is only through field testing that lubricants can be certified as meeting the demanding requirements of railroad service.

Conclusion

A properly formulated engine lubricating oil can help maintain the engine's designed operating condition, increase longevity, and reduce maintenance costs. Knowledge of additive chemistry and technology can help make the correct selection of lubricant. However, only performance in field service can demonstrate that the selected lubricant achieves the desired level of performance.

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Table 1

SAE J300 MAY 2004
SAE Viscosity Grades for Engine Oils[a]

SAE Grade	CCS[b] Viscosity mPa-s, max	CCS[b] Temp °C	MRV[c] Viscosity mPa-s, max	MRV[c] Temp °C	Kinematic Visc[d] at 100°C, mm²/s min	Kinematic Visc[d] at 100°C, mm²/s max	HTHS[e] mPa-s min
0W	6200	-35	60,000	-40	3.8	--	--
5W	6600	-30	60,000	-35	3.8	--	--
10W	7000	-25	60,000	-30	4.1	--	--
15W	7000	-20	60,000	-25	5.6	--	--
20W	9500	-15	60,000	-20	5.6	--	--
25W	13,000	-10	60,000	-15	9.3	--	--
20	--	--	--	--	5.6	9.3	2.6
30	--	--	--	--	9.3	12.5	2.9
40*	--	--	--	--	12.5	16.3	2.9
40#	--	--	--	--	12.5	16.3	3.7
50	--	--	--	--	16.3	21.9	3.7
60	--	--	--	--	21.9	26.1	3.7

* - SAE 0W, 5W, and 10W oils

\# - SAE 15W, 20W, and 25W oils

[a] All values are critical specifications per ASTM D 3244

[b] Cold Cranking Simulator by ASTM D 5293

[c] Mini-Rotary Viscometer by ASTM D 4684 (Any detectable yield stress is a failure)

[d] Kinematic Viscosity by ASTM D 445

[e] High Temperature High Shear at 150°C by ASTM D 4683, D 4741, or D 5481

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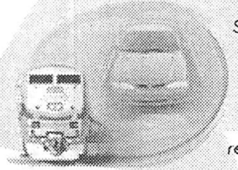

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- Trailers
- AirCraft
- Mining Equipment
- Buses
- Trains
- Cranes
- Rail Cars
- Coal Cars
- Box Cars
- Tanker Cars
- Asphalt Trucks
- Truck Caps
- Cement Trucks
- Garbage Trucks
- Dairy Trucks
- Rental Cars
- Rendering Trucks
- Tanker Trucks

TYPES OF APPLICATIONS

- Steam Cleaning/Detailing
- Acid Shock Treatment
- Rust Inhibitors
- Safety Solvents
- Non-Hydrofluoric Brighteners
- Floor and Shop Cleaners
- Dip Tank Cleaning
- Spray Wash Cleaning
- Immersion Cleaning
- Brake Cleaners
- Axle/Wheel Cleaners
- Lubricants/Rust Inhibitors
- Diesel Fuel Additives
- Electrical Cleaners
- Low pH cleaners
- Non-Hazardous Cleaners
- Alkaline Cleaners
- Waste Treatment Products
- Disinfectants
- Rinse Agents/Drying Agents
- Graffiti Removers
- Interior Tank Truck Cleaning
- Paint Strippers
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Table 2
Typical Viscosity Requirements for Railroad Oils[a]

Property	Temperature	Method	Units	Min	max	Comment
Kinematic Viscosity	100°C	D 445	mm^2/s	12.50	16.30	SAE J300
				12.55	16.27	EMD[b]
				13.90	16.30	GE
				15.00	15.80	Typical
Viscosity Index		D 2270	None	65	105	GE Monograde
				110	125	GE Multigrade
				60	100	EMD
CCS Viscosity	-15°C	D 5293	mPa-s	Note [c]	9500	SAE J300
	-10°C				5000	EMD
					5000	GE
MTHS after Shear[d]	100°C	D 6278	mPa-s	10.8		GE

[a] Many railroads have internal specifications that supersede this summary
[b] EMD limits approximate after conversion from different units
[c] Minimum CCS limit defined as greater than next lower "W" grade
[d] Medium Temperature High Shear after mechanical shearing to degrade polymers

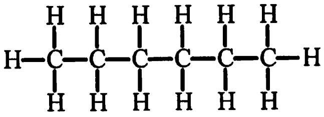
Table 3 compares detergents and dispersants:

Table 3
Comparison of Detergents and Dispersants

Property	Detergent	Dispersant
Molecule type	Surfactant	Surfactant
Metal	Yes	No
Polar Head	Strong	Weak
Non-polar Tail	Short	Long
Basicity	Strong	Weak

Table 4
Railroad Oil "Generations"

LMOA/GE Designation	Date Introduced	Nominal Minimum Base Number
Generation 1	1940	4
Generation 2 GE Superior	1964	7
Generation 3 GE Superior Class II	1968	7
	1970	10
Generation 4 GE Extra Performance	1977	13
Generation 5 GE Generation 4 Long Life	1984	Not defined by initial oil Base Number



$$\begin{array}{ccccccccccccccc}
 & & H & & H & & H & & H & & H & & H & & \\
 & & | & & | & & | & & | & & | & & | & & \\
H & - & C & - & C & - & C & - & C & - & C & - & C & - & H \\
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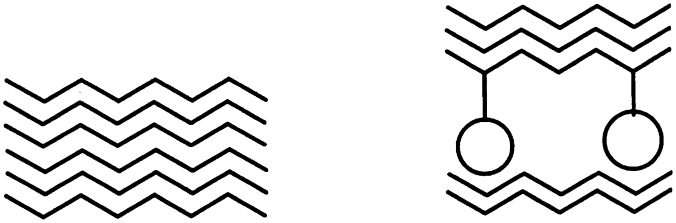
\end{array}$$

Paraffinic – no ring structures (normal hexane, C_6H_{14})

Naphthenic – ring without double bonds (cyclo-hexane C_6H_{12})

Aromatic – ring with alternating double bonds (benzene C_6H_6)

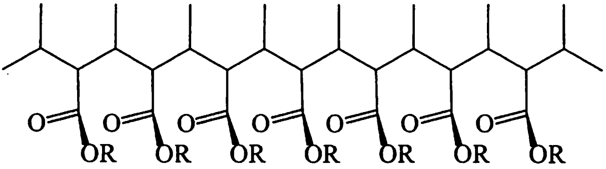
Figure 1 – Paraffinic, Naphthenic, and Aromatic Molecules



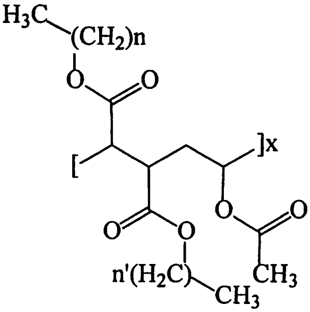
Without PPD
Regular-shaped wax molecules form large crystals

With PPD
irregular shaped PPD interferes with crsytal growth

Figure 2 – Mechanism of Pour Point Depressants

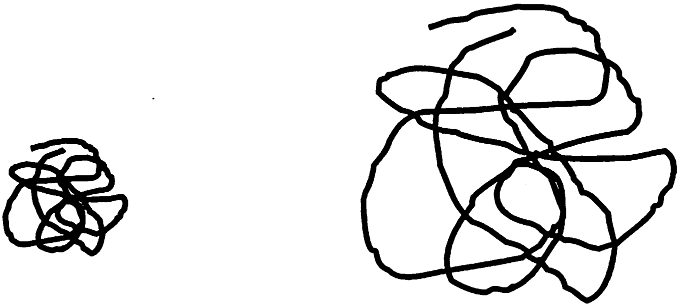


Polymethacrylate



Fumarate Vinyl Acetate

Figure 3 – Common Pour Point Depressants



Low Temperature
Polymer coil contracts
Provides less thickening

High Temperature
Polymer coil expands
Provides more thickening

Figure 4 – Relative Polymer Volume Changes with Temperature

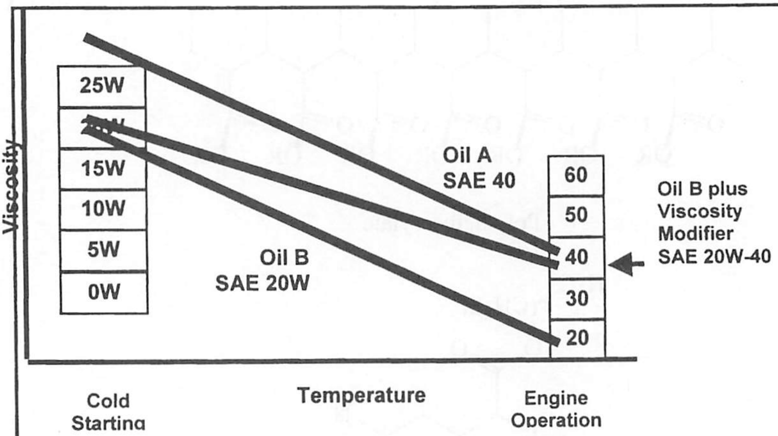
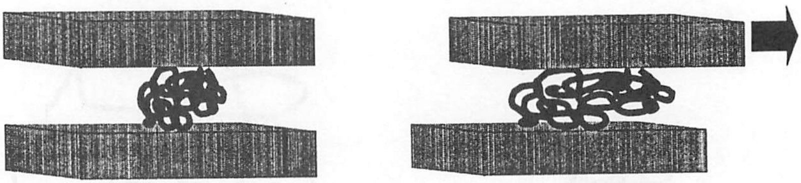


Figure 5 – Illustration of SAE J300 Viscosity Classification System

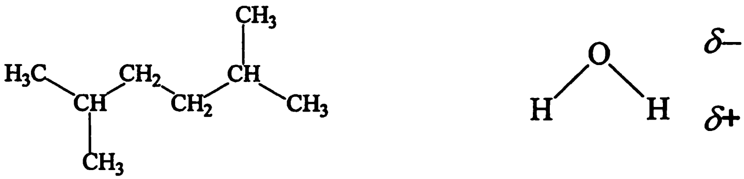


Absence of Flow
Spherical polymer coil

High Speed Flow
Polymer coil aligned
and extended

In extreme cases, this can
break the polymer molecule

Figure 6 – Mechanical Polymer Degradation



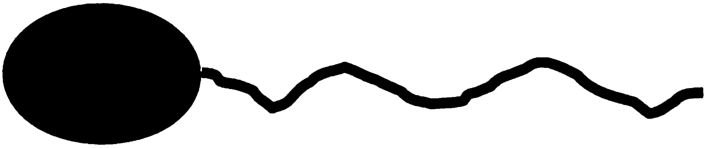
Non-Polar Molecule

(a) Hydrocarbon
Carbon and hydrogen
attract electrons
approximately equally

Polar Molecule

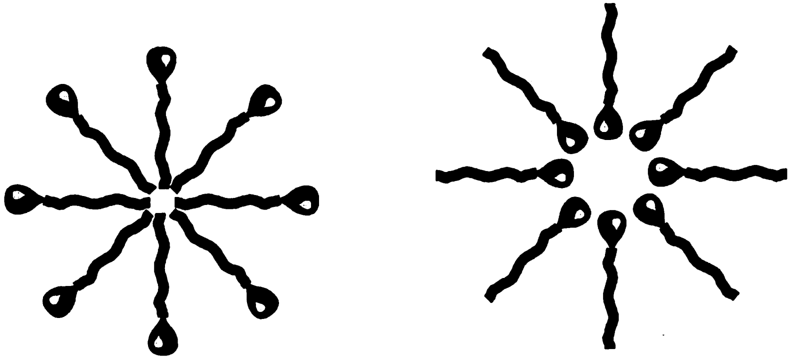
(b) Water
Oxygen attracts electrons
more than hydrogen
Causes a partial
separation of charges

Figure 7 – Polar and Non-Polar Molecules



A surfactant combines polar and non-polar ends in one molecule

Figure 8 – A Surfactant Molecule

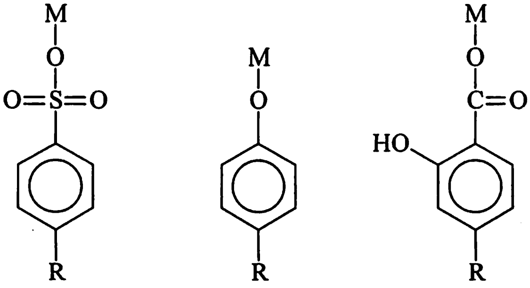


(a) In Water
Polar heads out
Non-Polar tails in

(b) In Oil
Polar heads in
Non-Polar tails out

These are normally three-dimensional structures

Figure 9 – Micelles

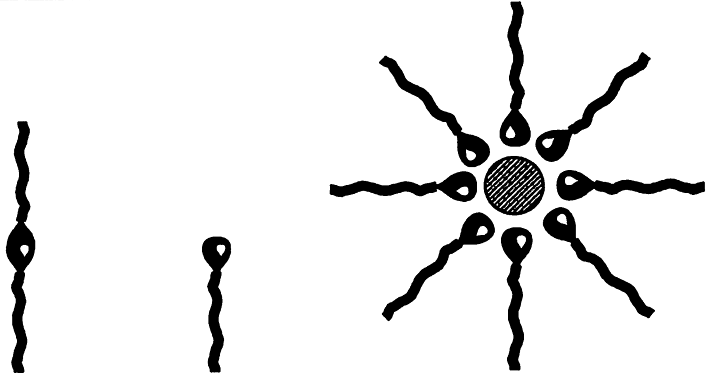


Sulfonate Phenate Salicylate

M is a metal atom, usually calcium
R is a hydrocarbon "tail" to make the detergent soluble in oil

All three detergents are surfactants, with a polar head containing the metal atom and a non-polar hydrocarbon tail.

Figure 10 – Common Detergent Additives

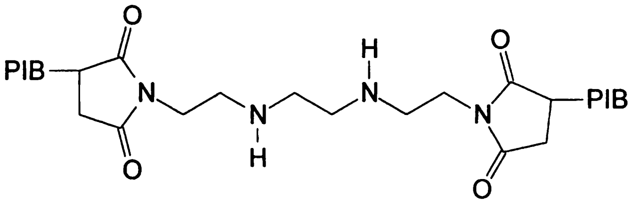


<u>Neutral</u>
Metal
completely
reacted
with
tails

<u>Basic</u>
Metal only
partially
reacted with
tails, leaving
basic “loose end”

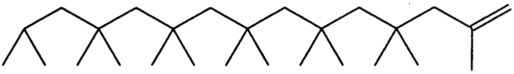
<u>Overbased</u>
Use of detergent as a
surfactant to solubilize
“extra” strong base,
such as calcium
carbonate

Figure 11 – Neutral, Basic, and Overbased Detergents



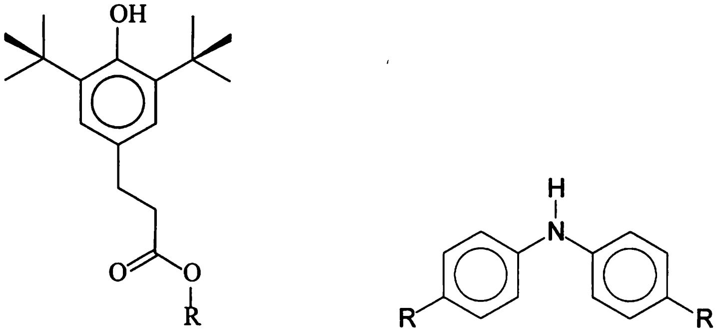
PIBSA/PAM = PIB-Succinic Anhydride/PolyAmine

where PIB is PolyIoButylene:



The molecular weight (length) of the PolyIsoButylene tail can be varied.
The number of nitrogens (size) of the polar “head” can be varied.
The ratio of tails to heads can be varied (this shows two tails and one head).

Figure 12 – PIBSA/PAM Dispersant

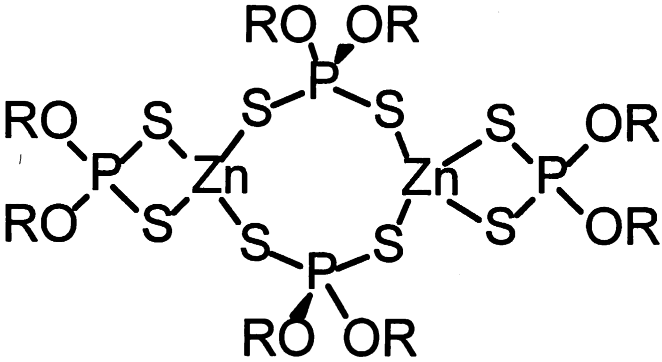


Hindered Phenol

DiPhenyl Amine

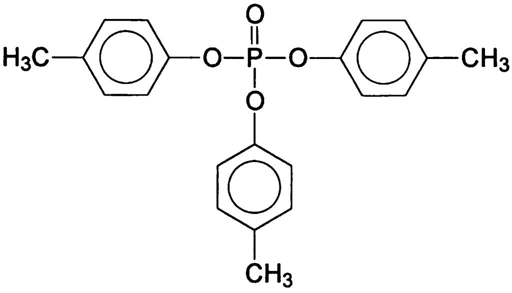
R is a hydrocarbon "tail" to make the molecule soluble in oil

Figure 13 – Common Anti-Oxidants



Zinc DialkylDithioPhosphate = ZDDP
(used in all engine oils EXCEPT railroad)

Figure 14 – ZDDP



TriCresylPhosphate = TCP

Figure 15 – TCP, a Non-Zinc Antiwear Additive

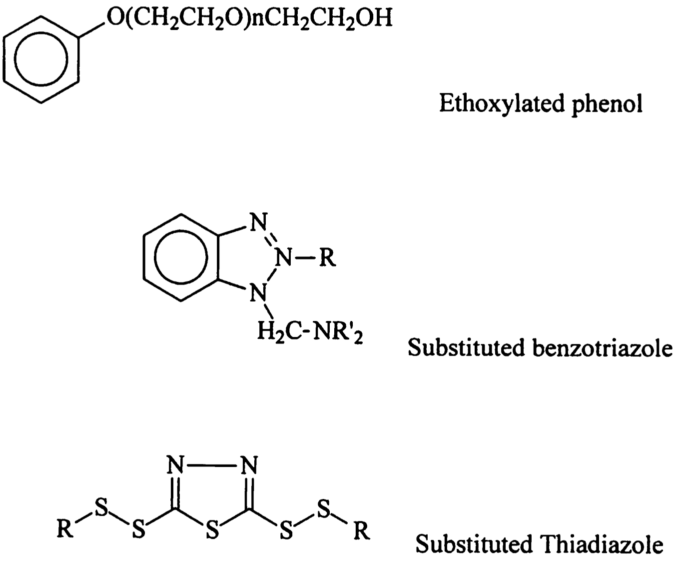
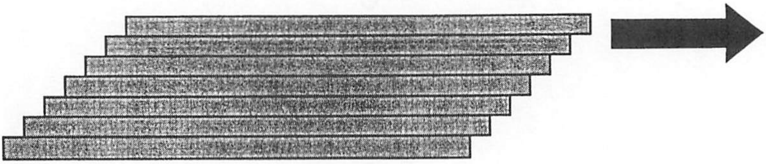


Figure 16 – Common Rust and Corrosion Inhibitors



Solid friction modifier
(graphite, molybdenum disulphide)
"Flat plates" slide easily over each other, reducing friction

Figure 17 – Mechanism of Solid Friction Modifiers

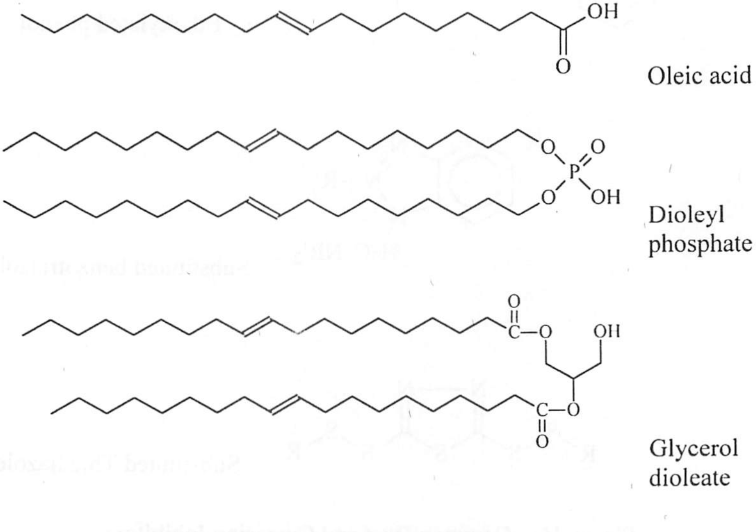


Figure 18 – Common soluble friction modifiers

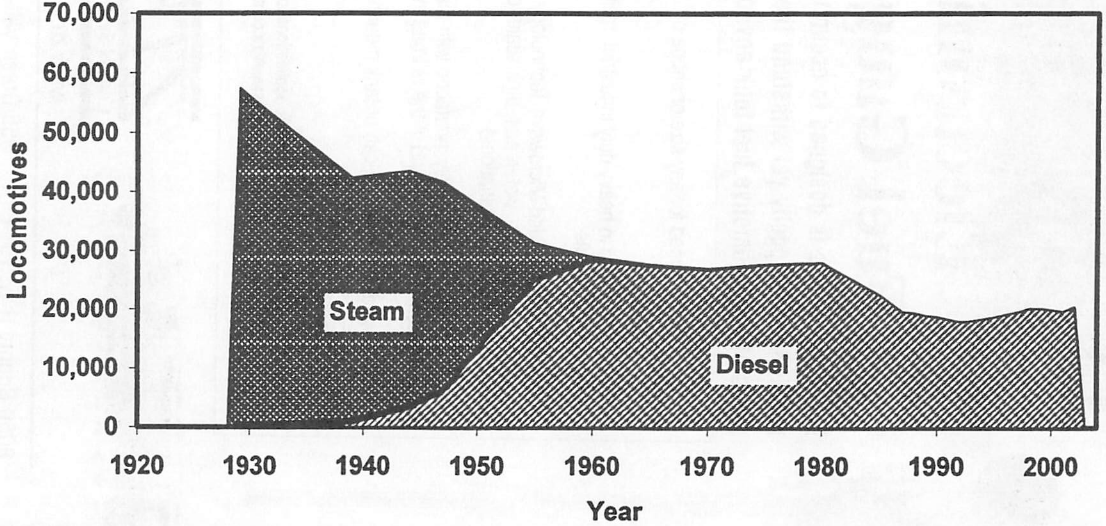


Figure 19 – Transition from steam to diesel locomotive engines

III. USED OIL ANALYTICAL RESULTS, WHAT DO THEY MEAN, HOW TO INTERPRET THE RESULTS, AND HOW DO YOU RESPOND?

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Presented by:
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Introduction

Railroads and Original Equipment Manufacturers (OEMs) should depend on the results of oil analysis to determine the condition of the oil and to detect potential problems in the equipment. Used oil analysis is the practice of collecting samples from equipment on a frequent and regular basis, analyzing the samples with established routine procedures, noting any unexpected or unexplainable variations in the results and providing the end user with maintenance recommendations based on these results. The goal is to identify as accurately and as quickly as possible any variation to minimize equipment damage and expenses.

With recent railroad personnel reductions there appears to be a loss of understanding of some of the necessary tests, how the tests relate to each other, how to interpret the lab results and how to respond to the results. The trend toward the use of contract laboratories also contributes to the loss of understanding in that personnel may understand the tests but have little or no knowledge regarding how the results relate to locomotive engines and recommendations regarding corrective maintenance.

This paper is an attempt to provide answers to these questions for the major tests and to offer guidance in what steps are required to resolve any identified problems.

Tests and Discussions

There are six major parameters that should be determined for each sample:

- Viscosity
- Pentane Insoluble (PI) content
- Base Number (BN)
- Oxidation
- Water content
- Metal concentrations

Viscosity

Viscosity is a measurement of a fluid's resistance to flow and is greatly affected by temperature. The viscosity is important in defining the oil film thickness or the amount of separation between moving parts as shown in the following simplified equation:

Oil Film Thickness =
Viscosity * Speed / Load

As the viscosity decreases the oil film thickness also decreases. Once the oil film thickness drops below the design parameters for the equipment, metal to metal contact can occur increasing wear rates or, in the worst case, causing catastrophic failure.

Conversely, as the viscosity increases, the oil film thickness also increases. The problem with excess viscosity is the inability to pump the oil in sufficient quantities to the needed areas. If insufficient oil is present, metal to metal contact will occur. Also, oil with excessive viscosity requires more energy to move and as a result fuel consumption increases.

Viscosity varies with temperature, decreasing with increasing temperature. To minimize testing temperature effects, viscosity measurements are generally performed either at 100°C or 40°C. The recommended procedure for testing viscosity is ASTM D-445.

During use, viscosity increases with time as the oil oxidizes and solid contaminants increase. Along with the high viscosity, the oxidation number and the PI value should also be elevated and the BN value should be reduced. If these values do not confirm the viscosity number, the accuracy of the viscosity should be questioned.

With the introduction of multigrade oils, an initial drop in the viscosity is seen. This drop is due to partial shearing (break-in shear) or degradation of the viscosity index improver (VII), the component that gives the oil its multi-viscosity property. The magnitude of this loss is typically 1 cSt at 100°C. Figure 1 shows a generalized graph of how the viscosity normally changes with time along with the three major trends seen during the life of the oil. After the initial viscosity loss, there is a gradual increase in the viscosity as the oil slowly degrades (normal running). Once the anti-oxidant components of the additive package are consumed, the viscosity increases exponentially - a factor that should be considered when scheduling a locomotive for an oil change due to high viscosity.

A drop in viscosity can be caused by several factors including dilution with fuel from leaking injectors, fuel jumper lines, poor injector spray patterns, addition of new oil, addition of improper oil and shearing of the VII. Fuel in the oil can be confirmed by gas chromatographic methods, a flash point test, through the use of a fuel sniffer and possibly by infrared analysis. Low viscosity can lead to rapid and catastrophic failure and should be addressed immediately.

Whenever the viscosity is out of the acceptable range, the oil and oil filters should be changed and if the use interval is shorter than normal the cause should be determined and corrected.

Pentane Insolubles

Pentane insolubles (PI) material consists of soot, wear metals, oxidation/nitration products and "dirt." Soot is typically the major component representing 70% to 90% of the total weight percent. Elevated levels of PI contribute to sludge and deposit formation, increased wear rates, filter plugging and poor lubrication. Although PI generally does not cause immediate problems, the long term effects can be significant. Sludge and deposit formation can contribute to increased combustion chamber temperatures as deposits form an insulating layer between the heat generating source and the coolant (the oil). Figure 4 shows piston undercrown deposits that inhibit heat transfer contributing to burnt pistons. If the deposits form in the oil cooler, heat transfer will be reduced and the oil temperature will increase. Since viscosity decreases with increasing oil temperature, greater deposit formation results in higher temperatures and lower viscosity, thereby increasing the potential of elevated wear rates. Wear rates can also increase from PI due to abrasion - particles being trapped between the contacting surfaces. This is typically a slow process but over time significant wear can occur. A PI value of 3% represents about 100 pounds of solid contaminate dispersed in a 400 gallon crankcase. If the dispersive components of the oil are depleted, the insoluble material forms aggregate particles of sufficient size to be collected by the filters. If sufficient material is collected on the filters, they will plug causing the engine to de-rate or bypass the filters.

The recommended and reference procedure is LMOA Standard Insolubles Test Method Revision 3[1].

Elevated PIs are normally seen toward the end of the oil's useful life due to the build-up of contaminants. High PIs are normally found in conjunction with low BN values and increasing viscosity numbers. High PIs require the oil and oil filters be changed. If the PI increases more quickly than normal, the temperature controls should be examined for proper operation, fuel injectors should be tested for defects, and rings inspected for excessive blow-up in addition to the oil and filter change.

The LMOA procedure is time consuming and difficult for a production lab to perform. Many labs are looking for screener or surrogate tests that can be run more economically. Meters based on electrical conductivity and infrared are currently being used. Before values from any alternate procedure are accepted by the railroad, sufficient correlation studies with the LMOA method must be conducted to fully understand how the results of the procedures compare. It must also be recognized that any changes to the base oils or additive packages used may change the relationship of the alternate procedure to the LMOA procedure. Diesel engine reliability depends on the accuracy of the results. If poor correlations are used, the engine is at greater risk of problems and failure.

Base Number (BN)

One of the functions of the lubricating oil is to protect the engine from corrosive attack. This protection is furnished in the form of alkaline or basic material that will neutralize acids formed during fuel combustion and oxidation of the lubricating oil. The BN of oil is an indicator of the amount of alkalinity or base available. The BN depletion rate should be monitored, especially as the oil approaches the end of its useful life. Figure 2 shows a typical BN depletion curve over time. However, the depletion rate is greatly affected by makeup oil requirements and utilization level so one may see a steeper curve. Once the BN is sufficiently depleted, acids may attack the metallic components of the engine reducing the life expectancy of the engine.

One must be cautious in the interpretation of BN values. Although the number may be positive indicating base is present, acids may also be present as they can coexist in the oil. In addition, there are several accepted methods of measuring BN but the results vary depending on the method employed. The preferred methods for used oil is ASTM D-4739; however, some labs modify this procedure, thereby yielding different results. There is a current belief a relationship exists between the BN and the Acid Number (AN) is that once the AN rises above the BN, the oil becomes corrosive and lead values can increase rapidly (See Figure 3).

As with some of the other tests, BN is time consuming and costly to run. As a result, screener or surrogate tests are used. Infrared is becoming the analytical tool of choice due to speed and ease of use. However, there are currently no standard procedures for use of infrared and most labs use their own procedure. The closest to a standard procedure comes from the Joint Oil Analysis Program of the military that requires approved instrumentation and software to generate identical results for a given sample.

It is the responsibility of the lab to document the correlations between the procedure used and ASTM D-4739. It is also the responsibility of the railroad to understand what procedures are being used, how the procedure differs from the standard test and how the results correlate with the standard test results. To protect the engine, an understanding of any surrogate procedure's limitations and its correlation with the reference procedure must be known. The OEMs should be contacted and informed on any test deviations as a precaution to using a procedure of questionable benefit. They may also be available for assistance in correlation studies.

Low BNs can be seen from overextending the oil life, excessive blow-by, overheating, improper oil type and possibly an incomplete oil change. Low BN requires a change of the oil and oil filters. If the oil life is less than expected, the cause of the low BN should be determined.

Oxidation

Locomotive operating temperatures are sufficiently high that oxygen will react with the oil at a measurable rate. Current oil formulations contain additives to minimize the reaction rate, but over time the additives deplete and the oxidation rate increases. The presence of certain cations, such as copper II, in the oil and oxidizing agents in the combustion gases can accelerate the reaction rate. As the oil oxidizes, organic acids form and the oil viscosity increases. The products of the oxidation reactions form polymers, creating varnishes and resins that contribute to sticking rings, filter plugging and deposit formation.

The level of oxidation is determined by infrared analysis. Elevated oxidation numbers should be seen with increasing viscosities and PIs along with low BN values. Changing the oil and oil filters is required when oxidation numbers are high.

Water Content

The presence of free water in the oil indicates contamination from a source that may include internal coolant leaks, condensation or even wash water. The most common source of water in locomotive engines is from an internal coolant leak. The presence of water can be easily determined by a hot plate or splatter test although more sophisticated and quantitative tests are available (i.e., infrared analysis, Karl-Fischer titration, distillation or centrifugation). Oil and water don't normally mix but the current engine oils contain detergents and dispersants that will emulsify the water. The presence of water in the oil can interrupt the oil film, contribute to the formation of sludge, cause swelling of cellulose-based filter media and react with other combustion products to form an acidic condition. The destruction of the oil film is most critical as this can lead to rapid and immediate catastrophic failure. Sludge and acid formation does not present the immediate concern as destruction of the oil film but the long term effects can still be severe and irreversible. The short chain organic acids formed when the oil oxidizes are water-soluble. These water soluble organic acids can be aggressive to soft metals such as the lead used in bearings.

The source of the water contamination needs to be determined and corrected. The simplest methods is to look for elements in the oil that make up the coolant corrosion inhibitor package, assuming the cooling system is adequately treated. If the inhibitor elements are present and the cooling system is properly treated, the source is most likely an internal coolant leak. If no coolant elements are present in the oil and the cooling system is properly treated, the most likely sources are condensation, wash water or simply sample bottles contaminated by rain or other external source. When looking for cooling water elements, the level of treatment in the cooling system must be considered since the level in the oil is related to the level in the cooling system.

Engine bulk oil temperatures can run near the boiling point of water. At these temperatures, water from minor leaks will quickly evaporate leaving no free water in the bulk oil; however, the disruption of the oil film in the area of the leak and the potential for component failure will remain. In this situation the prevention of failure is still possible by using the elemental analysis to determine the presence and rate of increase of the coolant additives.

Whenever free water in the oil is confirmed, the oil and oil filters must be changed and the source determined and corrected.

Metal Concentration

The previous tests are concerned with the condition of the oil; the metals analyses provide information on possible problems in the engine. There are three facets to interpretation of the metals in the oil, additive components, contamination elements and components of wear.

Proper interpretation of the metal results requires knowledge of what engine components can be affected, component metallurgy, oil change/addition data, service/usage time and the trends of the historical data. An understanding of the limitations of current instrumentation is also important. The emission spectrometers commonly used today rely on vaporization of the metal particles. The amount of vaporization depends on the size of the particle, the residence time at the vaporization temperature and the amount of time at the detector window. Current emission spectrometers have an upper particle size limit of about 10 microns so wear particles with a size greater than this are not "seen." The size of mild rubbing and early fatigue wear particles typically fall within this range but more abnormal wear modes such as severe sliding, abrasive wear, scuffing wear and rolling fatigue wear tend to generate a much greater percentage of larger particles making these wear modes much more difficult to detect. Although not normally included as part of the routine testing by railroads, there are procedures and instrumentation that can look at these larger wear particles and provide information about the source and type of wear.

Additive components are the elements found in the additive system that makes up the oil. Current railroad formulations mainly contain calcium-based compounds with small quantities of silicon, magnesium, sulfur and possibly molybdenum. Other types of oils (automotive) can contain barium, phosphorous and zinc compounds. The zinc compound in non-railroad oils is an anti-wear additive, zinc dialkyldithiophosphate (ZDDP). ZDDP is corrosive to silver and since some locomotives contain silver components, the presence of zinc in the oil is a cause for concern. If the presence of zinc is confirmed, the oil and oil filters should be changed. Low levels of calcium can indicate the presence of improper oil or an analytical problem.

The major **contamination elements** of concern include sodium, boron, and silicon (elements of the common cooling water treatments in use today), silicon, aluminum, and magnesium (from ingress of dirt), and zinc and phosphorous from automotive oils. Increasing levels of sodium, boron, and silicon can indicate an internal water leak. However, the level of treatment in the cooling system must be considered when reviewing the results. If the treatment level is low, the level in the oil will also be low, possibly leading to a false sense that no water leak is present or it has already been repaired. Pressurization of the cooling system with internal and external examinations looking for signs of coolant leakage should be conducted when the analytical results indicate a leak is present. Silicon, aluminum, and magnesium are common elements found in sand, common dirt, clay, coal and most minerals. The presence of silicon, either alone or in conjunction with aluminum and/or magnesium and without sodium and boron, indicates dirt ingress into the engine. Generally these elements signify improper or insufficient air filtration and the filters should be examined for proper installation and/or replaced. Silicon alone can also be seen in new or overhauled locomotives if silicone sealants are used during assembly of components exposed to the oil.

Wear elements depend on the metallic components in the engine but generally include iron, copper, lead, tin, chromium, silver and aluminum. When establishing alarm limits or trend actions for these elements, several factors should be considered including: the type and age of the equipment, the size of the oil sump, the type of service and even the nature of a particular engine. The generation rate of wear elements for a switch engine will not generally be the same as that for a road engine. Also a particular series of locomotives may contain engines that generate at a significantly greater or lesser rate than the average for that series. Part of the difficulty in wear analysis comes from knowing whether the wear is generalized or if it is localized. Inspection when the wear is generalized typically reveals no major problems but if the wear is localized the chances of finding a specific problem is greatly enhanced. A review of previous failures coupled with the increasing elements should point to the most likely source of the wear in a particular type of locomotive. When new components are installed or a unit is overhauled, wear rates for some of the elements can increase rapidly due to seating of the parts. This is normal and should not be considered an abnormal condition requiring shopping.

Iron is a major component of current engines and when a sample shows a sudden jump or a sharply increasing trend, a potential problem exists. Rings, liners and crankshafts are possible sources. Figure 5 shows an example of liner scuffing identified from elevated iron in the oil.

Copper is found in the bearings, thrust washers, bushings, oil coolers and other components. Installation of an oil cooler can cause increased copper values without indicating a developing problem. Use of antiseize compounds containing copper during parts replacement or overhaul can also elevate the copper value.

Lead is a soft metal that is used as an overlay on and as a component of the bearings. Lead alone may indicate loss of the overlay, while lead coupled with increasing copper can indicate wear damage of the bearing.

Aluminum can come from piston skirts, roots blowers, or bearings. In addition, aluminum can come from contamination from clays or minerals ingested into the engine.

Chromium is plated onto steel surfaces to increase the surface hardness of the component. Rings, liners, and crankshafts are typical sources. When chromium is elevated, a check of the suspect components for rapid wear should be performed.

Tin is another soft metal used as a component of bearing materials and as a coating on piston skirts.

Silver can be found on wrist pin bushings and turbo bearings.

Other Considerations

Proper sampling and identification

Sample collection and handling prior to being received by the lab can have a significant affect on the test results obtained. If care is not taken, the sample can be contaminated, not representative of the bulk oil or even misidentified. As a result of improper sampling, analytical results may indicate a nonexistent problem causing an unnecessary shopping or not reveal a real problem. Either way, improper sampling can cause elevated maintenance costs.

Samples should be collected in clean, dry bottles. If the sample is collected from a sampling gun, the gun should be flushed at least three times with the oil to be tested before the actual sample is taken. If a sampling valve is used, the tip must be wiped clean and sufficient oil drained (4 to 6 ounces) from the valve to insure the sample will be representative of the bulk oil, not just the oil in the valve.

Once the sample has been collected, the bottle must be sealed, wiped off and properly identified with the equipment ID, the date the sample was collected and any other pertinent data.

Variations in result from oil additions

Locomotives consume oil over time and as a result periodic additions must be made to maintain the proper oil level. The level of oil in the crankcase at the time of sampling can affect the analytical results obtained. For example, assume a sample is taken when the crankcase is 15 percent low and a metal reading of 50 is obtained. If the next sample is obtained when the crankcase is full the metal reading could be reduced by 15% to 43. If the samples are randomly taken and the level of oil in the crankcase is not known, the historical results can show significant variation from sample to sample, making data interpretation more difficult.

Oil analysis results lack a trend

In use, it is expected that oil properties will change with time as previously discussed. The higher the megawatt hours produced in a given amount of time, the greater the expected changes. When reviewing used oil results, it is important to look not only at the latest set of results for a given unit but at the historical trend of the data, as well. Results that are within acceptable ranges but do not change with time (i.e., properties are not changing from consecutive samples) could also indicate a problem. It could be as simple as a unit not in service or in limited service or something more costly such as a high oil consumption rate. In addition to individual trends for locomotives, the trends for fleets of locomotives should also be periodically reviewed. Although a single locomotive may not show an increasing trend over time, a given fleet of locomotives will show a trend. If no trend is observed for a particular fleet, it is likely that inappropriate procedures are being used or there may be a calibration problem with the instrumentation[2].

The quality of the oil change

Many of the recommended tests may call for an oil and oil filter change. The quality or completeness of the oil change can have a significant affect on the life of the changed oil. Any spent oil remaining in the crankcase will dilute the new oil, thereby reducing its life. For example, if 50 gallons of oil that is 180 days old is mixed with 350 gallons of new oil, the average age of the oil in the crankcase on day one is 23 days. If the expected life of the oil is 180 days, the 50 gallons of spent oil will reduce the expected life to 157 days. In addition, deposit precursors, acidic components and other contaminants remain and can increase the rate of degradation of the oil so the actual oil life can be even less.

When an oil change is recommended, every effort should be taken to remove as much of the old oil as possible.

Feedback to the lab - continuous improvement

Experience of past failures in combination with the used oil results should be a tool to help guide future alarm and trend limits along with what actions to recommend. Interpretation of the results as related to engine condition and tailoring the recommendations to the most likely sources for the problems can only improve if there is feedback from the maintenance organization to the laboratory. If the lab always recommends a liner inspection for high iron and the shop always finds a broken crankshaft, the shop personnel lose faith in the recommendations of the lab and the lab never knows how to improve.

Summary

> "Any abnormal condition of used oil is usually accompanied by an abnormal condition of engine operation. Intimate knowledge of the diesel engine's operating parts and their compositions, immediate past history of the used oil analysis, and past experience of engine failures are needed to correlate current laboratory tests in order to ascertain what necessary corrections will be of benefit to engine operation and will correct future oil conditions. At times, analysis of parts is necessary to supplement this correlation. The wide variety of failures and the constant new types of conditions which are ever appearing makes the practice of routine testing of used oil much more interesting than a cursory glance might make it appear."[3]

With most railroads employing outside laboratories for their oil analysis needs, direct costs of the program have decreased. However, railroads need to maintain some expertise in the oil analysis area to monitor procedures, results, establish action limits and work with the lab to improve the value of the service.

Otherwise, the long term costs

associated with repairs, unnecessary shopping and increased failures due to missed or improper calls will increase and the value of the service will be degraded. The goal of any oil analysis program is to minimize equipment damage and associated expenses. If the lab operates in a vacuum and receives no information or feedback from the railroad as to component change outs, overhauls, oil changes, troubles found, changes in equipment or results of recommended actions, the railroad is the ultimate loser as it cannot achieve the goal of an oil analysis program. Open communications and understanding must be maintained regarding the tests and procedures employed, correlations to standard procedures, how the data are interpreted, recommended maintenance and the results of the recommendations to ensure the goals are achieved.

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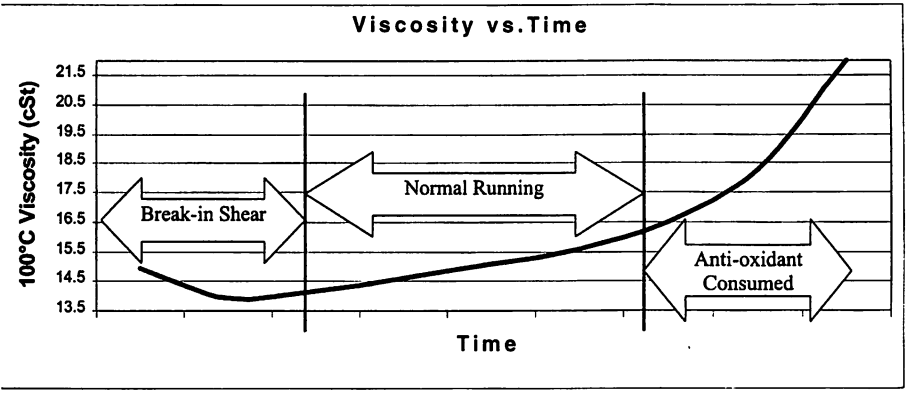


FIGURE 1

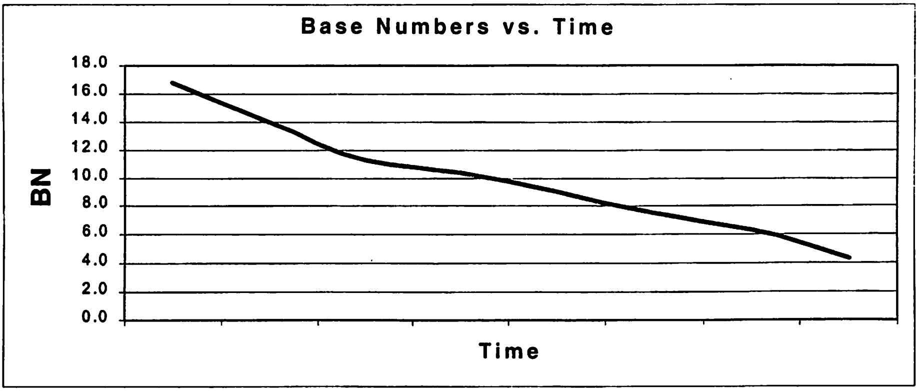


FIGURE 2

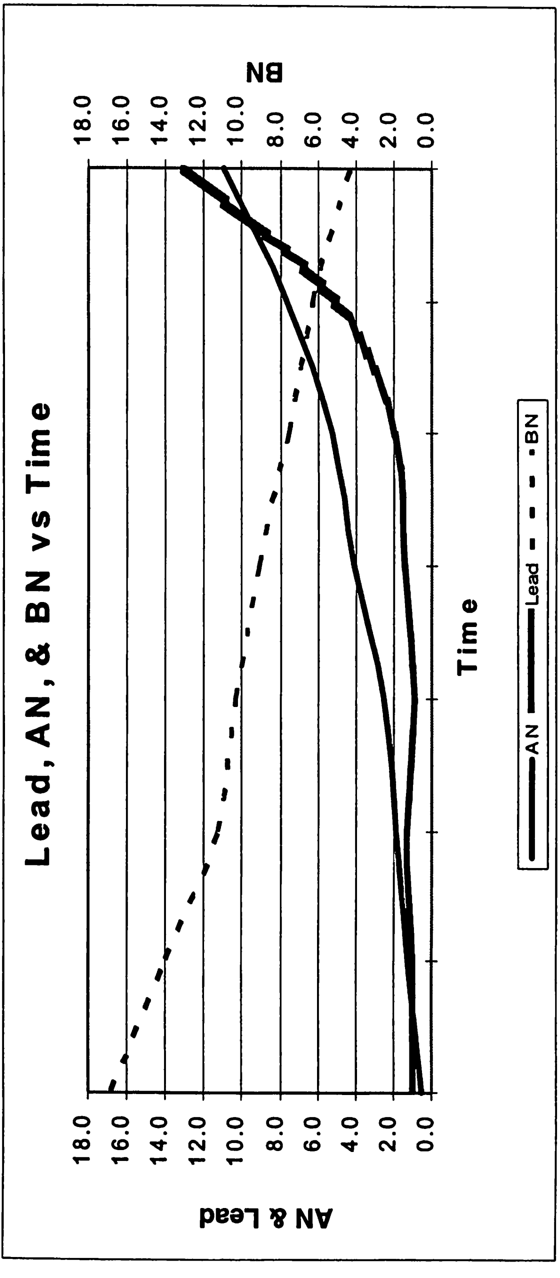

Lead, AN, & BN vs Time
BN
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
AN & Lead
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Time
AN
Lead
BN

FIGURE 3

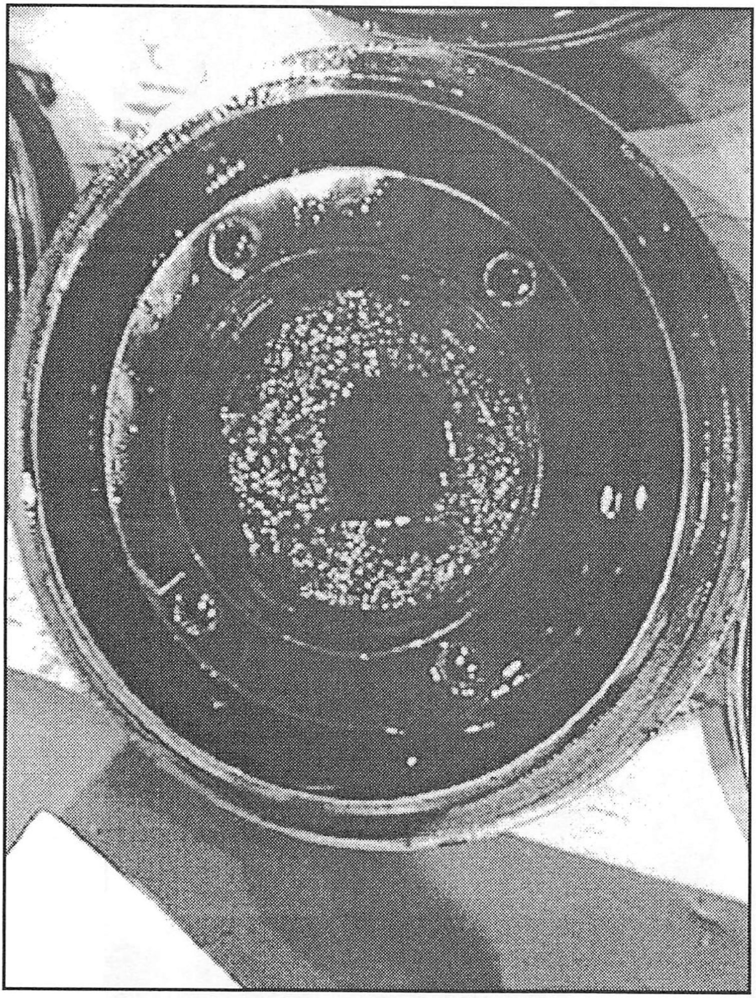


Figure 4

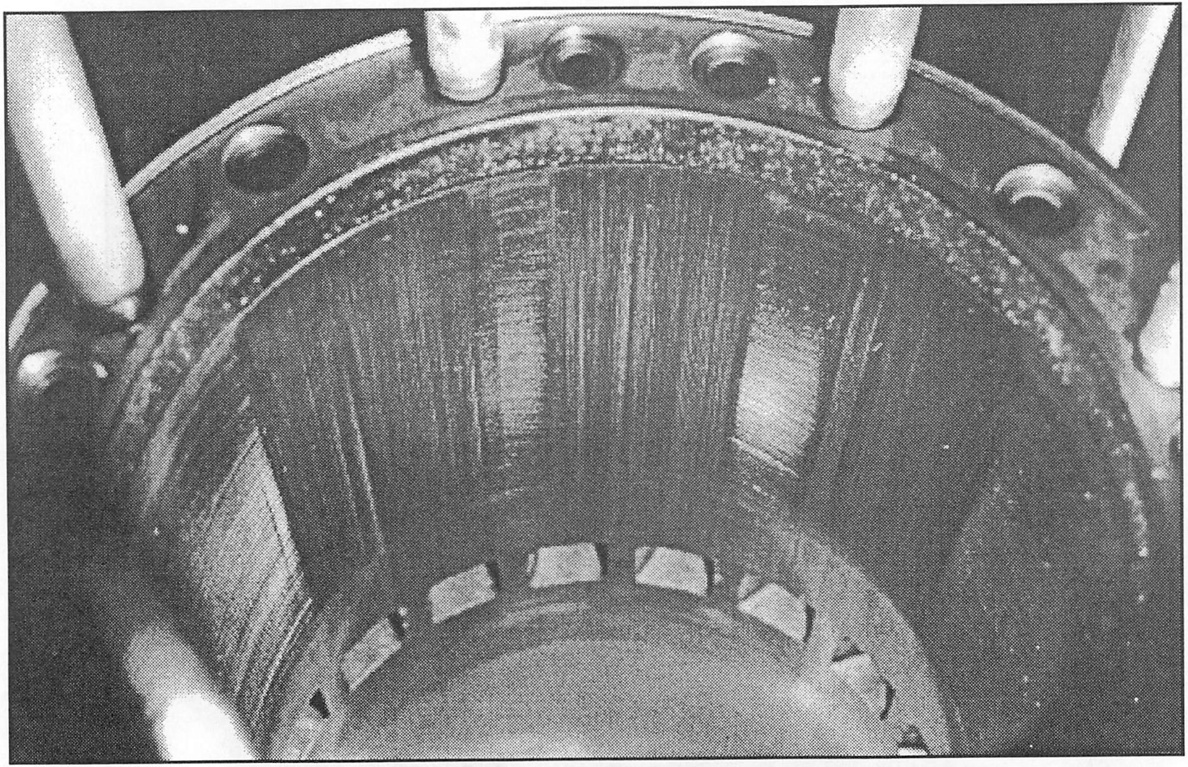


Figure 5

REPORT OF THE COMMITTEE ON SHOP EQUIPMENT AND PROCESSES

TUESDAY, SEPTEMBER 28, 2004
10:30 A.M.

Chairman
BILL PETERMAN
President
Peterman Railway Technologies
Baie D'Urfe, Quebec

Vice Chairman
TOM STEFANSKI
Field Services Manager
Locomotive Leasing Partners
LaGrange, IL

COMMITTEE MEMBERS

C. Aday	Facilities & Fleet Maint Mgr	Metrolink-SCRRA	Los Angeles, CA
K. Albrecht	Gen. Mech. Supt.	Montana Rail Link	Livingston, MT
K. Batley	Rail Products Manager	L&S Electric Inc.	Appleton, WI
R. Begier	Consultant	Portec Rail Products Inc.	Broomfield, CO
R. Brewer	Loco. Specialist	CN RR	Homewood, IL
R. Collen	Product Manager	The Macton Corp	Oxford, CT
C. Fette	President	TESCO	Erie, PA
G. Lapinas	Mgr-Process Engineering	Canadian Pacific Rwy	Calgary, Alberta
R. Mckim	Manager-Locomotives	Amtrak	Beech Grove, IN
J. Morin	President	NEU Inc.	Paoli, PA
M. Stromenger	Mgr.-Service Market Develop	GE Transportation Rail	Erie, PA

NOTE: Ron Brewer is a new member of this committee.

THE SHOP EQUIPMENT & PROCESSES COMMITTEE WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO THE FOLLOWING COMPANIES FOR HOSTING AND SUPPORTING THEIR COMMITTEE MEETINGS IN 2004

TESCO – ERIE, PA
MARCH 2004

AMTRAK – WILMINGTON, DE
JUNE 2004

THANK YOU,

THE SHOP EQUIPMENT & PROCESSES
COMMITTEE

I. UNDER THE HOOK LIFTING DEVICES

Presented by: Chris Fette,
President, Tesco

History, Utilization and general construction guidelines

In the past, when railways had extensive back shops with machining and fabrication capability, they produced many of their own under the hook lifting devices. The current trend is to procure these devices from a variety of lifter manufacturers that provide design and manufacturing capability.

Railways utilize under the hook lifting devices extensively

ASME B30.20 latest revision offers excellent guidelines for the manufacturing, testing, use training, timely inspections and other general cautions.

Most lifter manufacturers have a long history and can provide technical assistance to the rail user

Return of lifting devices to the manufacturer for re-certification or re-rating can be as simple as a cost for labor and material to a recommendation for scrapping. The manufacturer learns the "personality" of the service life of the lifter during this process.

General construction guidelines

The minimum design factor is three times rated load to yield of load bearing structural components (approaches five times to ultimate for A-36 structural lifting devices). A minimum load test of 25% in excess of rated load shall be imposed. Lifters shall display markings to include manufacturer's name and address, date of manufacture, serial number, lifter weight (if over 100 pounds), and rated load. As a manufacturer, we also use a comments legend to display additional pertinent information.

Severe service applications require daily, or as used safety inspections by a qualified inspector.

Approaches to lifter design and construction

GE power assembly lifter

(Figure 1)

A-36 structural designs

Benefits:

- 36,000 PSI yield strength
- Least costly material
- Most ductile
- Provides a signal of distress by deformation

C-frame manipulator

(Figure 2)

A500B square and rectangular tubing design

Benefits:

- 46,000 PSI yield
- Moderate cost
- machines and fabricates to precision
- High bending and torsional resistance

Alternator rotor lifter

(Figure 3)

Heat treated alloy steel design

Benefits:

- Highest strength per section
- Excellent wear and abrasion resistance
- Long life
- 100,00 to 140,000 PSI yield strength

GE H series engine and alternator lifter

(Figure 4)

Lifters of combined materials

- A-36 structural
- A500B tubing
- Heat-treated alloy steel.

When testing prototype lifters, three times working load is imposed, then the lifter is fully inspected. In testing production lifters, two times working load is imposed, then the lifter is fully inspected. Figure 5 shows the certification stand.

Major railways and the OEM's have perfected processes covering the lifting of heavy equipment. These include the power assembly, air compressor, auxiliary generator, oil cooler, turbocharger, engine and alternator, and the list goes on. Successful, safe lifts have been accomplished in the millions over the years. Safety is the absolute target and can be accomplished, with the goal being 100%.

Problems surface that compromise safety and must be addressed. They include but are not limited to the following:

- Excessive sized cranes
- Defective crane controls
- Insufficient training and supervision
- Snagged lifts
- Worn or yielded lifting devices
- Human error.

Figure 6 - 12 show examples of defective lifting devices.

Figure 6 lifter mounting bolts T13791 please note these 1/2 inch 13, grade 8 bolts, have been stretched in tension in excess of 20,000 pounds each and are in failure mode from tension and bending. Observe the severe necking. These bolts came from a T-16065 GE power assembly lifter involved in a snagged lift. Potential snags include:

1. one or more of the four assembly bolts not removed
2. The rabbet fit of the power assembly requires the machinist to guide the lift for the first few inches. Should the power assembly pilot diameter seize, the assembly should be returned to the main frame and the lift retried paying strict attention to guiding. The crane may have to be slightly moved to accommodate the 22-1/2% exit angle.
3. The master rod bale must be positioned toward crank center to avoid binding in the mainframe power assembly bore.
4. Freeze damage to power assembly mounting interface.

Figure 7, power assembly lifter returned for repair, showing yielded spine. Figure 8 is an as-new installation.

Figures 9 and 10 show a .200-inch deep trench in a mounting pad caused by bolt head milling a flat on the pad. This was caused by using an impact wrench to mount the lifter to the power assembly. Impact wrenches should never be used for this purpose because the above result will occur and they can cause a torsional failure in the mounting bolt or pull the threads out of the anchor material. In this case, the anchor material is cast iron (grade 2), resisting the ability of grade 8 bolts to yield threads. The bolts returned with the lifter had cast iron imbedded in the threads. The .200-inch deep trench also allows the bolt to enter the power assembly that much deeper and potentially bottom in the tapped hole. Should this happen, the bolt is not in tension but bending failure mode. Note: This lifter had been in service for at least 20 years and should have been taken out of service well before it was.

Many lifting devices have been returned for inspection, repair, upgrade, or remanufacture and certification that are in good general condition and require a minimum of rework.

Figures 11 - 12 show a power assembly lifter with a yielded handle.

In conclusion, you should have a set inspection and re-certification schedule; every year is typical. You should immediately remove defective, safety-compromised lifting devices from service and you should communicate with the manufacturer should concerns arise.

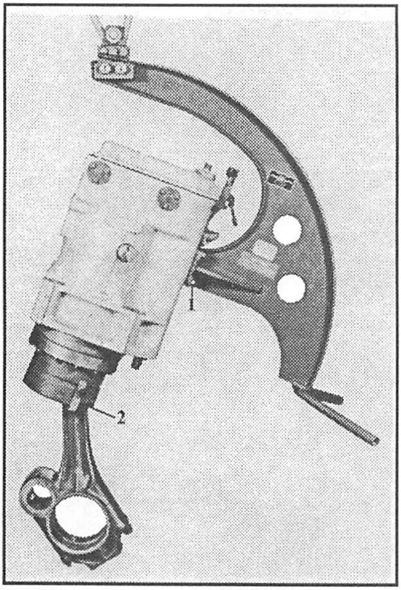


Figure 1 - GE Power Assembly Lifter

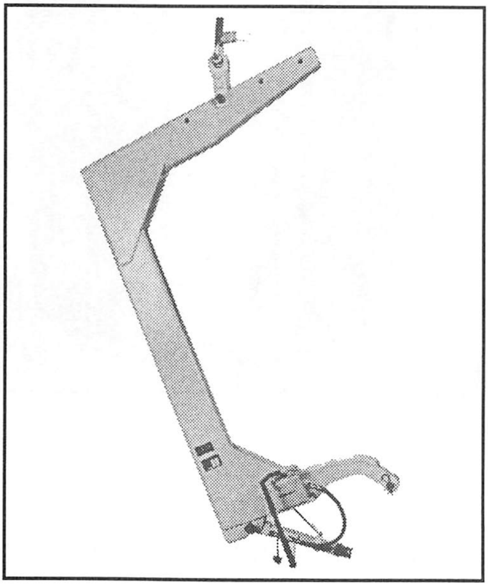


Figure 2 - C-Frame Manipulator

Figure 3 - Alternator Rotor Lifter

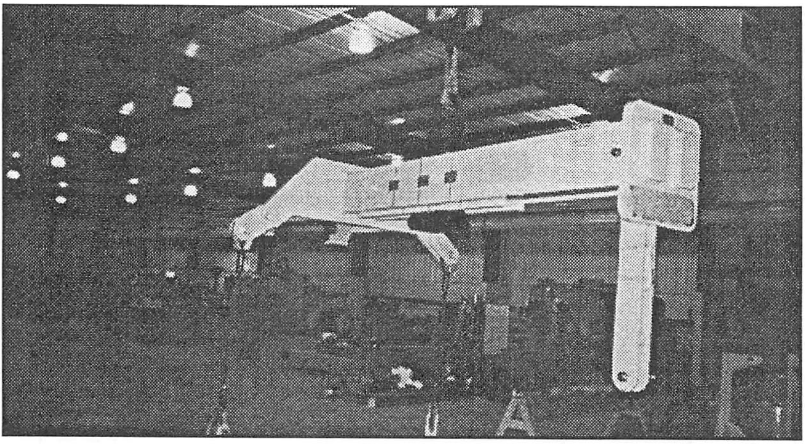


Figure 4 - GE H Series Engine & Alternator Lifter

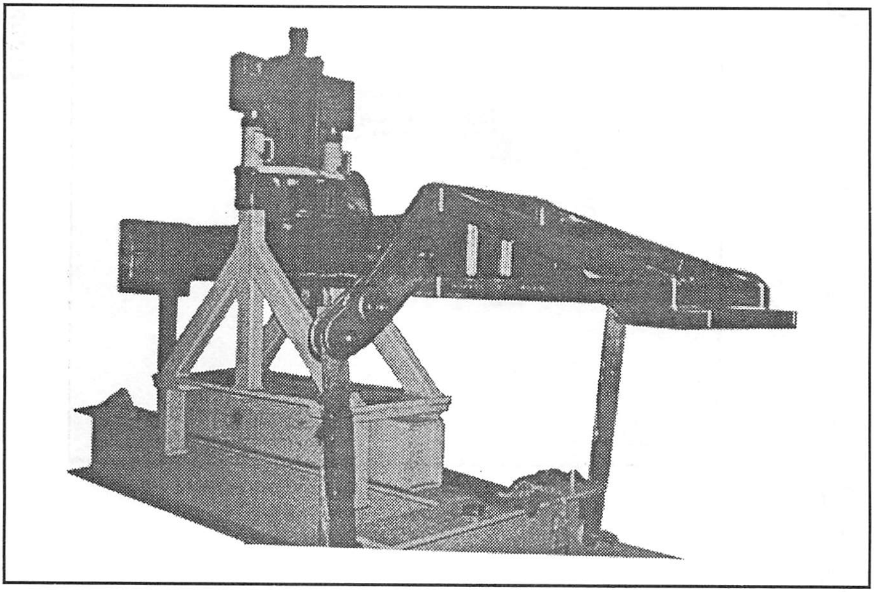


Figure 5 - Certification Stand

Mounting Bolts Returned With A Yielded GE Power Assembly Lifter

These bolts came from a lifter involved with a snagged lift

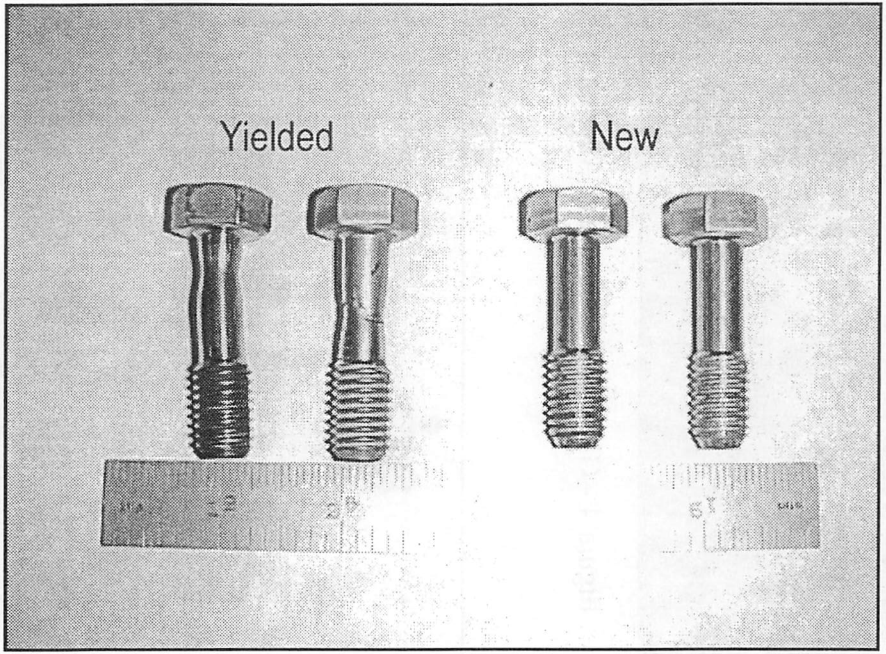


Figure 6

Power Assembly Lifter Example
Bent Spine

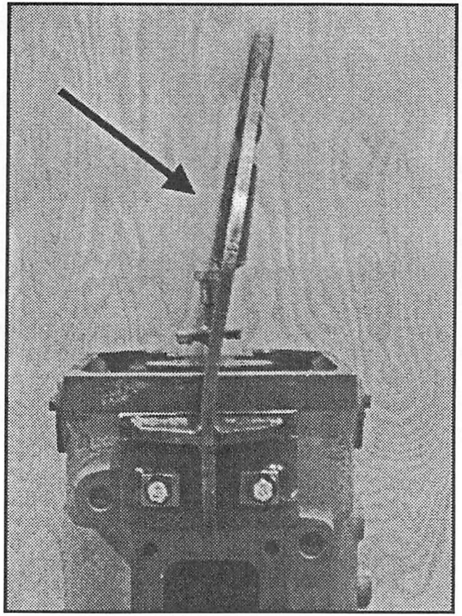


Figure 7

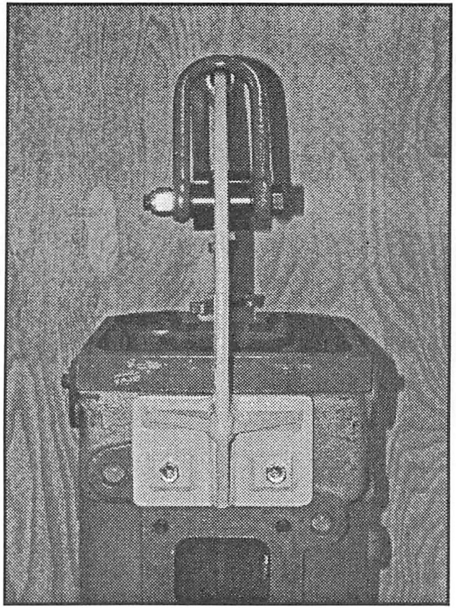


Figure 8

Power Assembly Lifter Example

Mounting Boly Machined Trench

*Trench is .200 deep

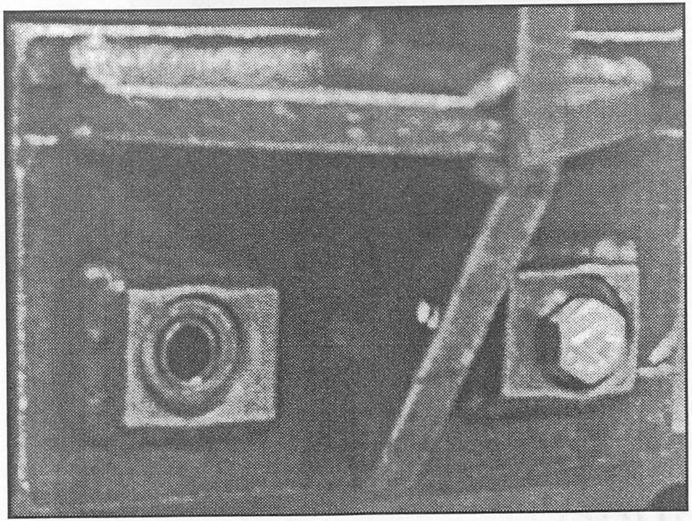


Figure 9

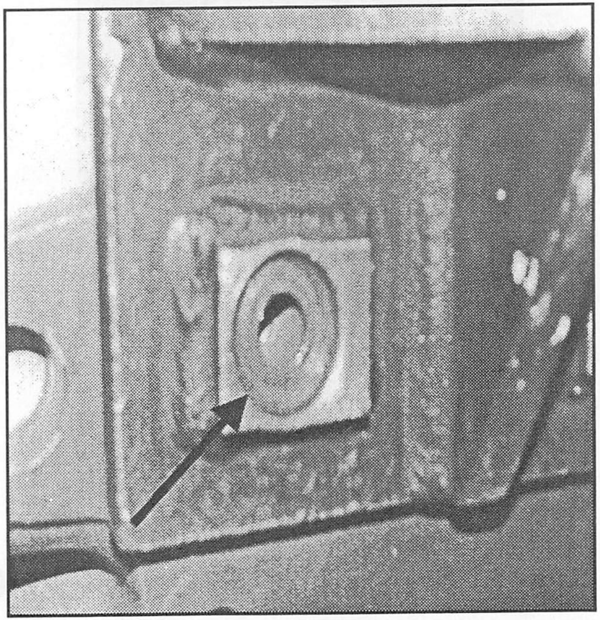
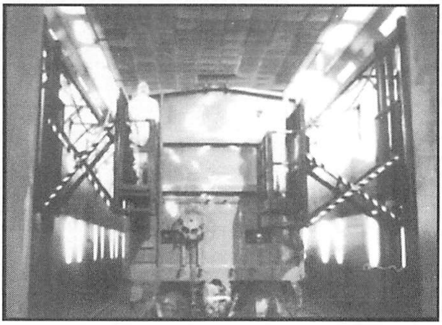
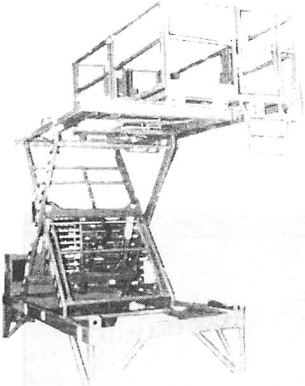
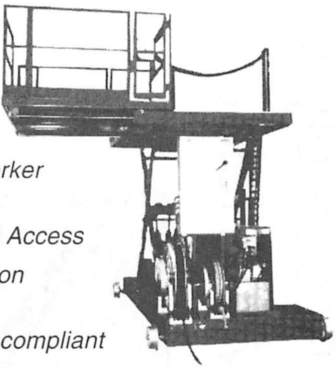
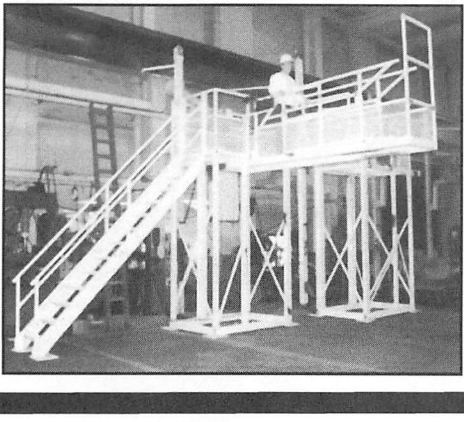


Figure 10









Power Assembly Lifter Example With Yielded Handle

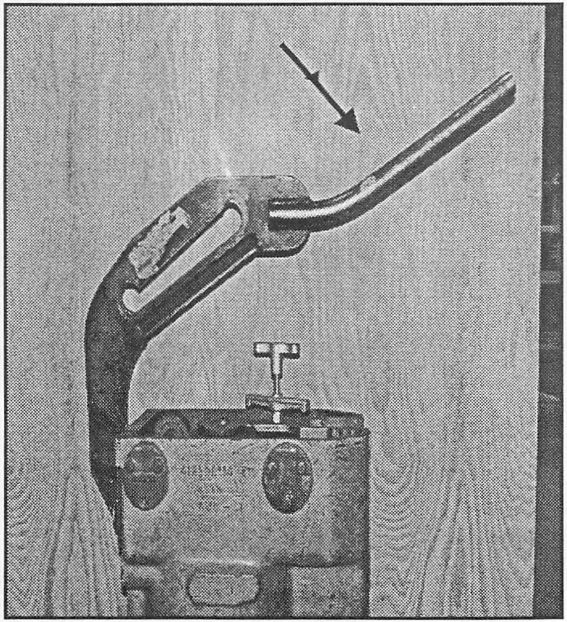


Figure 11

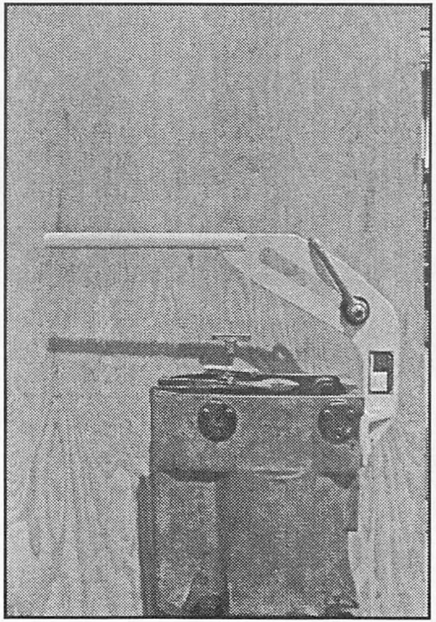


Figure 12

II. SANDING IN THE RAILROAD INDUSTRY – PART III, A GENTLE ANSWER FOR AN ABRASIVE SITUATION

By: Jack Morin,
NEU Inc.

On too many occasions, railroads are confronted with pneumatic conveying systems when purchasing new sanding equipment; and difficulties emerge almost instantaneously, as this technology is not a common practice on railroads.

The objective of this paper is to give a minimum background and knowledge in order to help railroads evaluate what will work best for them.

Definition

A pneumatic conveying system is the transport of solids in bulk in a stream of gas. The first challenge is to master the pressure drop created by the diphasic flow of gas and solid in a pipe routing, introducing the notion of "conveying phase." The second challenge is to control the gas/solid velocity in the pipe.

History

Nature offers the first good example of pneumatic conveying: wind (sirocco). Industrial applications came immediately following the invention of the fan (1866). There were only a few applications until the 1950's. There was a major expansion of this technology following the introduction of process plants and new manufactured products (food, chemicals, petrochemical [plastic], etc.).

Field application

Pneumatic conveying systems are used in all industry sectors which handle solids in bulk. Some of the industries are food, petrochemical, chemical, foundry, and railroad. Products vary from fibrous or granular to powdery with various particle shapes. They range from a few pounds to several hundred tons/hours over several miles.

Advantages

- Avoids product losses
- Adapts easily to new manufacturing processes
- Enables complex layout pipe routing
- Enables dust control
- Adapts to existing plant layout
- Enables use of inert gas for dangerous or fragile products
- Increased personnel safety in the work environment

Limits

The following physical and chemical characteristics of products are incompatible with the use of pneumatic conveying systems:

1. Sticky or humid products
2. Excessive voluminal mass
3. Excessive product temperatures incompatible with machinery used
4. Very fragile product losing value when damaged

Tips to remember

Pneumatic conveying technology has made tremendous progress in the past 40 years or so. This technology is still adapting to fast changing manufacturing processes and introduction of new products. Knowledge of the characteristics of the product to be conveyed should be determined which will dictate the choice of the functioning phase and equipment to be used. A few illustrations of pneumatic conveying systems are depicted in Figures 1 – 3. Choosing the proper pneumatic conveying system for railroad sand requires at minimum a two step process and lots of experience (see Figure 4).

1. Characterization of the product

- Rheological characteristics - Reflects the product flow-ability. A bulk product has a good flow characteristics if it can flow in the form of individual particles.
- Aerodynamic characteristics - Leads to the pressure drop in a conveying line
- Chemical and physical characteristics - Used to estimate product quality, choice of equipment and personnel safety

The product characterization of railroad sand is (1) hydroscopic, (2) fluidizable or porous, (3) dusty, and (4) very abrasive.

2. Things to consider when selecting the proper pneumatic conveying phase (Figure 5)

- Major phase densities used in pneumatic conveying systems
  - Lean (dilute) phase (Figure 6)
  - Continuous dense phase (Figure 7)
  - Discontinuous dense phase - (Figure 8) - (mandatory for railroad sand)
- Few tips to remember:
  - Discontinuous dense phase is what needs to be used for railroad sand handling application - translate into: solid to gas ratio: 30-40 to 1
  - Insufflators located at key points along the conveying line are necessary to assure smooth process (Figure 9)
  - For long distances, stepped pipe design is necessary to assure proper sand velocity

Technical summary

When selecting a proper pneumatic conveying system, understanding product physical characteristics will determine key technical choices when designing a sanding system for railroads. Discontinuous dense phase is the only proper design and represents the gentle answer for an abrasive situation.

In conclusion, a properly designed pneumatic conveying system will significantly improve system reliability. Technical solutions exist to eliminate abrasion problems currently experienced by the railroads. Think differently to integrate the advantages of the state of the art pneumatic systems and associated processes.

What is a Pneumatic Conveying System.

Few illustrations

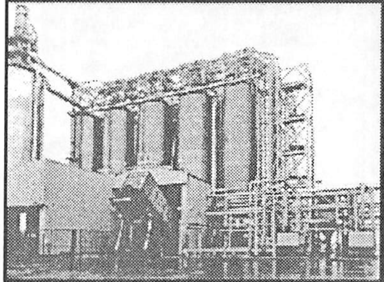


Figure 1

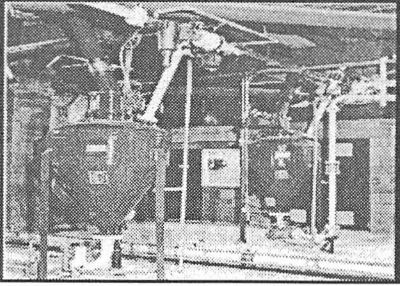


Figure 2

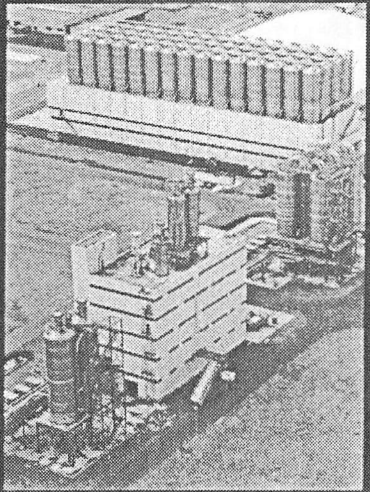
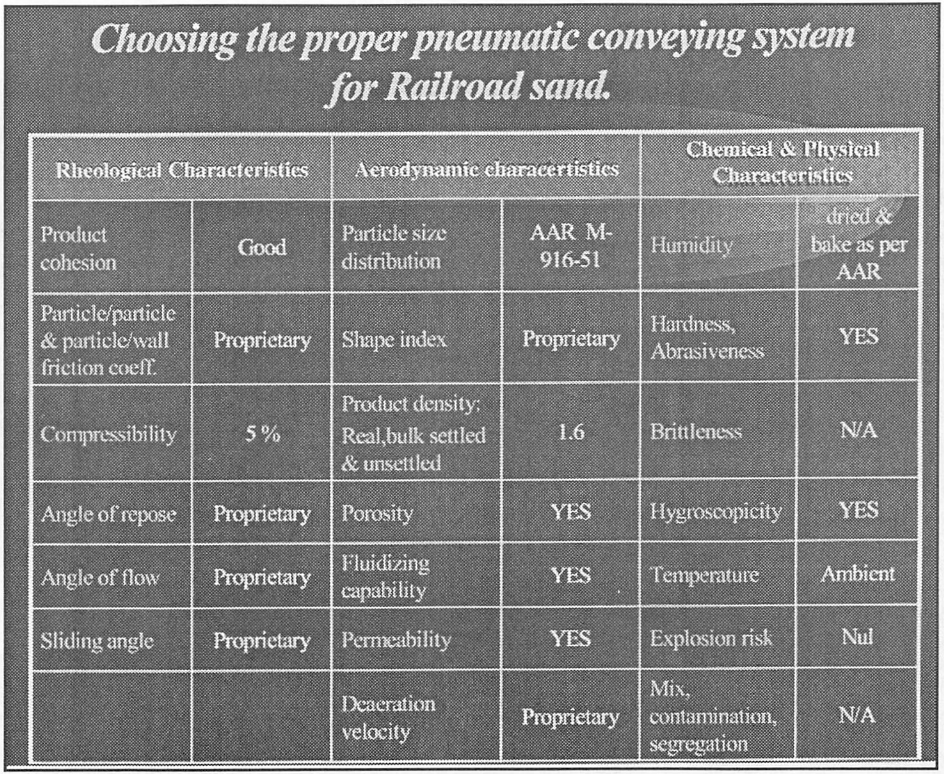


Figure 3



Choosing the proper pneumatic conveying system for Railroad sand.

Rheological Characteristics		Aerodynamic characertistics		Chemical & Physical Characteristics	
Product cohesion	Good	Particle size distribution	AAR M-916-51	Humidity	dried & bake as per AAR
Particle/particle & particle/wall friction coeff.	Proprietary	Shape index	Proprietary	Hardness, Abrasiveness	YES
Compressibility	5 %	Product density: Real,bulk settled & unsettled	1.6	Brittleness	N/A
Angle of repose	Proprietary	Porosity	YES	Hygroscopicity	YES
Angle of flow	Proprietary	Fluidizing capability	YES	Temperature	Ambient
Sliding angle	Proprietary	Permeability	YES	Explosion risk	Nul
		Deaeration velocity	Proprietary	Mix, contamination, segregation	N/A

Figure 4

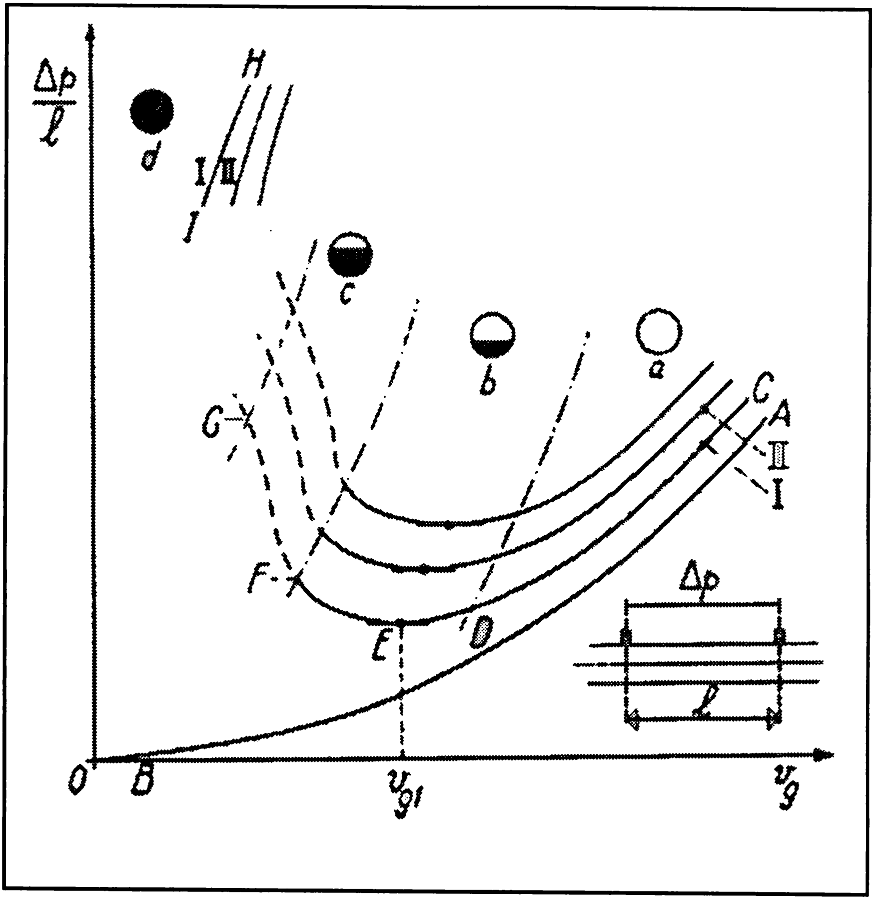


Figure 5

Major Phase densities used in pneumatic conveying

- **Lean (dilute) phase**

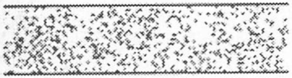


Figure 6

- **Continuous dense phase**

Figure 7

- **Discontinuous dense phase (Mandatory for railroad sand. !)**

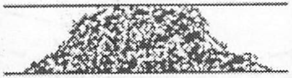


Figure 8

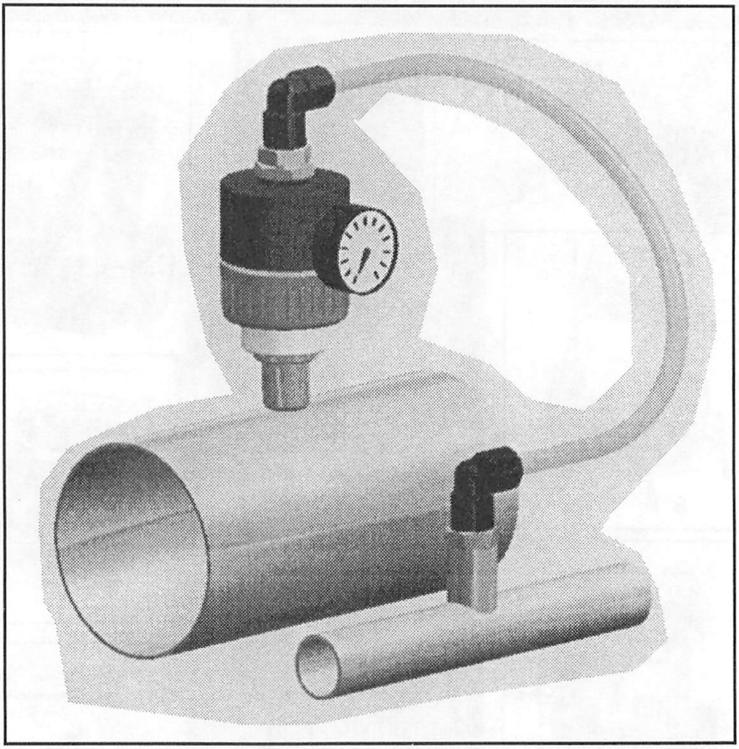


Figure 9

REPORT OF THE COMMITTEE ON DIESEL MATERIAL CONTROL

TUESDAY, SEPTEMBER 28, 2004
2:00 P.M.

Chairman
BENOIT GIRARD
Manager-Procurement-Locomotive
Canadian Pacific Railway
Calgary, Alberta

Vice Chairman
JOHN MINNIE
Materials Manager
BNSF Railway
West Burlington, IA

COMMITTEE MEMBERS

R. Delevan	Mgr.-Transp. Products	National Elect. Carbon	Dallas, PA
J. Fronckoski	Sr. Procurement Manager Mech.	CSX Transportation	Jacksonville, FL
J. Hartwell	VP-Sales	Progress Rail	Jacksonville, FL
B. Harvilla	Sales Manager	Standard Car Loco.	Strongsville, OH
C. Helbig	Parts - Sales (CSX,RA, FEC)	GE Transportation Rail	Jacksonville, FL
P. Johnson	Supt. Loco. Materials Dept	Norfolk Southern Corp	Atlanta, GA
J.C. Ouelette	Dir-Sales & Marketing	Alstom Transp.	Calgary, AB
G. Sumpter	Superintendent-Locos.	Florida East Coast	New Smyrna Beach, FL

NOTE: Mark Gast of CSX Transp. will be joining the committee this fall, replacing Jim Fronckoski

PERSONAL HISTORY

Benoit Girard

Benoit Girard is the manager procurement - rolling stock at Canadian Pacific Railway Calagary, Alberta head office, with over 25 years of experience in the rail industry.

He began his career with Canadian Pacific in January 1978 at Angus shop in the Material department in Montreal. In 1992 he became senior material supply specialist when Purchasing and Material merged. During the summer of 1997 he transferred from Montreal to Calgary when CPR decided to move its head office. Finally, in January 1999, he was appointed to his current position.

He and Sylvie, who have been married for 23 years have one son, Pierre-Olivier.

I. MILK RUN: NORFOLK SOUTHERN'S DEDICATED LOCOMOTIVE PARTS SHIPPING SYSTEM

Prepared by: Pat Johnson,
Supt. Locomotive Materials,
Norfolk Southern

This report is on Norfolk Southern's dedicated locomotive shipping system named the Milk Run.

This program and report go along with our committee's theme for this year which is strong railroad and supplier relationships for continuous improvement.

The partnerships we forge between the railroad Material departments and the suppliers allow us to better serve our mutual customers, the diesel shops and Mechanical departments.

As an overview of our presentation we will be discussing the problem statement which the Milk Run was initiated to resolve and the thought process behind its inception.

We will discuss the criteria used to select the suppliers and NS locations that were included in the program.

In addition we will discuss the phases of the implementation process.

We will show you the route which the milk run serves and how the route is separated into multiple runs.

And finally, we will share with you the payback that the Norfolk Southern has seen as result of implementing this program.

While working on a project focusing on reducing locomotive out of service time due to material shortages it was observed that the vast majority of the hold time was a result of material which was only in shortage at the location which needed it. For example, we might hold a locomotive at Conway for a module which is in stock at Enola and Bellevue.

In 2002, NS held locomotives due to material shortages, for 78,000 hours.

Another observation of these material shortages was that 80% of them were for rotable material (rotable material is defined as material which is repaired or reclaimed instead of discarded once removed from a locomotive). This material is in limited supply because of the high cost associated with increasing the pool.

If we could reduce the transit time of shipping material from location A to location B we could reduce the duration of inevitable material shortages.

The problem was most pronounced if a weekend was involved when short transit times were not cost effective. If a need for a part was identified on Friday, typically the need would not be resolved until Tuesday, resulting in up to 96 hours of out of service time. (The reason short transit times are not cost effective on weekends is that standard LTL and UPS service does not deliver on Saturday and Sunday, so premium service would be required for weekend delivery).

The funds that had historically been spent on LTL and UPS shipments were redirected to fund the dedicated shipping network. It was imperative that the milk run cost the same or less than the old shipment methods.

NS locations included must have enough freight volume to justify this dedicated service. For example, Elkhart is not included as a dedicated stop due to low volume.

NS locations selected must have enough locomotive material hold time that improvements would be measurable.

Suppliers were added to the milk run where it was geographically feasible and the freight expenses justified this service.

We started with NS locations only; then added suppliers and worked out service issues with each change.

Initial service began with three trailers and evolved to six trailers which operated in a relay fashion which means that drivers operate their segment of the milk run and swap trailers with drivers on adjacent segments at predetermined meeting locations.

Unfortunately, the 7th day of service is proportionally more expensive than the other 6 due to driver scheduling problems. Presently, we are not moving enough freight via the milk run to pay for a seventh day of service. The down day is Wednesday or Thursday depending on the run. The down day is in the middle of the week by design as we can use LTL in middle of the week and get reasonable transit times for a reasonable price.

Overnite Special Service Division is the service which was awarded the business (Figure 1). These trailers can be used to haul nearly any locomotive part with the exception of main alternators, traction motors and complete engines. The tractors are all equipped with Qualcomm GPS for easy tracking.

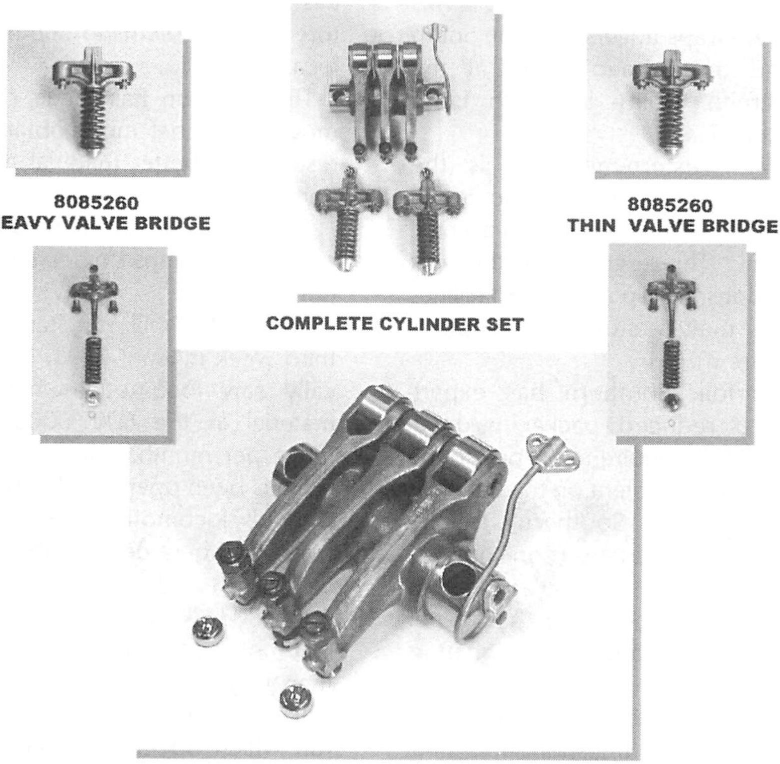
The containers, shown in Figure 2, are utilized to organize and protect small package deliveries by location.

The southern most leg of the milk run is Roanoke to Chattanooga to Roanoke, which is run six times weekly via team driver. This driver swaps trailers with the Roanoke to Williamsport driver at the Roanoke Locomotive Shop (Figure 3).

The next leg is Roanoke to Williamsport to Roanoke, which is run six times weekly via a single driver. This driver swaps trailers with the Williamsport to Altoona driver at an Overnite facility in Williamsport (Figure 4).

The eastern most leg of the run is the Altoona thru Enola to Williamsport thru Enola to Altoona six times weekly via a single driver. This driver swaps trailers with the Altoona to Cleveland driver at Juniata Locomotive Shop in Altoona (Figure 5).

The next leg is the Cleveland thru Conway to Altoona thru Conway to Cleveland six times weekly via a single driver. This



driver swaps trailers with the Cleveland to South Bend driver at the Overnite facility in Cleveland (Figure 6).

The next leg is the South Bend thru Bellevue to Cleveland thru Bellevue to South Bend six times weekly via a single driver. This driver swaps trailers with the South Bend to Chicago driver at the Overnite facility in South Bend (Figure 7).

The western-most leg is the South Bend to Chicago to South Bend five times weekly via a single driver. This segment of the milk run doesn't stop at any NS facilities only makes stops at suppliers (Figure 8).

Norfolk Southern has experienced reduced packaging/documentation requirements due to the fact that the freight on the trailers is all Norfolk Southern freight. Mailing labels used on popular destinations are as simple as preprinted labels with a 3 letter shop abbreviation, (i.e., Shaffers Crossing Locomotive Shop is SCX).

We have been able to reduce docking and transportation time due to this dedicated service yielding the same daily driver. The drivers know how to get in and out of our facilities and know how the freight needs to be staged within the trailers to make it as efficient as possible for loading and unloading.

Due to participation in the milk run we have developed improved relationships with key suppliers.

The primary benefit that Norfolk Southern has experienced is a significant reduction in total locomotive hold time. This has been primarily due to decreased duration of each locomotive hold and to a lesser degree decreasing the quantity of locomotives held.

We have also been able to avoid pool purchases where the milk run has facilitated consolidating inventory of critical items to one or two locations.

The milk run has made slower moving material more obtainable resulting in better material utilization.

The milk run has drastically reduced the transit times throughout the week.

Prior to the milk run startup the third week in April 2003, NS typically saw locomotives held for material in the 6000-8000 hour range per month. Since the milk run has been operating NS typically holds locomotives for material for 4000 hours per month (Figure 9).

In 2003, Norfolk Southern held locomotives for 18,000 hours less than in 2002. This improvement was mainly attributable to the milk run which operated in the last 8 months of 2003. This equates to $300,000 in locomotive service time savings.

Figure 1

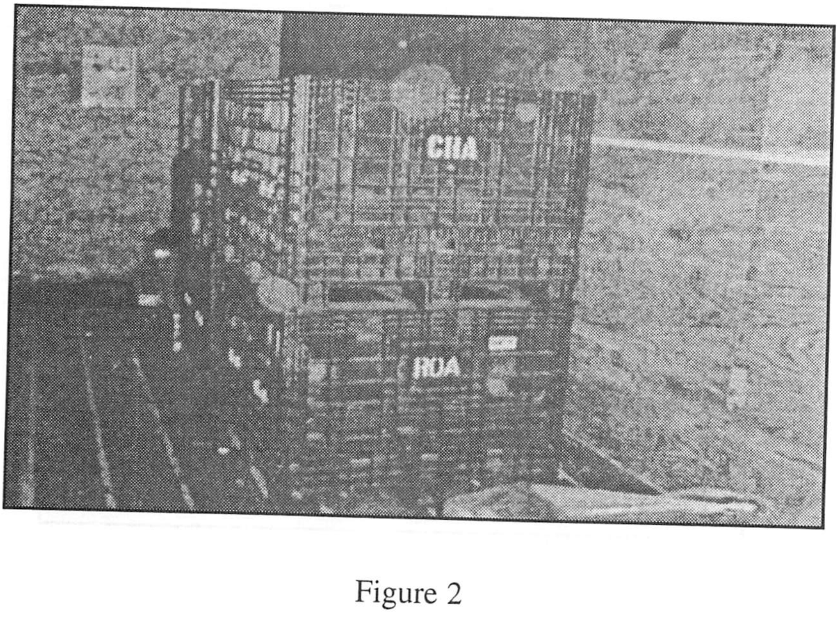


Figure 2

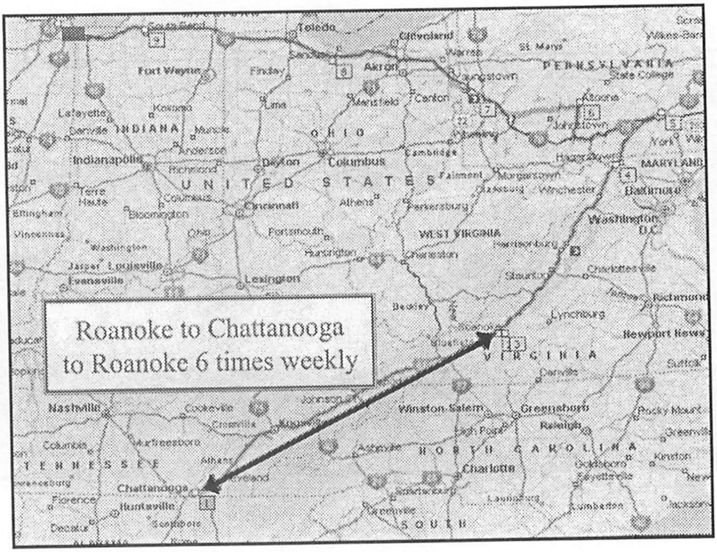


Figure 3

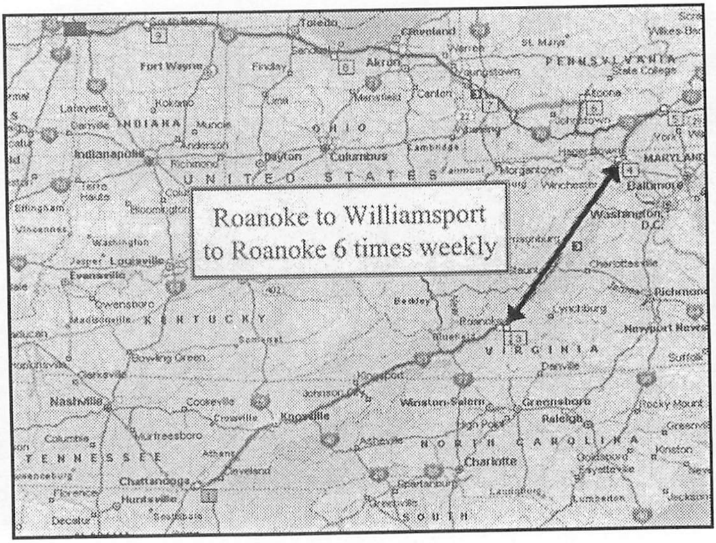


Figure 4


New And Remanufactured Water Pumps

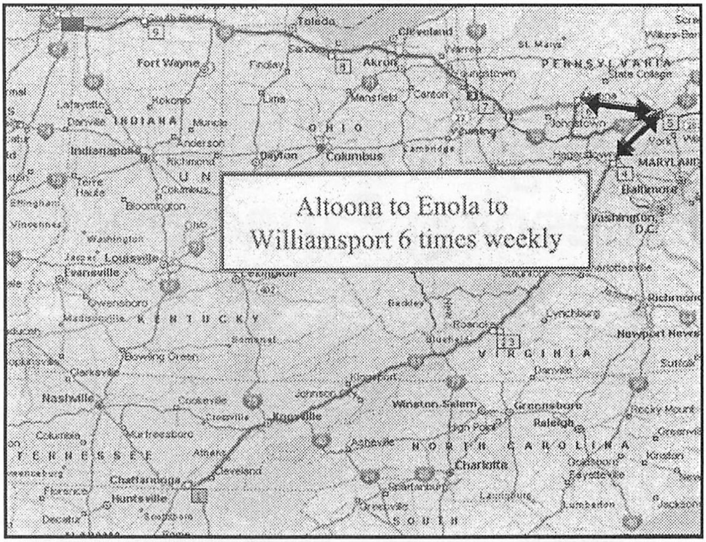

Altoona to Enola to Williamsport 6 times weekly

Figure 5

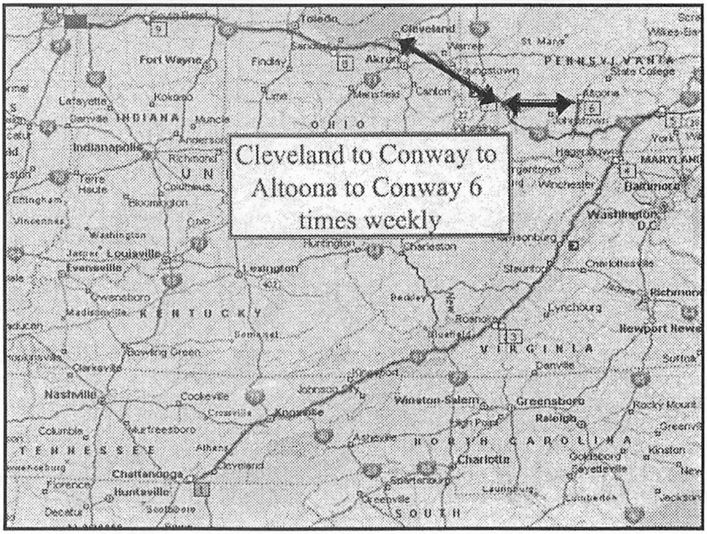

Cleveland to Conway to Altoona to Conway 6 times weekly

Figure 6

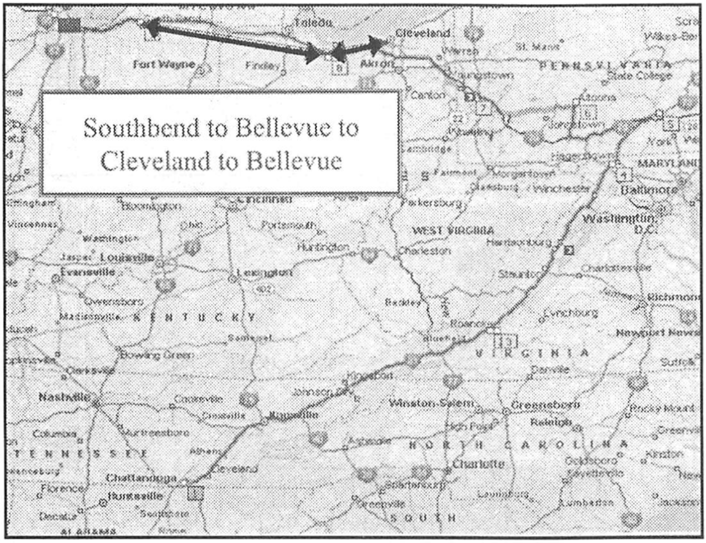


Figure 7

Figure 8

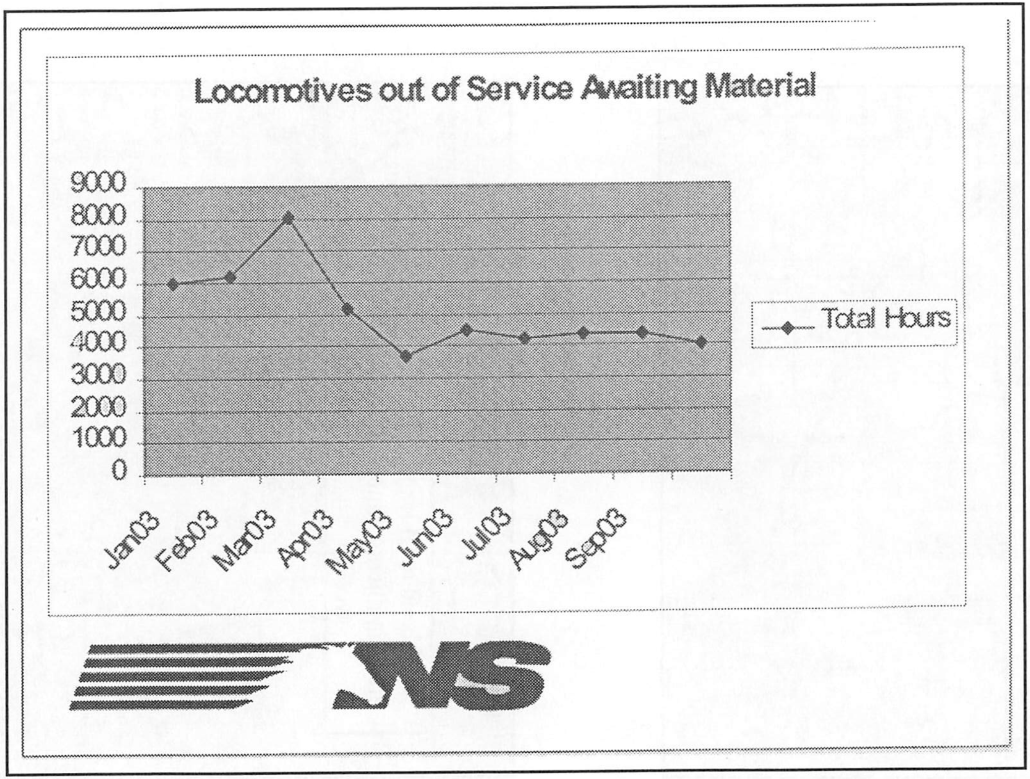

Locomotives out of Service Awaiting Material
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan03
Feb03
Mar03
Apr03
May03
Jun03
Jul03
Aug03
Sep03
Total Hours
NS

Figure 9

CONSTITUTION AND BY-LAWS LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION

Revised September 22, 2003

Article I - Title:

The name of this Association shall be the Locomotive Maintenance Officers Association (LMOA).

Article II - Purpose of the Association

The purpose of the Association, a non-profit organization, shall be to improve the interests of its members through education, to supply locomotive maintenance information to their employers, to exchange knowledge and information with members of the Association, to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad industry.

Article III - Membership

Section 1 - Railroad Membership shall be composed of persons currently or formerly employed by a railroad company and interested in locomotive maintenance. Membership is subject to approval by the General Executive Committee.

Section 2 - Associate Membership shall be composed of persons currently or formerly employed by a manufacturer of equipment or devices used in connection with the maintenance and repair of motive power, subject to approval of the General Executive Committee.

Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at the Annual Meeting, and shall have the privilege of voting or holding elective office.

Section 3 - Life membership shall be conferred on all Past Presidents. Life membership may also be conferred on others for meritorious service to the Association, subject to 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 shall not be permitted to attend the annual meeting, shall not be eligible to vote and/or shall not be entitled to receive a copy of the published Pre-Convention Report or the Annual Proceedings of the annual meeting. Failure to comply will result in loss of membership at the end of the current year. Life members will not be required to pay dues, but 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 successors are elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, continue to serve as an executive 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 current elective officers and the active Past Presidents, shall submit the slate of candidates for each elective office at the annual convention.

Section 2 - Election of officers shall be determined by a voice vote, or if challenged, it shall require show of hands.

Section 3 - Vacancies in any elective office may be filled by presidential appointment, subject to approval of the General Executive Committee.

Section 4 - The immediate Past President shall serve as Chairman of the Nominating Committee. In his absence, this duty shall fall to the current President.

Article VI - Officers - Duties of

Section 1 - The President shall exercise general direction and approve expenditures of all affairs of the Association.

Section 2 - The First Vice President, shall in the absence of the President, assume the duties of the President. He shall additionally be responsible for preparing and submitting the program for the

Annual Meeting.

The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers required to underwrite the cost of the **Annual Proceedings.**

The Third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly prepared and distributed, monitoring membership levels and reporting same at appropriate time to the General Executive Committee.

The Vice Presidents shall perform such other duties as are assigned them by the President.

Section 3 - The Secretary-Treasurer shall:

A. Keep all the records of the Association.

B. Be responsible for the finances and accounting thereof under the direction of the General Executive Committee.

C. Perform the duties of the Secretary of the Nominating Committee, and General Executive Committee, without vote.

D. Furnish surety bond in amount of $5000 on behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.

Section 4 - The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.

B. Monitor material to be presented by the technical committees to ensure reports are accurate and pertinent to the goals of the Association.

C. Attend and represent LMOA at meetings of their assigned technical committees.

D. Promote Association activities and monitor membership levels within their assigned areas of responsibility.

E. Promote and solicit support for LMOA by helping to obtain advertisers.

Section 5 - Duties of General Executive Committee:

A. Assist and advise the President in long-range Association planning.

B. Contract for the services and compensation of a Secretary-Treasurer.

C. Serve as the Auditing and Finance Committee.

D. Determine the number and name of the Technical Committees.

E. Exercise general supervision over all Association activities.

F. Monitor technical papers for material considered unworthy or inaccurate for publication.

G. Approve topics for the Annual Proceedings and Annual Meeting program.

H. Approve the schedule for the Annual program.

I. Handle all matters of Association business not specifically herein assigned.

Section 6 - The General Executive Committee is entrusted to handle all public relations decisions within LMOA and coordinated associations with confidentiality.

Article VII - Technical Committees

The technical committees will consist of:

Section 1 - A chairperson, appointed by the President and approved by the General Executive Committee.

Section 2 - A vice chairperson, selected by the chairperson and approved by the President.

Section 3 - Committee members, 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.

C. The Fuel and Lube Committee will include members from major oil companies or their subsidiaries as approved by the General Executive Committee.

D. At the direction of the General Executive Committee, non-railroad personnel may be allowed to participate in committee activities.

Section 4 - All individuals who are on technical committees must be LMOA members in good standing. (See Article III, Section 4).

Section 5 - Subjects for technical papers will be selected and approved by the General Executive Committee.

Article VIII - Proceedings

Section 1 - The Locomotive Maintenance Officers Association encourages the free interchange of ideas and discussion by all 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 papers 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 Roberts 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.

DIESEL MECHANICAL MAINTENANCE COMMITTEE
TWENTY-THREE YEAR INDEX

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 Electro Motive 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 Com-parison Between Regionals and Class I Railroads.
4. Amtrak Document Manage-ment.

1993

1. EMD's Three-Axle Radial Steering Truck
2. The Natural Gas Locomotive at BN RR
3. Locomotive Waste Oil Reten-tion
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 Reman-ufactured Locomotives.
2. The EMD 710G3A Engine
3. Improving Performance of Traction Motor Friction Sus-pension 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 Lubricators.
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.

DIESEL MATERIAL CONTROL COMMITTEE TWENTY-THREE YEAR INDEX

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 Solutions.
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 Dis-tribution Resulting from Shop Consolidations.
3. Outsourcing! Does Anyone Really Understand the Difference Between UTEX and Repair and Return and the Affect 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 Re-quisition System.
2. Electronic Data Interchange.
3. RAILING and Electronic Pur-chasing.
4. Quality Evaluation of Material Sourcing Decisions.

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. Bar Coding of Material.
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 Produc-tivity 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.

SHOP EQUIPMENT AND PROCESSESCOMMITTEE TWENTY-TWO YEAR INDEX

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 Replace-ment Equipment and Pro-cedure.
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 System.
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 Tech-nology.

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 Re-gulations 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 Pro-ductivity.
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 ELECTRICAL MAINTENANCE COMMITTEE TWENTY-THREE YEAR INDEX

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 Main-tenance

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.
4. 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
5. Adhesion Alternative
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 Elec-trical Equipment.
2. Locomotive Batteries
   - a. Storage Handling Proced-ures.
   - b. Recommended Maintenance Procedures.
   - c. Recommended Repair Procedures.
3. Amtrak's AC Traction Locomotives.
4. Modern Tooling for Electricians Recorders.
3. Why Can't We Have One Central Computer?
4. 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 Tape Event Recorders for Locomotive Maintenance.
2. Solid State Locomotive Data 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. On-Board Diagnostics.
2. GE's **CATS** (Computer Aided Troubleshooting System).
3. Fuel Conservation Through
4. Electrical Modifications.
5. Performance of Locomotives After Storage.

1983

1. Ground Relay Trouble Shooting.
2. Specification for remanu-factured 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 Trouble-Shooting.
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.

NEW TECHNOLOGIES COMMITTEE TWENTY ONE-YEAR INDEX

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 Condition-ing 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 Filteration-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 Tech-nology
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. Beltpack Locomotive Control System
2. The MK1200G Switching Locomotive
3. Advanced Traction Motor Testing

1994

1. Electronic Fuel Injection Sys-tems.
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 Develop-ments Retrofittable to Older Model Locomotives
3. Locomotive Applications of Catepillar Engines.
4. Wheelslip Control for Individual Axles.

1987

1. Electronic Fuel Injection Sys-tems.
2. Update on Electronic Gover-nors.
3. Recent Advances in Steerable Locomotive Trucks - the E.M.D. 4 Axle, 4 Motor HT-BB Articulated Truck.
4. Converting an F40 Locomotive to A.C. 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 E.M.D. Turbocharged Engines.
2. A.C. Traction Locomotives Update.
3. Natural Gas Locomotive Update.
4. Ceramic Coated Engine Components.
4. Locomotive Cab Develop-ments.

1984

1. G.E. Dash 8 Locomotives.
2. E.M.D. 50A Series Locomotives.
3. Natural Gas Locomotives.
4. Appraisal of the A.C. 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.

FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE
TWENTY-THREE YEAR INDEX

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 Evalua-tion 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 Lubri-cants
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 Lubri-cation.
5. Multi-Viscosity Oils as an Energy

Conservation Technique.

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