LMOA

Locomotive Maintenance Officers Association

Proceedings of the 63rd Annual Meeting

September 24 - 26, 2001

Chicago Hilton & Towers

720 S. Michigan Ave.

Chicago, Illinois

2001 ADVERTISERS INDEX

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2000 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 2000.

Name	Company	Committee
Alain Mercier	Alstom Transport	New Technologies
Dave Perkins	Montana Rail Link	Diesel Electrical
John Sadler	CN/IC Railroad	Diesel Mechanical
Dennis McAndrew	GETS	Fuel, Lube & Environ.
Bob Florczyk	GETS	Diesel Material Control

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

LMOA EXECUTIVE COUNCIL

PAST PRESIDENTS

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1941 -	J. C. MILLER (Deceased), MM, N.Y.C. & St. L.R.R.
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1947 -	S. O. RENTSCHILLER (Deceased) Chief Mechanical Officer, Bessemer and Lake Erie R.R.
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1949 -	J. W. HAWTHORNE (Deceased) Asst. Vice-Pres.- Equipment, Seaboard Coast Line R.R.
1950 -	G. E. BENNET (Deceased) Vice-Pres.-Gen. Purchasing Agent, C. & E. I. Ry.
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1953 -	S. M. HOUSTON (Deceased) Gen. Supt. Mech. Dept. Southern Pacific Co.
1954 & 1955 -	F. D. SINEATH, Retired Chief of Motive Power, Seaboard Coast Line R.R.
1956 -	T. T. BLICKLE (Deceased) General Manager - Mechanical, A .T. & S. F. Ry.
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1958 -	F. R. Denny (Deceased) Mechanical Supt., New Orleans Union Passenger Terminal
1959 -	E. V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry.
1960 -	W. E. LEHR (Deceased) Chief Mechanical Officer, Pennsylvania R.R.
1961 -	O. L. HOPE, (Deceased) Asst. Chief Mechanical Officer, Missouri Pacific R.R.,
1962 -	R. E. HARRISON (Deceased) Manager-Maintenance Planning & Control, Southern Pacific Co.
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1971 -	G. W. NEIMEYER (Deceased) Mechanical Superintendent, Texas & Pacific Railway
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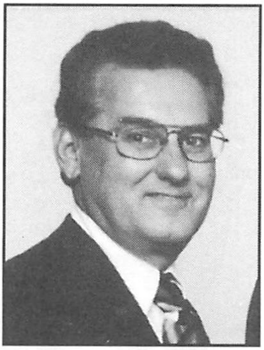

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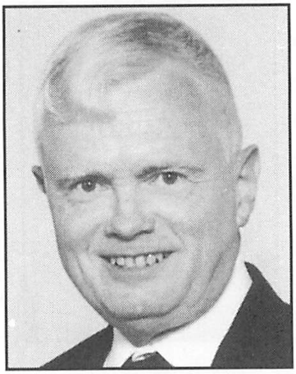
LJC Rail Consultant
Duncansville, PA 16635

Our Chairman of the Board
MR. RONALD R. LODOWSKI
Supt. - Locomotives
CSX Transportation
Selkirk, NY 12158

OUR OFFICERS



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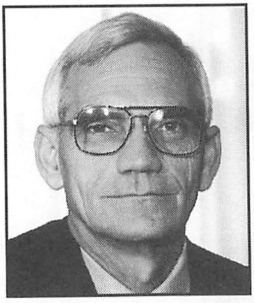
Roanoke, VA 24042



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Seattle, WA 98134

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Engineering & Quality
Union Pacific Railroad
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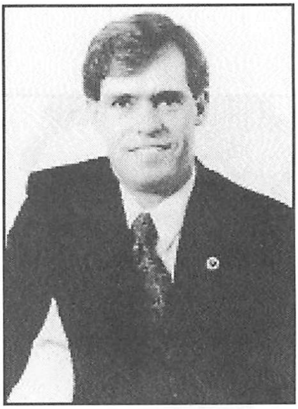

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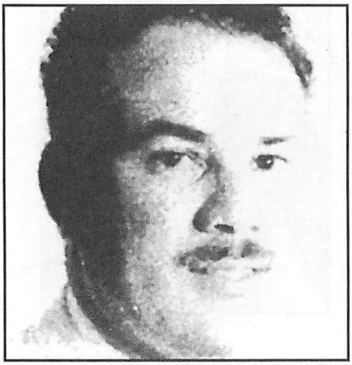
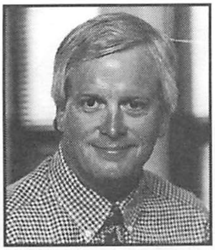
Ellcon National
Keller, TX 76248



MR. JAKE VASQUEZ
Superintendent
Amtrak
New Orleans, LA 70125

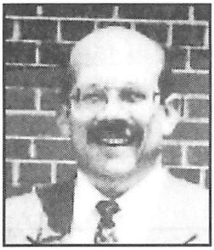
MR. DAVID M. WETMORE
General Supt. - Equipment
NJT Rail Opns
Kearny, NJ 07032

OUR REGIONAL EXECUTIVES

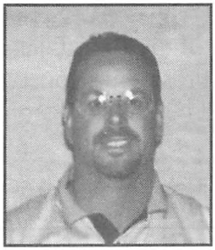


MR. GLENN BOWEN
Director - Lab Services
BNSF Rwy
Topeka, KS 66616

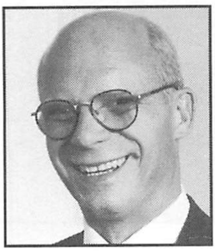
MR. JOHN BRAWLEY
Director-Material Management
Amtrak
Beech Grove, IN 46107



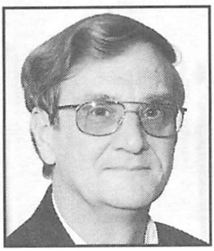
MR. BRUCE A. KEHE
Manager Mech. Svcs.
EJ & E
Gary, IN 46402



MR. MIKE SCARINGE
Asst. Chief Mechanical Officer - West
Amtrak
Beech Grove, IN 46107



MR. TAD H. VOLKMANN
Manager - Loco. Facility - Engine Components
Union Pacific
North Little Rock, AR 72114



MR. LES WHITE
District Service Representative
ElectroMotive Division
Montreal, PQ
Canada H3B 2N2

Chairman of the Board, Jake Vasquez, Amtrak, presents General Desk Set to outgoing President, Ron Lodowski, CSX Transportation, as President Elect, Lou Cala, LJC Rail, looks on.

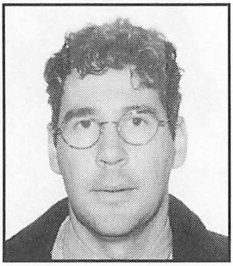
Outgoing President Ron Lodowski, CSX Transportation, presents gavel to President Elect, Lou Cala, LJC Rail. The ceremony was witnessed by newly elected 2nd Vice President, Brian Hathaway, Florida East Coast Railway.

Past President, Dave Wetmore, NJT Rail Operations, presents Past President's Pin to outgoing President Ron Lodowski, CSX Transportation. Newly elected 1st Vice President, Bob Runyon, Consutlant, witnessed the presentation.

LMOA Executive Committee Members: (seated, left to right)
Past President, Dave Wetmore, NJT Rail Operations, Past President, Bill Brown, BP Associates, Past President, Tom Hartley (retired), outgoing Chairman of the Board, Jake Vasquez, Amtrak.
(standing, left to right)
Newly elected 2nd VP, Brian Hathaway, Florida East Coast Railway, newly elected 1st VP, Bob Runyon, Consultant, President Elect, Lou Cala, LJC Rail, outgoing President, Ron Lodowski, CSX Transportation, and Secretary Treasurer, Ron Pondel, Triangle Engineered Products.

REPORT OF THE COMMITTEE ON DIESEL MATERIAL CONTROL

MONDAY, SEPTEMBER 24, 2001
2:30 P.M.



Benoit Girard, Chairman
Manager Procurement-Locomotive
Canadian Pacific Railway
Calgary, Alberta

Vice Chairman
John Minnie
Materials Manager
BNSF Railway
West Burlington, IA

COMMITTEE MEMBERS

R. Brandt	Director-Materials	VMV Enterprises	Paducah, KY
R. Delevan	Mgr.-Transp. Products	National Elect. Carbon	Wilkes Barre, PA
J. Fronckoski	Loco. Procurement Mgr.	CSX Transportation	Jacksonville, FL
J. Hartwell	VP-Sales	Progress Rail	Jacksonville, FL
B. Harvilla	Sales Manager	Standard Car Loco.	Strongsville, OH
M. Scalise	Manager-American Parts Mktg.	GE Transp. Systems	Erie, PA
G. Sumpter	Superintendent-Locos.	Florida East Coast	New Smyrna Beach, FL

PERSONAL HISTORY

Benoit Girard

Benoit Girard is the manager procurement - rolling stock at Canadian Pacific Railway Calagary, Alberta head office, with over 23 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 20 years have one son, Pierre-Olivier.

I. RAILMARKETPLACE.com - THE INDUSTRY'S MARKET EXCHANGE

Prepared by
Andrew Wrenshall,
Canadian Pacific Railway

Introduction

RailMarketplace.com[sm] is a B2B exchange serving the supply chain needs of freight and shortline railroads, commuter lines and suppliers to the rail industry. RailMarketplace.com, presently based in Chicago, will enable railroads and their suppliers to jointly reduce costs and improve efficiency in the rail supply chain and to share in the resulting savings.

According to Jeff Campbell, Vice President & Chief Sourcing Officer for the Burlington Northern and Sante Fe, and one of the founders of RailMarketplace, "the goal is create visibility, drive standardization, and bring efficiency to the supply chain so that suppliers will be able to save money..." and share these savings with the railroads. In addition to traditional sourcing savings there are other opportunities such as improved settlement, reduced rail and supplier working capital needs, decreased parts obsolescence, improved infrastructure and rolling stock up time through a shared parts network, and many others.

The growth of Railmarketplace is critical to the efforts of both buyers and sellers in the industry to become more productive in the face of intensifying competition in North America and elsewhere.

Through RailMarketplace, small, medium and large companies, in the rail and rail-related transportation industry, will be able to immediately trade information and goods, collaborate on supply-chain requirements, launch and sell new products and services faster than ever before. The RailMarketplace provides instant access to the rail community, and the benefits of a full complement of service components designed to enhance and automate supply-chain processes.

RailMarketplace was created by North America's six largest railroads, Burlington Northern Sante Fe, Canadian National, Canadian Pacific Railway, CSX Transportaion, Norfolk Southern and Union Pacific. GE Global eXchange Services is a technology partner.

RailMarketplace is an open and neutral electronic exchange intended to provide its members with an economical, modular service, which provides the flexibility to select the service components that will provide each company with the most benefit. Through RailMarketplace, buyers will have the opportunity to reduce their sourcing costs through improved spending controls, decreased purchasing cycle times and an expanded supplier base. Suppliers will have the opportunity to increase their customer base, as well as reducing costs associated with sales, order management, inventory and product standardization.

Among the collaboration components planned for the first phase of product rollout within RailMarketplace are RFP/RFQ (request for proposal/request for quotation), electronic auctions, and catalog e-procurements. The second phase will include offerings in order management, inventory reduction and standardization.

The Benefits of RailMarketplace

For buyers, RailMarketplace will make it easier and faster to locate new or existing sources of supply. Its use will improve cost performance by helping to negotiate better rates, leverage the buying power of larger companies, reduce transaction costs, and decrease the time to market for goods and services.

For suppliers, RailMarketplace should easily and cost-effectively help to identify new customers for their goods and services. Companies will be able to promote themselves through use of targeted micro-sites where the potential buyers are making their purchasing decisions. Suppliers will also be able to use the exchange to purchase more effectively from other suppliers.

In Phase II of the product rollout, an electronic interface will allow the suppliers to see their customers' buying schedules and automatically receive changes to those schedules. It will also include a financial settlement process to insure that invoices match the customers purchase orders and the electronic payments are made on time.

For both buyers and suppliers, RailMarketplace can increase supply-chain efficiency by automating manual or paper-based transactions. Time and geographic boundaries are no longer major considerations because the exchange takes full advantage of e-commerce technologies and services.

Conclusion

RailMarketplace is uniquely positioned to be the leading electronic marketplace in the rail industry due to the strong and tangible backing of its rail founders. Specifically, all six North American Class I railroads are not only invested in the company's success, but they are committed to using the services offered by RailMarketplace for transacting on a day-to-day basis with their respective suppliers, large and small.

RailMarketplace

In addition to streamlining the railroads' procurement process, RailMarketplace is focused on helping suppliers increase sales and reduce transaction costs thereby improving their margins.

Benefits include:

- **Increasing the size of the customer base without proportionately increasing marketing and sales costs**
- **Reducing the cost of supplier purchases of components and raw materials**
- **Reducing the administrative costs of providing quotes and processing orders**
- **Reducing excess production capacity and surplus inventory**
- **Increasing certainty of demand forecasts**

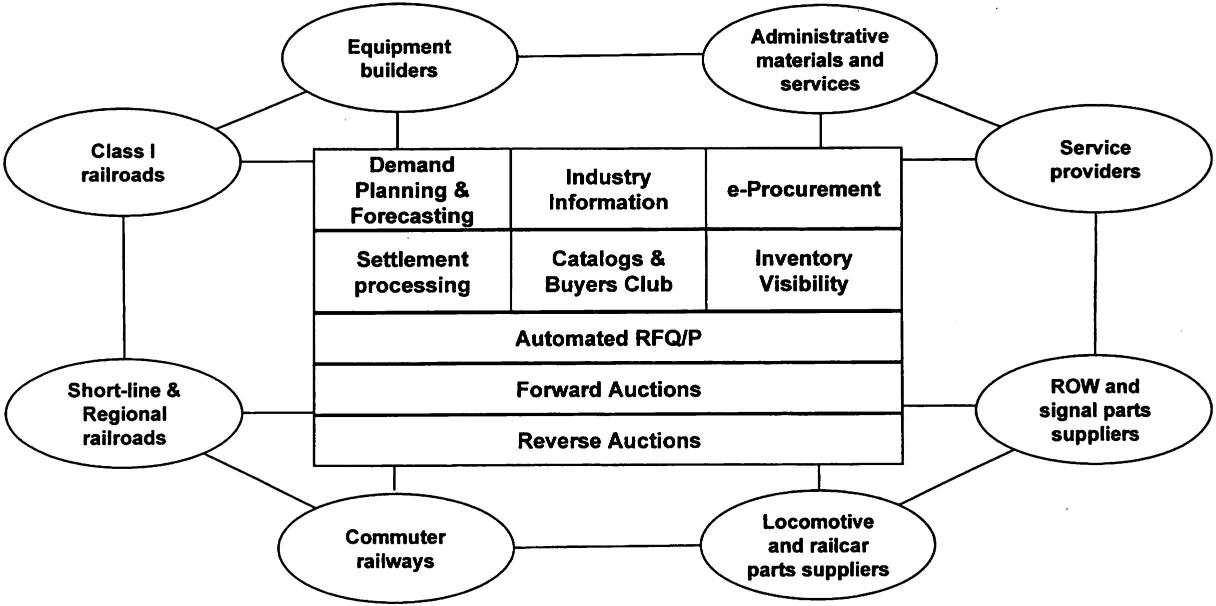
Background

RailMarketplace will enable railroads and suppliers to reduce supply chain costs and share in the savings.

What is RailMarketplace?	How did it start?
• RailMarketplace is a business-to-business (B2B) community • Serves the supply chain needs of freight and commuter railroads and their suppliers • Offers internet enabled products and services covering the entire spectrum of supply chain needs: – sourcing – demand forecasting – procurement/catalogs – financial settlement – e-marketing	• Founded in January 2001 by the largest freight railroads in North America – Burlington Northern Santa Fe – CSX Transportation – Canadian National – Canadian Pacific Railway – Norfolk Southern – Union Pacific

Connecting industry participants

RailMarketplace is community where members will come together to exchange products, services and information.



Supplier concerns

Suppliers identify a number of problems with rail industry procurement.

Key Supplier Concerns

High demand uncertainty

"How do I purchase raw materials and plan production when I have no idea how many ties my customers will need next year."
- Tie supplier

Complex and lengthy sales and order cycle

"It can take up to 30 days to develop a bid and more than half that time is taken up just gathering information."
- Construction contractor

Surplus capacity and inventory

"A railroad will give me an order in January, I buy the materials and step up production in February, then they cancel the order in March… I wish they were better at planning"
-Railcar parts manufacturer

Limited revenue growth

"My biggest challenge is finding out what projects are out there for me to bid on. Unless you have an established relationship, its very difficult to get new business."
- Construction contractor

Solutions

RailMarketplace will offer solutions to these problems.

Supplier Concern	Resolution	RailMarketplace Functionality
Demand uncertainty	• Increase awareness of customers longer term product requirements • Increase knowledge of customers available inventories	• Inventory visibility • Demand planning and forecasting tools • RFQ/P for long term agreements
Complex sales cycle	• Streamline information gathering and submission processes • Shorten sales and ordering cycle time • Simplify payment collection	• RFQ/P • Reverse auction • e-Procurement • Settlement processing
Surplus capacity and inventory	• Demand based production planning • Reduce surplus inventory and equipment	• Demand planning and forecasting tools • Forward auctions
Limited revenue growth	• Increase exposure to new customers and markets • Increase awareness of new business opportunities	• RFQ/P • Searchable catalog • On-line advertising

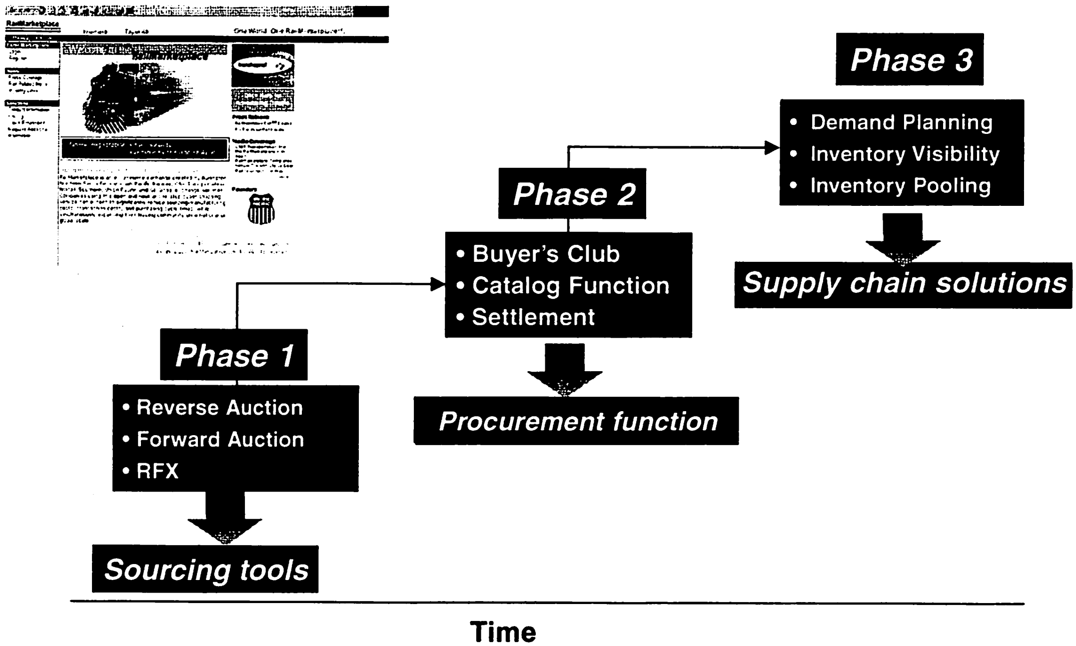
Balanced benefits

If benefits to buyers and sellers can be balanced by the RailMarketplace – everybody wins.

	Needs	Benefits
Buyers	• Reduce costs of purchases • Improve operating effectiveness • Improve procurement efficiencies	• Economies of scale achieved by aggregating demand • Access to more suppliers thus greater choice of products and prices • Reduced inventory costs from lower safety stock • Shorter procurement cycle requiring less manual communication and transactions
Sellers	• Increase access to limited set of customers • Reduce costs to improve margins in face of global competition • Process for easy clarification and specification for order fulfillment	• Greater potential to attract new business for smaller players • Access to more information on buyers needs and preferences, including price sensitivity to develop product/service offering • Real-time access to customers, fewer errors in order processing
Common	• Reduce administrative costs • Access to timely and comprehensive information	• Automate and integrate procurement processes resulting in less manual transactions • Improved planning ability (of supply and demand) thereby reducing excess capacity and inventory • More responsive supply chain

Development plan

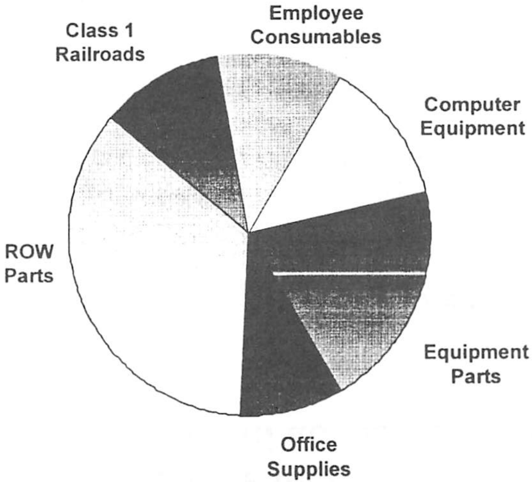
Core tools will be available immediately and value-added services will be rolled out in two additional phases.



Membership

RailMarketplace has generated a broad base of membership and interest even before its official launch.

Representation of Existing Membership



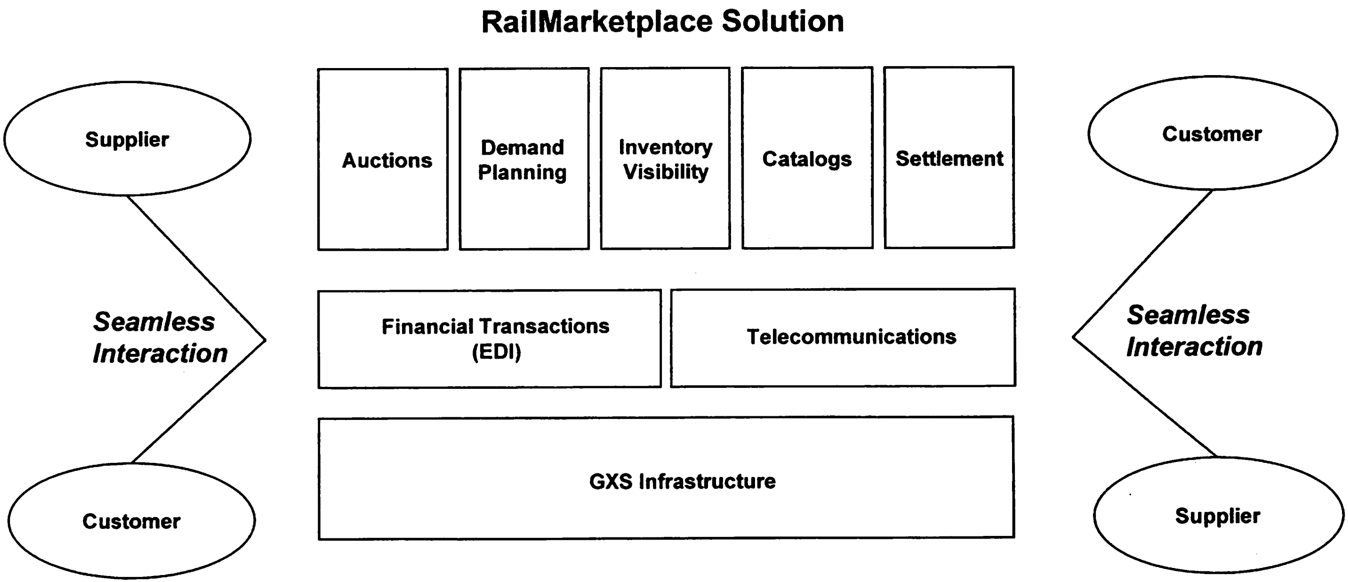
Suppliers: 56
Class 1 Railroads: 6
Total of 62 participants as of July 10, 2001

RailMarketplace Participation
• 56 suppliers registered and using marketplace • Almost 300 participants pre-registered for August 2001 launch

➡ **The community is growing very quickly.**

Technology

RailMarketplace technology will be 'best-of-breed' for each functionality and accessible through a common platform.

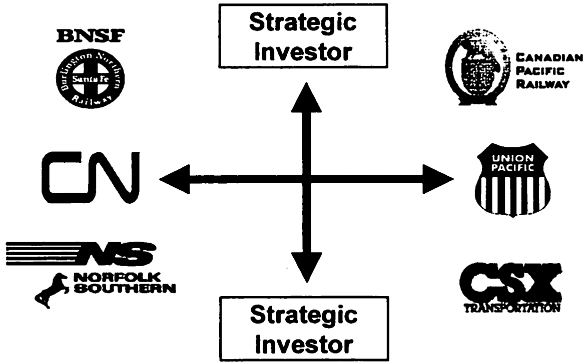


Strategic investor

An opportunity exists for one or more suppliers to become partners in developing this new community.

RailMarketplace Vision

- Represent all industry participants
- Provide a fair return to shareholders
- Deliver superior value to members



Benefits to Strategic Investors
• Offer a unique service in marketplace (i.e., own inventory visibility) • Influence future direction of the community - ensuring suppliers continue to benefit • Be the first to gain from process and supply chain improvements • Partake in equity upside of new company

Airline industry example

Similar exchanges and value-added providers have been formed in the aviation industry.

AirLiance	Cordieum
• Materials management service that provides access to high quality, traceable new and used after-market parts • Services offered to integrate entire supply chain include: – Material sales – Sourcing for products not in stock – Repair management services – Parts exchange – Parts kitting • Founding group of airlines include: – Air Canada – United Airlines – Lufthansa Technik	• B2B exchange jointly owned by buyers and sellers • Services offered to integrate entire supply chain include: – Inventory search and ordering – Planning and collaboration tools – Maintenance data management – Value added financial and logistics services – RFQ/P and procurement tools • Founding group of 9 global airlines and 3 global suppliers • Founding airlines include: – British Airways – American Airlines – Delta Airlines • Founding suppliers include: – BF Goodrich – Honeywell – United Technologies • Total of 17 airline participants

- Processed more than $70 million in surplus parts since 1998

- Airlines represent $45 billion in annual purchases
- Initial participants represent 17% of aviation industry revenues

Next steps

Now is the time to get involved with RailMarketplace.

- **Provide feedback on products and services**
  - ***Start with a clean sheet of paper***
  - ***What could RailMarketplace do to substantially increase your company's margins and shareholder value?***
- **Register as a member**
- **Use the services**
- **Become a strategic investor**

REPORT OF THE COMMITTEE ON NEW TECHNOLOGIES

MONDAY, SEPTEMBER 24, 2001 3:30 P.M.

Bruce Butts, Chairman
Manager - Corporate Accounts
National Electric Carbon Products, Inc.
Scottsdale, AZ

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

COMMITTEE MEMBERS

A. Mercier	Director	Alstom	Montreal, PQ
J. O'Kelly III	Director Engineering	Alstom	Rochester, NY
A. Oser	Product Development	GE Transp.	Erie, PA
R. Parent	Sr. Mech. Rel. Spec.	CN/IC Rail	Montreal, PQ
C. Prudian	Technical Prop. Manager	Electro Motive Div.	LaGrange, IL
B. Queen	Equipment Supvr.	BNSF Railway	Topeka, KS
D. Robey	Director-Mech. Engineering	CSX Transp.	Jacksonville, FL

PERSONAL HISTORY

Bruce M. Butts

Bruce M. Butts received his B.S. degree from the University of Wisconsin in 1970. His background experience includes DC motors, drives and drive systems and industrial pump design.

Bruce joined National Electric Carbon Products, Inc. in 1988. His current position is Manager, Corporate Accounts. He and Corinne, who have been married for 28 years, live in Scottsdale, Arizona.

I. Performance and Economic Aspects Of Various Environmentally Friendly Coatings For Rolling Rail Equipment

Prepared by: Max Winkler, Sigma Coatings

Introductions

There is very little discussion about the fact that rail equipment has to be protected. Carbon steel will corrode in almost any environment and not only is rusted steel unsightly, but it will also affect the suitability of the equipment as well as in many cases the safety of personnel and people in the surrounding area.

Depending on the use of the equipment, the coating or coating system chosen for protection against corrosion may also need to have some decorative or embellishment function. There is for instance a difference in the systems used for the exterior of a box car and a locomotive. In the case of the box car, an impact and corrosion resistant system is the most desirable. For the locomotive, apart from corrosion resistance, gloss and color retention will also play an important role.

Knowing the function and the expectations of the system required, many different generic and specific coatings and/or systems (primers and finishes) would be feasible; but other factors play an important role as well. Aspects such as safety, air pollution and cost are becoming at least as important.

A summary of the factors involving a choice of coating materials is presented in Figure 1.

Health/Safety

Much attention is paid nowadays to the development of coating materials with the least impact on health and safety. Nevertheless, it is essential that the corresponding material safety sheets (MSDS) are studied and measurements taken to avoid inhaling vapors and spray mist as well as skin contact. Even most waterborne coatings contain additives that can have a negative effect on the skin. Therefore, sprayers should always wear the required protective gear. Whattever the type of coating, HAP (hazardous air pollutant) reduction will become an important issue now that the EPA is preparing regulations (MACT = maximum achievable control techniques) for the HAP emission in the rail industry under the category miscellaneous metal parts. Most HAP's are VOC's (volatile organic compounds), but not all VOC's are HAP's.

Air Pollution

The coating industry has been able to reduce the amount of solvents in almost all coatings. Federal regulations dictate the minimum requirements, but local regulations are much more restrictive. Many car repair shops need to show the EPA that they are steadily improving their standards to get their permits renewed. Hardly any low solids coatings are around anymore.

Cost of Application

To increase productivity, the need for fewer layers of coatings to get the same performance is obvious. This in turn has triggered the concept of direct-to-metal (DTM) coatings, which act simultaneously as primer and as finish coats. However, trying to concentrate all properties of primer (optimum adhesion and corrosion resistance) and finish (optimum weatherability for exterior finishes) into one product, a one layer coating, is quite a challenge. In most cases a compromise has to be accepted. Because the corrosion protection of the equipment is still the most important property, gloss retention and color stability may be sacrificed. Most of the DTM exterior coatings on the market today are based on epoxy resins that are optimal in adhesion and corrosion resistance, but lack long-term gloss and color retention.

Cost of Material

Often the choice of material is based on the cost per gallon instead of the cost per square foot in the required film thickness. Higher solids coatings are in general more expensive than lower solids, because most solvents are still cheaper than most resins. Moreover other properties, such as faster drying/curing time and ease of application may completely compensate any extra cost spent on the coating material.

Cost of Hazardous Waste

Specialized companies, which are licensed by the EPA, must be used to haul hazardous waste. The costs are often substantial and the choice of coating material as well as the most efficient and economical packaging can play a role. Waterbone, single pack emulsion coatings in recyclable or throwaway plastic containers are attractive in this respect. For all materials the local regulations have to be followed carefully, because the fines for violating those laws are hefty.

Protection

Most of this paper will be dedicated to explaining and discussing the mechanisms by which coatings protect a metal surface. After World War II, the coating industry started to change from trial and error to a scientific approach. Not only a range of new resins became available, but also the equipment used to manufacture, test and apply coatings was greatly improved. The Clean Air Act certainly had a great influence on the push towards higher solids and wareborne coatings.

Appearance

Although protection against the corrosion of metallic substrates is the most important function of coatings in general, the color and gloss (or specified lower gloss) are still important in many cases. For rolling equipment, the colors and logos are identifying the equipment owners and a good-looking car or locomotive can contribute to the positive image of the company. To prevent change in color and gloss, the finish has to be resistant to UV light, rain and big temperature differences. The choices of resins and color pigments to optimize these properties are relatively few. Aliphatic polyurethanes are among the best UV resistant resins and are therefore extensively used on locomotives where color, gloss and easy cleaning are essential.

Types of Coatings. Composition and Film Forming

Coatings are commonly composed of:

1. one or more resins (monomers, oligomers, polymers). In two-component coatings, the curing agent or hardener will also contain a resinous material;
2. Pigments (for corrosion protection, color or reinforcement);
3. Solvents (organic or water); and
4. Additives (dispersing aids, anti-settling, flow, etc.).

The enormous number of different raw materials available in each category explains why there are so many different coatings. Even within the same generic group, differences can be very big. The resin(s) determine the generic type and name of the coating. Of course, all ingredients have a function. See Figure 2.

One of the classifications used in the coating industry is based on the distinction between a resin solution (mostly clear when not pigmented) and a resin emulsion (mostly milky). Although there are resins that are soluble in water, that category can be neglected for our purpose. Most resins are dissolved in organic solvents or are emulsified in water when they are used in coatings, but the development of solvent-free, liquid resins made it possible to produce solvent-free two-component coatings. Although not complete, the table, in Figure 3, shows that many resins originally available only in solvent borne form are now also available in an emulsified and solvent free variety.

Thermoplastic materials become soft when heated above a temperature specific for the polymer. Thermosetting materials cure due to crosslinking. In most cases, coatings based on those polymers consist of two-components that react with each other to form a network. Those coatings will resist softening at higher temperatures and are not soluble anymore after the reaction is completed, although they still may swell and soften. Coatings based on thermoplastics, linear polymers will dry only due to solvent evaporation and can be redissolved, (See Figure 4).

Both polymer systems have their advantages and disadvantages. The thermoplastic resins remain more flexible on aging. But the solids content of coatings based on these thermoplastic resins will be lower than that of many thermosetting materials.

Solvent-borne, thermosetting coatings are drying and curing simultaneously. It is essential that those two processes be controlled, because a too fast drying will hamper the active sites of the polymers to find and react to each other, while too slow drying would lead to solvent retention. Of the two extremes, the too slow drying is definitely worse. The graph (Figure 5) indicates the drying (solvent evaporation) and curing (crosslinking) stages relative to each other.

It is therefore necessary to use only the recommended thinner and not more than needed for a good application. The higher the solids content of the coating, the less residual stress will be built into the curing coating.

A drawback of high solids and certainly of solvent-free coatings is the shorter pot life after mixing of the components. The large amount of solvents in low solids coatings act as a "spacer" between the reactants and prevent a fast increase in the growing polymer mass. High solids coatings have a higher concentration of the reacting molecules. The reaction (polymerization) is therefore faster and often exothermic enough to accelerate the reaction even more.

To further reduce the use of solvents and thinners for the application of coatings, the use of heat to lower the viscosity of coatings and finishes is often feasible and recommended. Resins drop quickly in viscosity by increase of the temperature. This effect is of course stronger in high solids and solvent-free coatings than in low solids coatings. The pot life or workable time becomes further reduced, because the heat will increase the speed of the polymerization. For that reason, the plural component airless spray equipment was developed where the heated components are kept separated and pumped in the required ratio to a stationary mixer close to the spray gun. The "whip" beyond the mixing unit can be flushed with solvents as soon as spraying stops to prevent clogging of the gun.

It is expected that the plural component spray equipment will gain more acceptance in spite of its high price, because the amount of "hazardous" waste is greatly reduced. The components can be supplied in large tote tanks or drums that can be returned for cleaning, while the arduous and time consuming hand mixing and emptying of pails is avoided.

Substrate Cleanliness

The adhesion of coatings to the substrate they need to protect is of utmost importance. It is one of those aspects of coating application that creates a lot of discussion. The degree of cleanliness, the method of cleaning, the depth of the blast profile plays a role, (Figure 6).

Many of the premature failures of coating films and the subsequent corrosion are due to insufficient attention to the surface preparation. Often a lower standard of cleanliness is accepted because of time and cost restraints. But such a decision is going to call for a payback sooner or later. For new steel a "comercial blast" (SSPC-SP6) is the minimum standard and then only for surfaces not exposed to aggressive environments. For such conditions a "near-white blast" (SSPC-SP10) is the minimum. For old and in particular for heavily corroded and pitted steel, extra care has to be taken to remove all soluble salts from the pittings, because any soluble residue will create osmosis with subsequent blistering of the coating system.

Wetting and Adhesion

In the last 20 years, the coating industry has become aware of the importance of the wetting of the substrate by coatings in order to get optimum adhesion and therefore protection. Everything between the wet coating and the substrate will interfere with that adhesion. Although dry abrasive blasting may seemingly clean the steel surface, there can still be a lot of fine abrasive dust left in the profile that can prevent the wet coating from reaching the actual steel. Vacuum cleaning after dry blasting is good practice.

Good wetting is a matter of cleanliness, interfacial surface tension and viscosity. Fig. 7 shows the values of the *surface tension* of several resins (used in coatings) and substrates. The coating should not have a surface tension higher than that of the substrate to be coated. A liquid with a lower surface tension than the substrate will wet that substrate properly.

Wetting and adhesion can be improved or hampered by other factors than only interfacial surface tension. If the viscosity is very high, the material may not flow enough. A higher coating temperature may help. Thixotropy, which is the ability of the coating to become thin at the moment of application but thicken when it reaches the substrate, counteracts the flow to a certain extent. Fig. 8 illustrates these factors.

Fortunately, for a given coating, the wetting can be modified with additives that change the surface tension. Those substrate-wetting agents let the coating flow better but are very specific and a lot of experimenting to find the correct type and amount is necessary. Moreover they may affect other properties negatively especially when too much is used.

Corrosion Resistance

Although substrate cleanliness, wetting and adhesion are of prime importance for the protection of metals, there is still a difference between the generic types of coatings. Two of the laboratory test methods to check the corrosion resistance are the salt fog (ASTM B117) and the Prohesion (ASTM D5894) test. It is difficult to generalize these types of comparison tests, but Figure 9 gives an indication based on previous experiments.

These results show that the waterbone systems are doing well, especially when applied in two coats. After many years of lab work and field trials, waterbone coatings and systems are gaining territory. Especially the one-pack vinyl and acrylic emulsion coatings are becoming popular, because of their fast drying and easy application. They are also interesting from the viewpoint of mechanical properties and color stability.

There are, however, also reasons why waterborne coatings have not taken over the market yet. Practically all high quality acrylic emulsion coatings still contain some co-solvents. The VOC (corrected for water) is therefore around 1.0 lb./gal. The volume of solids of the same coating is around 40% and the cost per square feet is relatively high in comparison to solvent-borne epoxy/polyurethane systems. Figure 10 puts most of the properties together.

Summary

It was the intention of this paper to give you some insight into the factors and properties that affect the performance of coatings for the exterior of rail equipment and the trend that is expected to continue in the next couple of years. High solids systems will share the market with more and more waterborne coatings. The development of waterborne epoxy primers and waterborne polyurethane finishes will continue, but the cost prices will be close to 50% more than that of the solvent borne epoxy/ polyurethane systems. Savings can be achieved in other parts of the operation such as shorter curing times, less hazardous waste and reduced handling. For locomotives, the state-of-the-art coatings are still solvent borne epoxy primers top coated with solvent borne polyurethanes. The solid contents of both have been raised to meet all the VOC requirements. They have a high gloss and a hard finish, are easy to clean and keep their initial color very well. Unless the price comes down or the regulations get much tougher, the waterborne equivalents have to wait a little while. In the DTM arena, there are some "lights on the horizon". Polyurea, polyester/epoxies and "non-isocyanate polyurethanes" are candidates which have the attention of the resin and coating formulators.

Factor	Time/Material	Effect
Health/Safety	During Application	HAP/Skin Irritation
Air Pollution	During Application	VOC/Solvents
Cost	Of Application	Man Hours
Cost	Coating Material	Price per Sq. Ft.
Cost	Hazardous Waste	Hauling
Protection	Type/Number of Layers	Anti-Corrosion
Appearance	Finish Coat(s)	Color/Gloss

Figure 1

Ingredient	Function
Resin	Adhesion to substrate/film forming
Resin	Binding of pigment particles/glue
Pigment	Anticorrosive pigments in primer
Pigment	For color, especially in finish coat
Pigment	Reinforcement (flakes, fibers, fillers)
Solvent	Liquefying for application and flow
Solvent	Has to leave film. Induces stress
Additives	For special effects/properties

Figure 2

	Solvent borne	Waterborne/Emulsion	Solvent Free	Polymer
Alkyd Enamels	X	X	-----------	Thermosetting
Acrylic Enamels	X	X	-----------	Thermoplastic
Epoxy/Amine	X	X	X	Thermosetting
Polyurethane	X	X	X	Thermosetting
Acrylic/Epoxy	X	X	-----------	Thermosetting
Polyester/Epoxy	X	------------	X	Thermosetting
Polyurea	----------	------------	X	Thermosetting

Figure 3

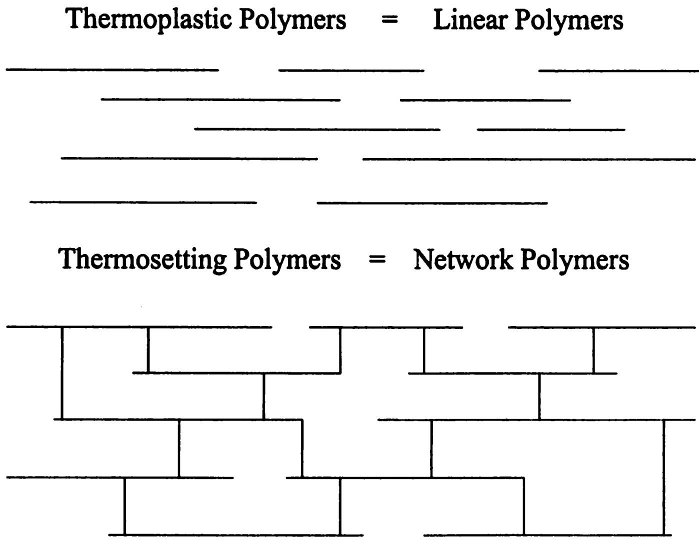
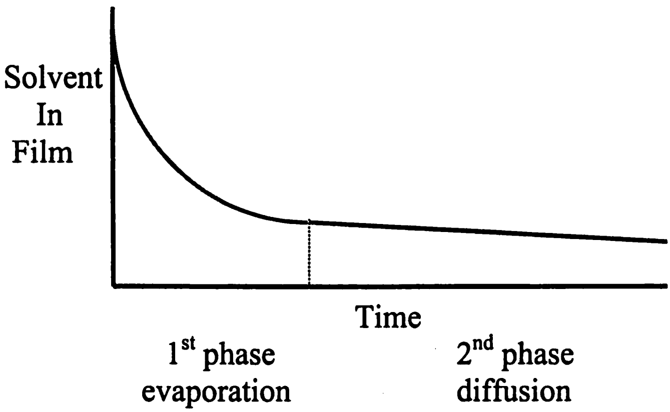


Figure 4



Speed of crosslinking > than 1^{st} phase evaporation results in more solvent retention and shrinkage.

Speed of crosslinking < than 1^{st} phase evaporation gives less shrinkage and less solvent retention.

Figure 5

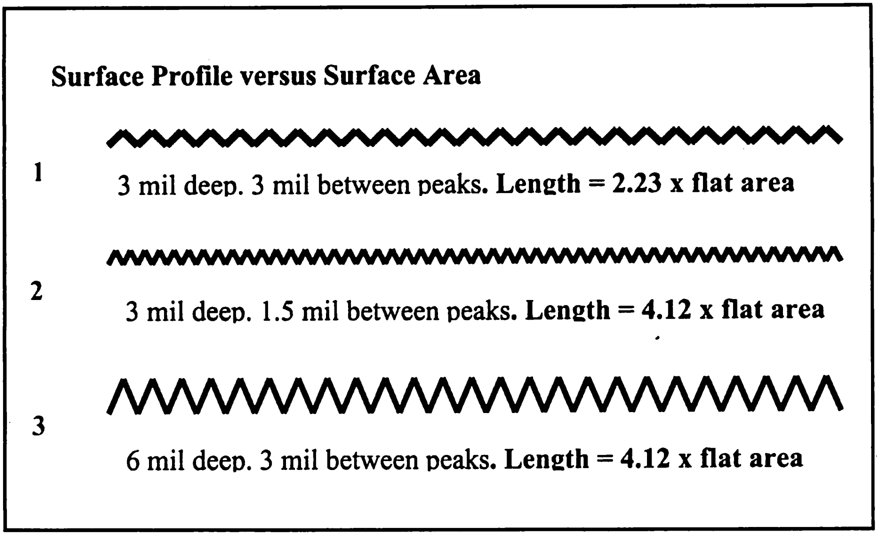
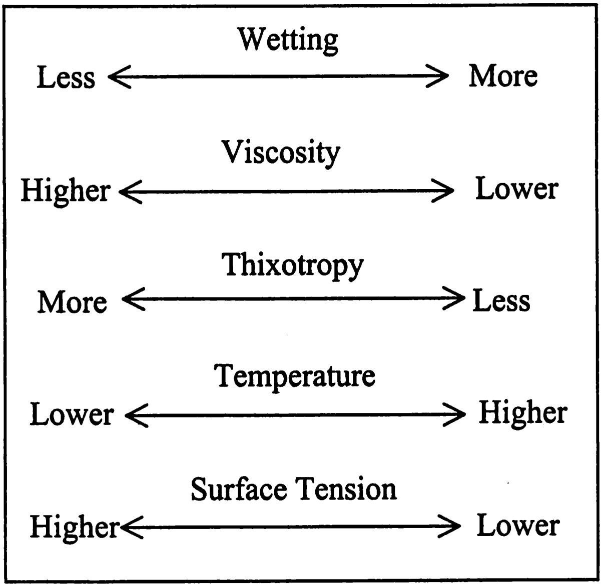


Figure 6

Substrates	mN/m	Resins	mN/m	Solvents	MN/m
Glass	73	Epoxy	45-60	Water	73
Phosphated Steel	45	Alkyd	33-60	Glycol	49
PVC	40	Polyurethane	40-48	Glycolethers	32
Tin plated Steel	35	Polyacrylate	32-41	Xylene	30
Untreated Aluminum	34	Vinyl	35-38	Mineral Spirit	27
Untreated Steel	29			MEK	25
Teflon	19			Butylacetate	25
				Butanol	23
				Hexane	18

Surface Tension of Several Materials
Figure 7



Factors Affecting Substrate Wetting
Figure 8

Coating System	Saltspray/Prohesion
Epoxy DTM	+++
Epoxy/Polyurethane	++++
Alkyd Primer + Enamel	++
Waterborne Acrylic/Epoxy	+++
Waterborne Vinyl Primer/Waterborne Acrylic	++++
Waterborne Acrylic DTM	+++
Waterborne Polyurethane	++
Waterborne Epoxy/Waterborne Polyurethane	++++

Comparison of Corrosion Resistance
Figure 9

	DTM Epoxy Solvent	Epoxy/Polyurethane Solvent borne	Acrylic Emulsion Waterborne (2)	Epoxy/Polyurethane Waterborne (##)
Corrosion	***	****	****	****
Adhesion	****	****	****	****
Flexibility	***	***	****	***
Hardness	***	****	**	****
Thermoplasticity#	***	****	**	****
Impact Resistance	***	***	****	**
Initial Gloss	****	****	***	****
Gloss Retention	*	****	***	****
Color Retention	*	****	****	****
Chemical	**	****	***	****
Cost index/sq. ft.	100	130	150	200

 # More starts means less thermoplasticity ## Development not finished

Figure 10

II. Non-destructive Testing: Crack Detection Technology - EMFaCIS

By James F. O'Kelly III, Director of Engineering, U.S. AlstomTransport, Service North America

Introduction

Figure 1 illustrates the type of problem we would all like to avoid.

Non-destructive testing (NDT) and inspection of components is a cornerstone of our current maintenance and overhaul practices. Visual, liquid dye penetrant, and magnetic particle inspections (MPI) are the most common forms of NDT employed in maintenance and backshops. In special cases, ultrasonic and radiographic inspection are also utilized.

It is the purpose of this paper to introduce another form of NDT testing, namely Eddy current inspection. Eddy currrent inspection, used widely in the Oil & Gas industry, is not, at this time, a commonly accepted practice for the rail industry in North America. Eddy current offers several advantages over existing technologies, including: inspection accuracy, repeatability, data recording and analysis, ease of use, and decreased inspection time.

Non-destructive testing (NDT): technical overview

NDT is the examination of materials and components in a way that allows materials to be examined without changing or destroying their usefulness. Aircraft, motor vehicles, pipelines, bridges, trains, power stations, refineries and oil platforms are all inspected using NDT techniques. The application of NDT allows monitoring of the integrity of the item or structure throughout its design life.

NDT is used typically for the following reasons: accident prevention, cost reduction, and improved product reliability. Preventing a road failure of equipment reduces the probability of an accident occurring, reduces cost by avoiding unscheduled repairs, and improves product reliability by keeping the asset in service condition.

The NDT method employed depends on several factors including: assumed defect size, material properties, skill level and experience of available inspection personnel, allowable inspection budget, industry standards, accepted practices, and the function of the component to be inspected.

Table 1 presents a comparison of the most common NDT techniques.

The most commonly used NDT techniques, visual, dye penetrant, and MPI, share some common disadvantages that reduce the overall effectiveness of the techniques:

1. Undetected human variability caused by either boredom, or lack of skill, leads to less than ideal test results.
2. All of the techniques have

limited possibilities of detection along with high probabilities of false positives.

3. None of the techniques are able to determine the defect depth.
4. All of the techniques require manual data recording.
5. All of the techniques require extensive surface preparation.
6. All of the techniques are labor intensive - clean, inspect, re-coat.

The limitations of common NDT techniques have long-term impacts on vehicle maintenance, component overhaul, and fleet reliability. For example, accurate data are difficult to collect and analyse. As such, we have a poor historical record of defect origination and growth. Given the limited probability of detection, either the frequency of inspections must be increased or else additional maintenance or overhaul activities must be undertaken in order to reduce the overall defect rate (better safe than sorry. . .). Finally, the required surface preparation and coating reapplication limit the opportunities for inspection due to cost and component availability.

Eddy current technology addresses the limitations of the commonly accepted NDT techniques.

Eddy Current Inspection – History and Description

According to the Center for Nondestructive Evaluation, Iowa State University, Ames: "Eddy current testing has its origins with Michael Faraday's discovery of electromagnetic induction in 1831. In 1879 Hughes recorded changes in the properties of a coil when placed in contact with metals of different conductivity and permeability, but it was not until the Second World War that these effects were put to practical use for testing materials."

Eddy current testing is an electromagnetic technique used on conductive materials. Eddy current will detect both surface and near surface defects. In addition, changes in material properties secondary to corrosion or material variation (i.e. hardening) can also be detected.

In similar fashion to UT testing, Eddy current testing employs probes to evaluate the specimen under examination. An energized coil (probe) is brought near to the surface of a conductive metal component. The AC current flowing in the coil induces eddy currents in the surface of the specimen. The magnitude and phase of the eddy currents will affect the loading of the coil as well as the impedance of the coil.

When the eddy currents in the specimen are distorted by the presence of the flaws or material variations, the loading and thus the impedance in the coil is altered.

Figure 2 illustrates the affect a defect would have on the induced surface eddy currents.

The current path extending

below the defect causes a disturbance known as an "absolute". The current path changes around the ends of the defect cause a "current perturbation (cp)". By utilizing a computer to analyse the return signals, the size and depth of the defect can be determined. Figure 3 illustrates the 2-D information gathered from a single probe pass. The top tracing indicates the depth of the defect. The middle tracing indicates the length of the defect, and the bottom tracing monitors "lift-off". With multiple sensors mounted within one probe unit it is also possible to obtain a 3-D inverted image of the defects as illustrated in Figure 4. Figure 4 is taken from the inspection of an axle using the Axle probe shown in Figure 5.

It is important to point out that the probe does not have to be in contact with the material in order to detect flaws. Depending on the material being tested, lift-offs, or the distance between the probe and the surface, can be as great as 10 mm. As the probe does not have to contact the actual metal surface, it is not necessary to remove surface coatings prior to testing.

Also, probes can be designed to fit any geometry from long curved sections to the interior of pipes. Figures 5, 6, 7 and 8 depict several different styles of probes.

The Eddy Current EMA (electromagnetic array) technology currently utilized by the Alstom EMFaCIS system has been used in the oil and gas industry, on North Sea oil platforms, since 1989. The following is a brief history of the technology:

- 1991 Electro Magnetic Array (EMA) technology is patented.
- 1991 ELF Aquitaine and SHELL introduce EMA for the inspection of the offshore platforms in parallel with MPI.
- 1994 Probability of Detection (POD) trials comparing EMA & MPI.
- 1994 EMA is applied by all major sub-sea engineering contractors as an industry standard for fatigue crack detection of North Sea oil rigs.
- 1997 NASA inspects the Shuttle launchers fuel tanks with EMA.
- POD final results are published by Shell; EMA is then specified for all their capital assets in the North Sea.
- 2000 EMA accreditation for use in the UK rail industry completed in March. Alstom EMFaCIS launched a new inspection service business.
- 2001 Rail Engineering Ecellence for the Year (UK) award for EMFaCIS.
- 2001 EMFaCIS used to inspect running rail in the UK.

Eddy Current Inspection – Alstom EMFaCIS (EMA) vs. MPI

In this section we will compare

the performance of the eddy current inspection system (EMA) with MPI inspections. We will look at three cases. The first case will be a review of testing conducted by Shell - Topside Inspection Project (TIP) - comparing EMA with MPI in the inspection of 50D Steel Tee-Butt specimens. The second case will be the comparison of EMA results with MPI results on the inspection of a cast truck frame. The third case will be a review of an inspection campaign conducted in the UK on failed drawbar components.

Shell TIP Study

The study was conducted in order to determine the probability of defect detection using MPI and EMA technologies. 69 specimens were prepared all containing defects of various sizes:

Crack Population

Range (mm)	Number
0-9	24
9-31	26
32-108	14
109+	5

The samples were inspected by three experienced EMA inspectors and three experienced MPI inspectors. The results are presented in Figure 9.

In all cases the probability of detection was much greater using EMA. In fact, with defects greater than 9mm, the detection probability was greater than 90%. The MPI probability of detection never reached 90%, even with defects larger than 109mm's.

cast truck inspection

In December 2000, we inspected a section of a cast truck frame previously inspected by Wet MPI. The MPI indications were marked on the truck by the MPI inspector. Figure 10 shows one critical section of the cast frame. The area shown in Figure 10 was re-inspected using EMA. A pencil probe was used to inspect the truck section. Figure 11 depicts the EMA inspection in progress.

The EMA inspection found four additional parallel cracks between the wear plate and the MPI indication in the lower right hand section of the truck frame photo.

The circle seen on the left side of the inspection screen indicates a defect has been located.

The test was repeated on a new cast motor mount and again, EMA was able to identify cracks missed by the MPI inspection.

These findings make a case for supplementing MPI, especially in critical areas, with EMA inspections.

UK Drawbar Tailpin Inspection

At one of our facilities in the UK there was a problem with drawbar tailpin fractures. 60 units of 310/312 fleet were suspect and required inspection. The NDT method employed by the shop (MPI) would have required the units to be dismantled to allow access to this component. Dismantling the units would have been costly in terms of both manpower and availability.

It was decided to try and use

the EMA technology in order to inspect the fleet. A probe was designed to meet inspection conditions and the inspections were completed over a period of several weeks without impacting the fleet availability. Several defective units were identified and replaced.

Employing EMA testing allowed for a quick, efficient, in-situ inpection, saving hundreds of man-hours of shop labor. Figure 12 is a photo of a car from the 310/312 fleet.

In all three cases, EMA proved superior to MPI inspections. EMA had a demonstrated higher detection probability, both in controlled tests as well as in actual shop inspections. In addition, EMA led to reduced shop hours by allowing inspection to take place without removing components from the vehicle, and without extensive on-vehicle preparation.

Eddy Current Inspection - Field Gradient Camera vs. Ultrasonic Inspection

NEWT International Limited has a new product called a Pedestrian Rail Inspection System. The system employs a field gradient camera (eddy current technology) to inspect the rails. Figure 13 illustrates the inspection system on a running rail.

The non-contact system, according to NEWT, can inspect rail even through a 4mm deep film of dirt and grease. The results are output on the LCD screen, with defects showing up as color images. The color and direction of the image indicate the severity and orientation of the defect.

NEWT compared the results from UT testing, dye penetrant testing, and field gradient testing for the inspection of rail with numerous transverse rail defects. Figures 13 and 14 present the results from the UT and field gradient test techniques. The dye penetrant testing, while not illustrated, depicted numerous transverse defects.

The UT results, as depicted in Figure 14, did not pick-up the transverse defects. NEWT explains that the UT inspection did not pick up the defects as they were parallel to the surface and did not penetrate the rail at an angle that would be picked up by UT testing.

While perhaps not conclusive, the results indicate some reassessment is in order in terms of UT testing of rail. In the UK, we recently received a contract from RailTrak to inspect rail using EMA instead of UT.

EMFaCIS vs. MPI: Cost Comparison

Previous sections have demonstrated the ability of the EMA to outperform MPI, and perhaps in some cases, UT inspection techniques. Up until this point we have not discussed the cost of EMA inspections in relation to other NDT techniques.

Shell, in a paper presented at the December 1994 "offshore" conference cited several levels of cost savings based on actual North

Sea operations:

- 30-60% savings versus MPI for sub-sea inspections.
- 90-95% savings versus MPI for topside inspections with difficult access.
  - The basis for the savings include several factors including:
  - No need for cleaning and recoating.
  - Low incidence of false positives in comparison with MPI.
  - Less operational support required.

Additional benefits included the ability to repeat inspections as well as the permanent record capability.

Our case cited earlier in this paper saved an estimated 80% of the cost that would have been incurred if the entire fleet had to have been dismantled. Internally, we investigated the potential impact of replacing traditional NDT methods with EMA testing. The investigation addressed several areas of savings, two of which we will discuss for this paper.

The total savings in labor hours, for the two facilities were estimated to be 15% or 1,184 hours per year.

Indirect savings were also estimated. The increase in inspection efficiency should have the impact of reducing unscheduled critical failures. Currently the estimated cost of critical failures for the fleet of 16,000 cars is valued at 1,806,976 USD per year. Reducing the failures by 15%, based on more efficient NDT inspections, would result in additional savings of $271,046 USD per year. The total estimated savings for the combined facilities was over $325,000 USD per year.

Summary of EMFaCIS advantages vs. other NDT techniques

Reduced cost (15 to 95%)

- Reach it - inspect it!
- Reduced NDT preparation time.
- No need to re-coat after procedure.
- Increase vehicle availability.

Higher reliability

- Increased probability of crack

Direct labor savings based on current contractural inspection requirements

Alstom maintenance contracts	Axle inspections per year	Current NDT labor hours	Reduced labor hours	Savings
Northern Line	1,296	1,404	1,081	23%
West Coast	3,972	6,620	5,759	13%
Total	5,268	8,024	6,840	15%

detection.
- Reduced operator variability.

Improve confidence
- Auditable trace available for quality control.
- Improve knowledge on component failure.

Increase safety
- Re-checking of weld repairs.
- Full traceability of component NDT history.

EMFaCIS:
Potential Applications

Locomotive Maintenance shop applications:

Maintainance shop:
- Engine cylinder welds - visual inspection
- Fork rods - visual inspection
- Fuel Tanks
- Weld repairs

Engine overhaul shop:
- Engine block inspection - replace dye penetrant

Wheel shop:
- Wheel and axle inspection

Track & Structure applications:
- Running rail inspection

Summary

Based simply on the potential cost reduction and the increased defect detection rate, eddy current NDT technology should be considered for inclusion into the railroad maintainer's toolbox. We would suggest shops focus on two potential applications:

1) Select a mission critical component currently inspected by either visual or MPI inspection. Substitute EMA inspections for 25% of the visual or MPI inspections and track the results. Reduction in inspection cost and increased asset availability would be the critical evaluation parameters.

2) Select a mission-critical component currently inspected by MPI. Augment 25% of the MPI inspections with EMA inspections. An increase in asset availability would be the critical evaluation parameter.

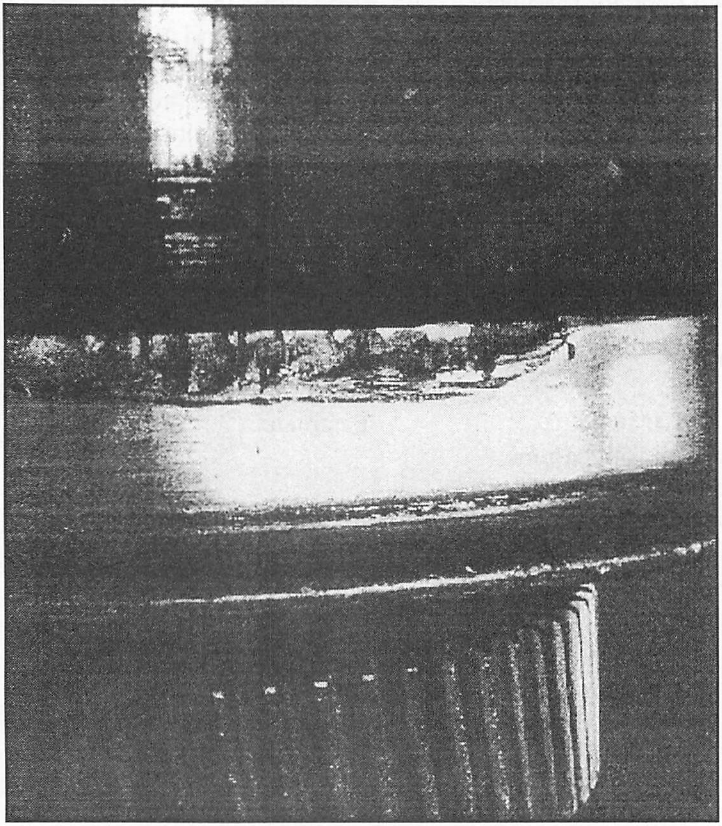


Figure 1: Wheel failure

Common NDT methods:			
Method	Description	Advantage	Disadvantage
Visual	Simple visual inspections. Most commonly used to inspect welds.	▪ Simple, low cost technique.. ▪ No special equipment is required. ▪ Knowledge of what to look for.	▪ Surface preparation required. ▪ Requires an experienced operator, good lighting, and good eyesight. ▪ Limited detection range. ▪ Manual documentation of results. ▪ Subjective results.
Liquid Penetration Inspection	Reveals surface breaking flaws by bleed-out of a colored or fluorescent dye from the flaw.	▪ Simple, low cost. ▪ Minimal instructions are required in order to apply the technique. ▪ Careful cleaning is required. ▪ Can be used on any material.	▪ Surface preparation required prior to testing. ▪ If surface penetrant is not fully removed, misleading indications will result. ▪ Surface must be cleaned following the testing. ▪ Manual documentation. ▪ No depth information.
Magnetic Particle Inspection (MPI)	Magnetic lines of flux will be distorted by surface and near surface material flaws.	▪ Allows for examination of large components. ▪ Commonly used technique.	▪ Only used on ferromagnetic materials. ▪ The material must be cleaned prior to testing. ▪ No depth information. Scratches are identified as flaws. ▪ Low incidence of small defect detection. ▪ Manual defect documentation.
Ultrasonic Inspection (UT)	Uses short wavelength, high-frequency sound waves to detect flaws in material.	▪ Detect both surface and interior flaws.	▪ Requires a skilled technician ▪ Requires surface preparation. ▪ Defect orientation may impact results.

Table 1: Common NDT techniques

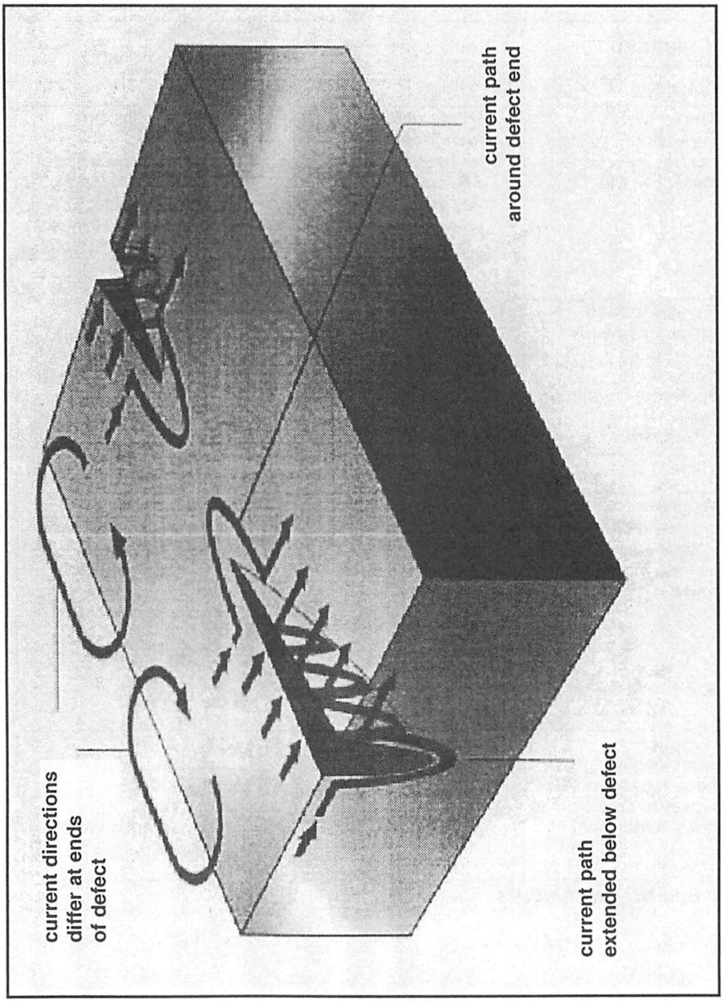


Figure 2: Eddy Current – Flaw detecetion

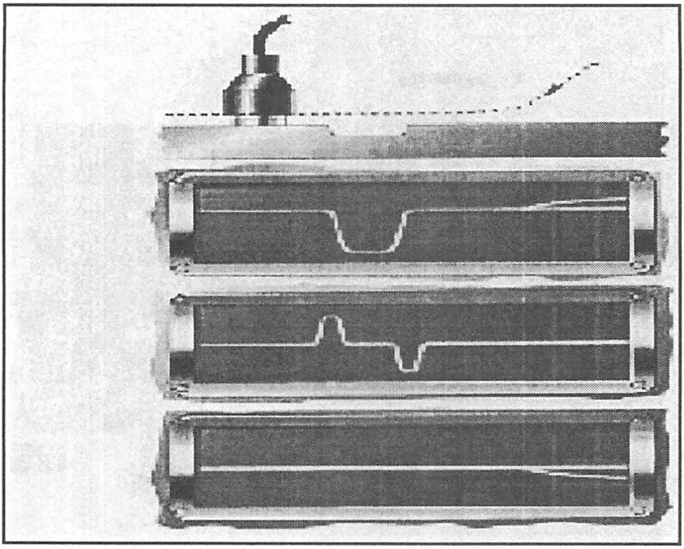


Figure 3: Eddy Current Probe Pass

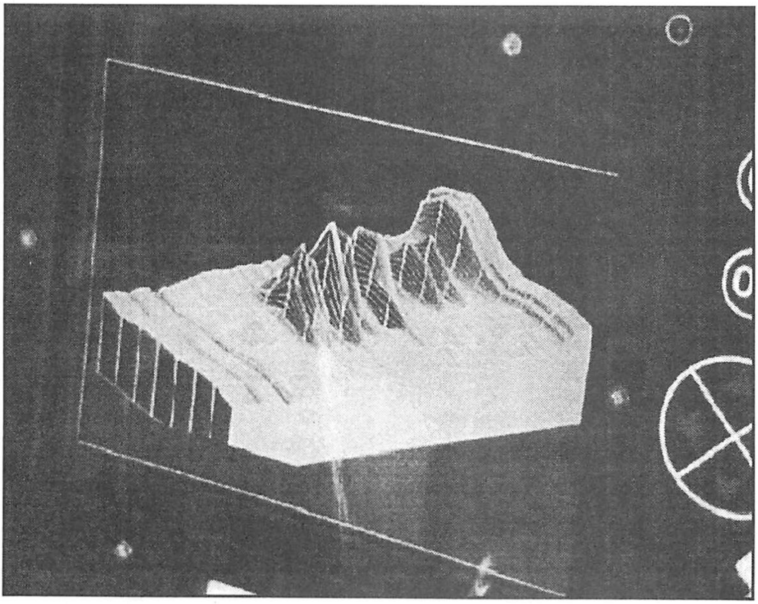


Figure 4: Axle Probe – 3-D image (inverted)

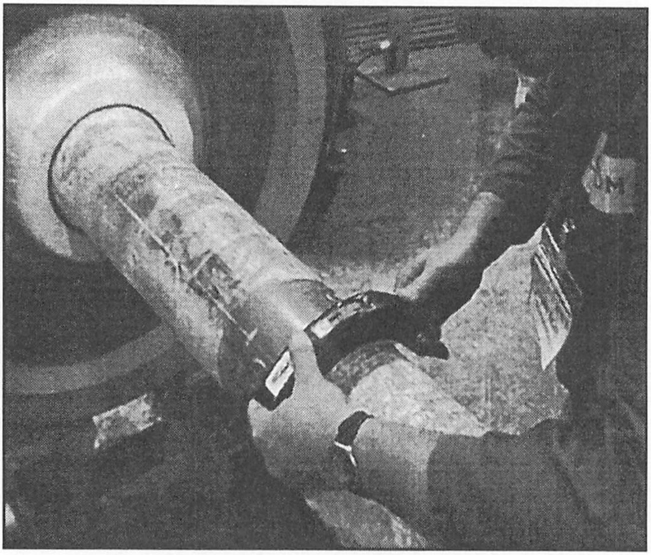


Figure 5: Axle Probe – manual

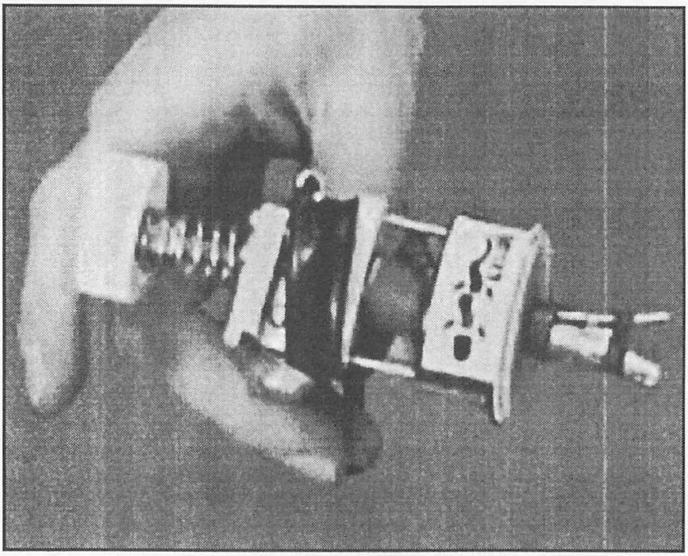


Figure 6: Rotary Hole Probe – Automated

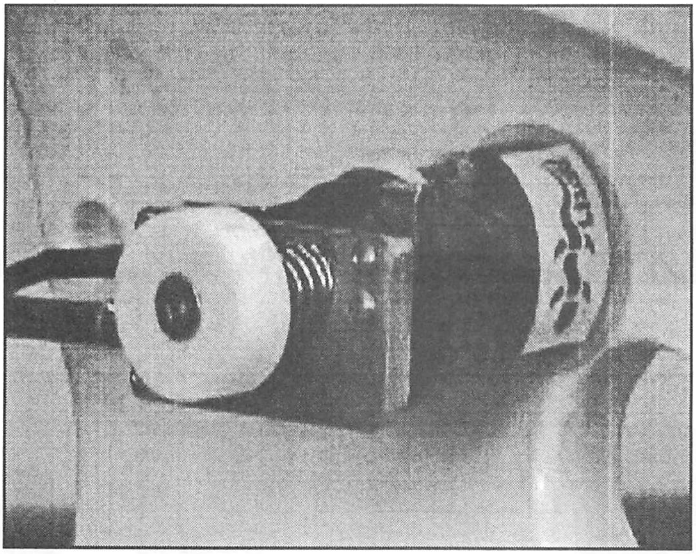


Figure 7: Rotary Hole probe – installed – radial/tangential cracks

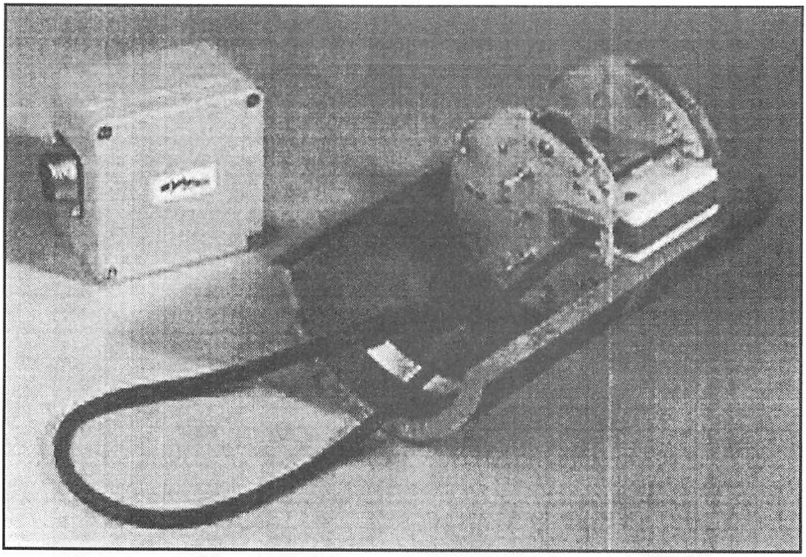


Figure 8: Pipe Probe – 100 meter lead

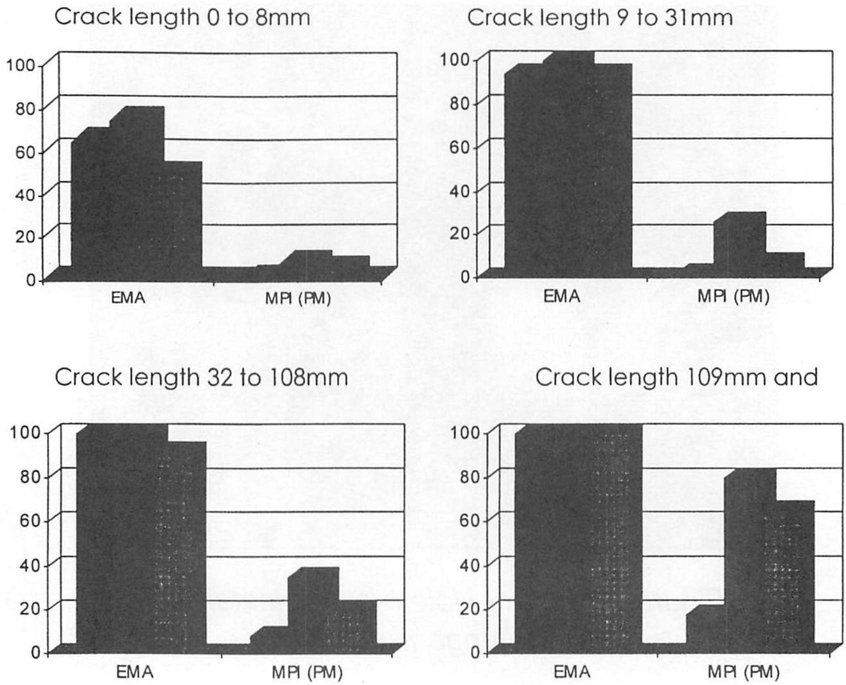


Figure 9: Shell TIP Results

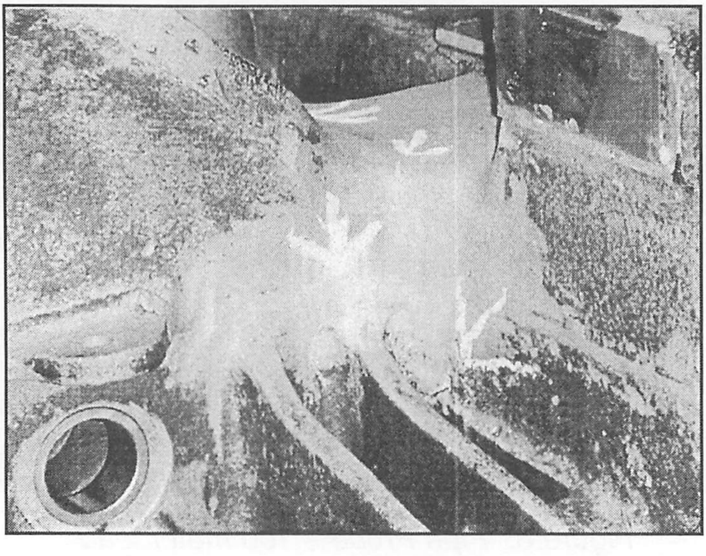


Figure 10: Cast truck MPI indications

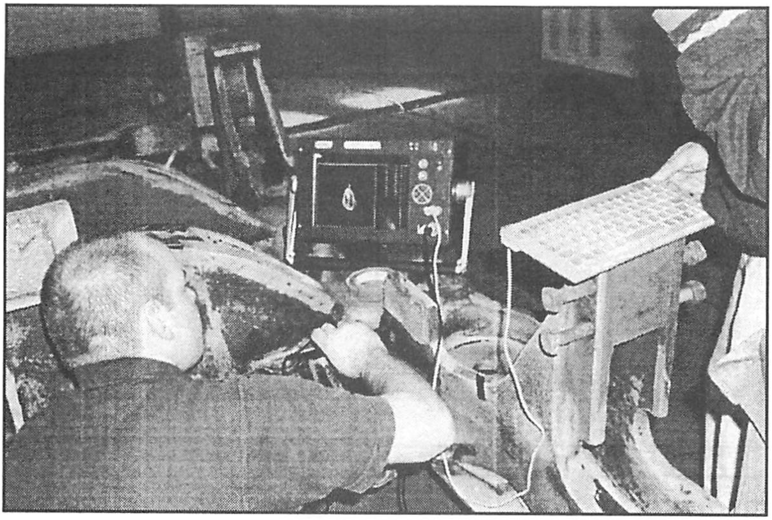


Figure 11: Cast truck – EMA inspection

Figure 12: In-situ EMA inspection

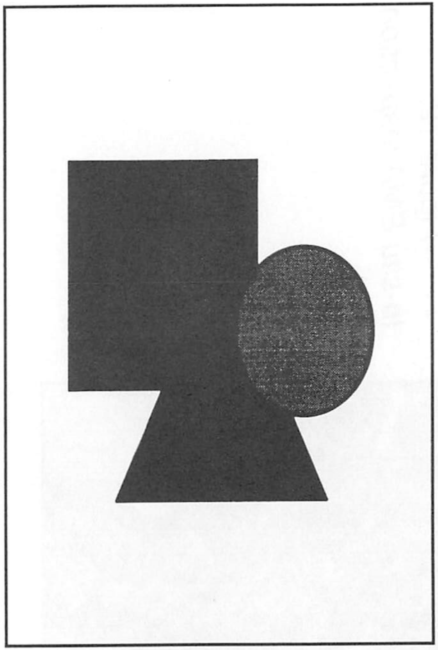


Figure 13: Pedestrian Rail Inspection System

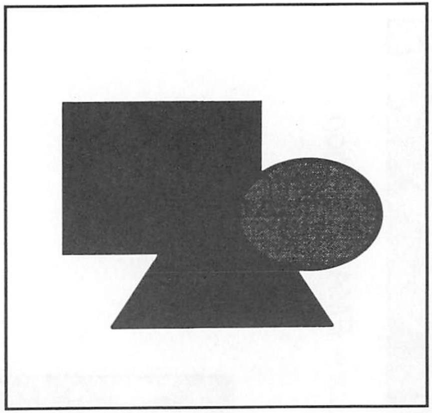


Figure 14: Rail inspection – UT results

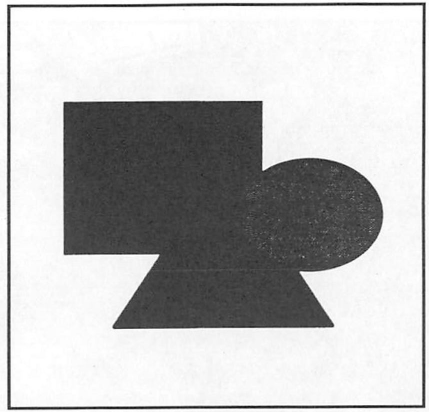


Figure 15: Field Gradient Camera LCD screen

REPORT OF THE COMMITTEE ON DIESEL MECHANICAL MAINTENANCE
TUESDAY, SEPTEMBER 25, 2001
9:00 A.M.

Pre-Convention Presentation:

Wabtec Railway Electronics

Jay Holley, Chairman
Director Mechanical Operations
CSX Transportation

Germantown, MD
May 2001

Vice Chairman
Dennis L. Nott
VP Sales O & M
Motive Power, Inc.

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D. Taylor	Manager Customer Support	G E Transportation System	Erie, PA

THE LMOA DIESEL MECHANICAL

MAINTENANCE COMMITTEE,

Wishes to express their sincere gratitude

to

Wabtec Railway Electronics,

for hosting their pre-convention

presentation at

Germantown, MD

in

May 2001.

PERSONAL HISTORY

Jay J. Holley

Jay J. Holley, Chairman of the LMOA Committee on Diesel Mechanical Maintenance, was born August 4, 1944 in Huntington, W. Va.

Jay began his career with the former Chesapeake and Ohio Railway as a machinist apprentice in October, 1963.

Jay has been most recently appointed director mechanical operations for CSX Transportation. He is responsible for managing the locomotive and car fleet to ensure maximum availability and reliability and a minimum of shop detention time. He is accountable for the impovement of locomotive performance. He is responsible for ensuring proper locomotive flow for scheduled maintenance, program repair and failed locomotives to the maintenance shop in an expeditious manner.

Jay joined the LMOA in February of 1991. He received the LMOA "MVP" Award while on the Diesel Mechanical Committee.

Jay and his wife Candy have been married for 37 years and reside in Jacksonville. They have 2 children, Jeff and Amy.

I. TROUBLESHOOTING ELECTRONIC FUEL INJECTION ON GENERAL ELECTRIC LOCOMOTIVES

Prepared by:
Dennis Taylor
GE Transportation Systems

Listed below are the topic areas that will be covered in this paper:

- What is electronic fuel injection (EFI)?
- What are the major benefits of EFI?
- How does the GE EFI system work?
- Troubleshooting the GE EFI system.

What is electronic fuel injection?

The difference between the EFI system and the mechanical fuel system is the ability of EFI to control fuel delivery timing. A solenoid, which receives electrical signals from the EFI computer, can precisely control and change fuel delivery timing.

Purpose

Sequentially delivers an appropriate amount of fuel, at the appropriate time to each of the cylinders of the diesel engine.

Key Features:

- Variable fuel injection timing
- Higher injection pressure
- Monitors engine parameters
- Reduces mechanical components

Major Benefits of EFI:

- Fuel efficiency
- Reduced emissions
- Reduced maintenance

Sensors within the EFI system send the microcomputer information relative to the engine's operating condition. The microcomputer system software utilizes this information to calculate air-to-fuel ratios and loading rates.

Additionally, there are improved engine diagnostic capabilities. The system monitors and identifies certain engine operating parameters, and, if detected as being outside of normal units, will alert the microcomputer system to reduce engine speed and/or alternator load/excitation.

It provides tighter control of fuel delivery to optimize engine performance.

How does the system work?

The EFI system is broken down into four major subgroups:

- EFI controller
- Diesel engine speed and top dead center sensors
- Systems sensors
- Mechanical components

EFI controller - engine governing unit (EGU)

The main function of the EGU is to control engine speed. It does this by controlling solenoids that are attached <u>individually</u> to the high-pressure fuel pumps located on <u>each</u> cylinder assembly.

Through the control of the solenoids, the EGU can vary not only the fuel timing but also the amount of fuel to be delivered to each cylinder. Figure 1. shows the input and outputs to/from the EGU.

Diesel engine speed and top dead center probe

To calculate correct fuel delivery timing, the EFI controller must know two things:

- Engine position in relation to rotational position of the left cam
- Engine speed (RPM)

Let's look at the magnetic pickups that provide information to the EGU.

Engine position sensor

The engine position sensor is located on the left cam gear cover. It is a magnetic pickup that sends pulses to the EGU. The EGU uses this information to determine the rotational position of the engine.

Crank sensor #1 & #2

Magnetic pickups detect engine speed by means of a tone ring located at the alternator end of the split gear on the crankshaft. The magnetic pickups feed this information to the EFI controller of the EGU.

System sensors

The systems sensors send information to the EGU. The EGU uses this information for a couple of different reasons. Let's look at the system sensors that supply information to the EGU and see the important role that each one of these inputs provides.

- Fuel management sensor inputs

- To calculate the correct air to fuel ratio to be delivered to the cylinders, the fuel injection manifold air pressure (FIMAP) takes a pressure tap off the air intake manifold. The fuel injection manifold air temperature (FIMAT) takes a temperature tap off the air intake manifold.

- Engine protection sensor inputs

- To provide engine protection, the EGU monitors certain engine support parameters:

1. FIOP1 (fuel injection lubricating oil pressure) - This sensor supplies lubricating oil pressure to the EGU to protect the engine from serious damage resulting from low oil pressure. If the EGU receives information that the engine's oil pressure does not support the throttle and load call, it will adjust the engine's speed to match the present oil pressures. If the minimum pressure is not present to run the diesel engine, the EGU will shut down the engines.

2. F1WPS (fuel injection water pressure sensor) - This sensor supplies engine cooling water pressure to the EGU to protect the engine from serious damage resulting from low water pressure. If the EGU receives information that the engine's water pressure does not support the throttle and load call, it will adjust the engine's

speed to match the present water pressures.

3. FIEWT (fuel injection engine water temperature) - This sensor provides engine water temperature information to the EGU and provides hot engine protection as required.

EFI mechanical components

Each cylinder on the 7FDL diesel engine is equipped with a high-pressure fuel pump, high pressure fuel line and an injection nozzle. The injector works like a check valve, releasing the fuel into the combustion chamber when required pressures are reached.

High pressure fuel pump

The high-pressure fuel pump is a solenoid controlled booster pump. The pump receives a steady supply of fuel oil supplied by the locomotive's low-pressure fuel system. It takes the low-pressure fuel (90 psi) and boosts the pressure up to very high pressures. The signals from the EGU control the solenoid located on each individual high-pressure fuel pump. The EGU controls the closing point of the solenoid, which will vary fuel timing, also the duration of the solenoid, which will control the amount of fuel being delivered.

High pressure fuel line

The high-pressure fuel line connects the high-pressure fuel pump to the injection nozzle.

Injection nozzle

The injection nozzle receives the high-pressure fuel from the high-pressure fuel pump. After the fuel in the injection nozzle reaches a predetermined pressure the fuel will be injected directly into the combustion chamber. The combination of high pressure and small orifice size in the tip atomize the fuel for combustion.

Figure 2 shows the high-pressure fuel pump, the high-pressure fuel line and injector used on the 7FDL diesel engine.

The main areas of the troubleshooting features of the GE EFI system consist of the following:

- Built into the design
- Manual troubleshooting guide
- PC tool box
- Weak cylinder detection
- Remote monitoring and diagnostics
- Troubleshooting wizards

Built into the design

Troubleshooting is built through a modular design that includes features such as:

1. A single EGU board
2. Connectors that make for easy replacement of EGU
3. Connectors that allow for easy isolation of problems

It utilizes lessons learned:

- Same interfaces to electronic control as mechanical governor system.

- Ease of transition to EFI from governor because of familiarity.
- Power piston gap, load pot, etc.

- Automatic programmed "POP test" capability.
- Detection of failed sensors for diagnostics.
- PC tool box for Bosch system.

Manual troubleshooting guide:

What to do if:

- Engine will not make load (load pot 98%)
- Engine will not make load (load pot = 100%) but speed control erratic
- Engine cranks but will not start
- Crankcase over-pressure trips
- Engine shutdown - Low Oil Pressure
- Engine shutdown - Low Water Pressure

PC tool box (figures 3,4 and 5)

The use of a laptop computer allows for the following:

- Real time monitoring of operating parameters
- Data recording of real time parameters
- Fault code reading, 50 fault buffer
- Software uploading with few clicks

Weak cylinder detection test (figure 6)

The weak cylinder detection test is a field diagnostic tool developed for Bosch EFI fuel system. It assesses relative performance of cylinders. The weak cylinder detection test is a quantitative approach and drives removal of proper components. It reduces unscheduled time in the shop.

Remote monitoring & diagnostic (figure 7)

In the future, we will have equipment on board the locomotive that will send information back to Erie where troubleshooting experts will analyze data for trends and make proactive recommendations.

Troubleshooting wizards

The wizards allow us to:

- Capture the experts' knowledge

- Standardize the best process across all personnel... immediately

- Integrate critical pieces of decision making information within the process

- Pictures, standards, instructions, videos

- Reduce the subjectivity of the troubleshooting process

- Eliminate the need for the expert to assist the "Troubleshooting team"

The end benefits are:

- Reduced troubleshooting cycle time
- Reduced locomotive unsched-

uled shoppings

- Ensures that the correct components are replaced

"Transferring the expert knowledge base across all personnel"

In summary, more thorough electronic fuel injection troubleshooting results in fewer road failures and unscheduled shoppings; and the reduced troubleshooting cycle means less time in the shop.

The author wishes to express his sincere appreciation and thanks to the GE Transportation Systems' personnel listed below for their contributions:

Vince Dunsworth
Tom Sonney
Rob Cryer
Chris McQuown
Jim Kostrubanic
Mike Cerulo
Adam Oser
Rocco Volpe

Troubleshooting Electronic Fuel Injection

Figure 1 shows the inputs and outputs to the EGU.

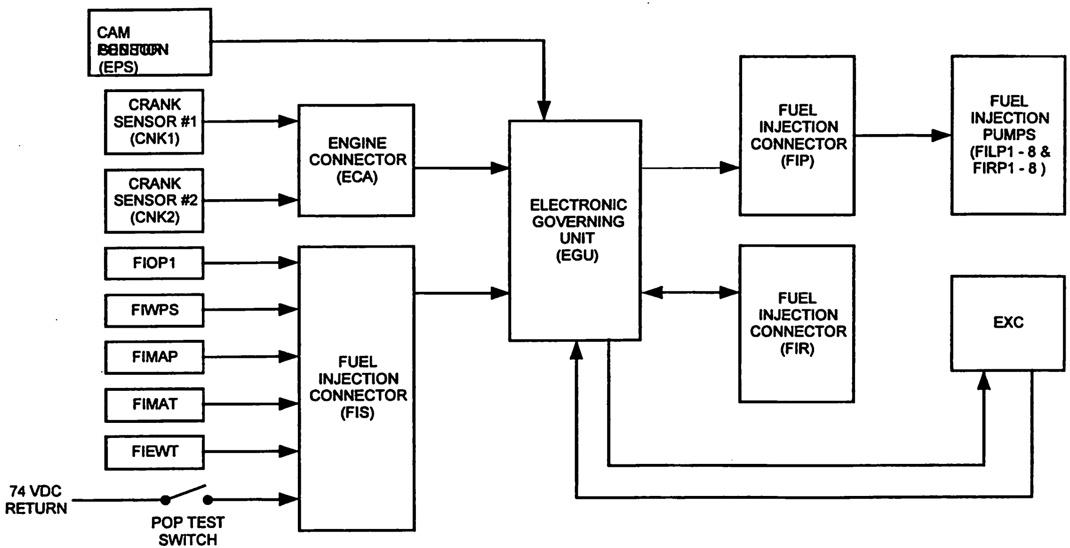


Figure 1

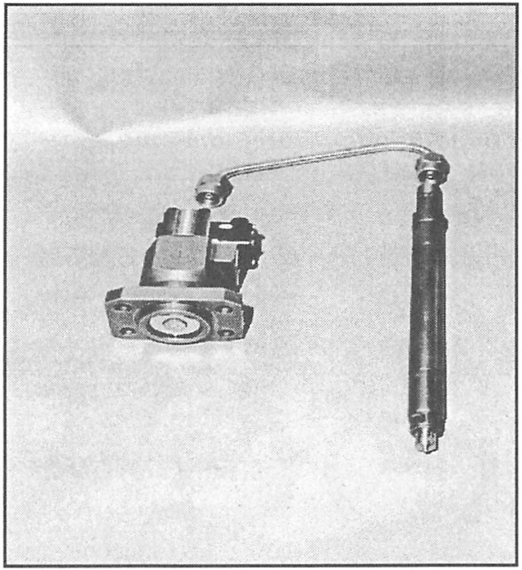


Figure 2
shows the high-pressure fuel pump the high-pressure fuel line and injector used on 7FDL Diesel Engine.

Troubleshooting Electronic Fuel Injection

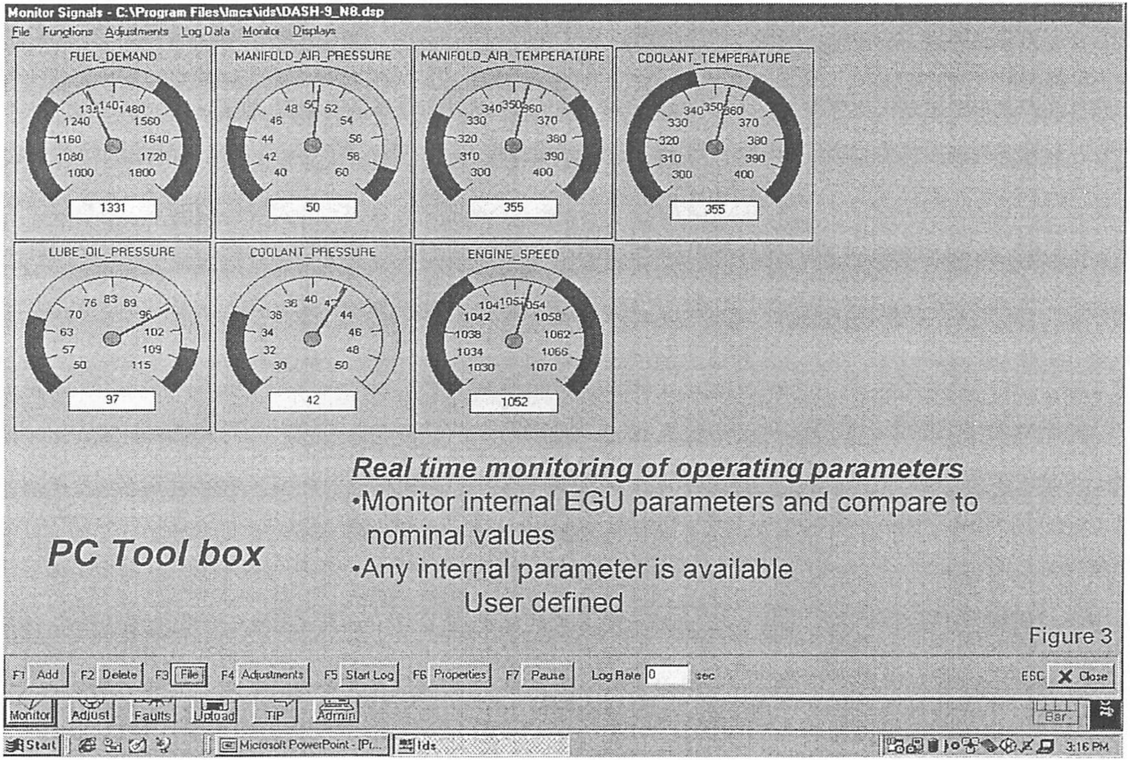
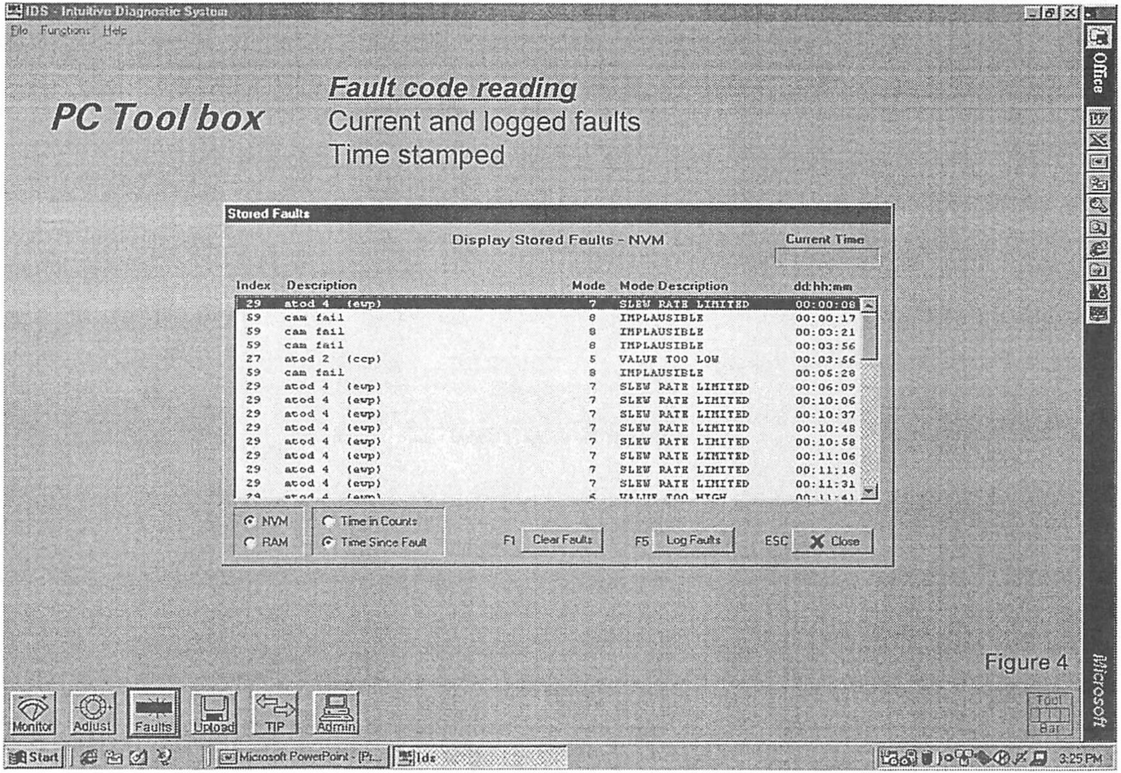
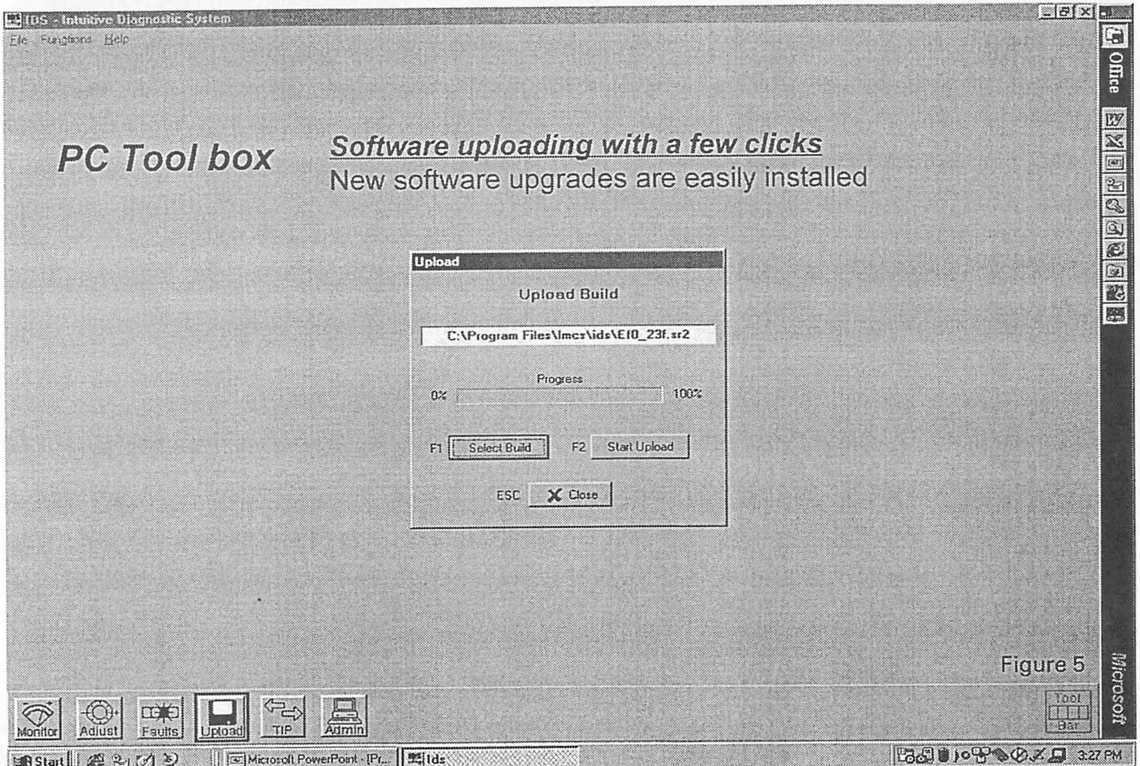


Figure 3

Troubleshooting Electronic Fuel Injection



Troubleshooting Electronic Fuel Injection



Troubleshooting Electronic Fuel Injection

Weak Cylinder Detection Test

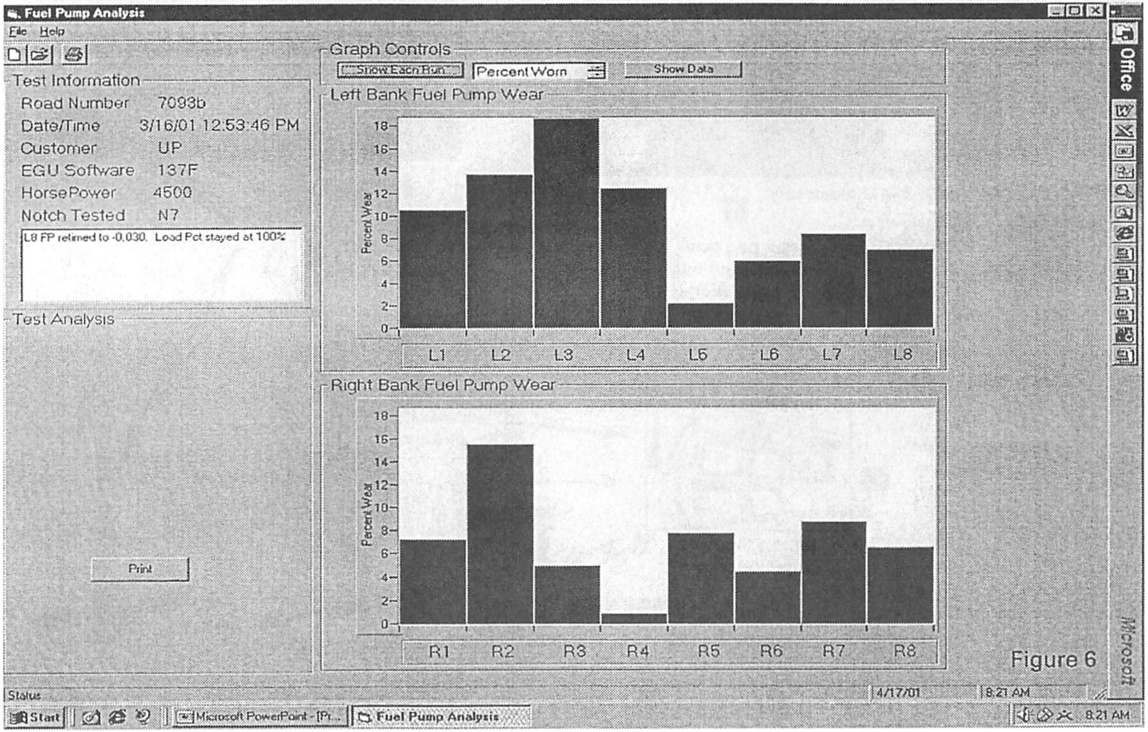
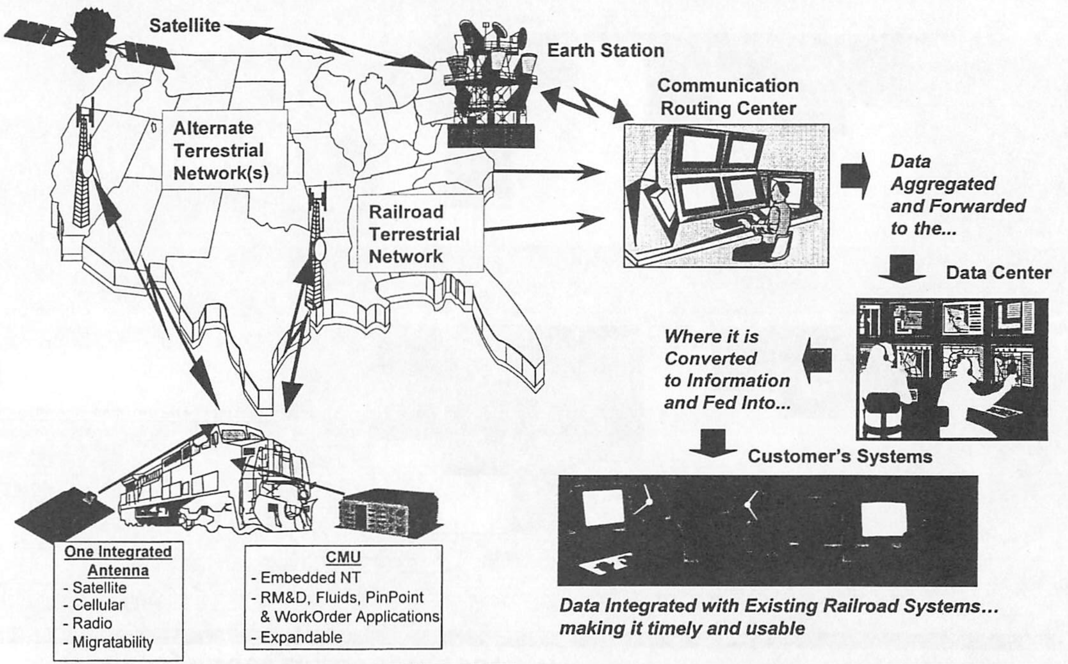


Figure 6

Troubleshooting Electronic Fuel Injection



Expert on Alert^{TM} Leverages the Established I-based Services Infrastructure

Figure 7

II. TROUBLESHOOTING ELECTRONIC FUEL INJECTION - EMDEC ELECTRO-MOTIVE DIVISION, TWO-STROKE ENGINES

Prepared by:
Rich Marchese and, the Electro-Motive Division Customer Training Center

Preface

While the primary focus of this paper is the diagnosis and troubleshooting of EUI fuel injection problems it is very necessary that the reader have a basic understanding of the systems. The following paragraphs will serve to describe and compare the systems. This paper is written based on the two-stroke engine system. While the fuel injection system on the EMD four stroke engine is essentially similar in function, it is sufficiently different so that inclusion in this paper might only serve to confuse. Special thanks to the EMD Customer Training Center and Service Publications departments for their help in preparing the materials that were referenced in the preparation of this paper.

Description

The Electro-Motive diesel engine control (EMDEC) sytem is an electronic engine speed control and fuel management system. It is designed to provide optimal control of critical turbocharged engine functions, which affect fuel economy, smoke, and emissions. The system also provides the capability to protect the engine from serious damage resulting from extreme operating conditions, such as high engine temperature or low oil pressure. These attributes are made possible by the system's ability to sense changes in engine or ambient conditions, and adjust fuel delivery rates and injection timing to compensate.

An additional benefit of the EMDEC system relates to versatility. By altering the software programming within the control modules, the same physical components can be used on different engines, or for different performance ratings.

The major "on engine" sub systems of EMDEC include:

- The engine control module(s) (ECM), Figure 1;
- The electronic unit injectors EUI), Figures 2,3,4 and 5;
- Engine sensors;
- Wiring harness (external, injector, sensor and power).

MUI to EUI comparison

There are similarities between the EMDEC EUI systems and EMD MUI systems, because both are required to perform the same functions:

- Control of engine speeds under varying load conditions,
- Protection of the engine against support system failure,
- Feedback to the control system of engine performance.

Both injection systems use a similar type of primary fuel delivery system, Figure 6. Fuel is pulled from the tank by a primary fuel pump, and passed through two stages of filtration before delivery under low pressure to the unitized fuel injectors. This fuel is used for combustion, as well as lubrication and cooling of the injection equipment. Fuel in excess of injection requirements is returned to the tank.

Both systems use unitized fuel injectors to inject the fuel into the combustion chambers. Although the control portions of the injectors differ, both use a high-pressure pump (*upper portion*) to raise fuel pressure for injection. The camshaft operates the pump plunger through a rocker arm mechanism. Forcing down the injector's plunger creates the pressure necessary to open the needle valve in the tip of the injector, and inject fuel.

The *lower portions of the injectors* are also similar, consisting of spring loaded needle valve, seat, and spray tip. Pressure generated by the pump plunger lifts the needle off its seat to allow fuel to flow through the spray tip. The combination of high pressure and small orifice size in the tip atomize the fuel for combustion.

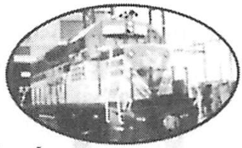
Engine speed signals (throttle position) are relayed to both the EUI and MUI systems as identical governor solenoid commands. However, once the signal reaches the injection system, they are handled in a different manner. The MUI uses a mechanical/electrical system to control engine speed via the governor by use of a mechanical layshaft and rack mechanism, which adjust the fueling rate *pulse width or duration* of all injectors. The EUI system accomplishes this function electronically via a wiring harness to each unit injector, Figure 7.

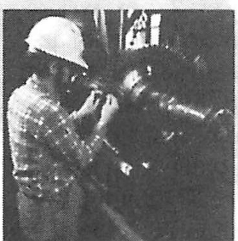
Both systems also provide a feedback of engine performance/condition to the control system. This feedback allows the control system to balance excitation (generator load) against the engine's ability to produce horsepower. While the MUI utilizes a governor driven load regulator to control engine load based on the feedbacks, the EUI system utilizes the main system control computer (EM2000) to accomplish the same goal.

EMDEC system diagnostic and troubleshooting procedures:

Diagnostic tools for EMDEC

The following diagnostic tools are required for troubleshooting, loading software, and injector calibration. The equipment is necessary to access the EMDEC engine control module (ECM's). Also covered are procedures for using the PC reader program with a portable computer (laptop), the annunciator panel for applications with a one-way serial link, and the integrated cab electronics (ICE) or functionally integrated railroad electronics (FIRE) display for applications equipped with a two-way serial link. Note that the use of a diagnostic data reader (DDR)





is no longer approved for use with the EMDEC system.

PC reader (diagnostics with a portable computer)

The PC reader kit, Figure 8, is the recommended EMDEC interface tool.

The PC reader enables the troubleshooter to:

- monitor all sensors inputs to the ECM's;
- view ECM outputs to the injectors (*pulse width and timing*);
- view injector response time;
- calibrate the injectors;
- load ECM software;
- view and download fault data.

The software is a DOS based program that generates a diagnostic screen and interface protocol on the portable computer. To use the program it must be loaded into the laptop, the laptop connected to the EMDEC system through the cable and translator assembly, and the program initiated.

On most applications there are two access locations for EMDEC, Figure 9. The two ports are identical in function; the diagnostic procedures are the same for either port. One port is located in the cab of the locomotive, inside the center door of the computer chassis cabinet. The EMDEC access port is located to the right of the EM2000 locomotive control computer chassis, and is labeled "EMDEC".

The second access port is located on the interface module mounted to the 24 VDC power supply. It is usually found in the AC cabinet in the engine compartment.

If the software is loaded correctly, and the system is properly connected to the EMDEC system, a main screen will appear on the laptop, Figure 10. The two systems (EMDEC and PC reader) are communicating when the green light on the translator box is illuminated, and the red light is flashing.

PC reader main screen

The main PC reader screen consists of six separate information areas, or *dialogue boxes*, plus a list of functional keys located across the bottom of the screen, Figure 11. Each of these areas operates independently of the others, and portrays a different type of data.

The three boxes across the top of the screen display the ECM identification data for the sender, and receivers 1 and 2. Receiver 2 is for use with a 20 cylinder engine, so information fields in the receiver 2 box will remain blank when working with an 8, 12, or 16-cylinder engine.

The information contained in these boxes shows:

- the MID code for the ECM,
- the calibrated number, and,
- version of ECM software.

This information is useful when determining if the software loaded in the ECM's is correct for the application. The information in these boxes also serves to show that the ECM's are communicating correctly with the PC reader.

Engine parameter data box

On the left side of the main screen is a large box labeled "Engine Parameters". The data shown in this area are real time feedback from the various engine sensors. In addition, other data critical to engine operation are also displayed in this box. This additional information is based on ECM calculations, and signals sent to the EM2000 control computer.

All sensor feedbacks such as pressures and temperatures are displayed. The "Battery Voltage" signal is actually the output of the 24-volt DC power supply. This is an easy way to assess the condition of the output, which must be 24 VDC +/- 10%.

Also shown are the base pulse widths and the base start of injection for the sender and receiver ECM's. Normally the data shown for the different ECM's should be similar. A large variation between sender and receiver indicates a serious problem, and is very important information to have when it becomes necessary to diagnose engine problems.

Engine Ratio Signal

Two additional signals in this box are very valuable for trouble-shooting. The first is the engine ratio signal. This signal is expressed as "% max fuel (Engine R)" on the screen. The signal is expressed as a percentage and represents the percent of total available fuel for a given throttle position that is actually being used. During normal operation the engine will require approximately 78% to 80% of the total available fuel for a given throttle position. Should there be any problems with the engine, for example plugged air filters, performance will drop, and EMDEC will have to add more fuel to the engine to maintain speed against the load on the generator. The engine ratio signal increases proportionately to the increase in amount of fuel.

As long as the engine ratio is less than 87%, the EM2000 control computer will assume that the engine is capable of full power, and will regulate generator excitation to produce the proper kilowatt output for the respective throttle position. If the engine ratio rises to 87% for any reason, the EM2000 will assume that the engine is having difficulty maintaining horsepower, and will reduce excitation to prevent fueling from exceeding the 87% engine ratio. The LR%MAX (load regulation % maximum field) signal on the EM2000 diagnostic screen will drop from 100% to indicate this condition.

% Allowed Torque Signal

This signal is normally 100% but may be reduced by the sender ECM should certain support system parameters move outside the acceptable levels. These parameters include air pressure (boost), air temperature, fuel pressure, or turbine speed (H - engines only).

When a parameter(s) moves outside of acceptable levels, such as low boost pressure, EMDEC calculates that the engine is not capable of generating rated horsepower at desirable fuel levels. The % allowed torque signal is reduced, and the fuel maps are scaled downward (maximum fuel for each throttle position is reduced). As the % allowed torque signal is reduced, the engine ratio signal (because of the revised fuel maps) will increase which triggers the EM2000 to reduce generator excitation as mentioned above.

In a situation where the engine is not producing rated horsepower at a stable engine speed, this signal can be a good indication of engine condition. On a properly operating engine in a steady load state:

- % max fuel (Engine R) < 87%
- % allowed torque = 100%
- LR % MAX = 100%

Engine parameters to be monitored are selected, using the engine parameter selection utility screen, Figure 12. To change or rearrange parameters displayed in the dialogue box press the F1-Parameters key on the main screen.

Injectors Response Time

On the right side of the main screen are two smaller boxes, Figure 13. The upper of the two is labeled "Injector Response Time (ms)".

The data shown in this area contain real time feedback of injector response times from the ECM's. The display also indicates problems with the electrical side of the injectors. Response times should remain stable throughout the entire engine speed range. Response times should be between 1.20ms and 1.60ms, and there should be little variance between cylinders.

Real-Time Diagnostics (Fault Data)

The lower right box of the main screen is labeled "Real Time Diagnostics", Figure 14. The data shown in this area contain real time feedback of active and inactive system faults. The real-time diagnostic screen is limited in size and the type of information displayed. Therefore an identification number and brief description of the fault are shown. Active faults will be shown in blinking black type, while inactive faults will be displayed in solid white type.

Diagnostic Screen (Fault Data Screen)

Due to main screen limitations, a more extensive fault diagnostic screen is provided, Figure 15. The list of archived diagnostic will be displayed on the screen. Active faults are shown in red, inactive faults are shown in green, or light on dark text on monochrome screens. These data can be viewed, and/or downloaded, Figure 16.

Sensor A/D Value Screen

This screen, Figure 17, lists the sensors by name in the left-hand column. Some values will not be displayed, specifically if the sensor is not configured. The right hand column lists the voltage as seen by the Sender ECM. The sensor voltage feedback should be within the specified voltage range provided in the sensor troubleshooting procedures.

Digital I/O pin screen

This screen provides a list of input and output pin locations and their respective state, Figure 18. The output functions correspond to the state the EMDEC is in such as shutdown status or ECMON, etc. The INTENDED column lists the desired state, and the ACTUAL column shows the real time status of the function. For example, if the engine shutdown bit was activated, the shutdown function's actual state would flash ON to OFF.

Other PC reader functions

In addition to all of the real time diagnostic functions mentioned previously, the PC Reader can be used to enter the injector calibration codes, Figure 19. Each EMDEC injector requires the correct calibration code to be entered into the computer. This calibration code compensates for assembly line tolerance differences of the mechanical portion of the injector.

The calibration changes the output of each injector to bring it to a nominal standard. Therefore units having trouble making horsepower with good injectors will benefit from this feature. It is best described as the electrical equivalent of "setting the rack", and must be done any time an injector is renewed. Codes should also be verified on a periodic basis.

The PC reader can also be used to check individual injectors using the EMDEC PC reader cylinder cutout feature.

Annunciator (Fault) Panel

The annunciator or fault panel is normally located on the side of the AC electrical cabinet, when equipped, Figure 20. The panel is the center of the EMDEC engine protection and diagnostic system. It contains the LED indicating lights and switches available to the operating or maintaining crew to control the EMDEC system operation and diagnostic functions.

The fault indicating lights are used to determine if a specific condition has caused an engine protection shutdown. The hot oil temp, low oil pressure, low water pressure, and crankshaft pressure lights are self explanatory. More detailed descriptions are available in the EMDEC operating and troubleshooting guide.

The stop engine light will come on to indicate that a potential engine damaging condition has been detected. If the system is programmed to shut down the engine for this condition, the engine will shut down in approximately 30 seconds and a corresponding fault indicating light on the panel will come on.

The stop engine light is also used to "flash out" the active fault codes using the code test switch. An active code is a fault that is currently keeping one or both of the diagnostic lights on, as well as a corresponding fault light. Active codes are displayed (flashed) in order from the most recent to the oldest based on engine running hours. Active codes are also immediately stored in the ECM memory as inactive codes.

The check engine light will come on to indicate that a fault has occurred and lasted for at least 2 seconds in duration. If the fault goes away, the light will go out, but a fault code will be stored in the ECM memory as an inactive code. The condition should be diagnosed at the next unit service or maintenance checkpoint.

The check engine light is also used to "flash out" the inactive fault codes using the code test switch on the panel. All inactive codes are faults that have previously occurred. Inactive codes are displayed (flashed) in order from the most recent to the least recent.

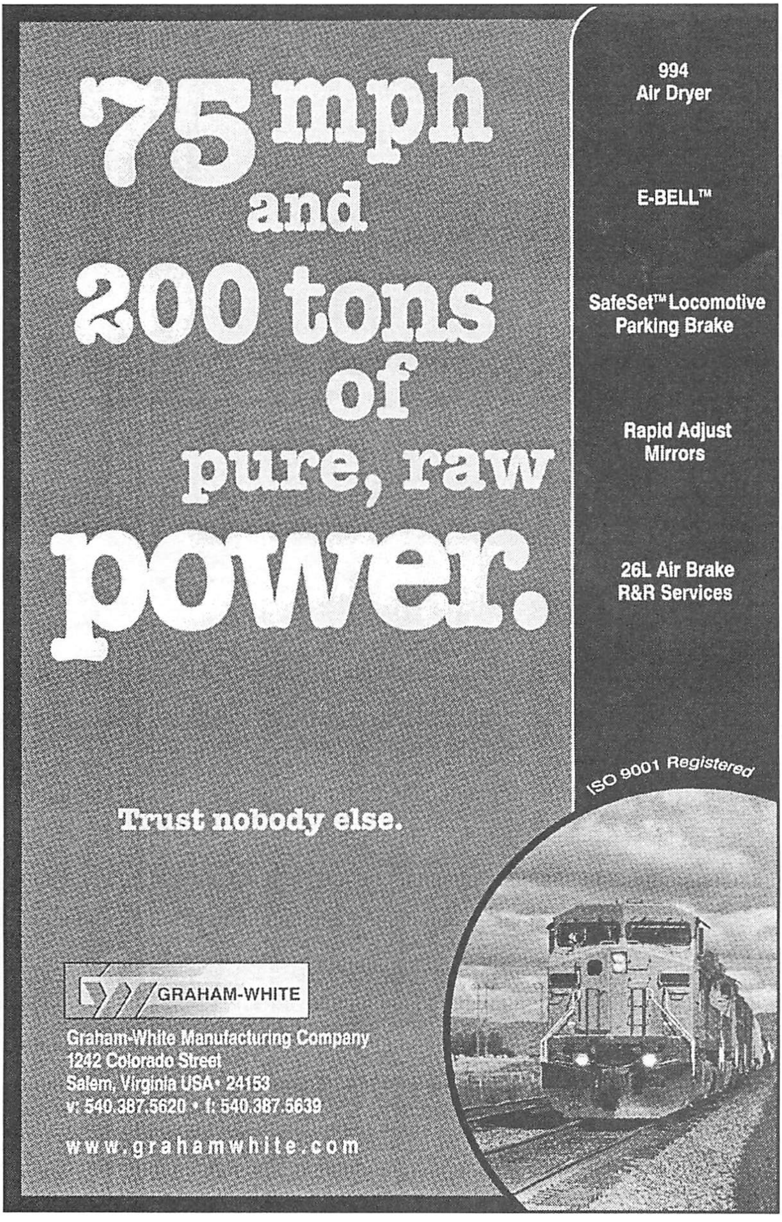
Fuel Injection Switch

This two position latching toggle switch must be in the RUN position in order to start and operate the diesel engine. It enables the fuel injection system. The engine will shut down whenever this switch is placed in the STOP position, which disables the fuel injection system.

To clear a fault indication from the annunciator panel, the switch is placed momentarily in the STOP position. When returned to RUN, the fault light should be off and the system ready light should come back on.

System Ready Light

This light will be on provided that power is being supplied to the EMDEC system. This light will be off if the engine has been shut down using the emergency fuel cut-off (EFCO) switch, the MU engine stop switch, or the throttle handle stop position, and the engine shutdown circuit has not been reset.


75 mph
and
200 tons
of
pure, raw
power.
Trust nobody else.
994
Air Dryer
E-BELL™
SafeSet™ Locomotive
Parking Brake
Rapid Adjust
Mirrors
26L Air Brake
R&R Services
ISO 9001 Registered
GRAHAM-WHITE
Graham-White Manufacturing Company
1242 Colorado Street
Salem, Virginia USA • 24153
v: 540.387.5620 • f: 540.387.5639
www.grahamwhite.com

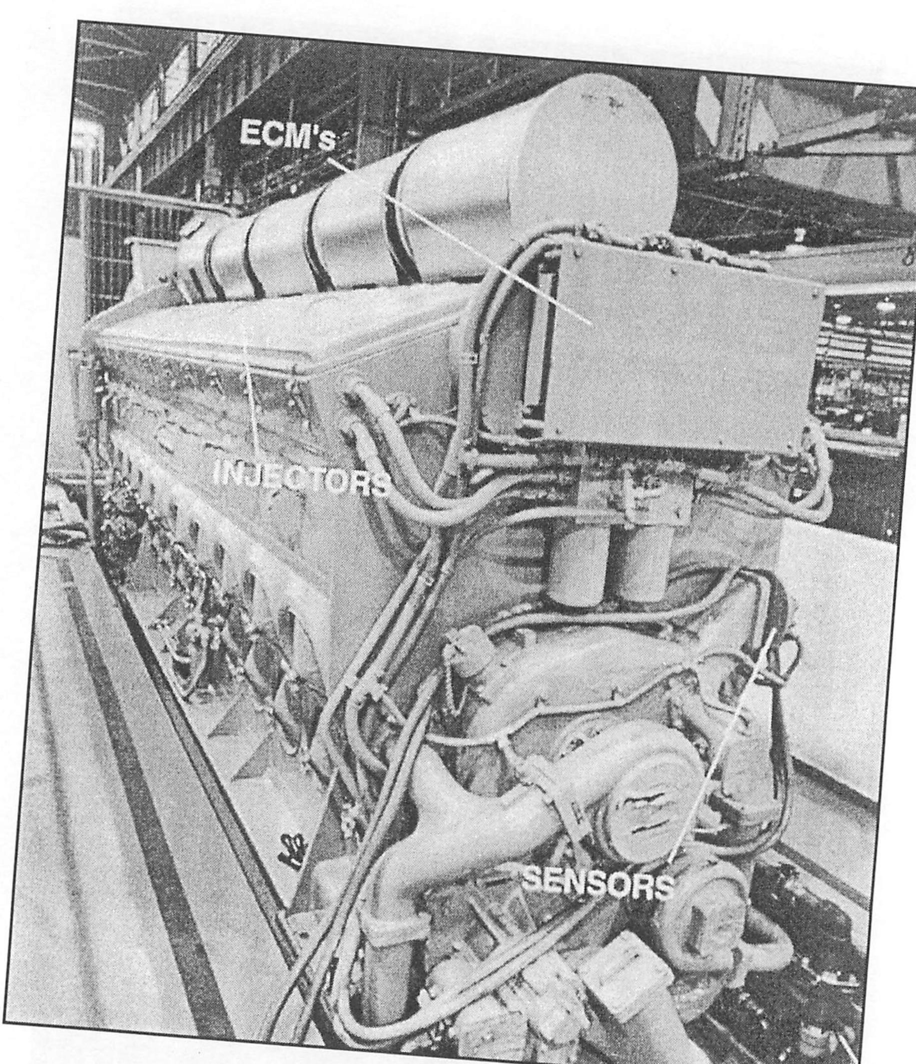


Figure 1

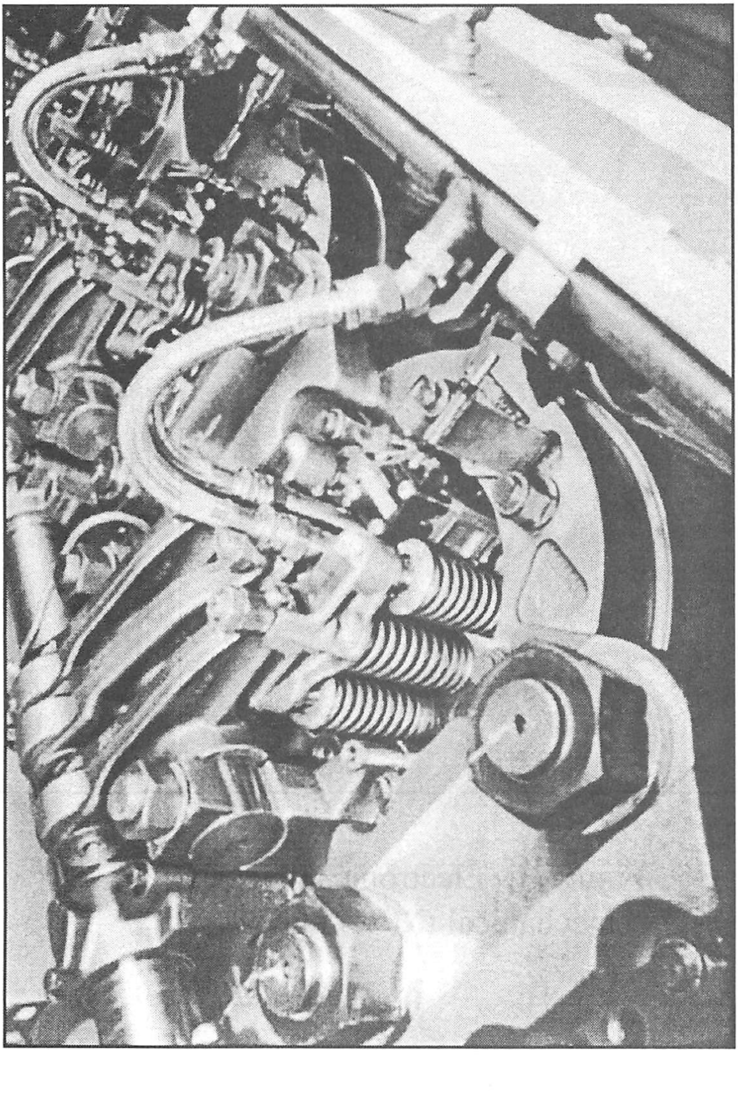


Figure 2 - Electronic fuel injectors

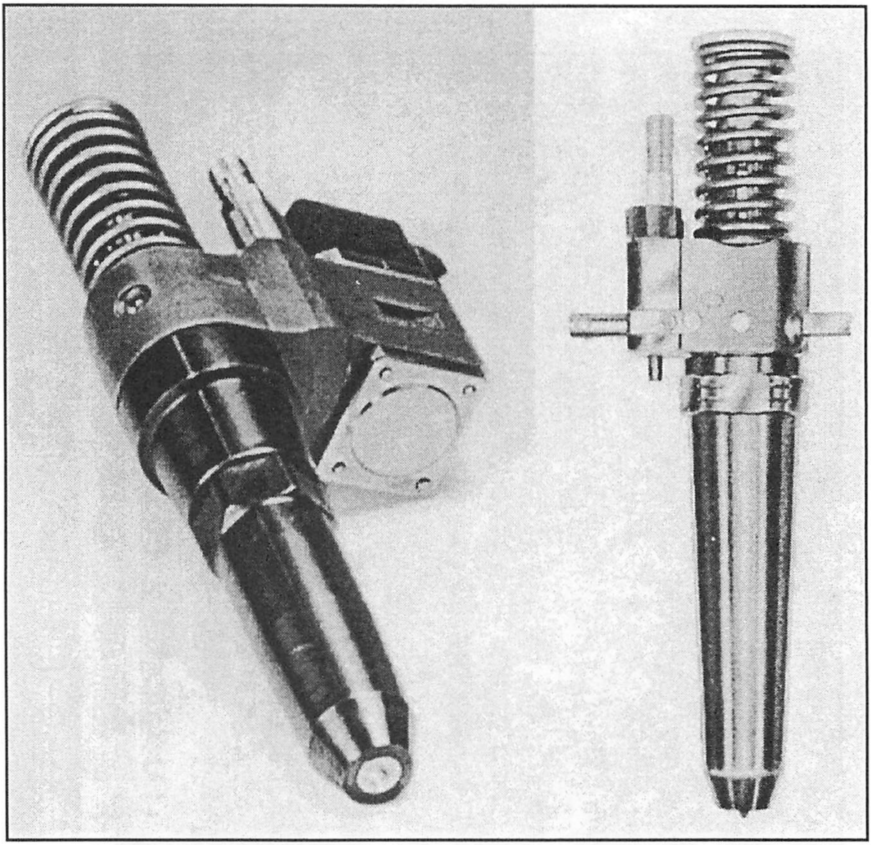


Figure 3 - Electronic (EUI) and
mechanical (MUI) injectors

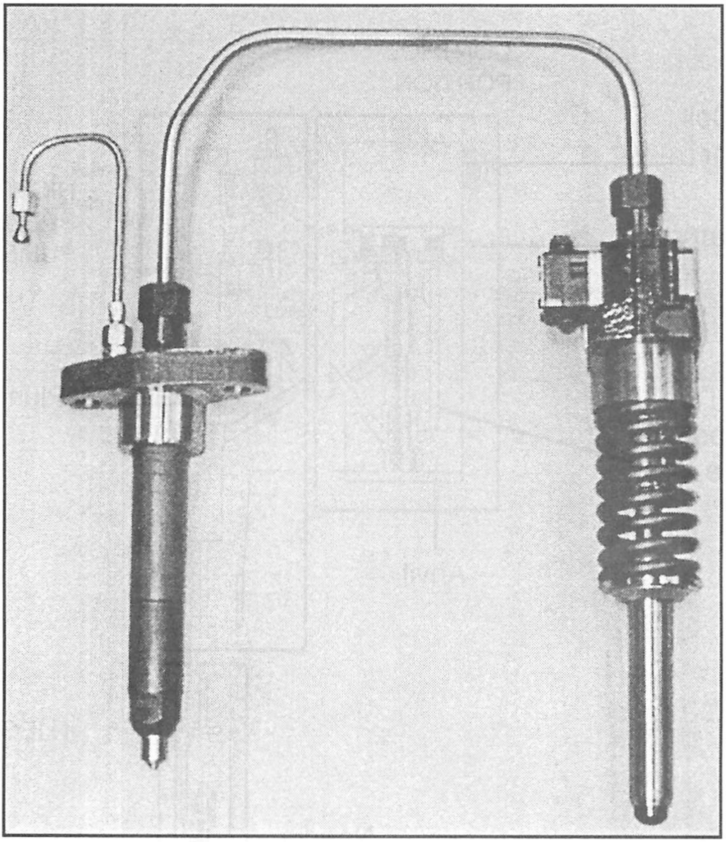


Figure 4 - H-engine injection pump and nozzle

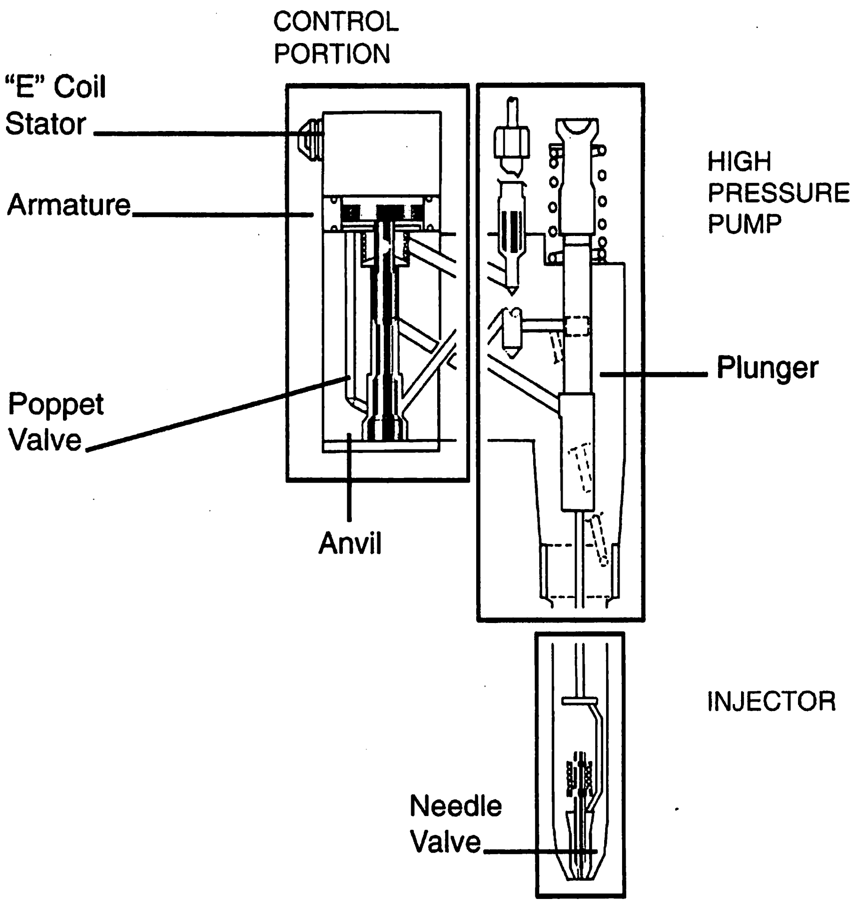


Figure 5 – Cross sectional view of the EUI injector

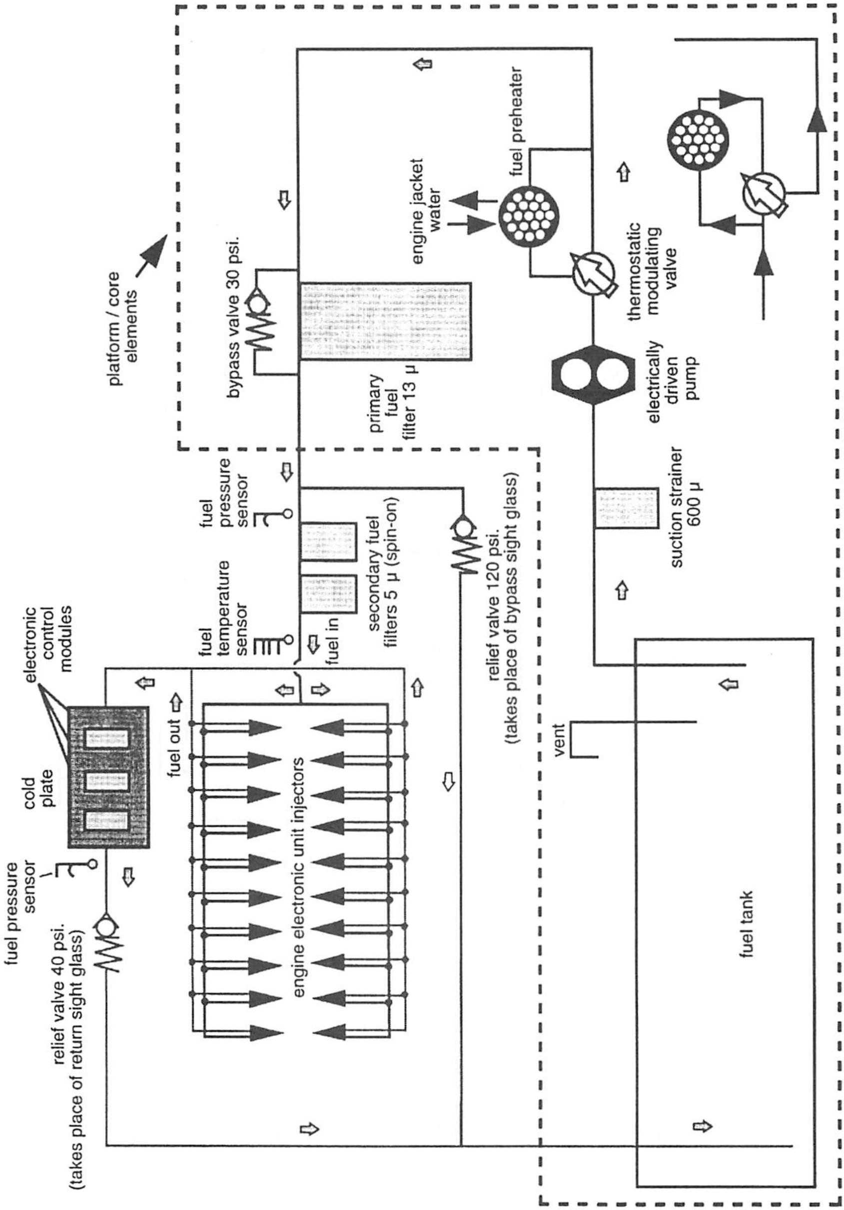


Figure 6 – 710 engine type EUI fuel system

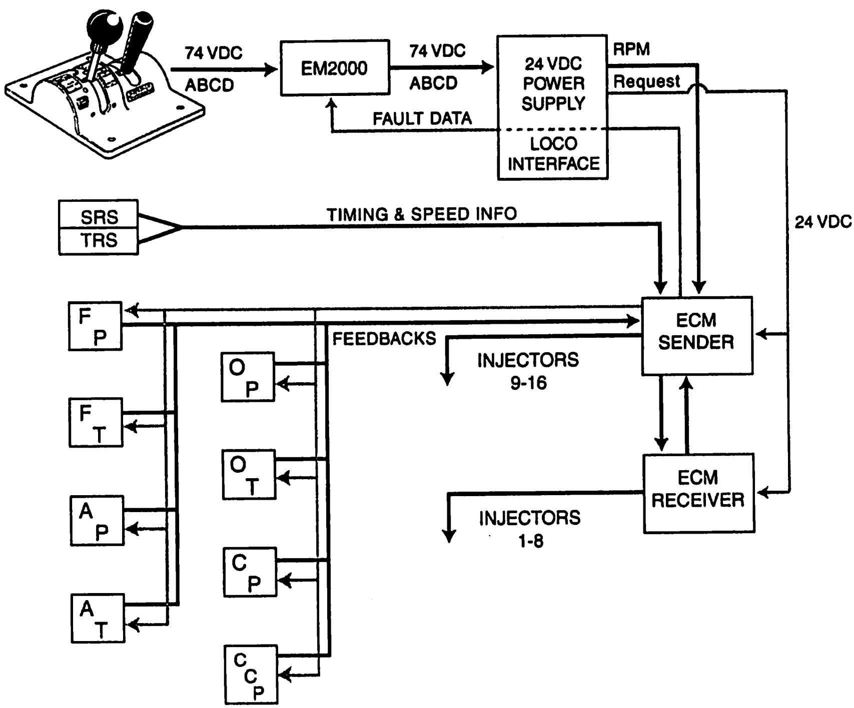


Figure 7 – 16-cylinder EMDEC system

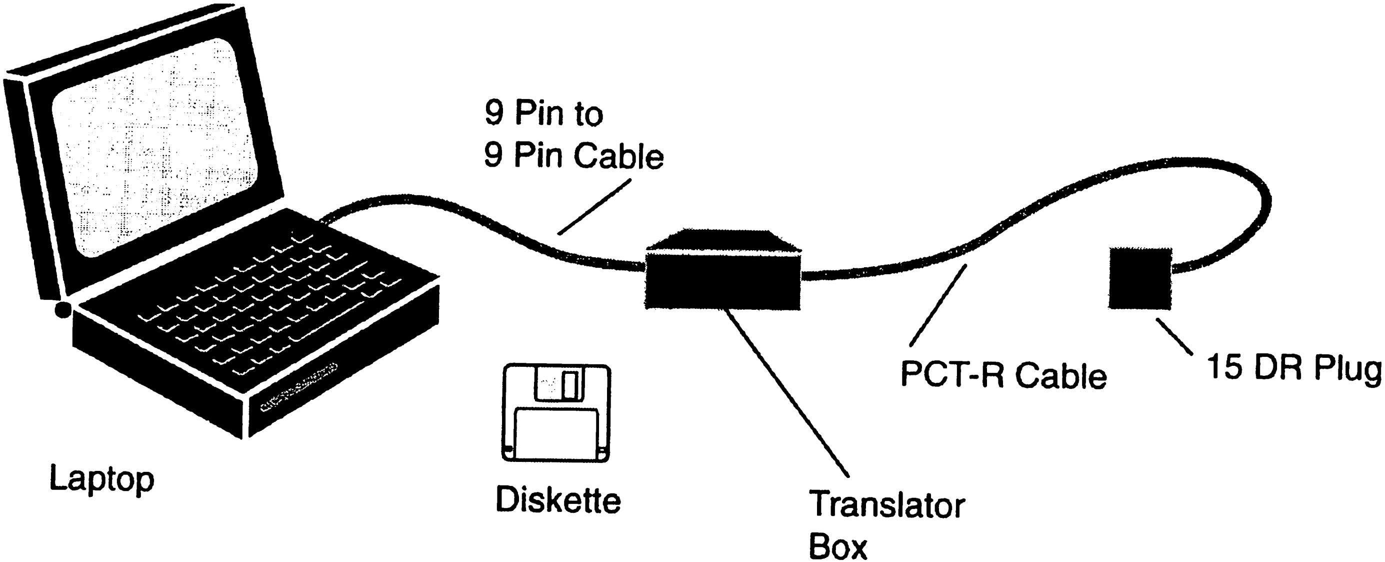


Figure 8 – PC reader diagnostic kit

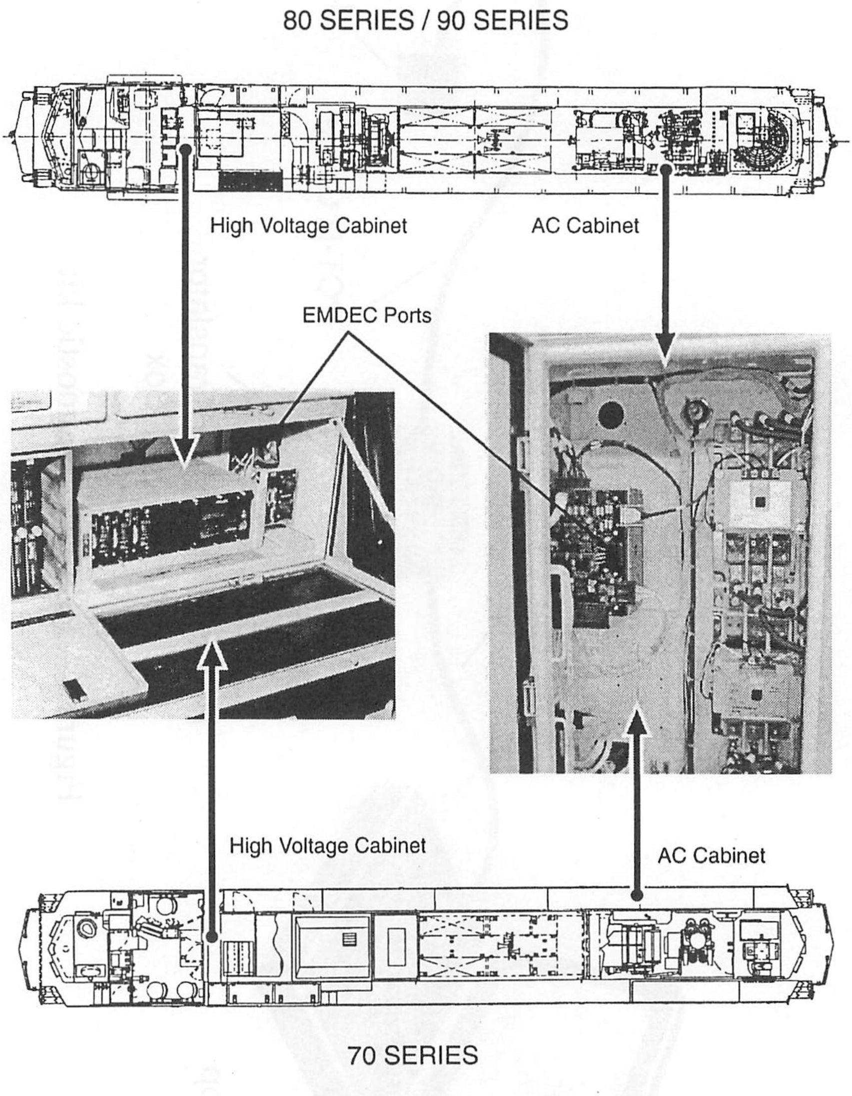


Figure 9 – EMDEC access ports

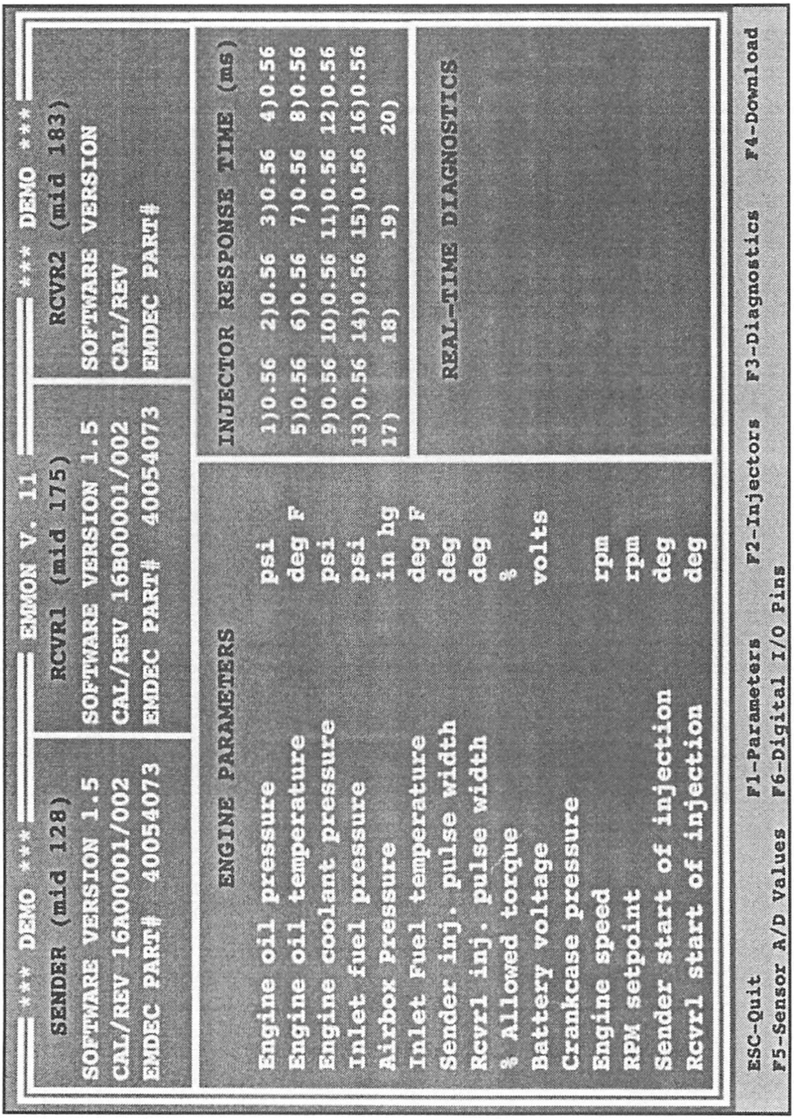


Figure 10 – PC reader main screen

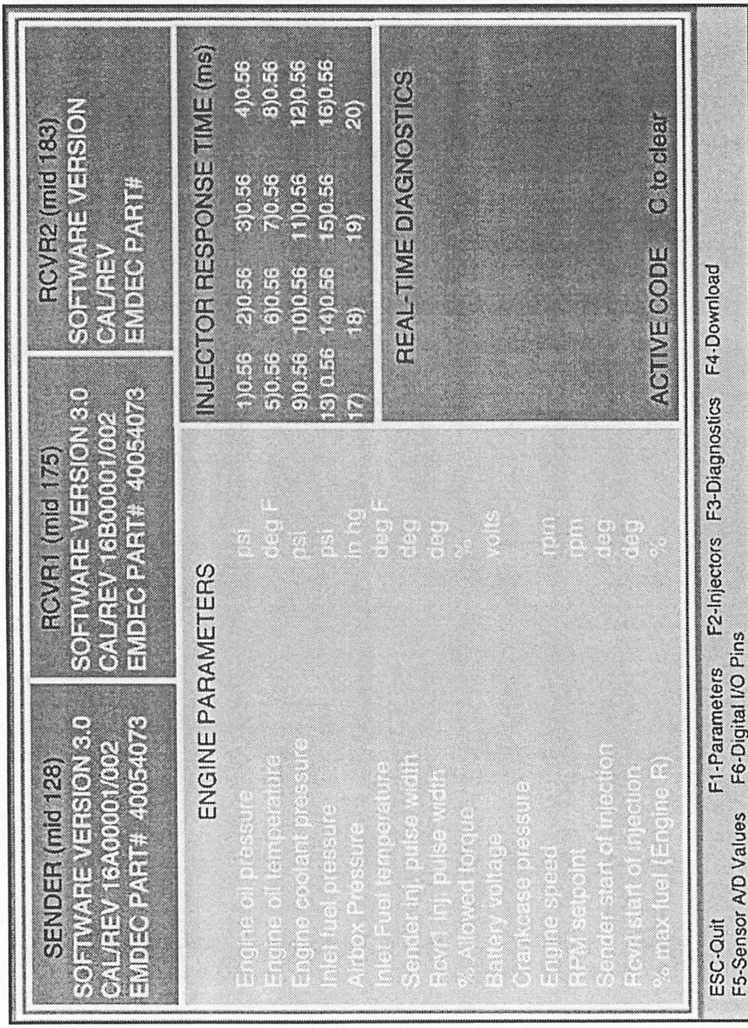


Figure 11 – Engine parameter dialogue box

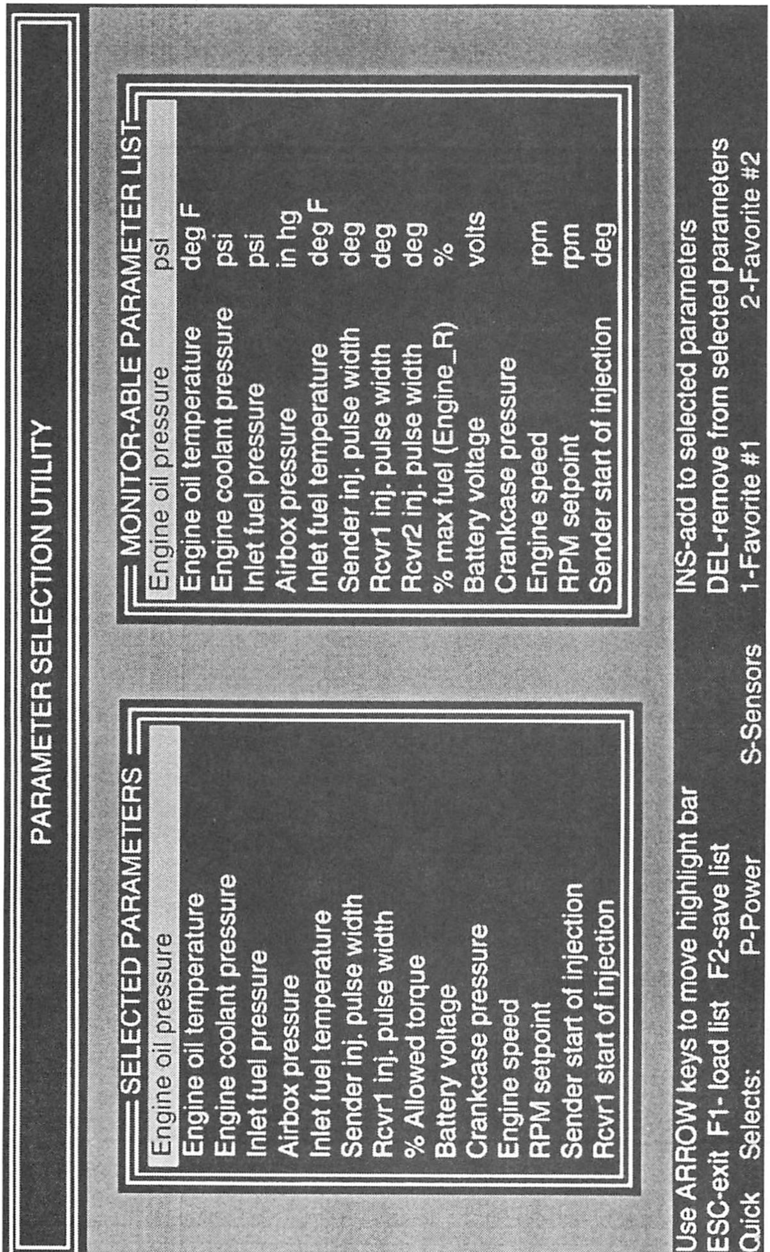


Figure 12 – Engine parameter selection utility screen

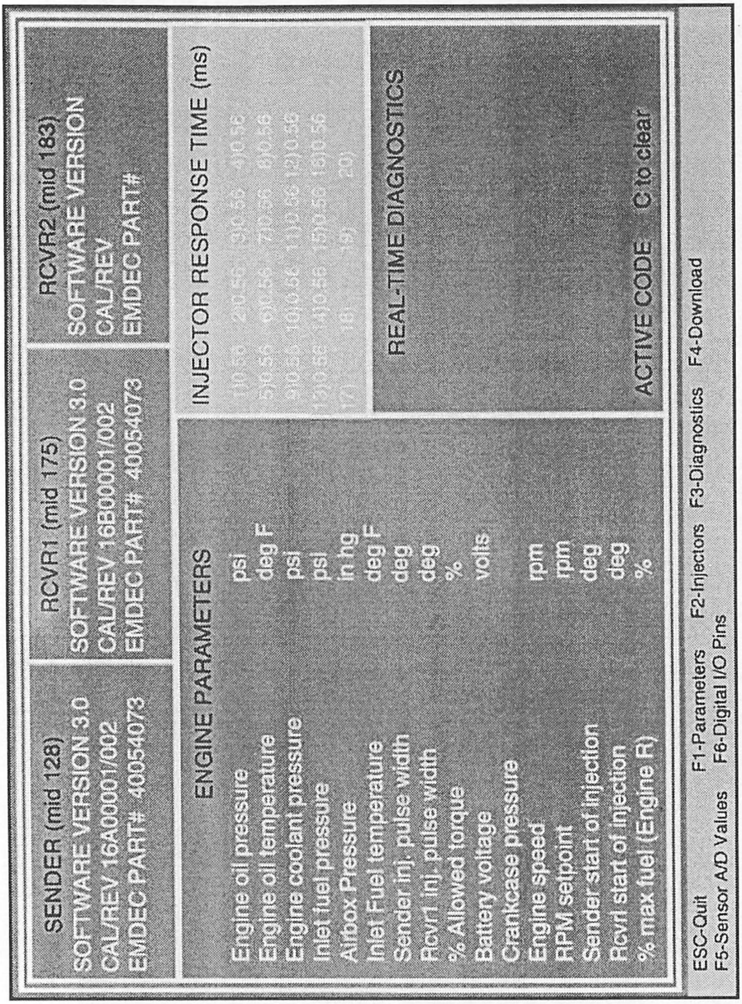


Figure 13 – Injector Response Times

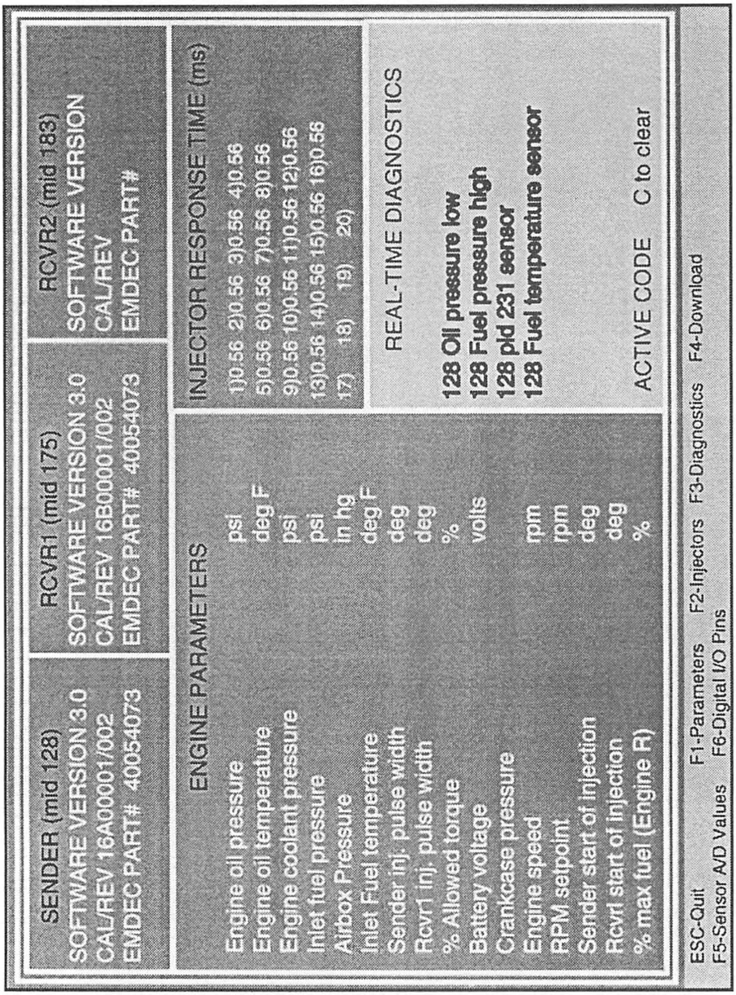


Figure 14 – Fault data – real time diagnostic

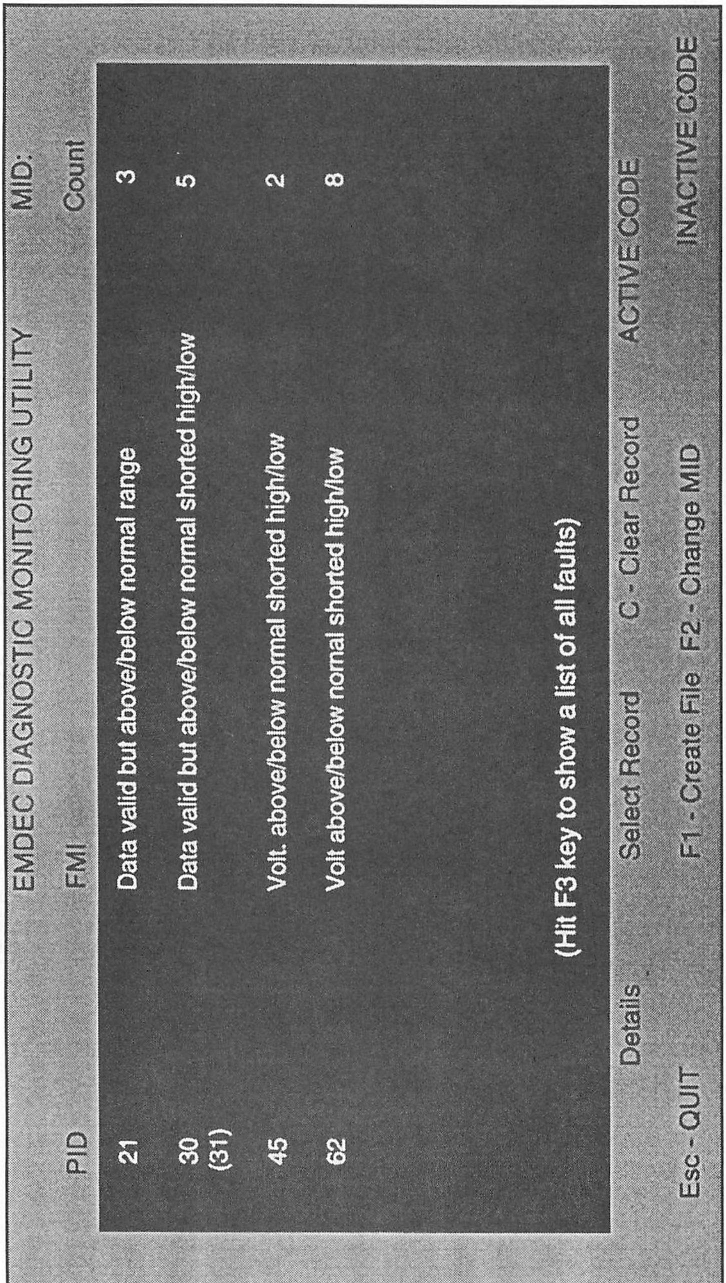


Figure 15 – Fault data – diagnostic screen

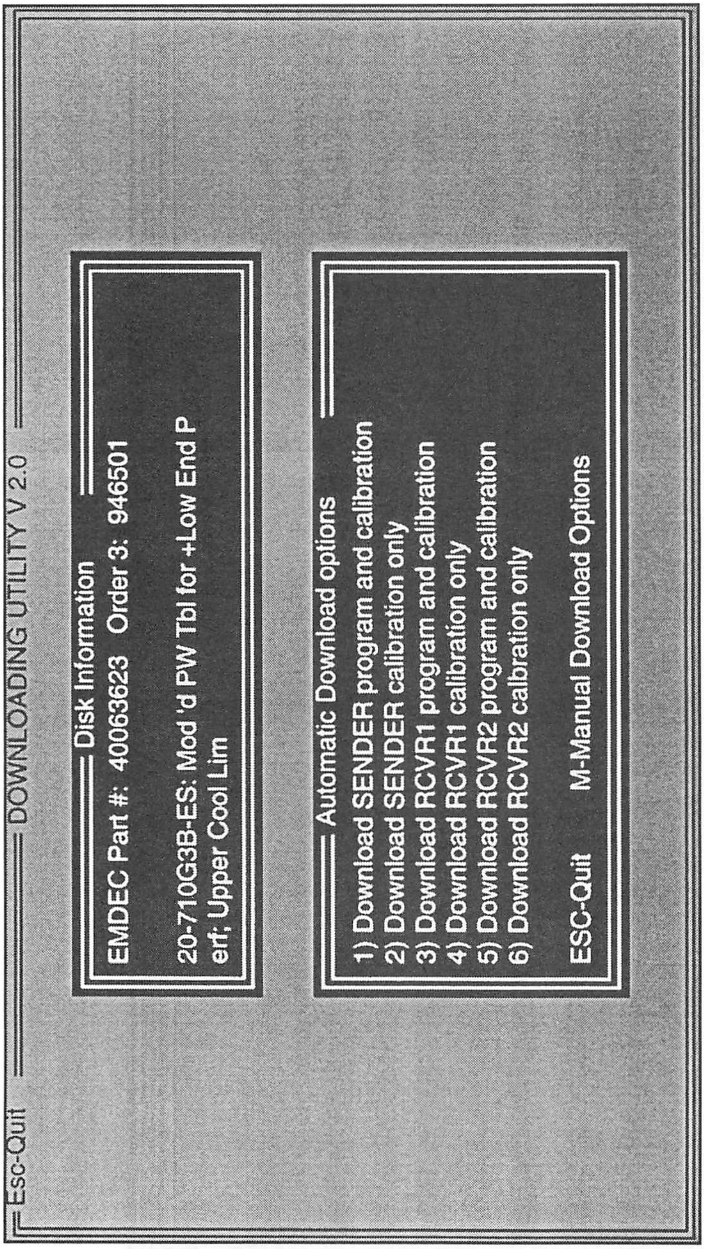


Figure 16 – Downloading utility screen

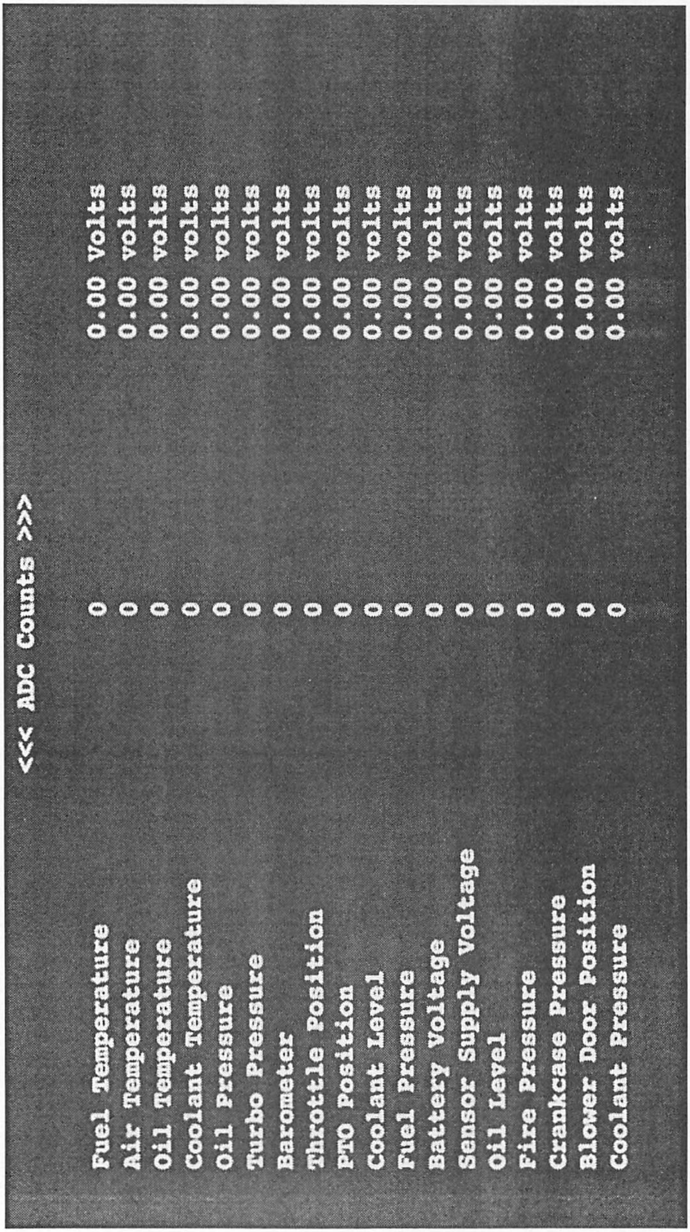


Figure 17 – A/D value screen

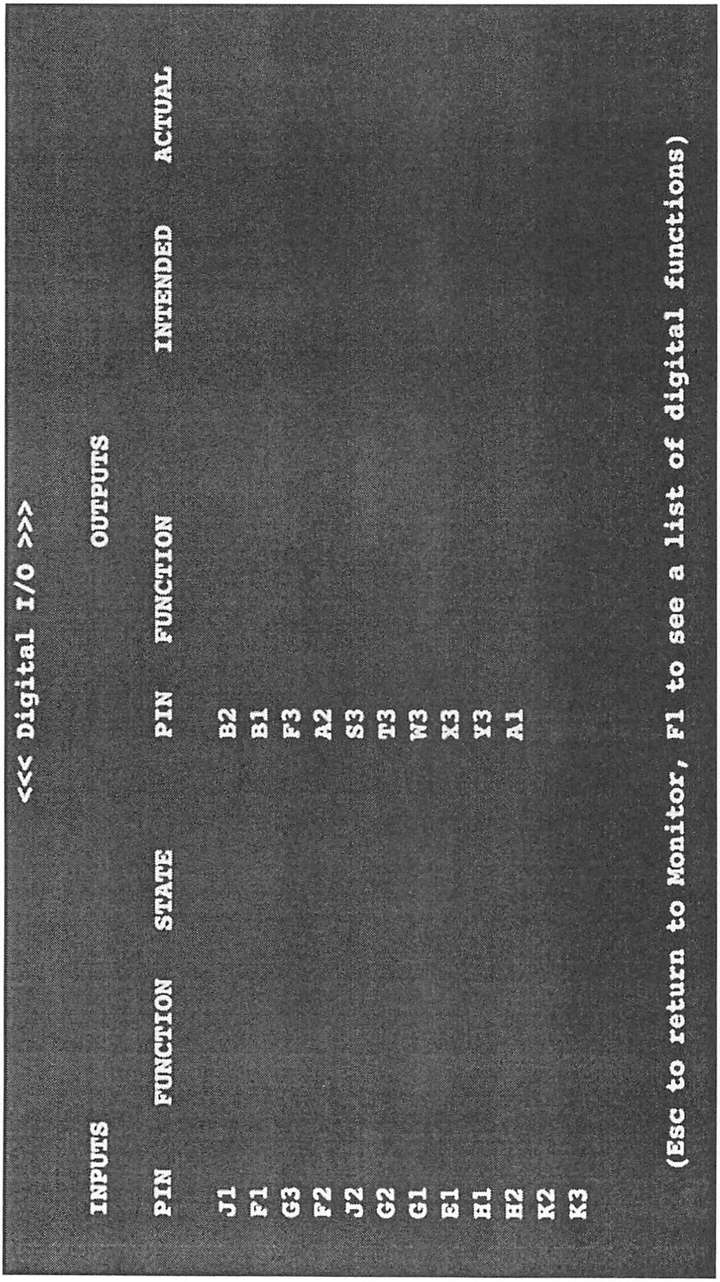


Figure 18 – Digital input/output (I/O) screen

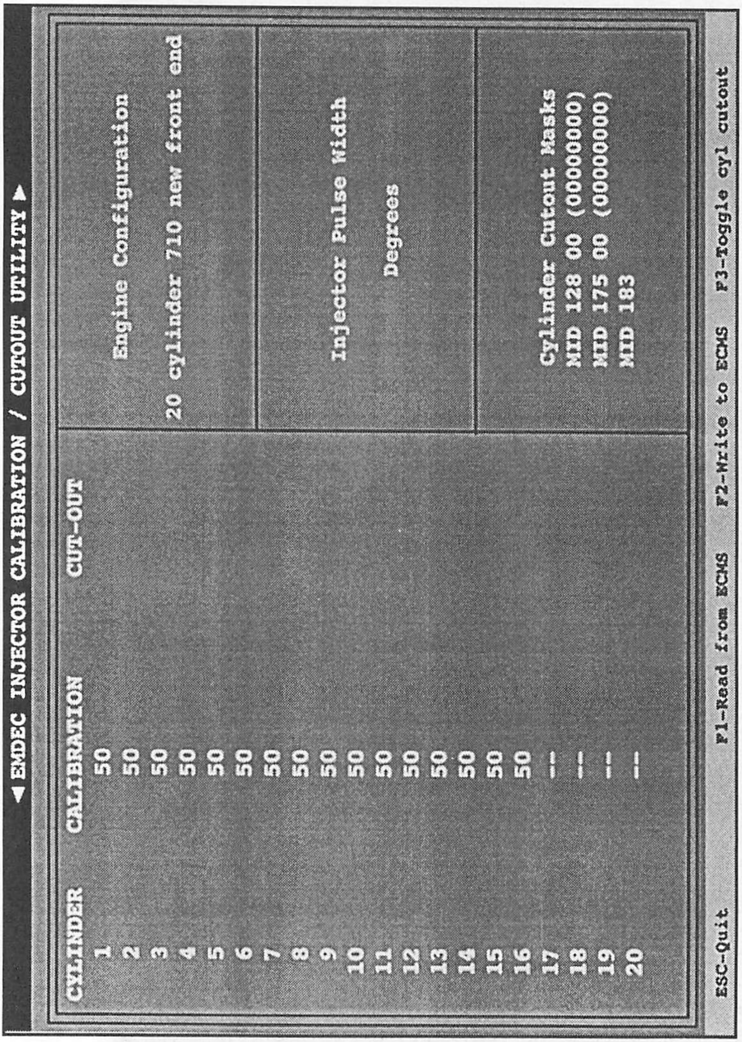


Figure 19 – Injector calibration screen

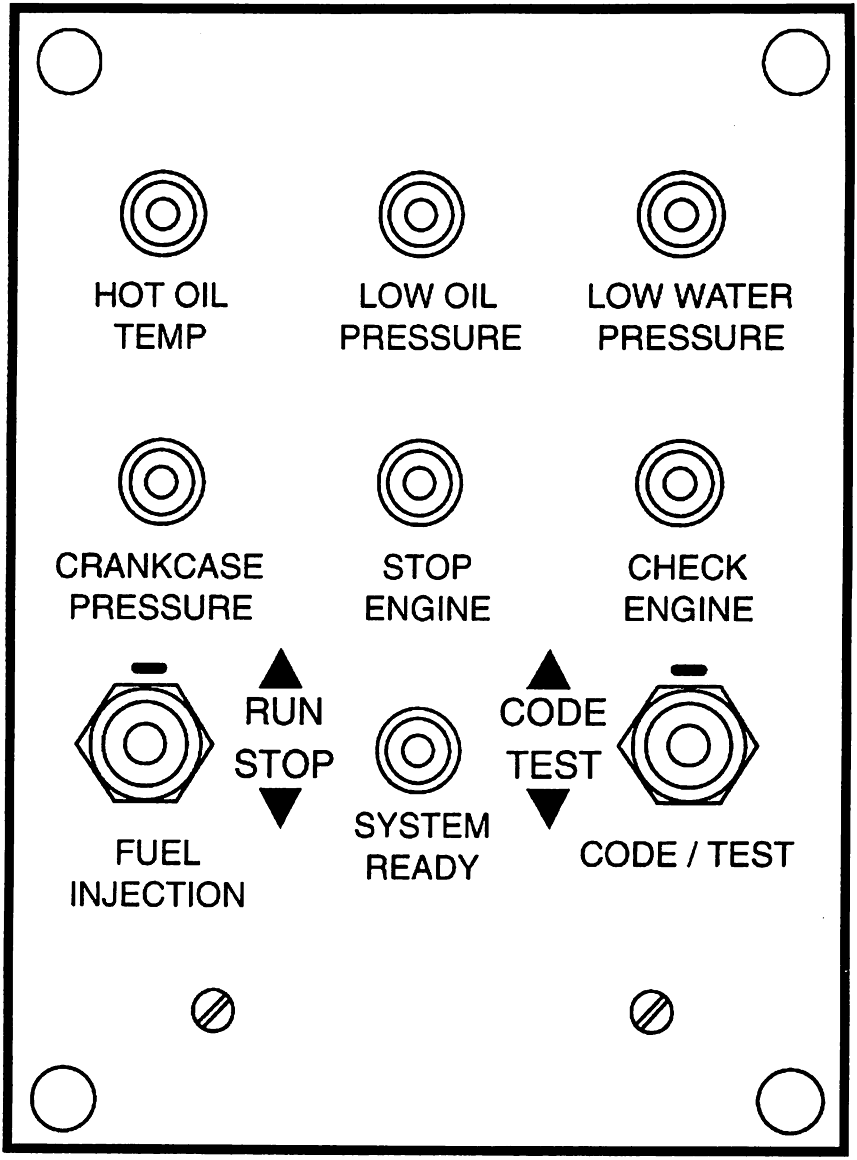


Figure 20 – Annunciation panel

III. HOW TO MAINTAIN ALCO LOCOMOTIVES IN THE 21ST CENTURY

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(508) 755-4000 Ext. 411

Executive Summary

ALCO locomotives have not been manufactured since late 1982. This paper discusses maintenance issues concerning ALCO locomotives, including obtaining parts and components. This paper is designed to help regional and short line railroads find hard to get to parts for ALCO locomotives. This paper addresses the MLW 420 locomotive but other models of ALCO will apply.

Although there are many vendors listed in this report, the Diesel Mechanical Committee of the Locomotive Maintenance Officers Association (LMOA) does not endorse any particular vendor listed. In addition, if a pertinent vendor has been left out of this report, please contact me at the Providence and Worchester Railroad. An updated vendor list will be made available at the next annual meeting.

The following original equipment manufacturers (OEM) gave their permission to reproduce the maintenance instruction documents presented in this paper:

- National Railway
- FM ALCO
- Globe Turbocharger.

1. History

In 1924, American Locomotive Company (ALCO) built their first successful diesel electric locomotive for the Central Railroad of New Jersey. From 1940 to 1945, ALCO was a major supplier of heavy machinery and diesel electric locomotives. In 1948, ALCO produced its 75,000th locomotive. In 1955, ALCO changed its name to ALCO Products to put emphasis on non-locomotive products. In 1964, ALCO Products became a wholly owned subsidiary of Worthington Corporation, later Studebaker-Worthington, Inc. In 1969, ALCO Products, Inc. sold its design to Montreal Locomotive Works (MLW). In 1998, National Railway (NREC) along with Fairbanks Morris (FM ALCO) and Globe Turbocharger, took over all rights to ALCO locomotives and are the original equipment manufacturers (OEMs) for replacement parts and components.

1.1 Original Equipment Manufacturers

The OEMs for ALCO can research their archives for particular locomotives if they are provided with the serial number and model number. They can provide information on the original owner of the locomotive, electrical and mechanical blueprints, and maintenance instructions. The OEMs rebuild parts and equipment for particular components of the locomotive:

OEM	Component
NREC	All components except for the diesel engine and the turbocharger
FM ALCO	Diesel engine
Globe Turbocharger	ALCO turbocharger

Contact information for these companies is provided in Appendix A.

ALCO manufactured the following locomotive models:

C Series
Century Series; the final USA series of locomotives the ALCO produced

RS
Road Switcher. This is used to designate a series of locomotives

S
Switcher

M Series
Montreal Locomotive Works, Montreal, Canada

HR Series
Montreal Locomotive Works (Bombardier)
Higher Reliability Service

The following are early models:
HH
High hood style cab, 531 or 539 engine

PA
Passenger service, 244 engine

FA
1950s era locomotive designated for freight service, 244 or 251 engine

DL
Dual service locomotive used for road service or switching with "RS".

In general, these models share similar major components and parts. Although this paper focuses on the M Series MLW 420, the information can be applied to the other model locomotives.

1.2 The M Series Locomotive

The M Series locomotives were manufactured in Montreal, Canada. MLW 420 designation means the following:

- The "4" indicates that the locomotive has four axles and
- The "20" indicates that the unit has 2000 horsepower.

The MLW 420 has a Canadian-style comfort cab and has a 26 LUM air brake system and may or may not have dynamic brakes. The MLW 420 diesel engine is an ALCO 251C3 engine. It has 12 cylinders and it is configured to use a 131 or 165 turbocharger, not the typical 520 turbocharger. This configuration is unique to this model series. The ALCO model 251C3 diesel engine is still widely used in various other industries. This engine is used as power on oil rigs and in power plants. They also power tugboats.

2. Locomotive Inspection Requirements

Each locomotive should be inspected every calendar day (49 CFR 229.21) it is used. A periodic inspection is required every 92 days (49 CFR 229.23). Six-month and yearly inspections are also conducted to inspect additional components not inspected during the more detailed 15-, 45-, and 92-day inspections. In addition to these inspections, a tri-annual inspection is done on the 26 LUM air brake system (common to the MLW 420 locomotive).

To ensure the locomotive is within lubrication and wear limit standards, the 92-day inspection is typically broken down into 15-day increments. Below is a summary of what is typically conducted at the 15-, 45-, and 92-day inspection. Note that at the 45-day inspection, the 15-day inspection is also conducted; at the 92-day inspection, the 15-day and 45-day inspections are also conducted; at the 180-day inspection, the 15-, 45- and 92-day inspections are conducted; at the 365-day inspection, the 15- through 180-day inspections are also conducted.

<u>15-Day Inspection</u>

- Inspect the engine overhead
- Inspect and service all driveshafts and couplings
- Service the traction motor support bearings. At a minimum, the support bearing oil level should be checked every 15 days. In heavy snow accumulation regions, the locomotive support bearing wells should be checked for water contamination each round trip during the winter months
- Service traction motor gear cases
- Inspect the wheels for defects
- Inspect the running gear
- Take a lube oil sample
- Check ground relay and seal
- Inspect all electrical circuits.

<u>45-Day Inspection</u>

- Check journal bearings
- Verify operation of fuel cut-offs
- Visually check engine intake filters
- Check car body filters
- Change all fuel filters
- Drain condensate from fuel tank
- Ensure proper function of engine protection devices
- Check battery water
- Inspect and replace as needed all motor brushes
- Inspect traction motors, leads, brushes, and interior.

<u>92-Day Inspection</u>

- Check engine overspeed
- Change air compressor filters, check fluid levels
- Inspect couplers and draft gears
- Clean fuel sight glass
- Complete a thorough wheel inspection report
- Change motor support oil as needed
- Test wheel slip controls
- Check for low voltage grounds

- Change all lube oil filters
- Check battery blocking, wash battery tops
- Inspect MU receptacles
- Inspect main generator and brushes
- Inspect auxiliary generator and brushes
- Inspect crankcase exhauster motor and brushes
- Inspect cab heater motors and brushes
- Replace fire extinguisher with qualified
- Pressure check coolant system
- Inspect and test hand brake
- Download event recorder
- Verify and calibrate operation of head end telemetry device
- Measure decibel readings in cab and of horn per CFR
- Test air brakes and test all air gauges.

180-Day Inspection

- Remove and verify support bearing wicks
- Clean and wash generator compartment
- Clean nose compartment
- Lubricate and inspect governor linkage
- Test auxiliary generator voltage
- Lubricate all car body hinges and hatches.

365-Day Inspection

- Blow out generator compartment and inspect area
- Test timing of time delay switches
- Inspect/change brushes on heater motor and any other motor
- Inspect and stencil handbrake
- Inspect and clean sand traps
- Wash the entire locomotive
- Clean the cab
- Load test the locomotive engine
- Clean air brake system filters and dirt collectors
- Clean and test all reservoir drain valves.

Tri-Annual Air Inspection

The following air portions need to be cleaned, tested and reinstalled:

- Brake cylinder relay valve
- Brake pipe vent valve
- Distributing or control valve
- Automatic Brake valve
- Brake application valve
- Independent brake valve
- MU2A valve
- Charging cut of pilot valve
- Selector valve
- Magnet valve
- Main reservoir check valves
- Brake cylinders
- Safety valves
- Reducing valves
- Double checking valves
- Horn
- Bell.

2.1 Load Testing

Load testing is conducted on a diesel engine during the 365-day inspection to ensure optimum operating horsepower. A detailed maintenance instruction for load-testing a diesel engine can be obtained from the OEM. The document number is MI - 24022A. The formula for determining the horsepower rating provided in the maintenance instruction requires that the generator efficiency be determined. However, it is an industry practice to eliminate this step and use the simplified equation provided below.

Simplified Horsepower Calculation:

$$\text{Observed HP} = \frac{V \times I}{700}$$

Where: HP=Horsepower input to generator

V = Volts
I = Amperes

3. Locomotive Maintenance

Along with the need to locate parts to repair ALCOs, proper maintenance is necessary. The locomotive inspection, maintenance and lubrication guide is a guideline to ensure the locomotive is maintained to OEM specifications. Refer to MI 17006D. This guide addresses inspection and maintenance on a mile, hour or kilometer basis. Depending on each individual railroad's locomotive usage, this may be translated into days or months.

Lubrication specifications (MI 17105) list lubricants and the specifications for each lubricant used on the rotating components of the locomotive. Although lubrication schedules are included in the locomotive inspection, maintenance and lubrication guide, each locomotive may require lubrication on a unique schedule due to age or use. The operating railroad's mechanical department determines scheduled duty cycles for diesel engine lubricant change-out. In addition to scheduled lubrication, engine oil can be analyzed to determine if it needs to be changed.

Rotating components that typically fail are discussed below. These are a few of the known components that need maintaining on a regular basis to ensure locomotive longevity.

<u>Air Compressor Coupling</u>

The locomotive air compressor is connected to the engine by forged steel flexible couplings and a spacer. Each coupling is made up of a hub and a sleeve connected through gear teeth that transmit power from one shaft and hub through the spacer to the other. When not lubricated, these couplings become very noisy and are not noticeable when the air compressor is engaged.

The air compressor drive couplings require lubrication on a regular basis, typically every 30 days. However, a more conservative schedule of every 15 days can improve the reliability of this component. MI 16536 provides information on disassembly, inspection, reassembly and lubrication.

<u>LO-REZ Flexible Couplings</u>

The LO-REZ flexible couplings are an integral part of the drive train to absorb shock when components are engaged. The LO-REZ flexible coupling is so named because of the low resonant frequency of torsional vibration that it dampens when it is engaged. Although there is no mechanical wear or lubricant needed, the LO-REZ flexible couplings should be inspected internally every six months in accordance with the MI 16541. This MI provides information on general design of the component, preventative maintenance, troubleshooting, disassembly and reassembly.

Eddy Current Clutch

The eddy current clutch consists of an inner coil, exciting coil, and outer coil. When the coil is energized the inner rotor is coupled magnetically to the diesel engine to drive the fan. Varying the current in the exciting coil controls the relative speed of the fan. As the current in the coil is applied in response to a temperature signal, the slip between the inner and outer rotor decreases to drive the fan. Refer to the MI 16541 for monthly, yearly and overhaul maintenance instructions. Note that the eddy current clutch bearing is packed with Type 11 grease. The specifications for this grease are listed in the Lubricant Specifications MI 17105. Also, ensure the copper lining on the the hub is not deteriorating when conducting the monthly inspection.

Radiator Fan Drive Assembly

The unit is a right angle drive gearbox that drives the radiator cooling fan. The eddy current clutch assembly drives this unit. Service the radiator fan drive assembly every 45 days. This service should include a thorough inspection of the housing, fan blades, and gear box fluid level. A visual inspection inside the gear box should be done every six months. MI 16541 provides inspection and reassembly of the unit.

Traction Motor/Blower Motor Drive

The traction motor blower is connected to the alternator power take-off shaft by a Zurn geared flanged sleeve and hub and a Vulkan flexible coupling. As with all rotating equipment, ALCO drivelines should be inspected and lubed every 15 days. MI 16529A provides cleaning, disassembly and lubrication.

3.1 Diesel Engine Maintenance

The locomotive inspection, maintenance and lubrication guide outlines the maintenance required on the ALCO 251C3 engine. Every 35,000 hours, a major overhaul of the diesel engine is recommended. The work scope from the OEM for this overhaul is provided in Appendix B. Also provided in Appendix B is a torque chart for the 251 Alco engine.

3.2 Major Overhaul/Rebuild

Although scheduled maintenance is conducted on ALCOs, major components failures will occur. As an industry standard, major locomotive components are put through a major overhaul every 10 years. The OEM also has recommended major component maintenance schedule listed in the locomotive maintenance, inspection and lubrication guide under Maintenance Group 8A that specifies an inspection and rebuild every 8 years. This schedule was designed to protect the locomotive warranty.

For major rebuilds and modifications, there are many companies that will conduct a major overhaul and rebuild major components for ALCO locomotives. A mailing list of these companies is provided in Appendix A.

4. Parts Availability

Maintaining ALCO locomotives is becoming increasingly difficult because they are no longer being manufactured. Although some parts are being manufactured, the majority of parts must be rebuilt, retrofitted from other locomotives or taken from scrap locomotives.

4.1 Low Availability Parts

One of the many challenges in maintaining ALCO locomotives is the availability of electrical parts. Most of these parts are not being manufactured and existing parts cannot be continuously rebuilt. Therefore, the parts supply is decreasing. The key to maintaining electrical systems is interchanging parts from one type of locomotive to another. For example, depending on the type of failure, the alternator on a MLW 420 is interchangeable with a General Electric alternator of a similar type; however, the new part may need to be retrofitted. If there is a complete failure of the alternator, it may have to be rebuilt or replaced in kind. Smaller railroads are finding that parts such as reversers, diode banks, contactors, interlocks, module cards, panels, and relays need to be rebuilt in-house with spare parts or sent out to be repaired. In-house repairs can be time consuming for smaller railroads due to limited manpower. The electrical component vendors listed in Appendix A can supply these components with adequate lead-time.

4.2 Readily Available Parts

The following parts and components are available with little to no lead-time:

- Parts and components for the diesel engine. Most parts are rebuilt, although new bearings, injectors, and some fuel pump components are manufactured.
- Wheels and journal box sets. Note that the journal boxes are unique to MLW 420 locomotives. In some cases, these components are available unit-exchange.
- Water pumps.
- Power assemblies, including pistons and rocker arms.
- Engine gasket kits.
- Air compressor coupling.

- New LO-REZ coupling parts. Replacement, used LO-REZ parts are difficult to find. New or rebuilt parts are available from LO-REZ.
- Eddy current clutch. Typically, the vendor listed rebuilds the eddy current clutch including relining the hub, renewing the bearing and qualifying the coils.
- Drivelines can be purchased or machined.

5. Vendor Contacts

The locomotive can be divided into 3 major areas by location on the locomotive: above deck, below deck, and cab. Parts and components for these major areas can be obtained from specific vendors. The vendor list in Appendix A is organized into the respective area of the locomotive.

Above Deck

Above deck includes the following components:

- Auxiliary generator
- Main generator
- Electrical system
- Electronics
- Turbocharger
- Diesel engine
- Exhaust sections
- Pumps
- Governor
- Air compressor and related air portions
- Eddy current clutch

Below Deck

- Truck
  - > Wheels
  - > Springs
  - > Bushings
- Traction motors
- Couplers and draft gears
- Fuel tank

Cab

- Seats
- Control stand
- Cab accessories.

APPENDIX A
ALCO Locomotive Parts Vendor List

Below Deck Vendors

Axles and Wheel Sets

Name	Address	Phone Numbers	Internet
Birmingham Rail & Locomotive Company	P.O Box 530157 Birmingham, AL 35253-0157	800-241-2260 205-424-7245 Fax: 205-424-7436	Email: bhamrail@aol.com Website: www.bhamrail.com
Burnington Incorporated	523 West 2nd Street Alliance, NE 69301	308-762-8716 Fax: 308-762-8717	Email: burnigt@btigate.com Website: www.burningtons.com
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	Jfsenecal@canac.com
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	
ORX	1 Park Avenue Tipton, PA 16684	814-684-8484 Fax: 814-684-8400	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	Email: mikeallen@simpatico.ca

Traction Motors

Name	Address	Phone Numbers	Internet
AZ Railway Supply, USA		514-426-9133 Fax: 514-426-9177	
Birmingham Rail & Locomotive Company	P.O Box 530157 Birmingham, AL 35253-0157	800-241-2260 205-424-7245 Fax: 205-424-7436	Email: bhamrail@aol.com Website: www.bhamrail.com
Broadway Rail Equipment	1404 E. Broadway Alton, IL 62002	618-377-5642 Fax: 618-462-9321	
Burnington Incorporated	523 West 2nd Street Alliance, NE 69301	308-762-8716 Fax: 308-762-8717	Email: burnigt@btigate.com Website: www.burningtons.com
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	Jfsenecal@canac.com
Canada Allied Diesel	155 Highway 20 Lachine, Quebec Canada H8S1B4	514-634-6224 Fax: 514-634-4280	Website: www.cadiesel.com
Engineering International	6477 US Highway 93 South – N 114 Whitefish, Montana 59937-8238	406-863-9696 Fax: 406-863-9695	
Flam Progress Industries, India Contact person: Mr. D.K. Mehta	X-47, Okhla Industrial Area Phase Ii New Delhi, India 110 020	Tel: 91+11+6913976, 91+11+6842701 Fax: 91+11+6821054	

National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	
Rail & Traction Canada Inc.	460 Aime Vincent Vaudreuil, Quebec Canada J7V-5V5	450-424-4628 Fax: 450-424-4630	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	**Email:** **mikeallen@simpatico.ca**
Rotomac Electricals Pvt. Ltd., India	105 Park Street Calcutta, India 700 016	Fax: +091 33 249 4177	
Tranz Global Inc.	120 B Broad Street Falls Church, VA 22046	703-531-0181 Fax: 703-531-0188	Website: www.tranzglobal.com

Traction Motor Support Bearings

Name	Address	Phone Numbers	Internet
Magnus	South Bell & Viaduct Fremont, NE 68025	402-721-9540 Fax: 402-721-2377	
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	

Wicks

Name	Address	Phone Numbers	Internet
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	jfsenecal@canac.com
Canada Allied Diesel	155 Highway 20 Lachine, Quebec Canada H8S1B4	514-634-6224 Fax: 514-634-4280	Website: www.cadiesel.com
Durox	12312 Alameda Drive Stongsville, Ohio 44136	800-238-5360 Fax: 440-238-5773	
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	

Gear Cases

Name	Address	Phone Numbers	Internet
Birmingham Rail & Locomotive Company	P.O Box 530157 Birmingham, AL 35253-0157	800-241-2260 205-424-7245 Fax: 205-424-7436	Email: bhamrail@aol.com Website: www.bhamrail.com
Burnington Incorporated	523 West 2nd Street Alliance, NE 69301	308-762-8716 Fax: 308-762-8717	Email: burnigt@btigate.com Website: www.burningtons.com
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	Jfsenecal@canac.com
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	Email: mikeallen@simpatico.ca

Springs

Name	Address	Phone Numbers	Internet
ALCO Spring	2300 Euclid Avenue P.O. Box 188 Chicago Heights, IL 60411	708-755-0438 708-709-5000 Fax: 708-755-0056 Customer Service 800-736-2526	
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	

Journal Boxes

Name	Address	Phone Numbers	Internet
Birmingham Rail & Locomotive Company	P.O Box 530157 Birmingham, AL 35253-0157 800-241-2260	205-424-7245 Fax: 205-424-7436	Email: bhamrail@aol.com Website: www.bhamrail.com
Burnington Incorporated	523 West 2nd Street Alliance, NE 69301	308-762-8716 Fax: 308-762-8717	Email: burnigt@btigate.com Website: www.burningtons.com
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	Jfsenecal@canac.com
National Railway	1400 S. Robey Street	P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487
ORX	1 Park Avenue Tipton, PA 16684	814-684-8484 Fax: 814-684-8400	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	Email: mikeallen@simpatico.ca

Trucks / Pins and Bushings

Name	Address	Phone Numbers	Internet
Hadady Corporation	510 W. 172nd Street South Holland, IL 60473	708-596-5168 Fax: 708-596-7563	Website: Www.Hadadycorp.com
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	Email: mikeallen@simpatico.ca
Wabtec	1325 Pratt Boulevard Elk Grove, IL 60007	800-621-3068 Fax 800-329-9772	Website: **www.MotivePower.com**

Shock Absorbers

Name	Address	Phone Numbers	Internet
Lynn Industries	40 New York Avenue P.O. Box 975 Westbury, NY 11590	516-997-1996 Fax: 516-338-4118	
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	

Fuel Tank Fillers

Name	Address	Phone Numbers	Internet
Snyder	P.O. Box 381 Nixa, MO 65717	800-641-4512 Fax: 417-725-4846	

Retention Tanks

Name	Address	Phone Numbers	Internet
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	

Couplers and Draft Gears

Name	Address	Phone Numbers	Internet
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	Jfsenecal@canac.com
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	Email: mikeallen@simpatico.ca

Air Equipment

Name	Address	Phone Numbers	Internet
Multi Service	Ferry Street & Avenue "C" Leetsdale, PA 15056-1384	412-741-1500 Fax: 412-741-3320	
Red River Air Brake	3-30 Durand Rd. Winnipeg Manitoba R2J 3T2	204-231-4111 Fax: 204-231-5132	Website: www.redriverairbrake.com
Wabtec	1325 Pratt Boulevard Elk Grove, IL 60007	800-621-3068 Fax 800-329-9772	Website: www.MotivePower.com
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	
Graham White	P.O. Box 1099 Salem, Virginia 24153-1099	540-387-5600 Fax: 540-387-5639	Sales@grahamwhite.com

Above Deck

Prime Mover

Name	Address	Phone Numbers	Internet
Applied Energy Corporation	2442 Gunnison Street Colorado Springs, CO 80909	719-227-1821 Fax: 719-227-7498	Email: Applied@JTP.COM Website: www.JTP.COM/Applied
Birmingham Rail & Locomotive Company	P.O Box 530157 Birmingham, AL 35253-0157	800-241-2260 205-424-7245 Fax: 205-424-7436	Email: bhamrail@aol.com Website: www.bhamrail.com
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	Jfsenecal@canac.com
Canada Allied Diesel	155 Highway 20 Lachine, Quebec Canada H8S1B4	514-634-6224 Fax: 514-634-4280	Website: www.cadiesel.com
Flam Progress Industries, India	X-47, Okhla Industrial Area Phase Ii New Delhi, India 110 020	Tel: 91+11+6913976, 91+11+6842701 Fax: 91+11+6821054 Contact person: Mr. D.K. Mehta	
Francis Legac Railway Services International, Inc.	38 Sheffield Road Gansevoort, NY 12831	518-584-9407 Fax: 518-9241	
Hitesi	3340 B Greens Road Suite 650 Houston , TX 77032	281-590-6322 Fax: 281-590-6311	Email: mwis816137@aol.com Website: www.hitesiusa,qpg.com
National Railway	1400 S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	

Name	Address	Phone Numbers	Internet
NREC Power Systems	P.O. Box 3016 5222 Hwy. 311 Houma, LA 70361	800-851-6732 504-872-5480 Fax: 504-872-0611	Power@nrecps.com
Preco	6828 La Paseo Street Houston, TX 77087	713-644-2063 Fax: 713-644-0734	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	Email: mikeallen@simpatico.ca
TLC	P.O. Box 1130 Jackson, Michigan 49204	517-764-6001 517-764-6002 Fax: 517-764-6068	Email: jkoebbe@theloco.com
TCM	7180 Warwick Blvd. Newport News, VA 23607	757-244-1100 Fax: 757-244-0900	

Tools & Equipment & On Site Services

Name	Address	Phone Numbers	Internet
PLS	2800 Bernice Road, Bldg. #22 Lansing, IL 60438	708-418-3185 Fax 708-418-3187	
Hydratight Sweeney, A Dover Diversified Company	12508 East Briarwood Avenue Unit 100 Englewood, Colorado 80112	800-448-2524 Fax: 303-749-6001	Website:www.teamsweeney.com
Western Rail, Inc.	8225 W. Trails Suite 202 Spokane, WA 99224	509-624-7207 Fax: 509-459-0126	Website: www.westernrailinc.com

Governors

Name	Address	Phone Numbers	Internet
Illinois Auto Electric	656 County Line Road Elmhurst, Illinois 60126	630-833-4300 Fax: 630-832-6104 800-683-9312	Email: *info@iaeco.net*
Woodward Governor	5001 N. Second St. Rockford, IL 61125	815-877-7441 Fax: 815-639-6033	Website:www.woodward.com
Sardello Incorporated	1000 Corporation Drive Aliquippa, PA	800-681-7056 421-375-4101	Fax: 412-375-4290

Turbochargers

Name	Address	Phone Numbers	Internet
Elliott Turbocharger	901 North Forth Street Jeannette, PA 15644-1473	724-527-2811 800-488-4242 Fax: 724-600-8442	Website: www.elliott-turbo.com
Globe Turbocharger	201 Edison Way Reno, NV 89502	775-856-7337 Fax: 775-856-7338	
Hatch & Kirk	5111 Leary Avenue N.W. Seattle, WA 98107-4888	206-783-2766 Telex WUI 32-8714 ITT 4740064 Fax: 206-782-6482	
TCM Turbocharger & Compressor Maintenance	7180 Warwick Blvd. Newport News, VA 23607	757-244-1100 Fax: 757-244-0900	
TLC	P.O. Box 1130 Jackson, Michigan 49204	517-764-6001 517-764-6002 Fax: 517-764-6068	Email: jkoebbe@theloco.com

Electrical/ Electronics

Name	Address	Phone Numbers	Internet
AZ Railway Supply, USA		514-426-9133 Fax: 514-426-9177	
Burnington Incorporated	523 West 2nd Street Alliance, NE 69301	308-762-8716 Fax: 308-762-8717	Email: burnigt@btigate.com Website: www.burningtons.com
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	Jfsenecal@canac.com
Canada Allied Diesel	155 Highway 20 Lachine, Quebec Canada H8S1B4	514-634-6224 Fax: 514-634-4280	Website: www.cadiesel.com
K&L Electronics	P.O. Box 9690 #7 Portea Drive Pine Bluff, AR 71611	870-535-8262 Fax: 870-535-3643	
Logan	555 7th Avenue Huntington, WV 25701	800-669-1967 Fax: 304-526-4777	Email: loganloco@logancorp.com
National Railway	1400S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	
Romic/Marc Rail Inc.	220 Place Frontenac Pointe-Claire Quebec, Canada H9R 4Z7	514-697-2424 Fax: 514-697-0088	Email: mikeallen@simpatico.ca

Dynamic Brake Grids

Name	Address	Phone Numbers	Internet
Mosebach Resistors		412-220-0200 Fax: 412-220-0236	Website: www.mosebachresistors.com

Air Compressor

Name	Address	Phone Numbers	Internet
Mosebach Resistors		412-220-0200 Fax: 412-220-0236	Website: www.mosebachresistors.com
Red River Air Brake Inc.	3-30 Durand Rd. Winnipeg Manitoba R2J 3T2	204-231-4111 Fax: 204-231-5132	Website: www.redriverairbrake.com
Wabtec	1325 Pratt Boulevard Elk Grove, IL 60007-5710	847-228-4141	Website: www.wabtec.com

LO REZ Couplings

Name	Address	Phone Numbers	Internet
LO-REZ Vibration Control LTD.	186 West 8th Avenue Vancouver, BC Canada V5Y1N2	604-879-2974 Fax: 604-879-6588	Email: lo-rez@LO-REZ.com

Radiators

L&M Radiators	1414 East 37th St. Hibbing, MN 55746	218-263-8993 Fax: 218-263-8234	www.mesabi.com

Eddy Current Clutch

Name	Address	Phone Numbers	Internet
Canac	1100 University Street, Suite 500 Montreal, Quebec Canada H3B 3A5	514-399-7481 Fax: 514-399-4600	jfsenecal@canac.com
Eastland Industries Inc.	4115 W. Washington Hillside, IL 60162	888-701-6500	Website: sales@eimotors.com
National Railway	1400S. Robey Street P.O. Box 2270 Dixmoor, IL 60426	708-388-6002 Fax: 708-388-2487	

Drive Couplings

Name	Address	Phone Numbers	Internet
American VULKAN Corporation	2525 Dundee Road P.O. Drawer 673 Winter Haven, FL 33882	863- 324-2424 Fax: 863-324-4008	
The Zurn Company Driveline is replaced by Ameridrives	1802 Pittsburgh Ave P.O. Box 4000 Erie, PA 16512	814-480-5000 Fax: 814-453-5891	Website: www.amerdrives.com

Cab Equipment

Name	Address	Phone Numbers	Internet
Prime Manufacturing	7730 South 6th Street Ok Creek, WI 53154	414-764-1400 800-657-0707 Fax: 414-764-0945	
Motive Equipment, Inc MEI	2925 South 163rd St. New Berlin, WI	262-780-0169 Fax: 262-780-0316	Sales@motiveequipment.com www.motiveequipment.com

Rebuilders of ALCO Locomotives

Name	Address	Phone Numbers	Internet
Alstom Transport Attn. Keith Gilbert	1830 Le Ber Street Montreal, Quebec, Canada H3K2A4	514-925-3530	
Birmingham Rail & Locomotive Co. Attn. Locomotive Department Steve Baker	P.O. Box 530157 Birmingham, AL 35253	205-424-1000	
National Railway Attn. Lawrence Beal	1400 S. Robey St. P.O. Box 2270 Dixmoor, IL 60426	708-388-6002	
Progress Rail Attn. Jerry Bozeman	6931 Highway 84 East Patterson, GA 31557	912-647-1433	
RMDI Attn. Ron Delevan	P.O. Box 791 Pittston, PA 18640	570-603-0565	
TCM Attn. Bob Kappesser	7108 Warwick Blvd. Newport News, VA 23607	757-244-1100	

Internet Resources

http://www.railsupply Search Engine
http://members.tripod.com/~Jmech/ALCOHunt.html The ALCO Bulletin Board
http://www.aqua.net.au/aquamsgs/mgs/4792.html Posted by Mark Reynolds 618-465-9270 or email: markareynolds@home.com or bmre98@aol.com
http://www.crossrail.com Trade, sell by parts
http://www.nrecps.com/ NREC Power Systems
http://www.bhamrail.com Birmingham Rail & Locomotive Company
http://www.MotivePower.com Wabtec
http://theloco.com/ TLC
http://alcoworld.railfan.net/spare.htm ALCO spare parts Yellow Pages
http://gelwood.railfan.net/manual/rs3-toc.html Operation Manual 1600HP Loco
http://www.dnaco.net/~gelwood/manual.html Operator Manuals
http://www.westernrailinc.com Western Rail Incorporated

APPENDIX B

251 Torque Values
Diesel Engine Major Overhaul Work Scope

TORQUE VALUES FOR 251 PLUS ENGINE

	FT. LB.
BALANCE SHAFTS	
BALANCE SHAFT GEAR NUT	850
CAMSHAFT	
CAM GEAR NUT – TURN TIL CRANK ROTATES + 1 FLAT OR	1600
CAM SECTION NUTS	90
FREE END STUDS AND CAPSCREWS	80-85
CRANKSHAFT	
SPLIT GEAR CAPSCREWS	INITIAL 50 TO FINAL 300
CRANK TO ALT./GEN	1100-1250
CRANK TO FLYWHEEL	850
CRANK EXT. SHAFT, DRIVE GEAR, VIBRATION DAMPENER	450-500
CRANKSHAFT DEFLECTION	0.0008 (0.0018 TOTAL)
MAIN BEARING STUD STRETCH (SEE MI-11066D, SHEET 5)	0.030 OR 0.040 IN.
CONNECTING ROD	
CONNECTING ROD BOLT STRETCH (SEE MI-11176D, SHEET 11)	0.015 OR 026 IN.
CYLINDER HEAD	
HOLDDOWN STUD NUTS	550
WATER INLET ELBOW BOLTS	60
INJECTOR NOZZLE HOLDDOWN BOLTS	50
INJECTOR TUBE CLAMP NUTS	50
VALVE LEVER ASM. CAPSCREWS	200
VALVE TAPPET ADJUSTING LOCKNUT	50
ENGINE BASE	
BASE TO BLOCK	320
EXHAUST MANIFOLD	
EXHAUST SECTIONS TO CYL. HEAD	120
STROND BACKS TO CYL. HEAD	320
BELLOWS CONN. TO TURBO INLET CASING	60
BELLOWS TO EXTENSION CONNECTION	60
FUEL PUMP SUPPORT	
PUMP SUPPORT MOUNTING BOLTS TO BLOCK	140-150
FUEL PUMP MOUNTING BOLTS	60
HIGH PRESSURE FUEL LINE NUT TO PUMP	150
FUEL PUMP INLET BOLT	125
GOVERNOR DRIVE	
PINION DRIVE NUT	75
BEVEL GEAR NUT	60
LUBE OIL PUMP	
DRIVE GEAR LOCKNUT	300
FACEPLATE NUTS	100

	FT. LB.
PISTON	
CROWN NUT ASSEMBLY	250
VIBRATION DAMPENER	
DOWEL BOLTS	150
DAMPENER BOLTS	240
WATER PUMP	
DRIVE GEAR NUT (WITH LOCTITE 271)	300-350
IMPELLER NUT	125
TURBOCHARGER (131-165 MODEL)	
TURBINE DISC TO SHAFT	100
AIR DISCHARGE CASING NUT	30-35
IMPELLER TO INDUCER RING NUT	300
NOZZLE RING CLAMP BOLTS	5-6
GAS INLET CASING CAPSCREWS	30-35
STUB SHAFT TO AMIN SHAFT	100
MAXIMUM ALLOWABLE UNBALANCE OF ROTOR	.002 IN. OZ. IN EACH PLANE

END THRUST – BACKLASH – SIDE CLEARANCE	IN.
SPLIT GEAR	
SIDE CLEARANCE	0.007-0.023
SPLIT LINE CLEARANCE	0.0015 MAX.
CRANKSHAFT	
END THRUST – WITH BRG. SHELL	0.010-0.017
END THRUST – WITH THRUST COLLARS	0.012-0.021
EXTENSION RUNOUT	0.006 MAX.
CAMSHAFT	
GEAR BACKLASH	0.009-0.019
END THRUST	0.006-0.012
LUBE PUMP GEAR BACKLASH	0.006-0.009
RAW WATER PUMP GEAR BACKLASH	0.008-0.013
WATER PUMP GEAR BACKLASH	0.006-0.009
BALANCE SHAFT TO WATER AND LUBE DRIVE GEARS	0.010-0.014
BACKLASH BETWEEN BALANCE SHAFT GEARS	0.010-0.020
GOVERNOR GEARBOX DRIVE TO CAM GEAR	
NYLON GEAR	0.025-0.030
STEEL GEAR	0.015-0.020
INJECTOR NOZZLE OPENING PRESSURE	3700-4050 PSI
PISTON TO CONN. ROD SIDE CLEARANCE	0.013-0.024

Diesel Engine Maintenance

1. **ENGINE CYLINDER BLOCK CAP AND MAIN BASE:**

   - The cylinder block should be disassembled, washed, inspected and all critical welds magnafluxed. Bearing caps and fasteners are to be cleaned, inspected.

2. **MAIN BASE:**

   - The main base should be washed and critical welds inspected and repaired as necessary.

3. **CRANKSHAFT**

   - The crankshaft should be checked for straightness, magnafluxed, flushed, and all main journals and rod journals polished. Using MI 11069E can assist you in the rebuild process.

4. **CAMSHAFTS AND BEARINGS:**

   - Crankshafts and bearings should be qualified and renewed if necessary.

5. **FUEL PUMP SUPPORTS:**

   - Fuel pump supports should be qualified.

6. **PISTON/CONNECTION ROD ASSEMBLIES:**

   - Qualify pistons

   - Qualify connecting rods

7. **CYLINDER LINERS:**

   - All cylinder liners should be qualified or replaced with new hard chrome plated type.

8. **CYLINDER HEADS:**

   - Cylinder heads should be replaced with unit exchange M-1style heads.

9. VALVE LEVERS AND PUSH RODS:

- Valve levers should be replaced with unit exchange.

10. FUEL INJECTION SYSTEM AND COMPONENTS:

- All fuel injection pumps should be replaced with unit exchange or rebuilt and calibrated.

11. FUEL PUMP AND GOVERNOR CONTROL LINKAGE:

- Control shafts should be inspected.

12. TURBOCHARGER:

- The turbocharger should be qualified or replaced with unit exchange.

13. AFTERCOOLER:

- The aftercooler core should be steamed cleaned, inspected, hydrotested and covers re-gasketed.

14. EXHAUST MANIFOLD PIPING:

- Exhaust manifolds and piping should be cleaned, inspected, mating surfaces refaced, if necessary.

15. GOVERNOR AND DRIVE:

- The governor should be replaced with a unit exchange re-calibrated governor.

16. OVERSPEED TRIP ASSEMBLY:

- Overspeed mechanism should be cleaned, inspected and rebuilt.

17. TACHOMETER DRIVE:

- The tachometer drive should be cleaned, inspected and rebuilt.

18. LUBE OIL PUMP:

The lube oil pump should be replaced with a unit exchange.

19. JACKET WATER PUMP:

The jacket water pump should be replaced with a unit exchange pump.

20. CRANKCASE EXHAUSTER:

The crankcase exhauster assembly should be washed, inspected and fitted with new or rebuilt fan motor.

22. TESTING:

An 8-hour incremental break-in test progressively reaching full rated load and speed should be performed.

(Best Practices)
IV. CATASTROPHIC ENGINE FAILURES: SHORT LINES & REGIONALS

Prepared By
Darrell Nielson
Wisconsin Central Ltd.
&
Jor Richardson
Montana Rail Link

Most short line railroads normally do not have a scheduled rebuilding program, because of the low number of miles that they put on their fleet, resources, age of fleet, and locomotive usage and cost.

Locomotives on short lines may not be rebuilt until the engine has a catastrophic failure that can't be repaired without removing the engine from the car body. This is done with a crane rated at 14 tons for a 12 cylinder, 20 tons for a 16 cylinder and 22 tons for a 20 cylinder (Figure 1). This failure may include crankshaft breakage (Figure 2) or bearing failure (Figure 3), head pot or A-frame cracks or breaks (Figure 4), and rod damage (Figure 5). In cold weather areas, freeze damage may figure in (Figure 6). Whatever the reasons, time and cost are the biggest factors facing a short line railroad.

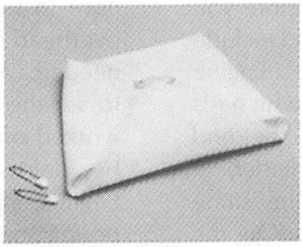
Our paper will address the three ways to get the job done, from buying a running take out engine, to repair on site, to rebuilding.

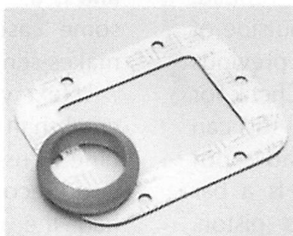
A number of questions need to be asked before any work is started. What does the engine duty cycle and age warrant? Do we have the space or ability to handle the project? What are we looking for after completion of the project? And the big one, do we have the funds?

Not all engines are good candidates for repairing or rebuilding. Most B, BC, (Figure 7), Alco and some 567 engines have seen their days. In these cases you may be further ahead to buy a running take out. The same can go for usage. If the engine only travels short trips, a running take out may make more sense. These locomotives normally have been retired due to uselessness or some failure. Scrappers or job shops pick these locomotives up and part them out.

Evaluating a Running Take out

If you do go ahead and use a running take out, you run the risk that you can end up in the same boat. A list of questions can be very helpful when talking to the party that is selling the engine. First, is the engine complete? Second, how is the engine being stored, outside covered or not, are the stacks on or off; are the covers on or off? An engine that's been stored outside uncovered most likely will need a lot of work to get it running. Third, engine block serial number. This can tell you the age of the engine and whether it's truly what you are looking for. Something to remember, the engine badge number may be from last rebuild records and you





may be surprised what you can find out. A trip to see and inspect the engine before buying it can be cost effective. You should put together a check sheet before you leave. The checklist should include some of the following. Engine block serial number which is located on an EMD at the end cylinder or on a 12 cylinder, at number 12 cylinder. The same goes for a 16 and 20. On the engine badge there may be some information on the last rebuild. Take a good look at the outside of the engine, looking for previous rod damage (Figure 8). Check for a patch by the test valves - this can indicate possible head pot damage. A helpful tool is a bar over sheet that includes piston, ring, and liner condition; ring land wear, piston to head clearance, lead readings, and a crank case inspection. You may want to include in your inspection, crankshaft lateral and gear train backlash. Record all findings. Also take pictures, which can be very helpful when trying to remember when you get back from your trip.

Repairs On Site

Next, we come to repairs on site. One of the most common catastrophic failures is the crankshaft. The crankshaft normally fails due to line bore alignment. There are suppliers that will come on site to line bore (Figure 9). In most cases the cost is lower than if you had to send the block out for line boring. Also there is portable line bore equipment that can be rented and in most cases training is provided.

Things to keep in mind when line boring on site: The engine will have to be split so some type of overhead lifting device will be needed. Also, you will need room to set the block so that it can be worked on and the area needs to be fairly clean. Advanced Engineering offers a portable line-boring machine (Figure 10). This machine takes little room to set up and is user friendly. Renting, or in some cases buying this machine makes sense for some railroads.

Next you will need to find a crankshaft. This is normally not the time to use a running take out. A good reconditioned crank that has had the main journal inspected and crank pins gauged may better fit your needs. When buying a reconditioned crankshaft the chrome should not exceed .032″, main journal diameter should be 7.500″ to 7.4965″, crank pin journal diameter 6.500″ to 6.4965″, thrust bearing clearance .008″ to .030″ and clearance diametric main bearing to crankshaft .0075″ to .0205″.

In many EMD engines head pot cracking is a problem. When head pot cracks are encountered the normal thought would be to just reweld the crack. The problem is that the assembly is working in the pilot bore. To keep this crack from reoccurring it will need to be completely cut out and rewelded. The heat from the welding and the movement will change the head seat surface and height. Due to

this, in most cases the head seat will have to be re-machined. Once again there are a number of companies that will repair it and train your employees how to make such repairs. After your employees have been trained, you can rent or purchase the equipment.

In the case of rod failure and freeze damage, these areas can be very tricky and will take a lot of work to bring the engine back. When looking at the damage it may appear that the job will be simple. But if the repair is not done right all the work will have to be redone and may create bigger problems. Once again there are a number of companies that will gladly come to your shop to make these types of repairs and do training.

When catastrophic engine failure happens and you decide to repair it on site, and if you hadn't made these repairs before, the best way to go is have an outside company come in and do training. Most engine manufacturers do provide a service to come on-site to make these repairs. Make sure you ask for the detailed written quote on what the repairs will cost.

Rebuilding the engine

That brings us to rebuilding the engine (Figure 11), which is the most costly and most time consuming. Before just picking out a manufacturer and sending out the block, an idea of what meets the railroad's needs and budget should be established. It would be great to bring each block back to OEM standards but as we all know, needs and cost may not warrant it.

You will have to pick a remanufacturer to do the work. This will take some calling and maybe a visit to its shop and meeting to talk over cost and time to complete the job. Once the remanufacturer has been picked and the block has been shipped, there is one item that will help you - a crankcase and pan survey.

The survey will break down the areas of the block with the cost to repair them. Some of these areas are: clean and hydro test the water manifold. The main bearing bore and serrations will be qualified and checked for cracks and repairs that are needed will be listed. Head seat surfaces will be checked to center of the crankshaft for wear and cracks. Upper and lower cylinder bores will be checked for sizing and cracks. Cam bracket surfaces are checked for alignment wear and cracks. Exhaust surfaces are inspected for wear steps. Piston cooling bracket bolt holes and tubes are checked for damage. Other items: water jumper bore, test cock tubes, air box and pan ports and doors, end plates, pan and mounting rails, pan structure, crankcase to pan fit. Any remanufacturer will gladly check these items, but they come at a cost. You will have to review the survey and make a choice on what you want repaired. This can be a good place to start putting your shop standards together. Once that is done you will need to find a crankshaft and make a choice on power assemblies (Figure 12), bearings, turbo or blowers and gaskets. If your budget can afford it the remanufacturer can completely assemble the engine and dyno test it.

There are a lot of options to look at when engine failure occur. This paper just gives a basic outline of repairs that may be needed. The one question that needs to be asked up front is, what are we looking for when completed and at what cost?

20-Cylinder Engine

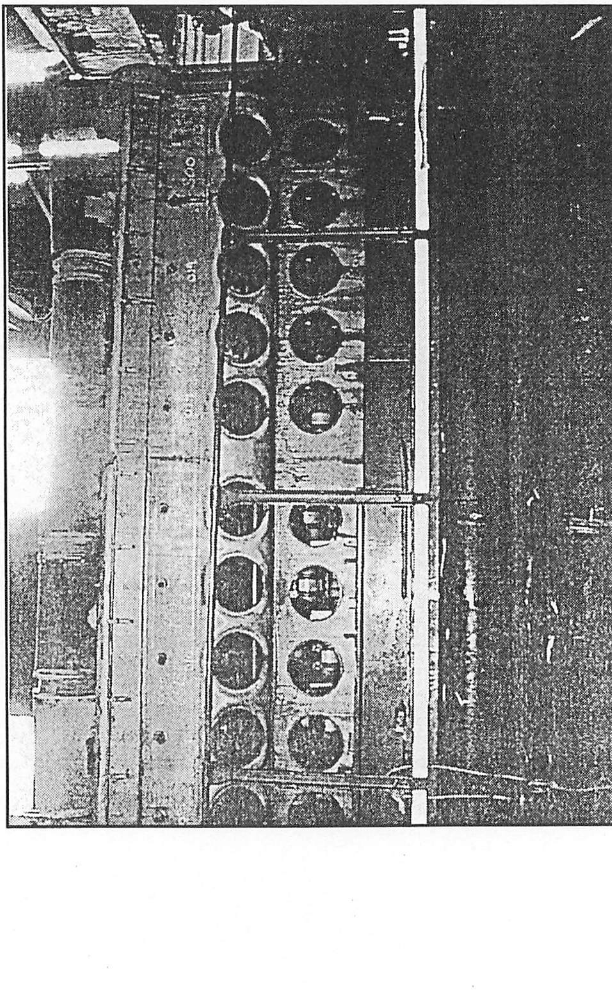


Figure 1

Crankshaft Breakage

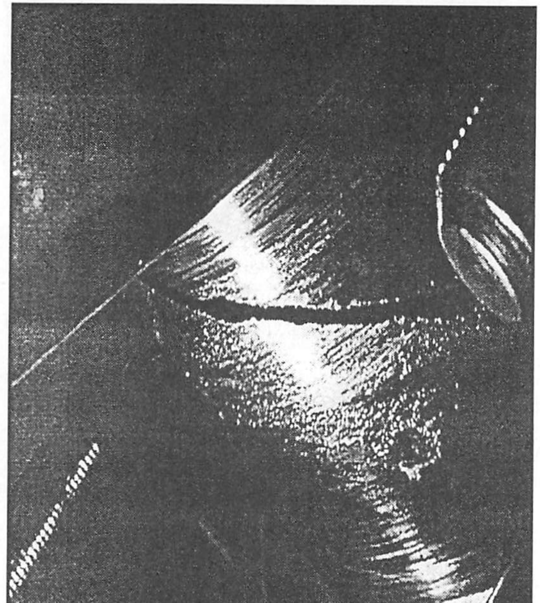


Figure 2

Bearing Failures

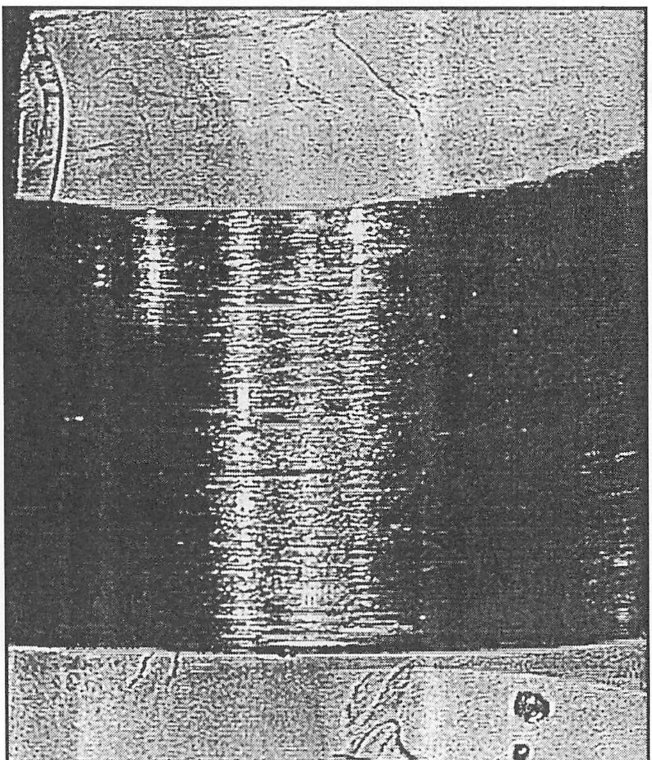


Figure 3

Head pot or A-Frame Cracks

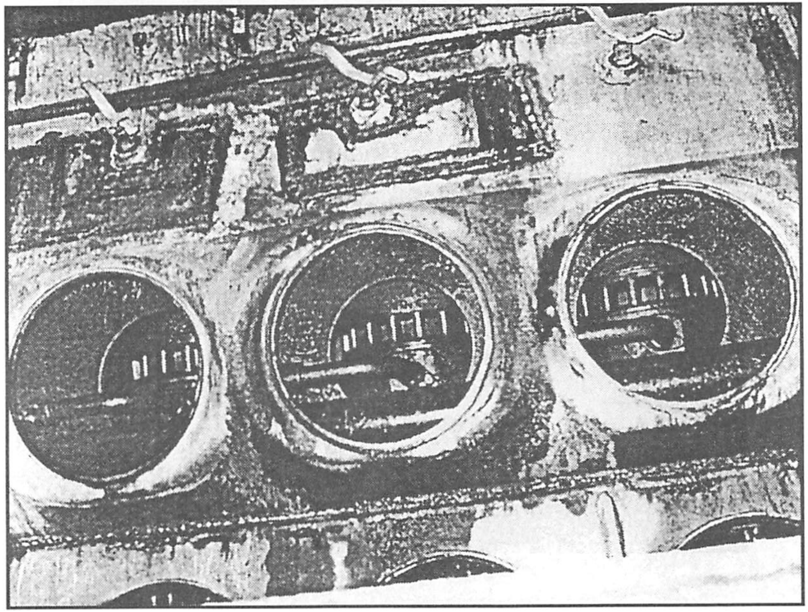


Figure 4

Rod Failures

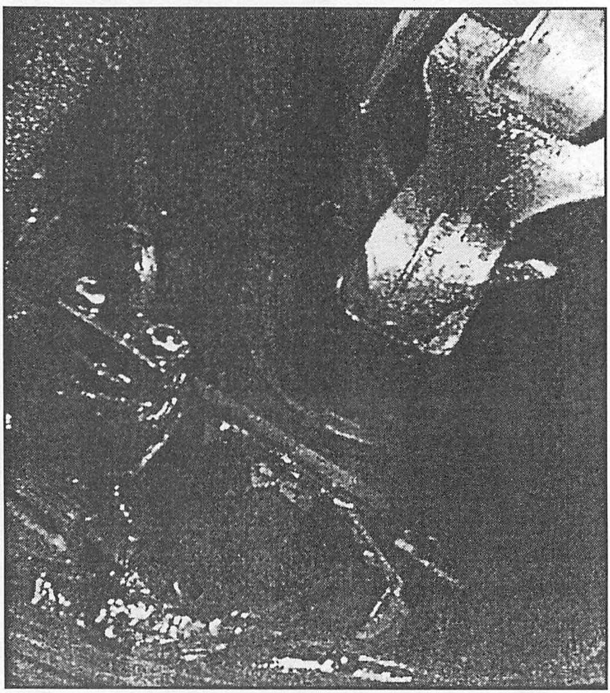


Figure 5

Freeze Damage

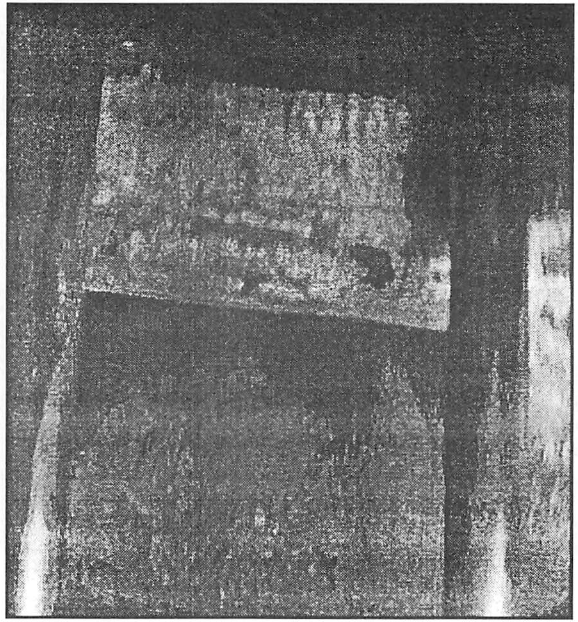


Figure 6

B Engines

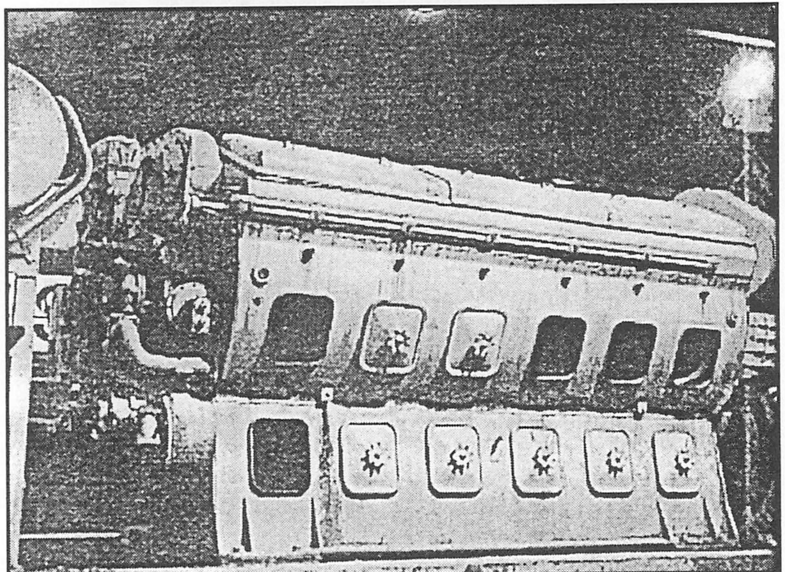


Figure 7

Inspect Engine for Damage

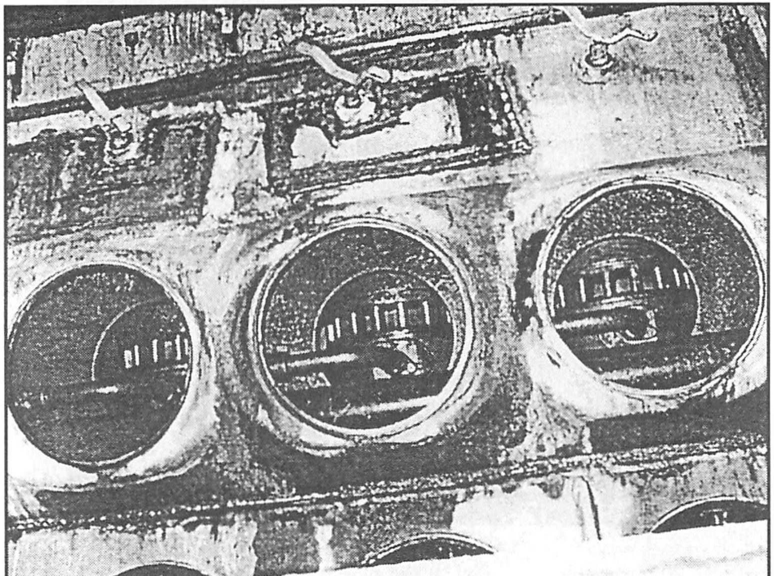


Figure 8

Line Boring

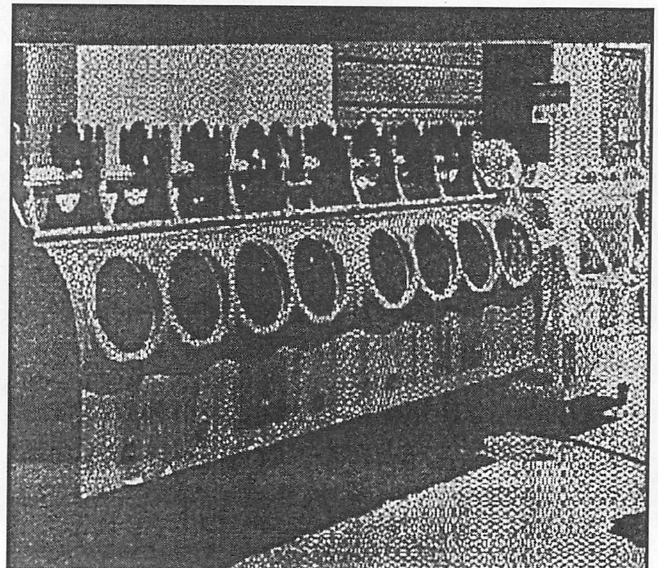


Figure 9

Portable Align Boring Machine

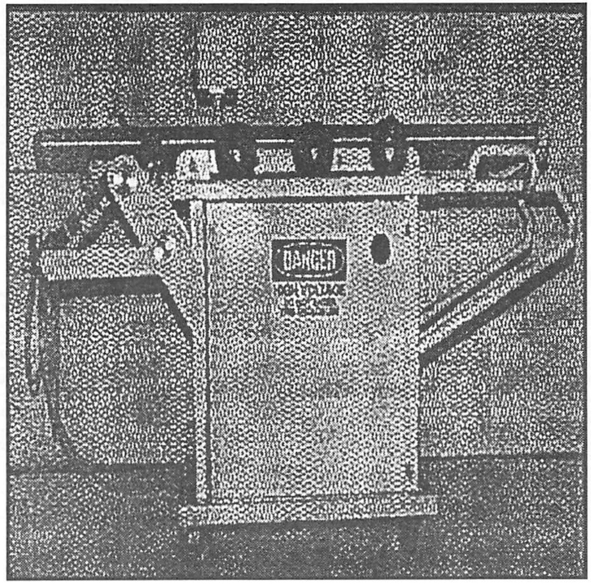


Figure 10

Rebuilding the Engine

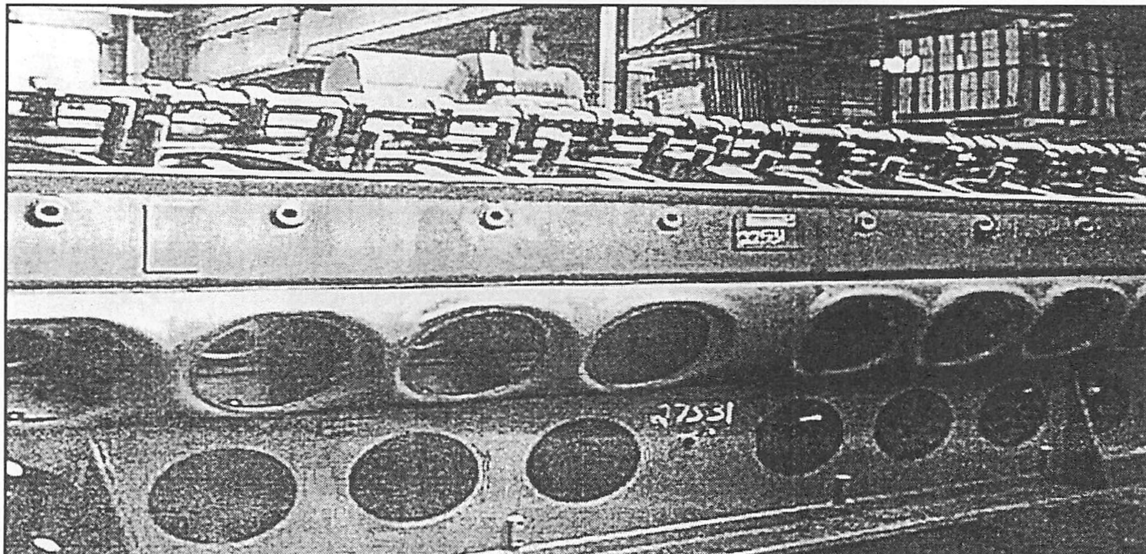


Figure 11

Power Assemblies

Figure 12

V. ARE WE READY FOR RELIABILITY-CENTERED MAINTENANCE?

By Dennis L. Nott,
Motive Power Inc.

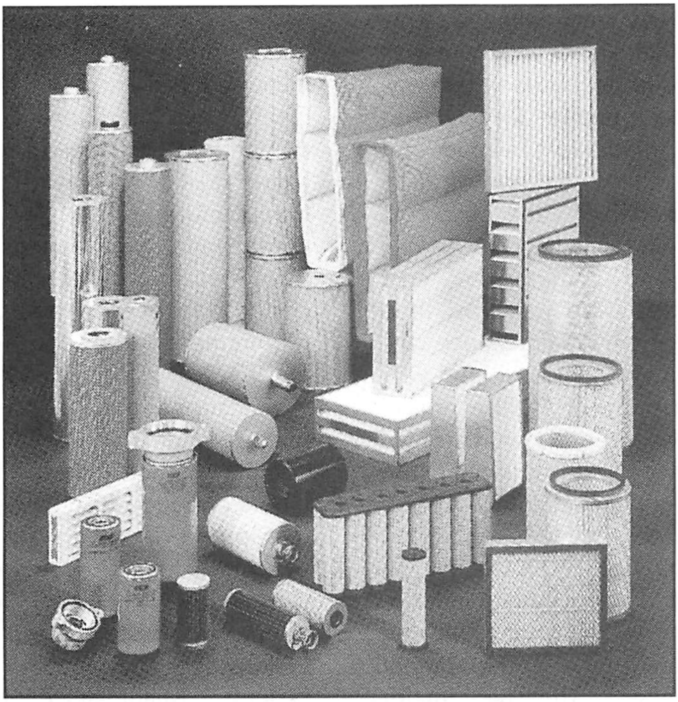
The theoretical basis of reliability-centered maintenance, or RCM, was first developed in the mid 1960's by United Airlines under the sponsorship of the Department of Defense. By the mid 1970's RCM was accepted by the airline industry and the military as a practical maintenance philosophy that emphasized the desired goals of flight safety, increased reliability and cost effectiveness for aircraft maintenance. Since that time the philosophy of RCM has spread to other industries and has become the standard maintenance philosophy for all US military equipment. Before we get into the details of RCM and how it might apply to locomotive maintenance, it is important to understand how maintenance philosophy developed over the last century and led to RCM.

First Generation

Until World War II the mechanization of industry was a slowly evolving process that relied on fairly simple machinery and processes. Early industries relied on steam or water wheel power to drive equipment via belt, chain or gear drive and evolved to other means of power such as electric motors and hydraulics. The machinery was robustly designed yet simple, labor was both abundant and inexpensive and there was no pressing need to prevent equipment failure as the consequences, or costs, associated with the failure were in general low. In most cases maintenance consisted of cleaning and lubrication. The main concept was "if it isn't broken, don't fix it".

Early locomotive maintenance philosophy was similar to other industries as the same common elements existed: the steam locomotive was a fairly simple machine, labor was abundant and cheap and the consequences of a failure were low. In addition, steam locomotives tended to be robustly designed for specific applications or territories. Since the steam locomotives tended to perform the same task within the same territory they were generally operated and maintained by the same people at the same location much as equipment would be operated and maintained at a site-specific factory. If a steam locomotive failed the opinion was "it took 5 minutes to determine the problem and 5 days to fix it". Railroads, however, were a little ahead of most industries during this time period, as most had instituted a structured overhaul schedule to help keep the locomotives running.

When a locomotive failed it generally wasn't of great consequence. Sure, trains were delayed and the customer service suffered, whether it was delayed delivery of goods or late



passengers. Remember, prior to World War II the railroads were virtually the only transportation network in the country and the vast highway and airline systems were in their infancy. There was really no competition, so there was very little penalty for delayed services. In addition, railroads and the rest of industry had virtually unlimited labor at low cost resulting in repair costs whose labor and material cost components were very low. It is easy to see why maintenance cost was not a very big issue and why the philosophy of "failure repair" was prevalent and overhauls of locomotives were considered the best preventative maintenance.

SECOND GENERATION

World War II changed industry and the way it viewed maintenance of equipment dramatically. The two major changes during World War II that affected industry the most were the dramatically increased demand for all products and the great reduction of the labor pool by the military. This led to more mechanized equipment and resulted in more complex and high cost machinery that required less labor to operate and maintain. After World War II more of the technical developments and achievements that were made during the war became available to industry and the equipment and processes of industry became more and more complex. As industrial equipment became more complex industry became more dependent on that equipment. At the same time labor to operate and maintain the equipment required higher skill levels and the competition for skilled labor increased causing labor costs to climb. In addition, a more demanding consumer required higher quality from every product manufactured. The final consideration was that as equipment became more complex its cost also increased leading to the requirement that its life be maximized.

Because of the dependency on plant equipment; its increasing complexity and cost and rising labor costs, industry began to develop preventative maintenance programs. In general, the preventative maintenance programs consisted of better maintenance planning and control systems. Maintenance began to take the shape of planned scheduled preventative maintenance that consisted of scheduled routine maintenance such as servicing, scheduled heavy maintenance such as overhauls; and record keeping for the scheduled and unscheduled maintenance performed provided the control. This philosophy of maintenance served most industries well during this period. However, as aircraft became more complex and the emphasis in airline safety grew in the 1960's, new methods of aircraft maintenance were needed and the seeds of RCM began to take root.

During the 1970's the aircraft industry totally embraced the RCM maintenance philosophy and other industries that shared the same characteristics of high cost, high production equipment began to take notice.

Locomotive design development during this period closely followed the development of equipment in other industries in that it became more complex and expensive. During World War II the diesel-electric locomotive began to replace the steam locomotive. This transformation was complete by the early 1960's. What the diesel-electric locomotive brought to the railroads was a piece of equipment that was many times more complex, was more productive, was cheaper to operate but had a unit cost much more expensive than the steam locomotive. However, because the diesel- electric was equally at home on the flatlands as it was in the mountains it could run anywhere on a railroad's system. By simply adding or dropping units, the motive power requirements for each change in operating conditions could be accommodated. The diesel-electric was also able to run hundreds of miles between fueling and other servicing, eliminating all the costs associated with cooling and water facilities of the steam locomotive. The bottom line, however, was that fewer diesel-electric locomotives were needed to operate the railroads and the overall cost to do so was less than the cost to operate the steam locomotive. Productivity gains had been achieved at a reduced cost.

With the diesel-electric locomotive the railroads had a complex locomotive design that consisted of several subsystems such as the diesel oil engine, a cooling system, an electrical control system, an electrical generation system and an electrical/mechanical transmission system that when put together provided tractive effort to move the train. The introduction of all of these subsystems introduced not only many more parts to the locomotive but also a new set of skill requirements from the labor pool at a time when labor costs were escalating.

Railroads soon realized that with fewer locomotives and constantly escalating costs the maintenance philosophy needed to change to reduce maintenance costs, increase reliability and maximize the life of the locomotive. Railroads began to keep more and better maintenance records, did more maintenance planning and introduced control systems into their planning process to improve the reliability and extend the life of the diesel-electric locomotive. With better records and planning the railroads were able to look at the subsystems of the locomotive and the components of those subsystems and were able to:

➢ Identify high maintenance cost subsystems and components;

- ➢ define what work should be performed between overhauls to extend the life between overhauls (increased preventative maintenance);
- ➢ determine the intervals that scheduled preventative maintenance and overhauls should be performed (time, age or mileage).

Third Generation

In the 1970's changes in technology fueled industry to new levels and expectations with major advances in mechanization and automation. Along with these technical advances came greater expectations from several fronts. Because automation and mechanization meant higher productivity, downtime of key equipment meant higher operating costs and reduced profit. Reliability and availability of equipment became increasingly important. Mass production and consumer standards also forced industry to consistently produce better quality products. Safety and environmental issues became more important as more and more legislation regulated the way industry does business. As mechanization and automation became more complex the cost of the equipment rose accordingly. Maintenance costs, driven by higher costs and specialized personnel, began to rise.

Industry, in general, was driven to make changes that would keep costs down to maintain a competitive position within the market. Industry began to look at new techniques to maintain high production and contain maintenance costs. New fast computers were developed for equipment control and data analysis. Study of failure modes and statistical analysis of failures led to new maintenance procedures and techniques such as condition monitoring. Equipment manufacturers responded with new and better designs that emphasize better reliability, availability and safety. In general, the concept that as equipment got older the more it would fail was abandoned along with the overhaul mentality. As we will see later the aircraft maintenance industry led the way for these changes.

Locomotive development during this period followed the advancements of other industries closely. Locomotives of higher horsepower with transistorized control equipment soon replaced locomotives of lower horsepower and relay logic, greatly improving reliability. The development of microprocessor controlled locomotives led to the ability to control and use even higher horsepower locomotives. The advancements in locomotive horsepower and the optimization of locomotive utilization by railroad operating departments meant fewer locomotives were needed to do more work.

Locomotive maintenance

philosophy, however, did not exactly follow the same pattern as the rest of industry. This is not to imply that locomotive maintenance practices remained static during this period. Rather, locomotive maintenance practice advanced by perfecting those practices that have been in place for years. In general, since World War II, railroads have been able to make economic and safety gains through better designed locomotives and steadily improving maintenance philosophy to control maintenance costs, improve reliability and productivity as well as extend equipment life. To some degree, all locomotive maintenance philosophy to date waits for something to happen before corrective action is taken whether that is failure; a specified time, age or mileage condition expires; or the system or component reaches a specified condition assessment. However, locomotive overhauls are still the prevalent method of renewing the asset they have been for almost 100 years.

Further, one of the underlying assumptions of the scheduled maintenance philosophy is that there is a fundamental cause-and-effect relationship between scheduled maintenance and operating reliability. This assumption is based on the belief that because components wear out the reliability of any piece of equipment is directly related to its operating age. This leads to the idea that the more a piece of equipment was overhauled the less likely a failure would occur.

With today's pressure to reduce costs even further, extend equipment life and increase the reliability of our locomotives we might be ready to try a more "proactive" approach to loco-locomotive maintenance. Reliability-centered maintenance, or RCM, is a more "proactive" approach to maintenance and maybe it has the answer.

Reliability Centered Maintenance

What does reliability-centered maintenance, or RCM, mean? John Moubray, in his book RCM II, actually defines "maintenance" first before he gives us a definition of "RCM". Mr. Moubray defines "maintenance" as:

"Ensuring the physical assets continue to do what their users want them to do."

He further defines "RCM" as:

"A process used to determine what must be done to ensure that any physical asset continues to do what its user want it to do in its present operating context." Think about this in its simplest form; all Mr. Moubray did was add the words "a process used to determine what must be done" to the definition of maintenance to define RCM.

That brings us to the question: What is the process?

The development of the process came from the aircraft industry. By the 1950's the aircraft industry had progressed well into the jet age. As the performance of the newly designed aircraft increased it led to more and more complex equipment on each new model. Aircraft maintenance, which had traditionally been acquired through experience, was being left in the dust by the complexity of the airplanes and the cost of the maintenance was rising accordingly. By the late 1950's it was clear that something needed to be done as actual operating data was beginning to contradict the basic assumptions of traditional maintenance practices.

In aircraft, it was also assumed that all reliability issues were related to operating safety. Again, in the late 1950's it was being proven that many types of failures could not be prevented no matter how aggressive the scheduled maintenance program was. Maintenance was not able to cope with the issue of operating safety but the designers were; hence, all of the redundant systems on airplanes that prevent operational failures.

Having been able to solve safety issues through redundancy, there were still maintenance issues that could not be addressed. The foremost was the issue that hard time maintenance procedures (scheduled maintenance) were not effective in controlling failures. It was found that, contrary to expectation, the likelihood of failure for many components did not increase with operating age. This led to the conclusion that a maintenance policy based exclusively on operating age would, no matter on how small the age limit is, have little effect on the failure rate.

At the same time that the airline maintenance industry was coming to the above conclusions the Federal Aviation Administration (FAA) was in the process of concluding that the airlines could not prevent the failure of certain types of jet engines without changing the scheduled overhaul policy. As a result, in 1960, a task force consisting of the FAA and representatives of the airline industry was formed to investigate the capabilities of scheduled maintenance. This led to a conclusion in November of 1961 by the FAA/Industry Reliability Program that reliability and time controlled overhauls are not necessarily related.

United Airlines, not satisfied that the issue of the reliability had been addressed, continued to study the relationship of scheduled maintenance and failures. In 1965 United issued a very rudimentary decision-diagram process that was further refined for another two years. The resulting process was later included in the document entitled <u>Handbook: Maintenance Evaluation and Program Development</u> and generally referred to as MSG-1. The MSG-1 was the product of an industry task force and government called the maintenance steering group formed in 1968. MSG-1 was used to develop the initial program developed by the FAA Maintenance Review Board for the Boeing 747. This was the first use of the RCM concept.

Subsequently the decision-diagram approach led to the issuance in 1970 of MSG-2: Airline/Manufacturer Maintenance Program Planning Document. This document was used to develop the maintenance programs for the Douglas DC-10 and the Lockheed L1011. It was also used for the several military aircraft projects.

The objective of MSG-1 and MSG-2 was to meet safety requirements and at the same time reduce costs. How effective were they? On a DC-8 there were 339 scheduled overhaul items; on the DC-10 there are only seven.One of the items determined not to require overhaul was the jet engine. This led to significant engine maintenance cost savings in labor and reduced the inventory of spare engines required by 50%.

Another example of savings came with the Boeing 747. On the smaller, less complex DC-8 United was expending over 4 million man hours on structural inspections to reach the 20,000 hour threshold on the air frame; on the Boeing 747 the number of hours for United to reach the 20,000 hour threshold on the air frame was 66,000 man hours.

In December of 1978, F. Stanley Nowlan and Howard Heap, both from United Airlines, issued a 476 page work titled Reliability-Centered Maintenance. This document, commissioned by the United States Department of Defense, takes MSG-1 and MSG-2 and Unites Airlines RCM maintenance philosophy and defines the process of RCM. This document has become the backbone of RCM.

RCM: The Process

Now that we have some feeling of maintenance history and where RCM originated we can discuss the process. In his book RCMII, John Moubray summarizes the concept of RCM as submitted by Nowlan and Heap in their 1978 paper. Moubray states that the RCM process begins with seven questions that lead to seven distinct characteristics of the process. Those seven questions are:

1. What are the functions and associated performance standards of the asset?
2. In what ways does it fail to fulfill its functions?
3. What are the causes of each functional failure?
4. What happens when each failure occurs?
5. In what way does each failure matter?
6. What can be done to predict or prevent each failure?
7. What should be done if

suitable proactive task cannot be found?

Asset Function and Performance

Defining the asset function and performance is the first step in the RCM process. In order to accomplish this task a team of individuals must be assembled. This team should be broad based and should cover all aspects of the asset including, but not limited to, individuals knowledgeable in the management, design, operation, and maintenance of the asset. In some cases, the customer, the manufacturer or the supplier of the asset may be a valuable member of the team.

The first steps for the team is to determine 1) what the user wants the asset to do; and 2) ensure that the asset is capable of doing what the user wants to start with. What the user expects can be broken down into two categories. The first is defined as the "primary functions" which includes why the asset was acquired and typically includes such performance parameters as speed, output, product quality and so on. The second is known as "secondary functions" and recognizes that every asset has qualities that fulfill more than the primary functions. Secondary functions can include such items as safety aspects, operator comfort, economy, efficiency, compliance with regulations and other parameters that are "pluses" to its primary functions.

This step in the RCM process can be time consuming. In some cases it can take up to 1/3 of the total time the RCM process takes. It also forces the team members to learn an inordinate amount of information about the asset and how it works.

Failures

The second and third steps in the RCM process are to identify and determine how the asset fails to fulfill its intended function and what caused it to fail. To most of us the only way that an asset fails to meet its performance obligations is to physically have a failure. The RCM process asks the team to:

1. Identify what circumstances amount to a failed state and;
2. What circumstances led to the failed state.

In RCM. failed states are known as "functional failures" and occur when the asset is unable to perform or fulfill the function it was intended to do. Performance is a key element in the definition of a functional failure. If a failure occurrence affects the performance of the asset in a manner that is not acceptable to the user, even if it is not a complete failure, it is still a functional failure. For example, if a locomotive has blown an engine the failure is obviously catastrophic and complete and the asset cannot be used. If, however, the dynamic brake system fails, the locomotive can still be used but its braking performance has been compromised and the dynamic brake failure is still a functional failure.

Once the list of functional failures has been determined the team can then proceed to identifying the likely cause for each functional failure. This is known as identifying the "failure modes". All aspects of the failure should be examined. The obvious failure mode is plain old wear and tear. However, the team should consider all possibilities such as human or operator error, changes in operating parameters, and maintenance practices, just to name a few. The team should also compare failure modes of all similar assets to determine if the failure mode is prevalent throughout.

Failure Effects

After the failures and failure modes have been identified the team needs to determine and list the "failure effects". This list should describe what happens when each failure mode occurs and should include enough information needed to support the evaluation of the consequences of each failure. Per Moubray, in RCMII, the list for each failure mode should include the following information:

➢ What evidence, if any, that the failure has occurred;

➢ In what ways, if any, does it pose a threat to safety or the environment;

➢ In what ways, if any, does it affect production or operations;

➢ What physical damage, if any, is caused by the failure;

➢ What must be done to repair the failure.

Failure Consequences

In the RCM process each failure must affect the performance of the asset or it would not be defined as a failure. The affect it has on performance, however, may not affect all members of the organization the same. For example, a locomotive failure may be deemed minor by the mechanical department if labor and material required to affect the repair are negligible. However, if that same failure causes a train delay resulting in late delivery or additional crew costs the transportation department will probably deem that failure a major failure. The point is all failures may not affect the organization the same.

The result of a failure is known as the "failure consequences". In RCM, the failure consequences are more important than the technical aspects of the failure. RCM recognizes that doing proactive maintenance is the only way to prevent the failure and avoid the consequences.

Failure consequences can be classified into four types:

✓ *Hidden Failure Consequences:* Those types of failures where the consequences have no direct impact but may expose the asset to multiple failures that may be catastrophic. An example would be a failure of a protective device that is not fail-safe.

✓ *Safety and Environmental Consequences:* A failure where the failure consequence may result in serious injury or death or result in some environmental law being broken.

✓ *Operational Consequences:* A failure where the failure consequence results in loss of production, product quality, or increases operating or repair costs.

✓ *Non-Operational Consequences:* A failure that does not affect production (operations), safety or the environment. The only consequence is the cost of the repair.

By forcing the team to classify and to determine the consequences of the failure the operations, safety and environmental issues are integrated into the maintenance function and maintenance management. In doing so, RCM focuses the team's attention to maintenance activities that have the most affect on performance of the whole organization. It also forces the team to consider ways to manage maintenance other than just failure prevention and to seek out other failure management techniques.

Data Management

Once the functional failures and their consequences have been determined a good way to flush out the maintenance tasks that will be required is the use of a decision tree. The decision tree should break a complex asset down by its systems, subsystems and components. For each failure mode a series of yes/no questions should be asked. The same series of yes/no questions should be asked for each failure mode regardless of what the failure is, what system of the asset it belongs to or what component of the system it is. Each failure consequence should also have a yes/no limb. As the team systematically works through the systems, subsystems, components and functional failures and consequences the team should be able to determine what type of maintenance task is appropriate for each failure mode.

Other data that will be of importance determining which type of maintenance task to pursue will be the statistical data collected on each failure mode. Richard Jones, in his book Risk-Based Management A Reliability-Centered Approach devotes a whole chapter to what he refers to as "responsible statistics". He states "statistics do not prove anything" however, he goes on to say that "statistics, on the other hand, help make decisions in the non-ideal world we call reality".

The data that most industries keep can be generally broken into three categories or types:

1. Operational data
2. Equipment condition data
3. Failure data.

Operational data and equipment condition data are measurements of success indicating everything is working. Obviously, failure data indicates when things are not working. We use failure data to measure failure to improve availability, safety and improve risk reduction.

Independent and Dependent Failure Data

Failure data will follow one of two patterns. The failures will not be related to each other and be independent or the failures will be related to each other and be dependent. Without considering if the data are independent or dependent before standard probabilistic and statistical methods are applied may result in questionable results.

In most cases in the real world very little that happens to systems is independent. This includes failures. In most systems the failure data are made up of failures that were dependent or influenced by another source. For example, a seal has failed on a pump and it is replaced. The seal fails again and is replaced a second time. After the second seal has been replaced the bearings in the pump fail and it is discovered that the alignment of the pump drive is incorrect and has been so since the pump was installed after overhaul. None of these failures was independent; they were in all probability caused by the faulty alignment of the pump when it was installed. These failures are all dependent because there was a relationship between the failure mechanisms.

The important factor here, however, is that statistical analysis cannot account for dependent data factors and is based solely on independent data and a second related assumption that the data are identically distributed. When the data are both independent and identically distributed it is known as IID and the data form the foundation of the application of the usual statistical analysis tools.

In most cases the data are not subjected to a review for independence before statistical analysis is performed. Most times this is due to a large amount of data and it can be time consuming to pour through the failure data looking for independence. Another factor is that enough data may not be available, as in the example of the pump alignment being the root cause of the failure, to determine if the failure was independent. Also, it is easier to apply the trend testing for the identical distribution factor. There are four methods of trend testing; Laplace; MIL-HDBK-189, rank; and linear reggression.

The procedure to determine

the validity of the IID properties for the failure data has four steps:

1. Perform trend analysis to determine if the identical distribution property exists. A trend contains three properties; the probability that a trend exists among data values over time; a trend type showing improvement or deterioration; and trend strength which is an indication of how fast the improvement or deterioration (reliability) is occurring.
2. If no trends are found then test the data for independence either by statistics or peer review.
3. If some of the data do not pass the independence remove these data and begin the analysis again.
4. If the data are independent the data are IID and the standard methods of statistical reliability such as Weibull distribution or exponential can be applied.

Statistical Analysis and Probability

Weibull distribution is a widely used method of statistical analysis used to determine the probability of a failure because it has a large variety of shapes enabling it to fit to many different kinds of data. The Weibull frequency distribution, or probability density function is shown in Figure 1.

Beta defines the shape of distribution and is called the shape parameter. Alpha defines the spread of the distribution and corresponds to the 63rd percentile of the cumulative distribution and is known as the scale parameter. When Beta = 1, the Weibull distribution is the exponential distribution. When Beta is between 3 and 4 it closely approximates normal distribution.

Before the United Airlines RCM study the predominant statistical failure mode was felt to a fixed interval failure mode where probability of failure was constant for a long period of time until it reached a wear out zone where the probability of failure increased dramatically (see Figure 2). Belief in this failure probability mode led to the maintenance philosophy of overhauls at fixed intervals.

In the United Airlines RCM study statistics determined that the probability of aircraft failures fell into six basic probability of failure modes or failure curves (Figures 2 through 7). They are:

Probability or failure mode "A" is commonly called a bathtub curve. It is a combination of two or more different failure patterns including traits of infant mortality initially, flat or gradual wear-out in the middle and definite age related wear-out in the final stages. It is speculated that the flat or gradual increasing portion that forms the bottom of the bathtub may be random failure.

Probability or failure mode "B" depicts age related failures and is a virtual duplicate of the traditional failure probability curve that has a low or gradual increasing failure rate that ends in a wear-out mode with a high probability of failure. However, very few failures modes follow this curve.

Probability or failure mode "C" shows a steadily increasing probability of failure with no real point where the item is worn out. This curve is usually, but not always, associated with fatigue types of failures that are caused by cycles of stress. The shape of the curve is also a little misleading as it shows failure starting at time "zero" when in actuality fatigue type stress induced failures do not usually start to occur until a minimum number of cycles have been absorbed. This curve can also be very flat or very steep and the slope will be governed by the Alpha parameter of the Weibull distribution (days to decades). If one were to plot the frequency of failure curve for this failure mode it would resemble the shape of the Weibull distribution curve when Beta = 2 albeit, it would be a shifted Weibull distribution as time does not start at "zero" in this instance. In addition, this mode of failure probability has been found to fit the failure of the insulation on windings of certain types of generators.

Probability or failure mode "D" has no infant mortality failures that with a rapid increase in failures that rapidly flattens out to a constant probability of failure. This probability of failure curve is most associated with the Weibull distribution curve where Beta is greater than 1 and less than 2.

Probability of failure mode "E" shows a constant probability of failure for the total life of the equipment and represents random failures. Because the failure mode is random the probability of a failure in one time period is the same as any other time period and it is impossible to determine how long any one item in the sample will last. With a constant conditional probability of failure the survival distribution curve becomes exponential which in theory means the process of decay would go on infinitely; however, in the real world it would end at unity. The mean time before failure (discussed below) for this failure mode is at the time 63% of the items have failed. Items that typically fall under this mode of failure are bearings and light current electrical and electronic equipment. When an item falls under this mode of failure it is virtually impossible to plan any sort of maintenance plan, reactive or proactive, to prevent the failure.

Probability of failure mode "F" shows a high initial probability of failure that drops off to a constant or very slowly increasing rate of probability of failure. This is the most common failure pattern. The shape of the curve indicates that the highest occurrence of failure is right after the equipment is new or has been overhauled. This is known as "infant mortality" and has a wide variety of causes:

- New design: New designs that have not been thoroughly tested or have not been in service long typically have a high infant mortality failure rate.
- Poor quality of manufacturing: If the equipment was poorly manufactured or had an inferior overhaul it will have a high number of infant mortality defects.
- Incorrect installation: If the equipment is not installed correctly (alignment, wrong foundation, too few mounting bolts, and so on) it will have a high infant mortality failure rate.
- Incorrect commissioning: If the equipment is not commissioned properly, for example, it is not run in or lubricated properly before starting up, it will have a high infant mortality failure rate.
- Incorrect operation: If a piece of equipment is put into service without proper instruction to operating personnel there is a good chance of infant mortality failures.
- Incorrect maintenance: If maintenance personnel are not trained properly the lack of maintenance, or even too much maintenance, may lead to infant mortality failures.

In the United Airlines study the percentages of failure modes that fit each probability curve were:

Probability Curve A (Figure 2):	4%
Probability Curve B (Figure 3)	2%
Probability Curve C (Figure 4)	5%
Probability Curve D (Figure 5)	7%
Probability Curve E (Figure 6)	14%
Probability Curve F (Figure 7)	68%

What the above did for the aircraft maintenance industry was point out that there was very little connection between reliability and operating age with 89% of the failures not benefiting from a limit on operating age (Probability Curves D through F). In fact, with the old overhaul maintenance philosophy failures were being introduced into the system through the introduction of infant mortality failures every time an overhaul was completed. While the above results may not apply exactly the same to other industries or locomotives it is felt by many in the RCM field that the more complex the asset the closer it will match the findings in the aircraft maintenance field.

There are other useful items that come from the statistical analysis of the failure data. The failure rate is the total number of failures divided by some measure of operating exposure such as hours or days. In the aircraft industry the failure rate is normally expressed as failures per 1,000 hours. As an example, if ten failures occurred over 8,000 hours the failure rate would be 1.25.

Weibull will also tell us the mean time before failure, or MBTF, which is a widely used reliability index. The MBTF is the reciprocal of the failure rate so in the example of ten failures in 8,000 hours the MBTF would be 8000/10 or 800 hours.

Weibull is also used to estimate the optimum time for preventative maintenance activities. From the reliability data the Weibull will also estimate the future probability of failure. This information, along with the failure rate and the MTBF all contribute to the type and frequency of maintenance to be performed.

Other items that can be analyzed or identified due to reliability based statistical analysis are:

- Root cause analysis of individual failure modes
- Identification of vibration related failures
- Identification of machine design problems
- Identification of system design problems
- Identification of equipment material problems
- Identification of construction problems
- Identification of unsatisfactory maintenance procedures
- Identification of improper operating procedures
- Awareness of inadequate preventative maintenance activities.
- Awareness of inadequate inspection.

Using the decision trees with statistical analysis the team can now look at what type of maintenance tasks to perform.

Failure Management

Failure management techniques and tasks can be viewed as two distinct categories:

1. *Proactive tasks:* Tasks that are done before the failure occurs. These tasks include predictive and preventative maintenance, schduled restoration, scheduled discard and on-condition maintenance.

2. *Default actions:* These tasks deal with the failed state of the asset and are used when no other proactive task is available. These tasks include failure-finding, redesign and run to failure.

In second generation maintenance thinking, the overhaul activity was perceived to be the best way to provide proactive maintenance at fixed intervals. This assumed that the equipment would work reliably for a determined period of time and then wear out. Probability Curve B best exemplifies this failure mode. In the aircraft industry 2% of the failures fell into this category.

As mentioned above, proactive tasks are those that are done before the failure occurs. RCM breaks proactive tasks into three distinct categories:

1. Scheduled restoration tasks

2. Scheduled discard tasks
3. Scheduled on-condition tasks.

Scheduled restoration is the remanufacturing or overhauling of a component or an assembly at or before a specified age limit is reached. Scheduled discard means discarding a component or assembly at or before a specified age limit regardless of the condition of that component or assembly at that age limit. Both of these methods are known as preventative maintenance.

On-condition tasks are based on the assumption that the equipment is kept in service "on the condition" that the equipment continues to meet the required or desired performance standards. The base premise is that potential failures are detected before they occur. Types of tasks that are "on-condition" include predictive maintenance, conditioned-based maintenance and condition monitoring.

In RCM there are three default actions:

Failure-finding: Tasks that involve checking for hidden functions on a periodic basis to determine if a failure has occurred. This differs from condition-based tasks, which involves determining if something is failing.

Redesign: Tasks that involve making any one-off change to the built-in capability of the system. This applies to hardware and once-off changes to procedures.

No scheduled maintenance: Nothing can be done to prevent the failure mode. This is also called run-to-failure.

Because the team has gone through the decision tree and statistical process, RCM provides the basis of what proactive maintenance task is feasible, how often the task should be applied and even who should do it (operator, maintenance team, contractor, manufacturer or other). The feasibility of the proactive task will be governed by the technical characteristics of the task. If the proactive task is worth doing will be determined by how well it deals with the failure consequences. If no suitable proactive task can be determined then a suitable default action must be chosen.

For "hidden failures" a proactive maintenance task is worth doing when the risk of multiple failures is reduced to an acceptable level. If the proactive task cannot be performed for any reason (physically cannot be done, time constraints, cost constraints, etc.) the default action would be to substitute a scheduled failure-finding task. If this is not possible a redesign will be required.

For failures that have safety or environmental consequences a proactive maintenance task is performed only if the task significantly reduces or eliminates that failure. If proactive task does not significantly reduce or eliminate the failure the operational process must be changed or the equipment redesigned.

For failures with operational consequences a proactive maintenance task is performed if the total cost of implementing the task, over time, is less than the operational losses from the consequences for the same time period. The task must be justified on economics. If a proactive task is not feasible the first default action is to do no scheduled maintenance. If the operational consequences are still too great the equipment must be redesigned.

For failures with non-operational consequences a proactive maintenance task is performed if the cost of the maintenance task is, over time, less than repair costs over the same time period. If the costs to perform the maintenance task are not justified the first default action is no scheduled maintenance. Again, this is an economic justification. If repair costs are still high with the default action, redesign is the last default action.

Using the above results in proactive maintenance tasks being assigned to failures that really need them, that is, have the highest cost consequences. This results in reductions in routine maintenance workloads and allows more time to do the proactive tasks properly. Maintenance tasks that may have been performed in the past to prevent failures with very low consequences can be reduced or eliminated. Again, this allows concentration on those maintenance tasks that prevent failures with higher cost consequences. Management can better direct scarce resources for higher productivity and reliability gains.

RCM and locomotives

Are we ready to use the RCM process for locomotive maintenance? The answer is in all probability a "qualified" yes. All of the elements that originally led the aircraft industry to RCM, and others to follow, are inherent in today's locomotives. Those would include such factors as:

- *High initial asset cost:* \$1.4 to \$2.0 million per locomotive
- *Highly complex:* Microprocessor control, electronic air brakes, advanced cab electronics, AC traction systems and new design high power engines.
- *Environmental:* Compliance to Environmental Protection Agency emissions laws.
- *Reliability:* Higher horsepower locomotives mean fewer locomotives on trains requiring higher reliability. The consequences of operational failures today are too costly.
- *High maintenance costs:* Labor and materials cost are not going down.
- *Productivity:* GPS and advanced traffic control systems are resulting in operational gains

with high locomotive utilization.

• *Safety:* Emphasis on crew protection and comfort.

Notice that the comment "in today's locomotives" was used for the above reasons RCM should be used. There are no rules for RCM that state that it cannot be applied to any piece of equipment (or locomotive) regardless of the age of that equipment. However, in that the RCM process itself is very complex and time consuming it begs to question if developing RCM programs on classes of locomotives that may have limited economic life is effective. RCM was developed by the aircraft industry to develop maintenance programs for new types of aircraft before they entered service. It just makes sense to start an RCM program with the segment of the fleet that is going to be around the longest and then work through the fleet towards the older locomotive classes or to the point where the economic life of the locomotive class justifies the effort. Remember, the goal is to extend the life of the locomotive, increase its reliability and do that with the lowest maintenance cost.

RCM will require the railroads to make an "investment" with people to be successful. RCM relies on the "team" to sort through the issues and the team has to be diverse to succeed. The success of the RCM process relies on the premise that decisions are made to benefit the total operation. Individuals from the railroad involved in locomotive maintenance, operations, quality and purchasing need to be on all or some of the teams. The railroad individuals should also be from management and the crafts. The locomotive manufacturers also need to be on the team and could include individuals from production as well as design. Someone with a statistical background will also be needed to interpret the data and supply the statistical analysis. Several software packages are available to assist in the statistical analysis. The teams should all work under the guidance of a highly trained RCM facilitator. This individual will ensure that the analysis is accomplished at the right level, that RCM is understood and correctly applied and to just keep the team focused to complete the process in a timely manner. The training and skill levels required for railroads to implement RCM will require a large investment in training and people. In addition, a major commitment by the railroads will be required to build a meaningful database of independent failure modes.

A locomotive is a complex piece of equipment that has many systems and subsystems with hundreds of components and thousands of failure modes. Again, there are no rules to RCM that dictate how the systems, subsystems and components are broken out; it just needs to be logical. Likewise, there are no

rules with what systems, subsystems or components are done first. Railroads have been keeping failure records for years; common sense says start with those that are high dollar costs to the operation due to maintenance cost or operational consequences.

Will implementation of RCM for locomotives be successful? The answer, unfortunately, is that not all will be successful. Probably the biggest challenge to railroads implementing RCM will be the discipline to follow through with the process. With the complexity of today's locomotives the investment in resources will be heavy and results may not be immediately recognizable. While it is very easy to find information about the successes of RCM, the failures are not well documented. Bryan Friehauf, in an article entitled "Er...Exactly Why Are We Doing This" in the April 2000, Reliability Magazine, has studied RCM type programs at more than 40 facilities over the last 12 years. His observations conclude that approximately 40% of the facilities fail to achieve the goals of RCM. Another 30% of the facilities achieve some success leaving only 30% that succeed. Friehauf concludes that those facilities that fail or only have partial success do not have good implementation of maintenance programs that they developed and their plans lack meaningful objectives and deliverables. Those that succeed all seem to have the common element that management is committed to make total facility improvement.

I would like to thank Mr. Stephen Smith of the Electro-Motive Division of General Motors for pointing me in the right direction for reference material for this paper.

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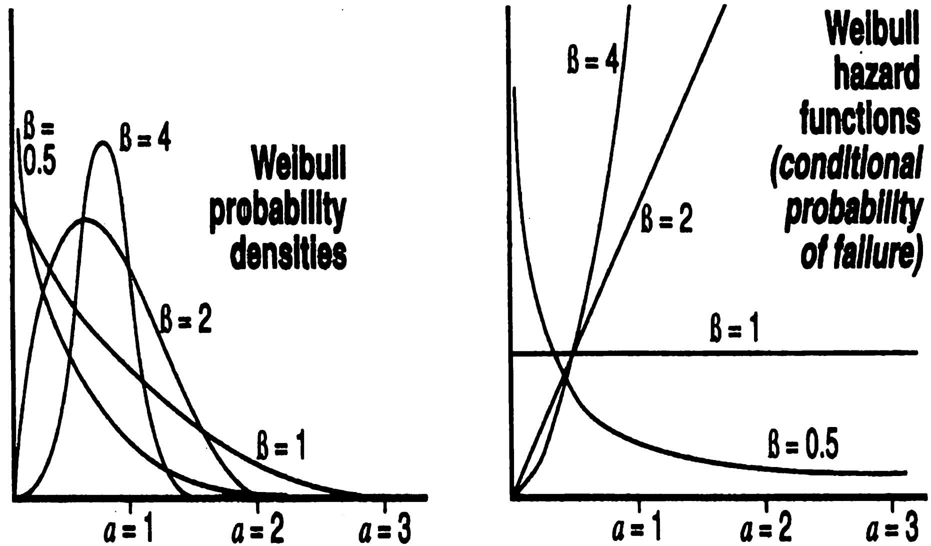
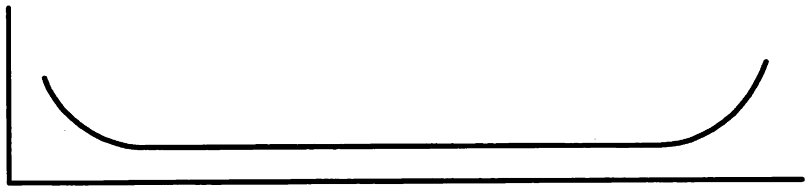
"Er...Exactly Why Are We Doing This", Bryan Friehauf, Reliability The Magazine For Improved Plant Reliability, April, 2000.

FIGURE 1
THE RCM PROCESS
WEIBULL DISTRIBUTIONS



Source: RCM II Reliability-Centered Maintenance, Industrial Press, Inc., 1992

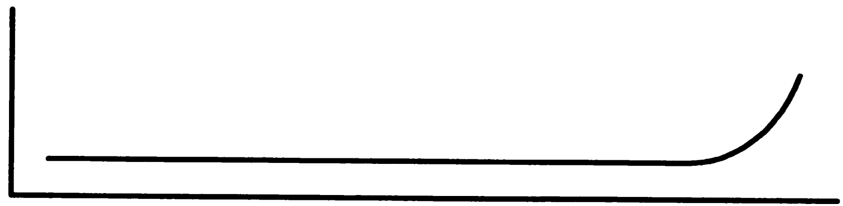
FIGURE 2
Age-Reliability Curves
CURVE A



Infant mortality followed first by constant or gradually increasing failure probability, and then by a pronounced "wearout" region. An age limit may be desirable, provided a large number of units survive to the age where wearout begins. (4% of study sample)

Source: Reliability-Centered Maintenance, Nowlan & Heap, 1978

FIGURE 3
Age-Reliability Curves
CURVE B

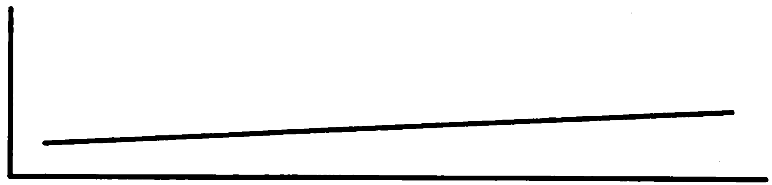


Constant or gradually increasing failure probability, followed by pronounced wearout region. An age limit may be desirable. (2% of study sample)

Few failure modes follow this curve.

Source: Reliability-Centered Maintenance, Nowlan & Heap, 1978

FIGURE 4
Age-Reliability Curves
CURVE C



Gradually increasing failure probability, but with no identifiable wearout age. It is usually not desirable to impose an age limit in such cases.

(3% of study samples)

Usually associated with fatigue failures caused by stress.

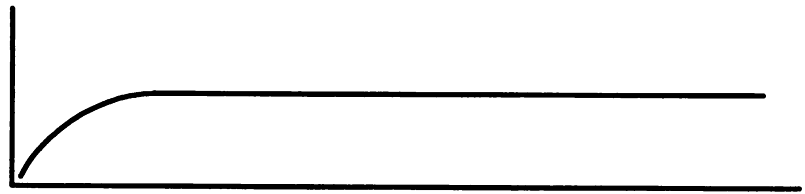
Curve can be very flat or steep; Governed by Alpha parameter.

Frequency of failure curve would resemble Weibull distribution curve for Beta =2, albeit shifted.

Fits failures for insulation and windings on certain type generators.

Source: Reliability-Centered Maintenance, Nowlan & Heap, 1978

FIGURE 5
Age-Reliability Curves
CURVE D

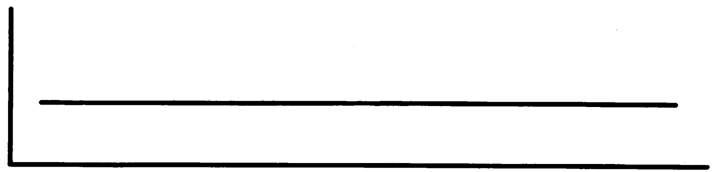


Low failure probability when the item is new or just out of the shop, followed by a quick increase to a constant level. (7% of study samples)

Associated with Weibull distribution curves where Beta is greater than 1 and less than 2.

Source: Reliability-Centered Maintenance, Nowlan & Heap, 1978

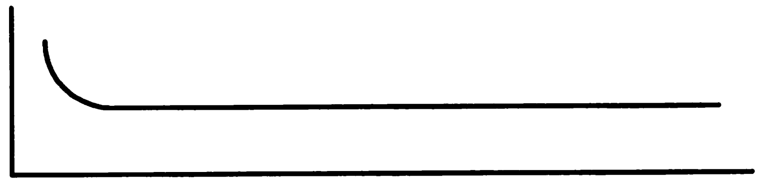
FIGURE 6
Age-Reliability Curves
CURVE E



Constant probability of failure at all ages.
(exponential survival distribution)
14% of study samples
Represents random failure.
With constant conditional probability of failure the survival distribution becomes exponential and the decay process would be indefinite.
MTBF is when 63% of items have failed.
Failure mode most prevalent in bearings and light electrical and electronic equipment.

Source: Reliability-Centered Maintenance, Nowlan & Heap, 1978

FIGURE 7
Age-Reliability Curves
CURVE F



Infant mortality, followed by a constant or very slowly increasing failure probability.

(68% of study samples)

Most common failure pattern.

Highest occurrence of failure at beginning and called "Infant Mortality".

Source: Reliability-Centered Maintenance,Nowlan & Heap, 1978

REPORT OF THE COMMITTEE ON SHOP EQUIPMENT AND PROCESSES

TUESDAY, SEPTEMBER 25, 2001
10:45 A.M.

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

Pre-Convention Presentation:
Sponsored by:
Southern & Southwestern Railway Club

July 20, 2001
Ponte Vedra, FL

Vice Chairman
JOHN MORGANO
Mechanical Superintendent
Wisconsin Central Ltd
Fond du Lac, WI

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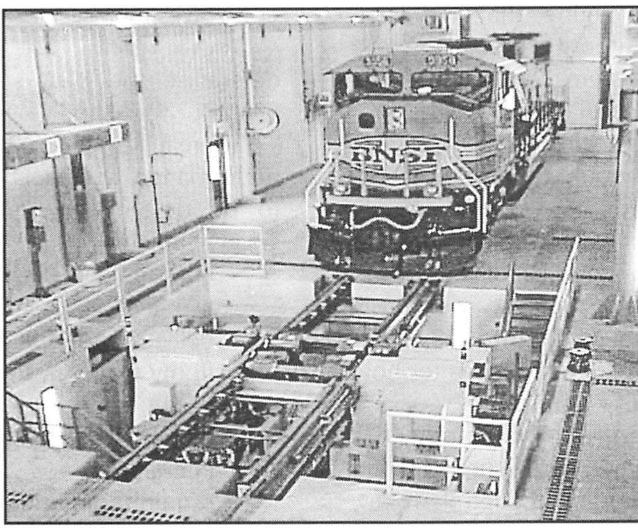


SANDING IN RAILROAD INDUSTRIES PART II – HOW TO SPECIFY RELIABLE AND SAFE SANDING SYSTEMS

Prepared by:
Leonard D. Buczkowske - Florida East Coast Railway and Jack Morin, NEU Inc.

Let's imagine that we have absolute authority to build the best sanding system for your service and inspection (S&I) building.

You may think that your biggest challenge would be money, when, in fact, you would immediately face technical challenges in choosing a good sanding system.

One bad choice can seriously impact the integrity of your sanding operation, no matter how much money you spend.

Locomotive technology has made tremendous progress in monitoring traction control. Today, with systems such as the IDAC (instant detection and correction), sanding on locomotives is done automatically, with sophisticated computers on board. By contrast, it is still common to see railroads using bags to put the sand in the locomotives. Is this fair?

Of course not, especially to our labor force. In last year's paper, the LMOA Shop and Equipment Processes Committee presented various ways of sanding - good or bad.

This paper is written to help you determine essential data, i.e. ease of use, plant wear, sand quality and effect on the environment at the inquiry stage.

The objective is to move away from specific vendor nut and bolt details, to simpler and clearer performance requirements (Figure 1).

Let's review the overall goals –

- Safety
- Reliability
- Investment value.

These goals will help us determine the best solution to meet our workshop's needs.

To reach these goals, various performance specifications need to be determined. A sanding system should –

- be compatible with locomotive fleet and operation;
- deliver sand to fit my need;
- fit my existing yard and shop layout;
- have a friendly labor interface;
- require minimum maintenance; and
- respect the environment.

Locomotive fleet operation

Certain factors need to be considered:

- Do we sand indoors or outdoors?
- How many units per day? (sandbox access)
- How many tracks do I want to service?

All the above affect system design and performance.

Sand distribution suited to my needs

- Storage - Figures 2 and 3 are views of sand storage silos (outside and inside). Apart from receiving the sand, the design of the silo should incorporate filters to avoid dust emission and protect the sand from high humidity.
- Quality - Since we all buy expensive conditioned sand, quality storage conditions have to be maintained (both for indoor and outdoor silos) including dehumidification.
- Rates - Current systems do not monitor sand consumption. Quantities vary tremendously from light rail vehicles (LRV's) to freight applications, and feed rates should be selected to match minimum workshop stopover times. The storage silo pump should be able to move from 2 to 10 tons/hour. Sand distribution to the locomotive or vehicle should be:

LRV	5 - 7 gal./min.
Commuter rail	6-10 gal./min.
Freight Railroad	10-12 gal./min.

- Truck delivery - Silo capacity should allow full truck deliveries to minimize transportation costs. The sanding operation should include a system for scheduling truck deliveries.

Workshop layout

Heavy fixed structures take up space and limit operating flexibility. Today's compact systems can easily fit into existing workshop facilities and allow for future expansions (Figure 4).

Make it user friendly

Flexible locomotive positioning should be considered to allow sanding systems, oiling and flushing operations to be located together, to limit train or locomotive movements. Sand filling devices should be light and easy to handle. Sand feed cutoff should be automatic when sandboxes are full, to avoid spillage (Figure 5, 6 and 7).

Modern systems should be monitored by simple PLC to give important information feedback. Major locomotive suppliers, as well as sanding equipment vendors, are now looking at ground level sandbox filling, to eliminate climbing hazards and fall risks.

Minimum maintenance

Specify that industrially proven, low velocity/dense phase systems be used to eliminate piping and valve wear, and maximize system availability. Dense phase should be a must throughout the entire system from the silo to the locomotive sandbox. Terminal product velocity should never exceed 3 to 7 ft./min., and solids to gas ratios are typically in the rate 30-40 to 1. This will keep abrasion to a bare minimum (Figure 8).

Notes:(A short video illustrating a dense phase mode was shown at the 2001 convention.)

The system should be conceived in such a way that sand dust is contained in the system and no particular maintenance task is required to eliminate it.

Respect the environment

Clean working conditions are essential for acceptance of sanding systems by our labor forces. This should include an integrated dust extraction system. (A video illustrating the differences between having and not having dust extraction was presented at the 2001 convention).

System specifications should clearly define health and safety standards relating to silica. Compliance with OSHA Standard 1910-1000 Z3 for mineral dust exposure should be part of the requirements. The system should be designed to minimize sand spillage.

Summary

Modern technologies exist to help design sanding systems better adapted to railroad needs. System flexibility should account for future fleet and operations requirements. Working conditions for operators should be our prime concern, in terms of ease and safety operation.

Conclusion

Let's remember that sanding systems are included in the FRA regulations, and therefore sanding facilities must be part of future projects.

There will always be lots of "ifs and buts" at the project launch stage. That's why technical specifications have to clearly define the goals and performance requirements of sanding systems for our industry. Give careful consideration to integrating the advantages that state of the art pneumatic systems can provide.

We hope that the above guidelines will help. The LMOA Shop and Equipment Processes Committee would be happy to share these recommendations and current design/safety developments with you. A future paper is planned with more details.

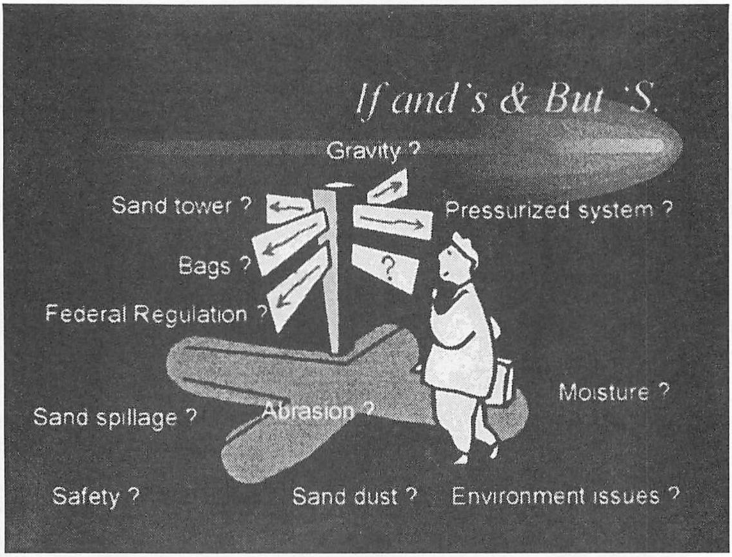
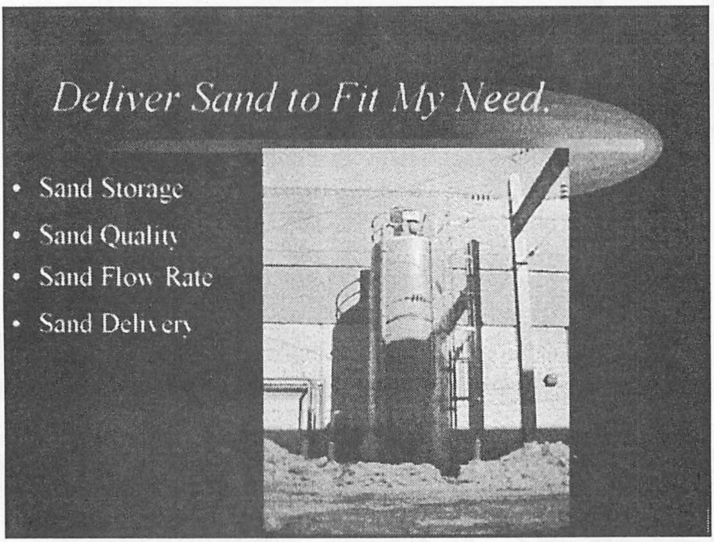


Figure 1



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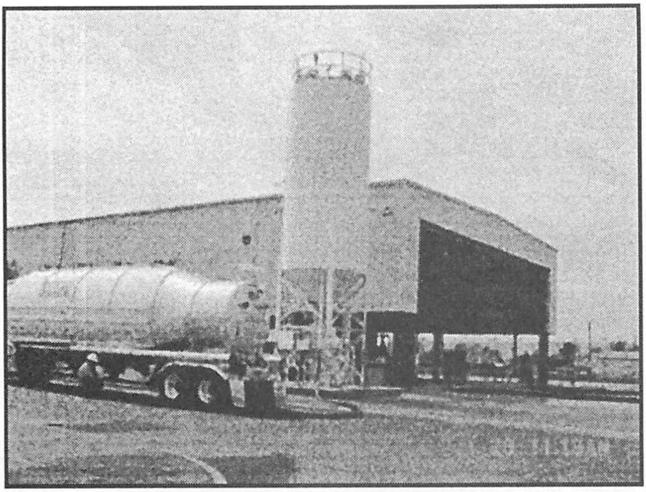

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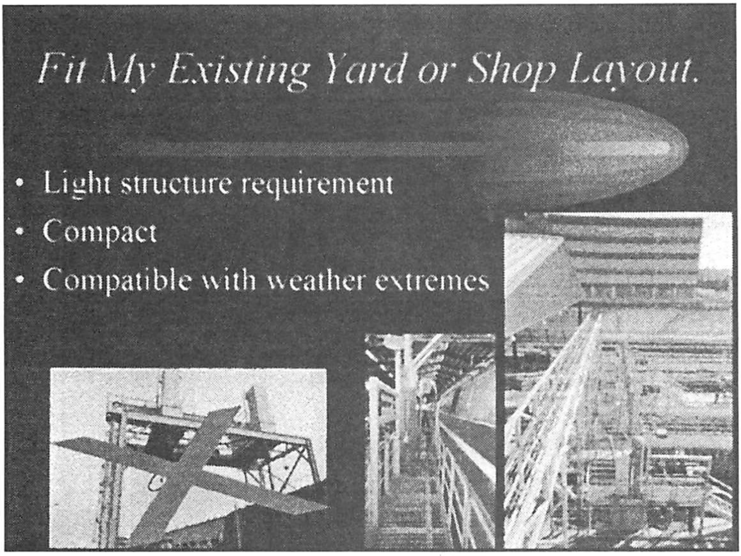

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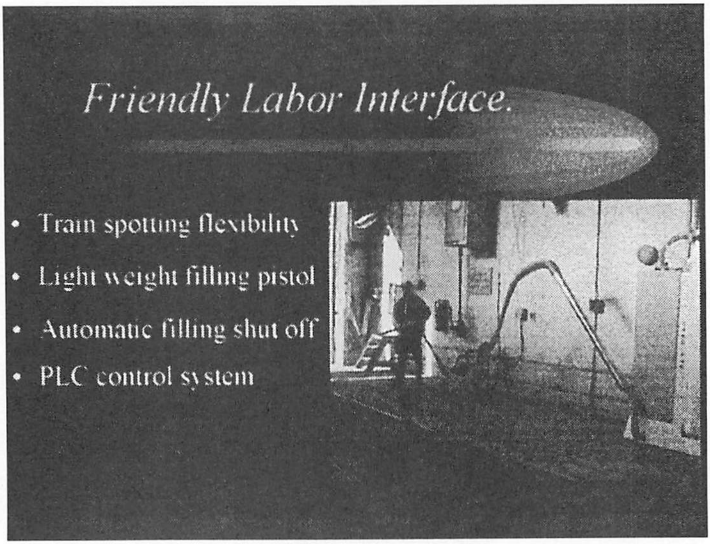

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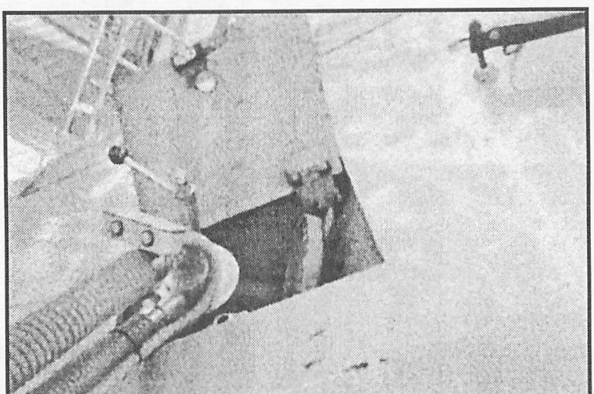

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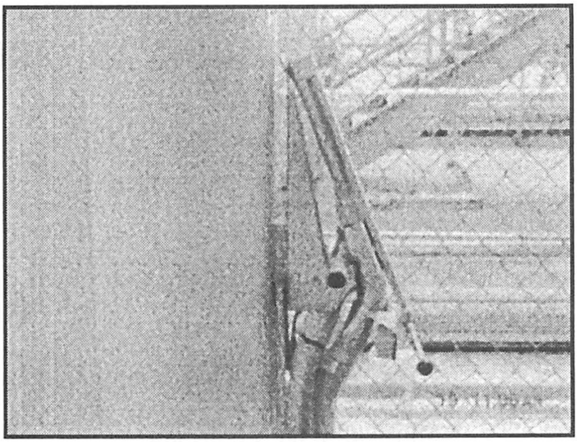

Figure 7

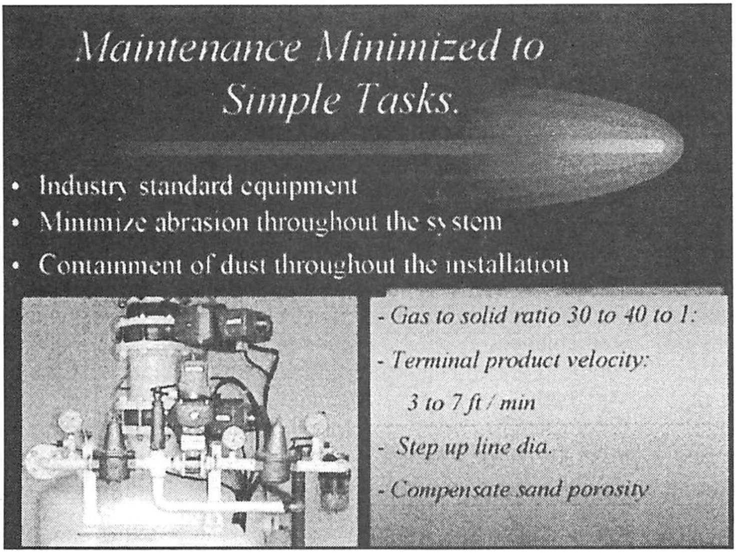

Figure 8

REPORT OF THE COMMITTEE ON FUEL, LUBRICANTS AND ENVIRONMENTAL

TUESDAY, SEPTEMBER 25, 2001
2:30 P.M.

Ron Lodowski, Chairman
Superintendent-Locomotives
CSX Transportation
Selkirk, NY

Vice Chairman
Robert Dittmeier
Technical Services Coordinator
Ethyl Petroleum Additives
Richmond, VA

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P. Whallon	Mgr.-OEM Sales	Clark Filters	Lancaster, PA

PERSONAL HISTORY

Ron Lodowski

Mr. Lodowski was born in Buffalo, New York on March 4, 1950. After his elementary and high school education, he scholared at Canisius University in Buffalo and received a Bachelor of Science degree in Chemistry in 1972.

He began his railroad career with the Penn Central as a Freight Carman in 1975. In March 1977, he transferred to the Locomotive Department and was promoted to General Foreman in Buffalo. In July 1984, he was transferred to Selkirk, New York and was promoted to Manager - Environmental Operations. In August of 1989, he was given the additional duty of Supervisor - Oil Control Labs. In March 2000, Ron was promoted to Superintendent - Locomotives at Selkirk for CSX Transportation.

Ron's hobbies are travel, photography, and he enjoys spectator sports such as hockey and football.

He has been married for 32 years and his wife's name is Susan. They have two children, Michael 31, and Nicole, age 15. Ron and Susan also have two grandchildren.

I. ON-BOARD OIL MANAGEMENT SYSTEM

Prepared by
Michael Melnyk, Ph.D.
GE - Lubrizol, LLC.

Introduction

GE Transportation Systems (GETS) and The Lubrizol Corporation (LZ) agreed in 1998 to develop, optimize, and produce on-board oil management systems that combines the chemical, analytical and lubrication knowledge of Lubrizol with the hardware expertise of Lubrizol system assembly subsidiaries and GETS. The family of products presently being developed and tested is rooted in cooperation with the Union Pacific Railroad dating back to August of 1996. Markets targeted for these products include railroad, mining, marine and stationary applications.

As a result of this cooperation, in June of 2000 GETS and LZ jointly formed GE Lubrizol, LLC charged with the development of solutions for scheduled maintenance optimization combined with fluid-related incipient failure detection. The scope includes regularly scheduled maintenance routine, which occurs throughout the year of an asset, such as a locomotive, a mining vehicle, a ship, or a stationary power plant. This paper discusses some of the technical aspects surrounding the development of the on-board oil management systems.

Summary

The automatic oil change and diagnostic system (AOCD), with two primary sensors, is able to determine four engine oil parameters. The first sensor detects if the crankshaft engine oil is contaminated with water/coolant and the amount of insolubles/soot. The second sensor looks at the oil's viscosity and diesel fuel leaks. A third secondary temperature sensor is used for normalization. A sensor is used in determining the engine oil's relative permittivity of the fluid. In other words, the engine oil is the dielectric isotropic fluid. As the engine oil flows past the sensor's plates, the engine oil's permitivity is measured. New engine oils have permittivity numbers that are initially in the range of approximately 2.2 - 2.4.

During operation, engine oils are contaminated with soot, oxidation products, fuel, and water. Contamination changes the permittivity of the fluid. The force acting between the two charge plates is affected by the change in the permittivity of the fluid. The oil's permittivity change has been correlated to the oil's insoluble materials increase. Water contamination is detected by a major shift in the permittivity of the fluid.

A second sensor is used to determine the engine oil's dynamic viscosity real time. This is accomplished by using an in-line spinning cup viscometer. The viscometer detects small changes in the fluid's viscosity due to oxidation, shear of the viscosity index improver, insoluble increase,


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and diesel fuel leaks. Small gradual changes in viscosity are expected; large or rapid changes are not. Normal laboratory measurements of viscosity cannot determine why the changes are occurring. The onboard viscometer will be able to differentiate between viscosity changes due to normal conditions such as oxidation, or changes due to abnormal conditions such as fuel leaks. This is accomplished by two methods.

One method is to simply look at the absolute viscosity number. If the oil viscosity falls below the lower condemning limit, it is strongly suggestive of a diesel fuel leak. A flag is set that informs the system that there is a likely fuel leak. The second method is to evaluate the rate of viscosity change. There is an expected loss of viscosity with new multi-grade engine oil. The rate and duration of viscosity loss due to shearing of the viscosity index improver can be differentiated from the rate of change due to a fuel leak. The combination of the two, i.e., absolute number and rate change, is used to signal a possible diesel fuel leak.

The automatic oil change and diagnostic module accepts a slip oil flow tapped from the engine oil pump output. This stream flows through the diagnostic section and the instruments monitor the oil condition. The oil is then returned via the lube oil to sump connector.

The AOCD controls a set speed on a viscometer motor. The power to the motor, which is proportional to torque, is monitored. This power reading is corrected, if needed, for component temperature drift and is normalized to set speed.

The motor load is directly proportional to oil viscosity. The calculated viscosity is then compared against expected viscosity at the measured temperature. A propriety algorithm developed by GM Lubrizol, LLC evaluates the current dynamic viscosity, the dynamic viscosity normalized to 100°C, as well as the percentage difference from the expected value and the rate of change of the normalized viscosity. The rate of change would allow monitoring a fuel fault condition, whereas the current reading would relate degradation that is more general. If the current rate of change would achieve a preset trip point within a set period, it would generate a warning non-restrictive alarm condition. Once a restrictive limit is reached, an alarm requiring intervention will be reported.

A similar algorithum functional set applies to the permittivity reading, its temperature lookup and rate of change due to pentane insolubles/soot or water/coolant. All appropriate readings are logged by the engine computer systems with date/time stamp.

Validation of On-Board Measurements

All measurement systems were designed and validated utilizing six sigma tools and applications.

These would include, but are not limited to, statistical measurement validation utilizing Gage R&R Isoplot℠, and process capability.

For the permittivity sensor, initial off-board (laboratory) validation was done using a sample set of forty (40) sensors. The design of experiment (DOE) included calibration standards as well as field drain samples.

The criteria for determining a vaild measurement system utilizing gage R&R are as follows:

- If the %study variation or %tolerance is less than or equal to 10%, the measurement system is considered valid.
- If the %study variation or %tolerance is greater than 10% but less than 30%, the number of distinct categories must be greater than or equal to four (4). If those criteria are met, the measurement system is considered valid.
- If the %study variation or %tolerance is 30% or greater, the measurement system is not valid.

The results of the off-board permittivity sensor validation indicated a %study variation of 2.43%. The measurement system is considered valid. The next step was to validate the measurement system in an on-board environment.

Systems were installed in parallel on a Dash-8 locomotive. Measurements made on-line were then analyzed using the same criteria as for the off-line analysis.

The results of the on-board permittivity sensor validation indicated a % study variation of 19.3% with the number of distinct categories equaling seven (7). The measurement system is considered valid.

With both on-board and off-board measurement systems validated, the overall agreement between these measurements (accuracy) was determined through process capability analysis. The results indicated an overall DPMO (defect per million opportunities) of 960. This represented an acceptable level of variation between on-board and off-board measurements.

The validation process described for the permittivity sensor was followed for the other on-board measurements (temperature and viscosity). The results of this study indicated that all on-board measurements were determined to be both valid and accurate.

Oil Regeneration

Oil regeneration is the process of draining small portions of the crankcase engine oil, mixing it into the fuel and replenishing the drained crankcase oil with fresh oil. This process is done continuously or at regular intervals while the engine is operating. The net effect of oil regeneration is to maintain the engine quality such that normal oil change intervals can be extended or eliminated.

GE Lubrizol's automated on-board oil management system (OMS) uses sensors to determine oil condition and control oil regeneration based on that condition. Since the sensors provide feedback to the control system on oil condition, the oil condition can be maintained at a constant level. The question arises: What oil condition is the "right" condition to maintain engine performance and emissions compliance, while maintaining oil consumption and hence cost? The answer lies in understanding the distinctions between oil condition and oil quality whereby oil quality is defined as those aspects of the oil that affect engine performance, while oil condition is the actual physical state of the oil as measured by off-line laboratory analysis or on-board sensor systems.

Oil regeneration has the potential to impact various engine performance characteristics and engine systems such as the following:

1. emissions
2. critical engine operating parameters (horsepower GHP, fuel consumption BSFC, peak cylinder pressure)
3. fuel system components (wear, deposits in fuel pump, injectors, filter, tank)
4. combustion chamber (wear of rings & liner, deposits on piston crown & behind rings)
5. engine bearings, cams, rings, and all other lubricated surfaces (oil quality).

The objective is to continuously regenerate oil with a process capability such that there is no significant impact on the first four items listed above while maintaining oil quality at a level necessary for a long engine life. No impact means that there is no difference between an engine operating with an OMS and one without. The mean value of the oil management system's process capability is determined by the oil regeneration set-point.

GE Lubrizol, LLC has done extensive testing and modeling to assess the impact of mixing oil into fuel on locomotive emissions, engine operating parameters and oil consumption. These results along with GETS' data on the impact of oil condition on engine component durability, and an understanding of lubricant additive chemistry permit GE Lubrizol to select an optimal set-point for constant oil condition which will have a negligible impact on emissions and engine operating parameters as well as reducing oil consumption since time based changes do not take into account variation in utilization which impacts oil condition.

Acknowledgements

The author wishes to thank GE Lubrizol, LLC for permission to publish this work. The author would also like to thank LMOA's FL&E Committee for their review of this paper.

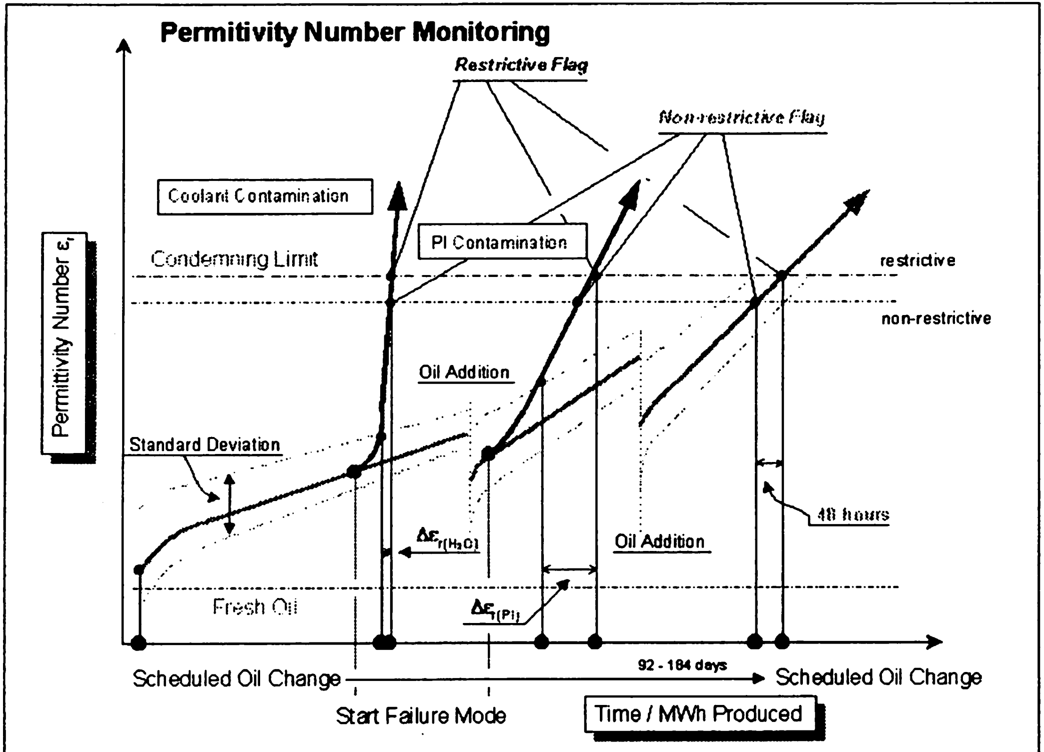


Figure 1: Permittivity Number Monitoring

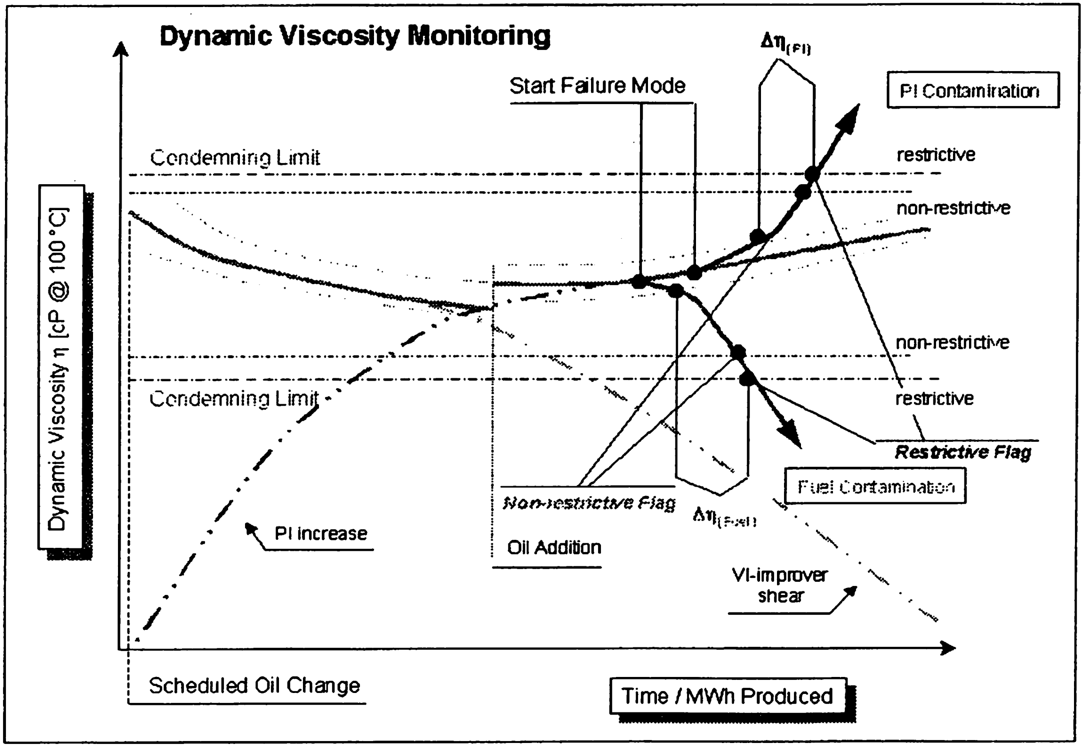


Figure 2: Dynamic Viscosity

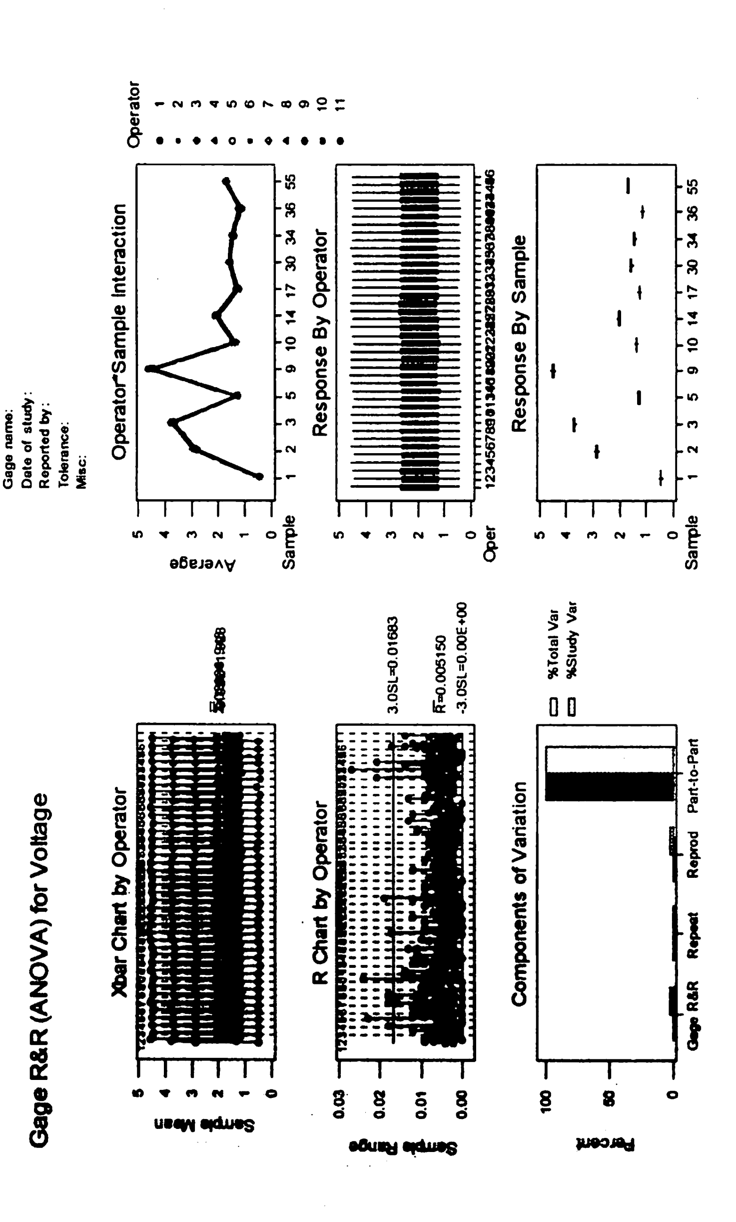


Figure 3: Off-Board Permittivity Sensor Validation

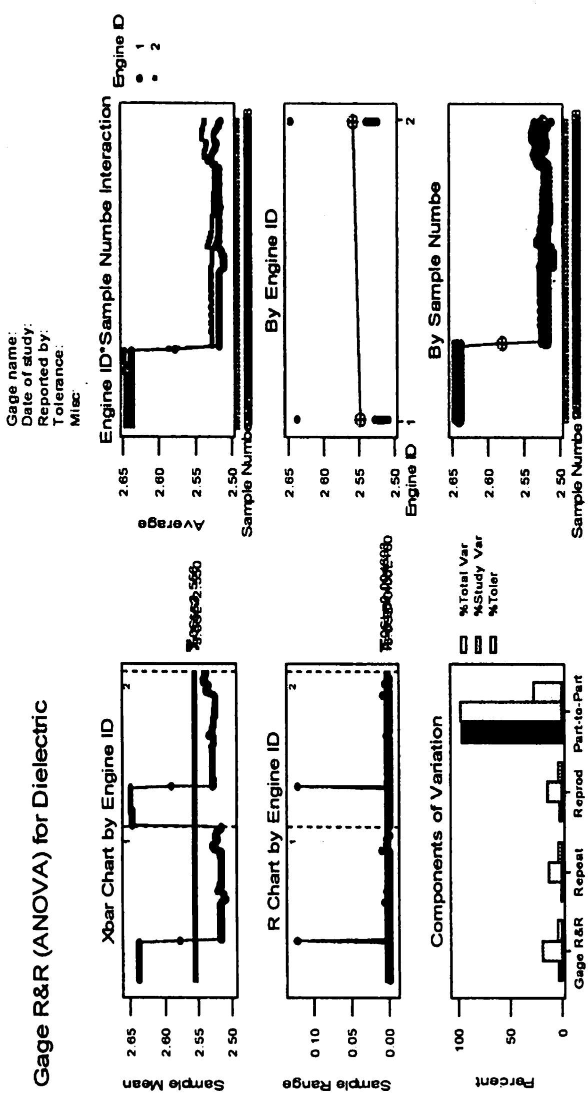
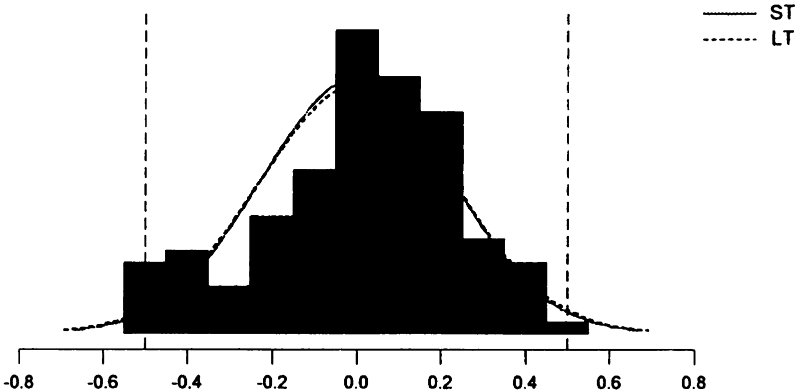


Figure 4: On-Board Permittivity Sensor Validation

Process Capability Analysis for Delta

Process Data	
USL	0.5
Target	*
LSL	-0.5
Mean	0.0
Sample N	123
StDev (ST)	0.224102
StDev (LT)	0.230929

Potential (ST) Capability	
Cp	0.74
CPU	0.74
CPL	0.74
Cpk	0.74
Cpm	*



Overall (LT) Capability	
Pp	0.72
PPU	0.72
PPL	0.72
Ppk	0.72

Observed Performance	
PPM < LSL	32520.33
PPM > USL	8130.08
PPM Total	40650.41

Expected ST Performance	
PPM < LSL	12836.31
PPM > USL	12836.31
PPM Total	25672.62

Expected LT Performance	
PPM < LSL	15187.44
PPM > USL	15187.44
PPM Total	30374.89

Figure 5: On-Board/Off-Board Process Capability for Permittivity Measurement

II. EVALUATION OF LOCOMOTIVE ENGINE OIL ANALYTICAL LABORATORIES

Prepared by
Dennis McAndrew - GETS

Introduction

Several railroads are considering outsourcing all or part of their engine oil analytical laboratories, and many have already done so. Whether the railroads choose to maintain their own laboratory or outsource it, the laboratory's primary function remains the same. That function is to generate high-quality, usable results quickly, precisely and accurately. If the oil analysis system functions as designed, it will increase asset utilization, and increase asset reliability. This paper will discuss GE's six sigma process in evaluating eight independent analytical test laboratories in achieving a quality laboratory.

Abstract

To facilitate high availability and reliability of locomotives, GE recommends frequent testing of lubricating oil for pentane insolubles, viscosity, water content, alkalinity reserve and wear metals. Additional tests such as infrared spectra, and dielectric measurements contribute to the understanding of the oil's condition. These tests should be performed in order to detect fuel dilution, water contamination, and corrosive or oxidized oil, thereby avoiding excessive deposits. These conditions could damage engine bearings and other components.

It is suggested that an advance warning trending system ("flagging" technique) be used for monitoring engine and engine oil condition. The trending system for monitoring used oil condition should consist of oil specimen collection, specimen and unit identification, evaluation in the railroads analytical laboratory or contract laboratory trending (using the OEM's recommended analytical methods), flagging possible problems, and taking corrective action. If the oil analysis trend indicates the used oil is approaching or close to exceeding the used oil condemning limit(s), a warning should be made to ensure the locomotive does not operate with this oil beyond the oil's useful life. If trending is applied correctly there will be a warning system that results in appropriate scheduling of maintenance, increased availability, increased reliability, proper corrective engine oil action, and component life improvement. Savings should be obtained from oil drains at proper times.

Incorrect used engine oil results will have an affect on whether to schedule or not to schedule engine maintenance. This in turn can affect locomotive availability and/or engine reliability. Additional problems can result if test methods are used that have not been correlated to OEM recommended used oil analytical methods. The interpretation of results obtained from other methods can be problematic if not

correlated to OEM recommendations. Ultimately the correlation needs to be to the engines.

This paper will focus on GE's process of evaluating eight analytical laboratories. This process looks not only at precision, accuracy, recommended analytical test methods, and alternate methods but also at the overall process. It is hoped that the railroads find this process for the evaluation of laboratories helpful and use a similar process in evaluating their own laboratory or a contract laboratory.

Process

Using clearly defined steps in the evaluation process has been found to be a valuable aid. The following five steps were followed in the GE evaluation of the laboratories.

- Define
- Measure
- Analyze
- Improve / Validate
- Control

We refer to the above as DMAIC. Each step of the process will be discussed.

Define

The define stage determines the critical parameters. Those critical parameters are items that are determined to be necessary and needed by the customer, who is the end user. The customer's upper level requirements are determined at this point by using a tool called quality functional deployment (QFD). A QFD analysis defines the requirements. The following lists some of the upper level requirements:

- Capability: is the laboratory capable of doing the required tests?
- Data validity: are the data accurate and precise?
- Cost: is it affordable?
- Cycle time: is the time to receive results within the needed time period?
- Expandability: is the laboratory able to have additional test runs if required?
- Presentation: how are the data transmitted (mail, fax, electronic, and in what form)?

After the customer's (end user) requirements were defined, the laboratory's requirements are defined, i.e., what tests are required of the laboratory. Additional factors other than the actual tests are also listed on the QFD.

The QFD is used to relate the customer's requirements to the requirements of the testing laboratory, see Table 1. In this table the customer's requirements are listed on the Y-axis and the laboratories requirements are listed on the X-axis. An imporatance is assigned as being high, medium or low and a numerical number to each level. The QFD is used later in the evaluation.

Measure

The measure stage started with a list of 14 potential laboratories. A checklist of questions was created prior to contacting the laboratories. The laboratories were then contacted to determine their willingness to participate in a round robin test. Each of the participating laboratories was asked the same questions from the checklist. Four were eliminated because they did not have the necessary instrumentation to run all of the tests. Two more were eliminated because their cost exceeded GE's critical to quality (CTQ) pricing requirement. Eight labs remained at the start of round robin testing. The primary purpose of the round robin was to determine both repeatability (within lab) and reproducibility (between labs) of all labs in the evaluation.

A laboratory's ability to produce the same results on a repeated analysis is an indication of the laboratory repeatability or precision. The repeatability is the variation in measurements obtained with one measurement instrument when used several times by one appraiser while measuring the identical characteristic. The precision is the total variation in the measurement system. If the measurements were repeatable (precise) it remains to be determined if there is a bias in the results. The bias is the difference between the observed average of measurements and the true value.

Reproducibility is the variation in the average of the measurements made by different appraisers when measuring the identical characteristic. Accuracy looks to determine if the average of the measurements deviates from the true value. These parameters were aids in the evaluation of testing laboratories ability.

Sample preparation

Fourteen used specimens and one new oil specimen were heated, strongly agitated, and subdivided into two samples each. From these thirty samples, each laboratory received a 200-ml sample in its own sample bottles. None of the laboratories knew which samples were duplicates.

Included in the measurement evaluation were the complete cycle times, i.e., turn around time. The cycle time was the total time it took from when the samples left our facility until the analytical results were received, by mail, fax, and electronically (e-mail).

Analyze

In the analyze phase the data were received and evaluated to determine each laboratory's repeatability. Laboratory repeatability was determined by linear regression analysis. The R^2 correlation values were used to determine how well a given laboratory was able to repeat results on the sample. FIgure 1 is an example of acceptable repeatability of an alkalinity (TBN by ASTM D4739) measurement. Figure 2 is an example of an unacceptable repeatability for the same test.

The calculated average and the

standard deviations for all tests were used to determine the reproducibility. This information was also used to look for outliers. (USE MINTAB and 95% limits). Figure 3 is a plot of the average tests results for the ASTM D4739 procedure. The plot also includes the laboratory with the highest R^2 correlation and the laboratory with the lowest R^2 correlation.

The determination of the oil's alkalinity can be a difficult test in determining the inflection point or buffer end points. Because of this the R^2 results were not expected to be high, and reproducibility (between laboratories) was not expected to be high. However, it can be seen that three laboratories had R^2 values above 9.0 with acceptable reproducibility.

The determination of the oil's viscosity was considered a relatively easy test with expected high repeatability and reproducibility. This was not the case. Figure 4 is an example of an acceptable repeatability of a viscosity (ASTM D445 at 100 C) measurement. Figure 5 is an example of an unacceptable repeatability for the same test.

Figure 6 is a plot of the average test results from the ASTM D445 procedure. The plot also includes the laboratory with the highest R^2 correlation and the laboratory with the lowest R^2 correlation.

Table 2 is a summary of the R^2 correlation of the entire test package for the eight laboratories, except the wear metals. For further evaluation, Table 2 was used as input to Table 3 and Table 4.

Table 3 represents how many times a laboratory had correlation values in a given range, e.g., how many test procedures demonstrated a repeatability correlation greater then 0.9.

Table 4 was developed from Table 3. For each count in a range a multiplication factor was applied. The multiplication factors are listed below:

A (worth 4 points) was assigned for an r^2 correlation greater than 0.9.

B (worth 3 points) was assigned for an r^2 correlation greater than 0.8.

C (worth 2 points) was assigned for an r^2 correlation greater than 0.7.

D (worth 1 points) was assigned for an r^2 correlation greater than 0.6.

F (worth 0 points) was assigned for an r^2 correlation less than 0.6.

The ranking results from the round robin testing were fed into the QFD. The QFD was then used to further rank and separate the laboratories.

A decision matrix was developed to determine the laboratories that were able to meet the original CTQ's. The CTQ's and their weighing factors were taken from the QFD results. The control laboratory was given a rating of 5 for all the CTQ's. The other laboratories were then given a rating based on whether they performed better or worse than the control laboratory. This information was inputted into the trade off analysis, see Table 5.

Improve

The improve stage consisted of working with the laboratories that were not familiar with some of the required tests. A few of these laboratories showed poor correlation. With some of these laboratories, repeated testing improved their repeatability. The improved stage also included a small number of experienced laboratories that were having some difficulties with a few of the tests. The laboratory validation was accomplished at this stage in the round robin test.

Control

Once the evaluation was completed, the same quality of results had to be maintained over time. A control program was needed to ensure continuation of quality results. The program required that the laboratory keep control charts on the instruments available for review, calibration schedule posted, instrumented maintenance scheduled, and certified or traceable standards. In addition, at a minimum, an annual blind test would be run.

Summary

Not all laboratories can produce the quality used engine oil test results needed. Vigilance is required in validating current laboratory capability, selection of a new laboratory, and in maintaining a quality laboratory to ensure quality results.

Conclusion

As some of the railroads outsource part of or their entire laboratory or decide to maintain their own laboratory it is important that the analytical results be accurate and precise. The quality of the results will help insure that the locomotive engines are adequately protected. A process such as a six sigma process can help in evaluating and maintaining a quality laboratory.

Acknowledgements

The authors (Dennis W. McAndrew and Matthew Baseler) wish to thank General Electric Transportation Systems for permission to publish this work. We would like also to thank the LMOA's FL&E Committee for its review of this paper. Additional thanks to Mr. John Donner and Mrs. Mary Schmidt for their assistance in the QFD and tradeoff analysis.

TABLE 1
Quality Functional Deployment (QFD)

Contract Lab Analysis QFD

Contract Lab Funct. Requirements

Cust Upper Level Req's	Importance	LMOA Pentane Insolubles	TAN	TBN	Accuracy	Repeatability and Reproducibility	Calibration Schedule	IR (soot)	21 Element Spectroscopy	Oxidation	Viscosity	Self Check	< $50	Days In Facility	Communication Options	# of Software and Configuration Options	Data Interpretation	New Method Recommendations	Ease of Prep	Sample Storage	Location	Particle Counts	API Gravity	Distillation	Octane	Chemical Composition Determination	Aromatic Content	Gas Chromatograph Simulated Fuel Distillation	High Temperature/High Shear	Volatility
Capability	5	H	H	H				H	H	H	H																			
Data Validity	5				H	H	H					H	M	L	L					M										
Cost	4	H	M	M	M	M	L	L	L	L	L	L	H		L	L			L											
Cycle Time	4	H	M	M			L	L	L	L	L	L		H	M	L			M		M									
Expandibility	2																	H				M	M	M	M	M	M	M	M	M
Presentation	2														H	H	H													
Total		117	69	69	57	57	53	53	53	53	53	53	51	41	39	26	18	18	16	15	12	6	6	6	6	6	6	6	6	6

Figure 1 - Laboratory 4
Base Number (ASTM D4739)

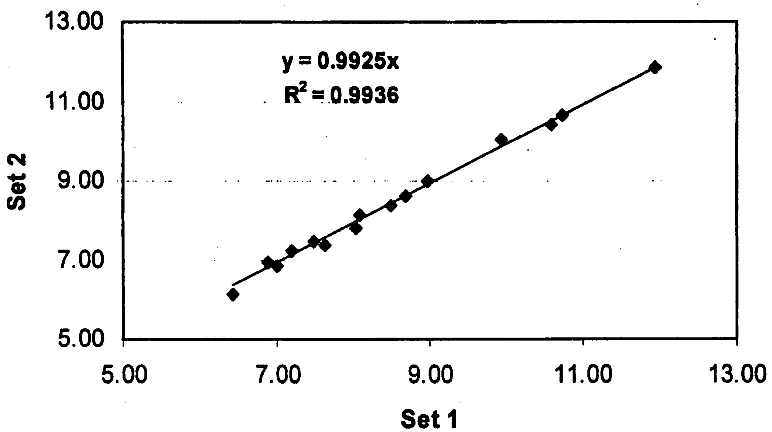


Figure 2 - Laboratory 3
Base Number (ASTM D4739)

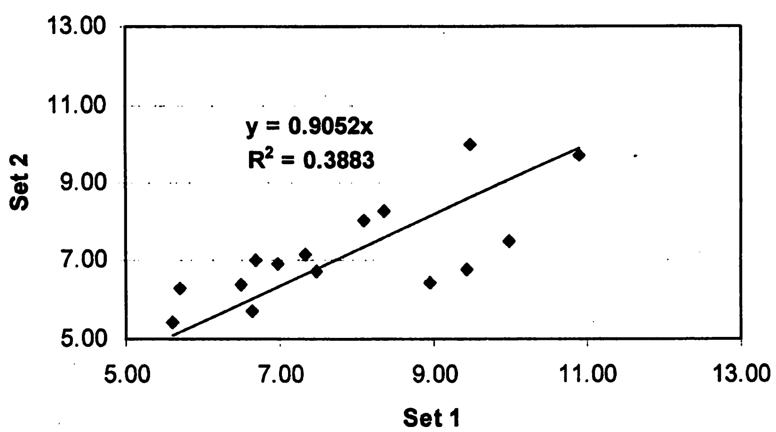


Figure 3 Average,Best, Worst

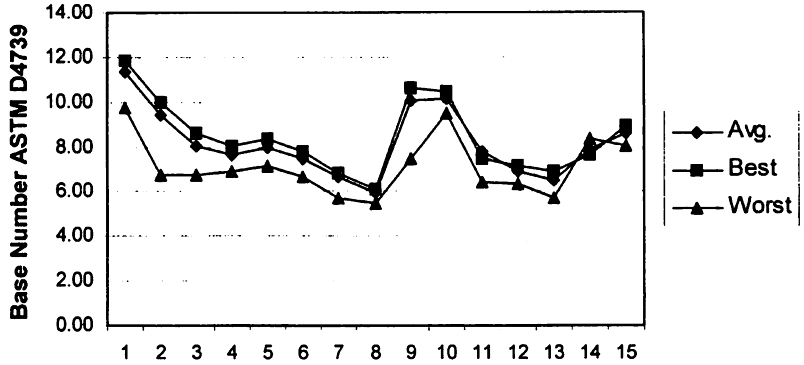
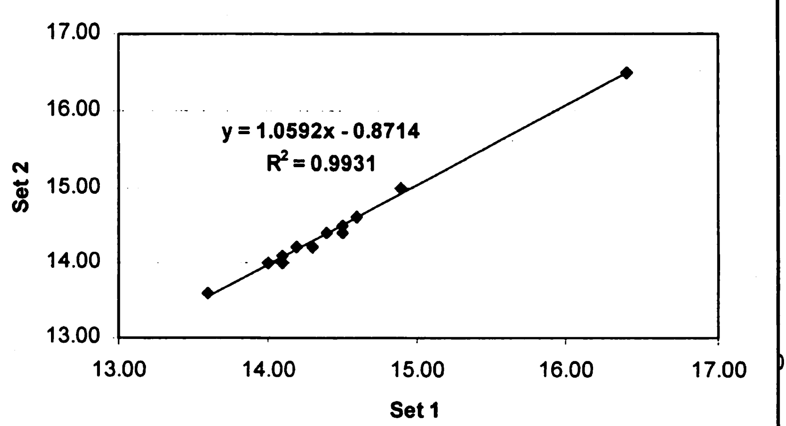


Figure 4 Laboratory 2
Viscosity at 100 C



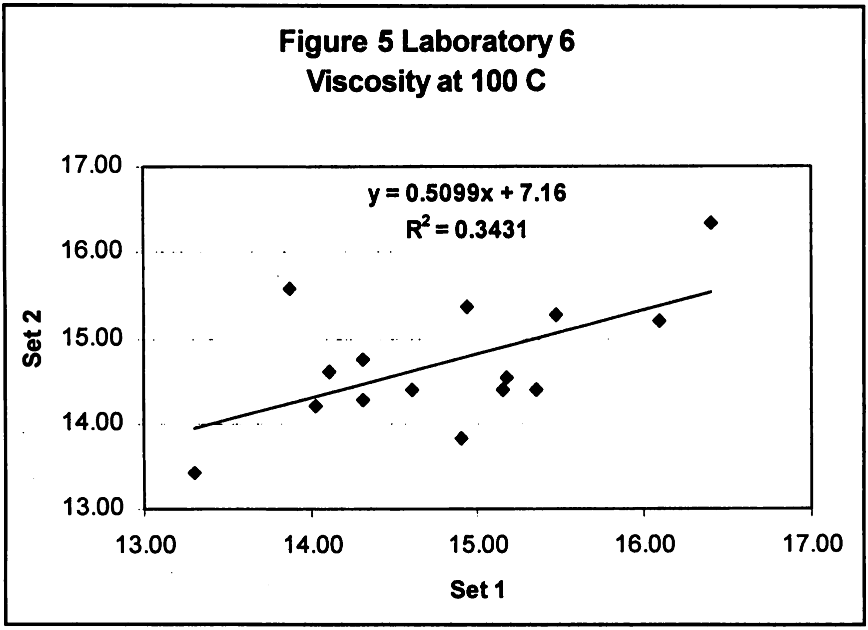


Figure 5 Laboratory 6
Viscosity at 100 C
y = 0.5099x + 7.16
R² = 0.3431
17.00
16.00
15.00
14.00
13.00
Set 2
13.00
14.00
15.00
16.00
17.00
Set 1

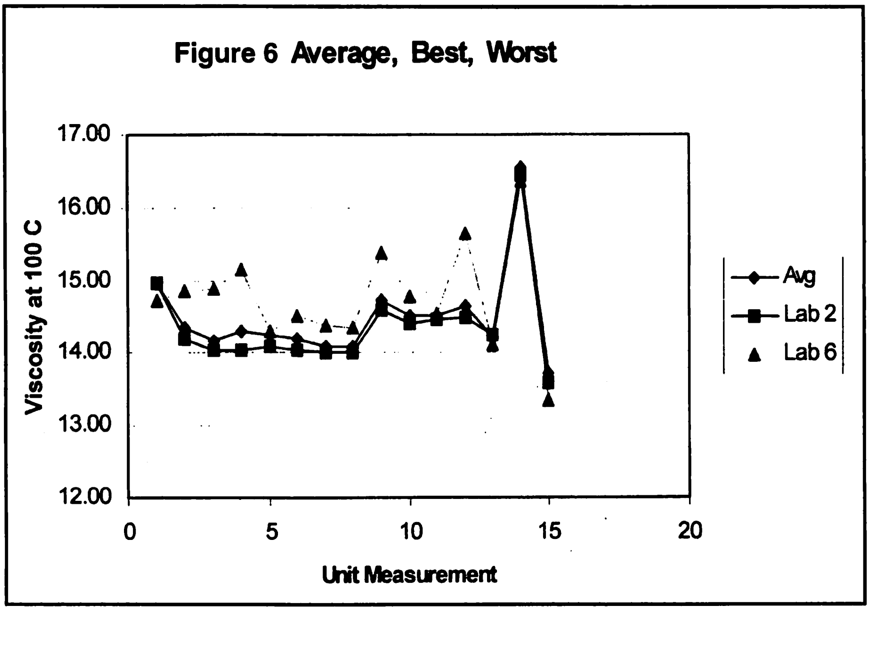


Figure 6 Average, Best, Worst
17.00
16.00
15.00
14.00
13.00
12.00
Viscosity at 100 C
0
5
10
15
20
Unit Measurement
Avg
Lab 2
Lab 6

Table 2

Test-->	Vis 40	Vis 100	Soot IR	PI LMOA	TBN	TAN	Oxid IR
Lab	R^2	R^2	R^2	R^2	R^2	R^2	R^2
1	0.988	0.780	0.997		0.370	0.436	1.000
2	0.996	0.998	0.997	0.720	0.997	0.7507	0.999
3	-0.640	0.035	0.977	0.808	0.388	0.838	-1.857
4	0.760	0.959	0.267	0.905	0.993	0.924	0.925
5	0.850		0.992	0.860	0.938	0.480	0.962
6	0.984	0.940		0.528	0.4402	-0.046	0.3703
7	0.997	0.937	0.997	0.888	0.881	0.946	0.927
8	0.999	0.989	0.988	0.928	0.731	-0.216	0.999

Table 3

Lab	A	B	C	D	F
7	5	2	0	0	0
2	5	0	2	0	0
8	5	0	1	0	1
4	5	0	1	0	1
5	3	2	0	1	1
1	3	0	1	1	2
3	1	2	0	0	4
6	2	0	0	1	4

Table 4

Lab	Rank	A*4	B*3	C*2	F*0	SUM
7	1	20	6	0	0	26
2	2	20	0	4	0	24
8	3	20	0	2	0	22
4	3	20	0	2	0	22
5	5	12	6	0	0	18
1	6	12	0	2	0	14
3	7	4	6	0	0	10
6	8	8	0	0	0	8

Table 5
Tradeoff Analysis

CTQ #			Ref Lab		Lab 3		Lab 4		Lab 6	
1	CTQ Description	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
2	Accuracy	45	5	225	10	450	5	225	-1	-45
3	Calibration Schedule	45								
4	Self Check	45	5	225	9	405	3	135	5	225
5	Repeatability	45	5	225	6	270	5	225	-1	-45
6	Reproducibility	45	5	225	10	450	5	225	0	
7	Sample Storage	15	5	75	5	75	5	75	5	75
8	Standard Analysis Cost	36	5	180	1	36	5	180	9	324
9	Shipping Cost	4	5	20	10	40	10	40	5	20
10	Other Costs	10	5	50	10	100	10	100	10	100
11	Days in Facility	36	5	180	7	252	3	108	1	36
12	Ease of Prep	8	5	40	6	48	6	48	3	24
13	Location	12	5	60	5	60	5	60	3	36
14	New Reccomendations	18	5	90	5	90	5	90	5	90
15	Other Specified Testing	6	5	30	4	24	10	60	8	48
16	Communication Options	18	5	90	5	90	5	90	5	90
17	Software Configuration Options	12	5	60	10	120	7	84	10	120
18	Data Interpretation	18	5	90	9	162	7	126	5	90
19	Standard Work Capability	45	5	225	4	180	5	225	5	225
20										
	Total Weighted Score:			2090		2852		2096		1413

III. FUEL ADDITIVES: FRIEND OR FOE

Prepared by Glenn Bowen - BNSF Railroad

Introduction

In today's competitive environment, all railroads are looking at means to improve locomotive energy efficiency, performance and availability. With the 30% increase in diesel fuel prices seen by most railroads in the year 2000, these efforts have only become more important (Figure1).

Undoubtedly, your railroad has been approached by a salesperson offering a fuel additive that can solve some if not all of these problems. Typical claims are that the fuel additives will provide increased fuel economy, improved engine cleanliness, reduced exhaust emissions, engine maintenance and down time.

As with most topics, there are opinions and evidence that the additives work as described and others that say they are ineffective. The purpose of this paper is to provide an unbiased view of these fuel additives: what they are, what they can do for you, how you might determine if they are needed, and if there is any benefit to be gained.

In the process you will find that fuel additives are commonly used in the fuels which you purchase today. Select fuel additives can be both beneficial and cost effective.

Before we look at the role of fuel additives it is important to understand the nature of the diesel engine, the orgin of diesel fuel, and the present diesel fuel specification.

Diesel Engines - Simple in theory but complex in operation

Diesel engines operate through the process of compressing air and injecting fuel into the combustion chamber as the compression stroke approaches its maximum. When the air is compressed, the temperature increases. If sufficiently compressed, the temperature rises to a point that when the diesel fuel is sprayed in the combustion chamber it will combust with no external ignition source. Although a simple process, many factors affect the efficiency of the operation and the subsequent power generated. The spray pattern and droplet size of the infected fuel, the amount of sulfur, high boiling components, and carbon residue in the fuel, the cetane number of the fuel, along with the condition of the combustion chamber, pistons, rings, and injectors all play important roles in the efficiency of this process.

Diesel Fuel - What it is and how it is derived?

Crude oil was formed by the incomplete decomposition of organic matter, both plant and animal, under elevated temperatures and with a limited oxygen supply. The source make up of the organic matter determined the chemical composition and characteristics of the crude oil. Diesel fuel is a complex mixture of hydrocarbons derived from the crude oil refining (mainly distillation) process and consists of these main classifications of compounds: paraffinic, aromatic, olefins, and naphthenic. Depending on the source of the crude oil, the ratios of these classes of compound and the make up of each can vary greatly, affecting the characteristics of the diesel fuel. Most diesel fuel used by the railroads meets the specification of the American Society for Testing and Materials (ASTM) D975 - a standard for the bulk properties of diesel fuels (Figure 2).

There are two points to be made. First, the characteristics of fuels meeting the D975 specifications can be quite different. For example, the minimum flash point for diesel fuel as described in D975 is 52°C (125° F) but in most instances the flash point ranges between 57 and 116°C (135 - 240°F). The flashpoint is related to the volatility of the components, the distillation range, and the proportion of each chemical in the mixture. The ignition and handling characteristics of a diesel fuel with a flash point of 57°C can be quite different from that of fuel with a flash point of 116°C.

Second, the specification contains no specific requirements, but rather guidelines, for fuel lubricity, cold temperature characteristics (example, pour point and cloud point) and thermal stability - parameters considered by most as critical to good engine and filter performance year round. Unless you know the characteristics of the fuel that you are purchasing relative to these parameters, there is no guarantee that fuel simply meeting the D975 specification will perform as needed. In many cases the refinery/supplier rely on fuel additives to meet these parameters.

Fuel additive types

Numerous additives are available to producers, transporters, and end users. For purpose of discussion, we will group these additives into 4 broad categories:

- Additives for improved fuel handling.
- Fuel stability additives.
- Engine performance additives.
- Additives for containment control/miscellaneous additives.

Specific information on each of the fuel additive types follows.

Additive for Improved Fuel Handling

Middle distillate flow improvers

Diesel fuel contains components classified as paraffin or wax. The amount of wax present is a function of the source crude oil and the refining process. When fuel temperatures are warm the presence of the wax is desirable as it contributes greatly to the BTU content of the fuel. However, as the fuel temperature decreases the solubility of the wax in the fuel also decreases. If a critical low temperature is reached, the wax crytallizes out and as the fuel flows through the system the wax can collect on the filters eventually plugging them and shutting down the engine (Figure 3). This critical temperature is called the cloud point of the fuel.

As fuel is cooled its viscosity increases. If the viscosity increases to the point that the fuel will no longer flow or pour, the fuel is said to have reached the pour point. The pour point is considered by railroads as the lowest temperature at which fuel can be used. The pour point is typically 3 to 8°C (5 to 12°F) below the cloud point (Figure 4).

As long as the temperature of the fuel is above the cloud point no problems should be encountered in handling or use. If the fuels temperature is below the pour point, it is probably unusable and the equipment will starve for fuel. The temperature range between the two may or may not be trouble free depending on the design of the fuel system.

Other terms you might hear with regard to the low temperature operability of diesel fuels are the low temperature flow test (LTFT) and cloud filter plug point (CFPP). The LTFT test was developed in the United States while the CFPP test is more recognized in Europe. The tests are similar in that a quantity of fuel is cooled and pulled through a standard screen. The minimum temperature at which the fuel can be pulled through the screen in one minute is the low temperature operability (Figure 5).

Although pour and cloud points are not part of the ASTM D975 fuel specifications, most diesel fuel suppliers recognize the problems associated with fuel waxing and adjust their product to eliminate problems during the winter months. This is achieved through either fuel blending or additizing (the addition of additives).

Blending lower viscosity materials, such as kerosene or jet fuel (No. 1-D), into the diesel fuel can reduce the low temperature operability limit. The cloud point of No. 2-D is lowered by 1.7°C (3°F) for every 10% addition of No. 1 blend. Although this approach works, the trade off is in greater material expense, loss of fuel lubricity, changes in cylinder pressure during combustion, and a loss in BTU value of the resulting blend (Figures 6 - 8).

A less costly approach is the use of additives called wax crystal modifiers that can effectively lower the operational temperature limit of the fuel by several degrees. These additives reduce the cloud point and pour point by modifying the shape, size or degree of agglomeration of the wax crystals (Figure 9).

It should be pointed out that not all diesel fuels respond to these additives and testing of each fuel must be perfomed to evaluate the effect. Further, when the wax crystal modifier is added to the fuel, the temperature of the fuel must be above the cloud point. If added below the cloud point no effect will be seen as the wax crystals have already formed. In addition, these materials typically will freeze well above 0°C (32°F) unless blended into a solvent system to improve the low temperature characteristics. Typical chemicals used for this application include ethylene vinyl acetate and polymers.

If you are concerned about the cloud or pour point of your fuel, ASTM tests such as D2500 (Cloud Point of Petroleum Oils, Test Method for) and D97 (Pour Point of Petroleums Oils, Test Method for) can be performed on your fuel. ASTM D975 provides maps of typical low temperatures seen across the United States in winter months and is useful in assigning winter fuel specifications.

De-icing agents

Water in locomotive fuel tanks generally comes from fuel storage tanks or from condensation. Water and fuel generally do not mix but polar compounds in the fuel coupled with the vibrations associated with running or moving locomotives will cause the water to form tiny droplets that disperse throughout the fuel. The presence of water in the fuel can accelerate the wear of injector parts and during cold weather the droplets can freeze and cause plugging of both the fuel filters and fuel lines. If water is a problem then the addition of small quantities of low molecular weight alcohols, glycols, or glycol ethers can lower the freezing point and solubilize the water allowing it to pass through the system. A common de-icing solution is a 50-50 mix of methanol/isopropyl alcohol (Figure 10).

Most Canadians and United States railroads do not see the necessity of adding the de-icing agents to their fuel if they frequently drain the bottoms from fuel storage tanks and annually drain the bottoms from their locomotive fuel tanks.

Antifoam agents

As fuel is pumped into a tank, there can be sufficient agitation that the air and fuel mix to form foam. Production of foam can lead to under-filling of the tank or cause the fuel to spill - both undesirable situations. Organo-silicone compounds have historically been the additives of choice for foam control as they are effective at low dose rates. They are typically added by the refinery and are not a necessary addition by the end user. The foaming characteristics of a diesel fuel can be tested by using ASTM D892 (Foaming Characteristics of Lubricating Oils, Test Method for).

Drag reducing agents

Pipelines are used to distribute various fuels throughout the country. Liquids pumped through pipelines are subject to frictional forces, partly due to turbulence, that increases the pressure required to pump a fixed volume of liquid through a fixed diameter pipe. If the pipeline is at capacity small additions of extremely long chain alpha olefin polymers (3 - 20 mg/kg) can be introduced to reduce the turbulence and thereby the frictional forces or drag. Once treated fuel passes through a pumping station the effect of the additive is severely diminished and retreatment is required to maintain effectiveness. The loss of effectiveness is due to shear degradation of the polymer. Studies to determine if these sheared additives have any affect on the atomization of fuels or detrimental effects on the parts contracted have been negative.

If a diesel fuel is overtreated with drag reducing agent or if the drag reducing agent is inadequately sheared at the pumping stations, fuel filter plugging can occur (FIgure 11).

Fuel stability additives

As fuel is exposed to heat, air and the metals in the fuel transfer system and engine, it can react to form gums and high molecular weight polymers. These materials will eventually form deposits that contribute to parts sticking, filter plugging, and modification of injector spray patterns. Potential negative results are fuel filter plugging, loss of engine efficiency and increased emissions.

Fuel stability additives are four general categories: antioxidants, stabilizers, metal deactivators and dispersants.

- Antioxidants interrupt the reaction between oxygen and reactive compounds in the fuel.
- Stabilizers neutralize acidic compounds in the fuel. Typical stabilizers are strongly basic amines.
- Metal deactivators tie up trace metals in the fuel, preventing their catalyzing oxidation of the fuel.
- Dispersant separate the products formed from fuel instability preventing them from becoming large enough to plug fuel filters or injectors.

Interest in fuel stability has increased over the last several years with greater emphasis on eliminating fuel filter plugging and extending filter life. For this purpose an improved method of defining fuel stability has been developed, ASTM D6468. In this test a quantity of fuel is heated at 149°C (300°F), filtered through a standard pad and the degree of darkness is determined with a reflectometer (Figures 12 & 13). Fuel stability measured in this manner is not presently a part of the D975 specification for D-2 diesel fuel. However, many users specify that their fuel must pass this test with a minimum 80% reflectance rating and most refineries have accepted this requirement.

Performance Improvement Additives

Cetane number improvers

The cetane number is a measure of the ignition quality of a diesel fuel; analogous to octane number for gasoline. Typical diesel fuels have cetane numbers in the 40 - 55 range. Increasing the cetane number improves fuel combustion and reduces emissions, particularly at low temperatures in diesel engine startup.

The natural cetane number of a fuel can be increased by the use of additives. The most common additive used to increase the cetane number is 2-Ethylyhexl nitrate (EHN), also referred to as octyl nitrate. At use concentrations it can add a 3 to 8 increase in cetane number to a given fuel.

Octyl nitrate is thermally stable and decomposes quickly in the combustion chamber, initiating combustion and shortening the ignition delay period.

ASTM D613 describes the standard method for determining the cetane number of diesel fuel. The method involves running a fuel in a single cylinder engine with a continuously variable compression ratio under a fixed set of conditions (Figure 14). It is an expensive and difficult test. For that reason, a procedure was developed to estimate the cetane number based on the density of the fuel, and its distillation temperatures at 10%, 50% and 90% volume recovery. This procedure, ASTM D4737, defines what is known as the cetane index. The typical cetane number improvers (additives) do not effect the density or distillation characteristics of the fuel and therefore do not change the cetane index. ASTM D 4046 is a procedure for determining the presence of octyl nitrate in a fuel.

Injector cleanliness additives

Diesel detergents work in two ways. Low molecular weight detergents form a protective layer on injector surfaces, preventing deposits from building up. High molecular weight detergents (dispersants) solubilize the deposit precursors, preventing their deposition on the injectors.

The diesel detergents can affect both emissions and fuel efficiency. Deposits within the injectors can impede the fuel flow and delay the onset of ignition. Deposits at the injector nozzle can affect the fuel atomization and spray pattern (Figure 15). For optimum performance the diesel fuel should be sprayed into the combustion chamber as a fine, uniform spray. The presence of improperly atomized fuel can lead to an increase in unburned hydrocarbons and particulate. Under extreme conditions, this can lead to reduced fuel economy and power.

The most recognized detergency test is the Cummins L-10 injector deposit test (Figure 16 and 17). In the test, a pair of Cummins 1988 L-10 engines are coupled in a tandem set-up, the coupled engines are cycled at 15-second intervals between closed throttle motoring and full throttle fueling for a total of 125 hours. This cycle has been found to cause injector deposits. Upon conclusion of the test the injectors are rated and flow tested.

Lubricity additives

Diesel fuel pumps and injectors are lubricated by the diesel fuel. To avoid excessive wear, the fuel must have a minimum amount of lubricity.

In traditional high sulfur fuels, good lubricity has been natural to the fuel. In the move to cleaner fuels (reduction in sulfur and aromatics) through severe hydrotreating, lubricity has been reduced. Two additive chemistries are commonly used to replenish this lubricity, fatty acids and esters. They contain a polar group that is attracted to the metal surfaces and forms a thin protective film. This film acts as a boundary lubricant when the metal surfaces come in contact.

The lubricity of a fuel is determined either by ASTM D6078 or ASTM D6079. In ASTM D6078, the Scuffing Load-Ball-On-Cylinder Evaluator (SLBOCLE) test, a ball-on-cylinder apparatus is immersed in the test fuel. The maximum load that can be applied without causing scuffing of the ball is determined. In ASTM D6079, the High-Frequency Reciprocating Rig test, a hardened steel ball oscillates across a hardened steel plate under a fixed load for 75 minutes while immersed in diesel fuel. The size of the resulting wear scar on the steel ball is a measure of the fuel's lubricity. Some repeatability problems have been encountered with the SLBOCLE test and the HFRR test is generally recognized as the best lubricity test.

Fuel combustion catalysts

Some oil soluble organometallic compounds have been found to be fuel catalysts. These are presented as additives offering both emission and fuel economy benefits. These are perhaps the most common and frequently promoted diesel fuel after-market additives. These fuel catalysts differ from cetane improvers in that they work late rather than early in the combustion cycle. For that reason they are often referred to as combustion improvers. Combustion improvers can act to reduce emissions by two means. Either the metal atom reacts with the water and produces hydroxy radicals that enhance soot oxidation, or they react directly with the carbon atoms in the soot, lowering the oxidation temperature. Unlike detergents that require a cleanup time to deliver benefits, the combustion catalysts give near instantaneous results.

Various polymers and other chemicals have also been promoted for increasing fuel economy and reducing emissions. Generally, the science describing how these additives function is either not well defined or unknown and the evidence for their effectiveness is anecdotal.

Claims of significant fuel economy benefits from combustion additives as well as other fuel aditives should be carefully considered and tested under very controlled conditions. The Southwest Research Institute, under the auspices of the U.S. Transportation Research Board, ran back-to-back tests of fuels with and without a variety of combustion catalysts. These tests showed that a catalyst usually made "almost no change in either fuel economy or exhaust soot levels" (Chevron). The Association of American Railroads developed a controlled, laboratory procedure (RP-503) to evaluate the effectiveness of fuel additives on the performance of a locomotive engine. This procedure, or a similarly documented and controlled procedure, can provide independent results showing any positive or negative results of additive use as compared to the baseline fuel.

A last precaution about the use of fuel combustion improvers is their potential environmental impact from the presence of any metals, solvents, or other chemicals in the additive and the potential effect the metals may have on used lubricating oil analysis.

Additives for Contaminant Control/Miscellaneous Additives

Biocides

In the world of microbes, there are some that consume fuel as food. Fuel contamination with these microbes can happen upon exposure to air, water, or previously contaminated fuel. The majority of problems from microbes develop in storage containers that are warm, contain water, and do not receive proper housekeeping. If allowed to proliferate, the microbes and their waste products (which can be acidic) can plug filters, block fuel gauges, and corrode tanks.

To minimize problems associated with microbial growth, good housekeeping practices are the best. The system needs to be kept as dry as possible. Regularly drain the water from all storage tanks and dispose of properly.

When the problem is severe there are three types of biocides that can be used to kill the microbes: water-soluble, fuel-soluble, and dual soluble, materials that are soluble in both fuel and water. The water-soluble products are used to treat tank bottoms but can do nothing about water pockets in the fuel and can not kill any growth in the fuel itself. Fuel soluble chemicals have the opposite problem, they cannot kill growth in the water phase. Dual-soluble materials work in both phases. Simple test kits, such as the Easicult kit from Orion Diagnostica, are useful in determining the presence of micro-organisms in the fuel (Figure 18).

Corrosion inhibitors

Diesel fuel can contain materials, such as sulfur compounds, that in the presence of water can attack and corrode components of fuel delivery systems, especially components containing copper. The potential for this corrosion can be measured using ASTM D665, Rust Preventing Characteristics on Inhibited Mineral Oil in the Presence of Water. In this test a sample of diesel fuel is stirred with either distilled water or sea water with a cylindrical steel test rod completely immersed therein. The test rod is observed for signs of rusting and the degree of rusting. A second corrosion test is ASTM D 130, Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test. In this procedure a polished copper strip is immersed in a quantity of fuel and heated for a time period. At the end of the test the copper strip is compared with ASTM Copper Strip Corrosion Standards and given a corrosion rating (Figure 19 and 20).

Additives can be added to the fuel to reduce the effects of these compounds. Corrosion inhibitors work by coating the metals in fuel storage, transfer systems and engines, thereby reducing contact between the metals and the corrosive agents in the fuel.

Demulsifiers

Diesel fuel primarily consists of nonpolar compounds whereas water is polar. Aa a result, when mixed fuel and water separate quickly and cleanly. However, if the polar compounds are present in the fuel they will tend to emulsify water, particularly if they are agitated together in a pump. The addition of demulsifiers to the fuel will break up the emulsion, allowing the fuel to separate on top of the water. ASTM D1094 is the test for the water/separation characteristics of jet fuel. The test is also applicable to diesel fuel (Figure 21).

Premium diesel fuel

In recognition that many customers are asking for diesel fuel with better performance, some refineries have started offering a "premium" diesel fuel. Until recently, it has been up to the individual fuel marketers to decide the characteristics of the "premium" diesel fuel.

The National Conference of Weights and Measures (NCWM) definition of "premium" diesel became effective January 2000. This definition provides a minimum standard for identifying a fuel as "premium" in many states. "Premium" properties are posted on the pump for easy identification by customers.

The NCWM definition of "premium" fuel is a cafeteria style definition. That is, in order to meet the criteria, a "premium" fuel must two of any of any of five selected criteria.

- Fuel injector cleanliness (< or = 10 CRC rating, Cummins L-10 injector test).

• Thermal stability (80% reflectance min.)
- Low temperature operability (10% min. ambient air temperature) measured by Cloud Point (D2500) or LTFT (D4539)
- Cetane number (47 min.)
- Energy content (138,700 BTU minimum)

Lubricity is not included as a parameter at this time because the test procedure for lubricity is not precise enough.

This committee promotes the inclusion of many of the "premium" diesel specifications as part of the D975 specification. It is our belief that these are necessary characteristics of good diesel fuel and inclusion of these characteristics in all diesel fuel will provide the benefits at lower costs to the users in the long run. A letter is being written by the LMOA FL&E Committee to the ASTM D-2 committee supporting this position.

Summary / Conclusion

To summarize, we hope to have provided an understanding of the major categories of fuel additives and an understanding of how they work. We think you will find that fuel additives are commonly used and can be beneficial and economical. Lastly, we hope to have provided you with an understanding of the tests available to determine whether an additive is effective or not. We hope that the next time a salesperson visits your facility promoting their fuel additive, you will have a better idea of what they are presenting and how you might determine if it fits your needs.

References

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Nalco Chemical Company, "Engine Cleanliness: Maintaining Cleanliness Can Result in Efficient and Optimal Operation Over the Life of Your Engine". Contributors: Dr. Kim Peyton, Ph.D., Dave Elvin, Dwight Beebe, John Thomas, and Tom Faust.

Acknowledgement

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FUEL PRICE BY YEAR

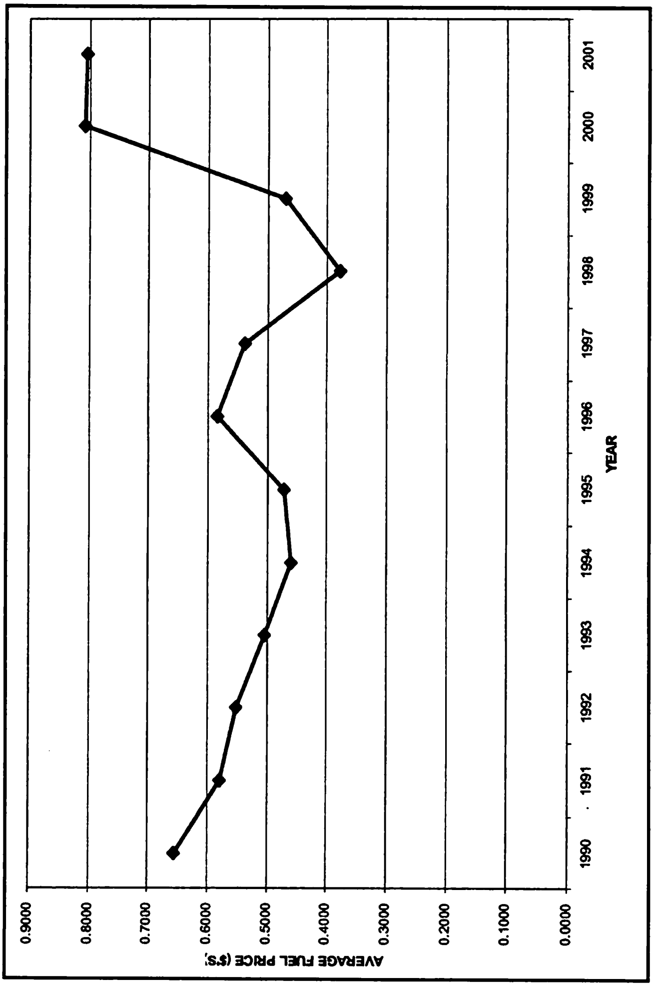


Figure 1

ASTM DIESEL FUEL SPECIFICATION

	D-2 Specification
Distillation temperature	
90% volume recovered	
min	282 °C
max	338 °C
Flash point, min	52 °C
Cetane number, min	40
Ash % mass, max	0.01
Sulfur % mass, max	0.05
Kinematic viscosity, mm^2/s @ 40 °C	
min	1.9
max	4.1
Copper Strip corrosion, 3 hrs. at 50 °C, max rating	No. 3
Ramsbottom carbon residue on 10% distillation residue, % mass, max	0.35
Water and sediment, % volume, max	0.05

Figure 2

FILTER PLUGGED WITH WAX

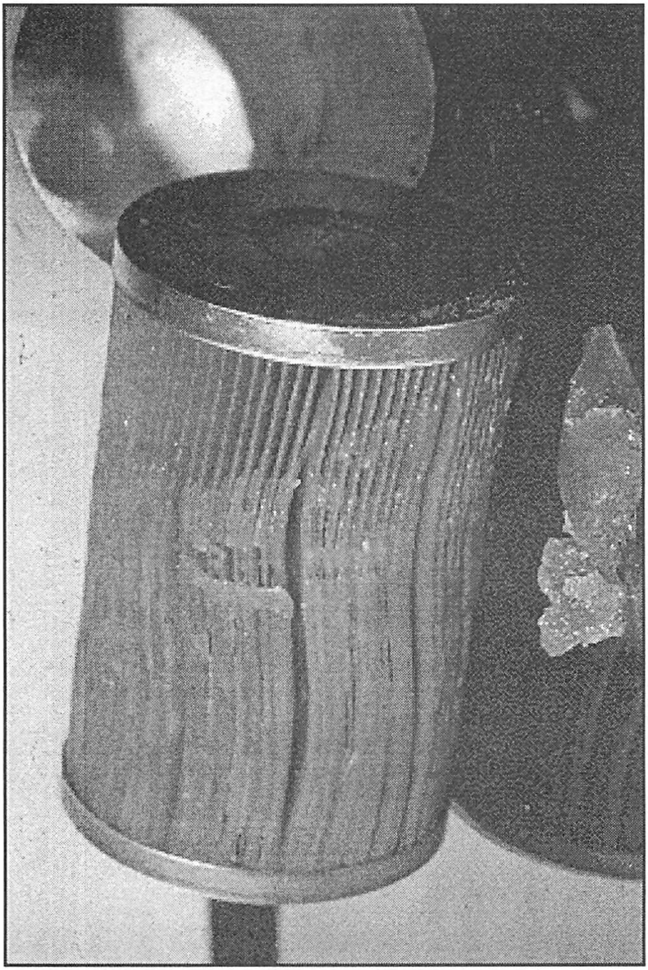


Figure 3

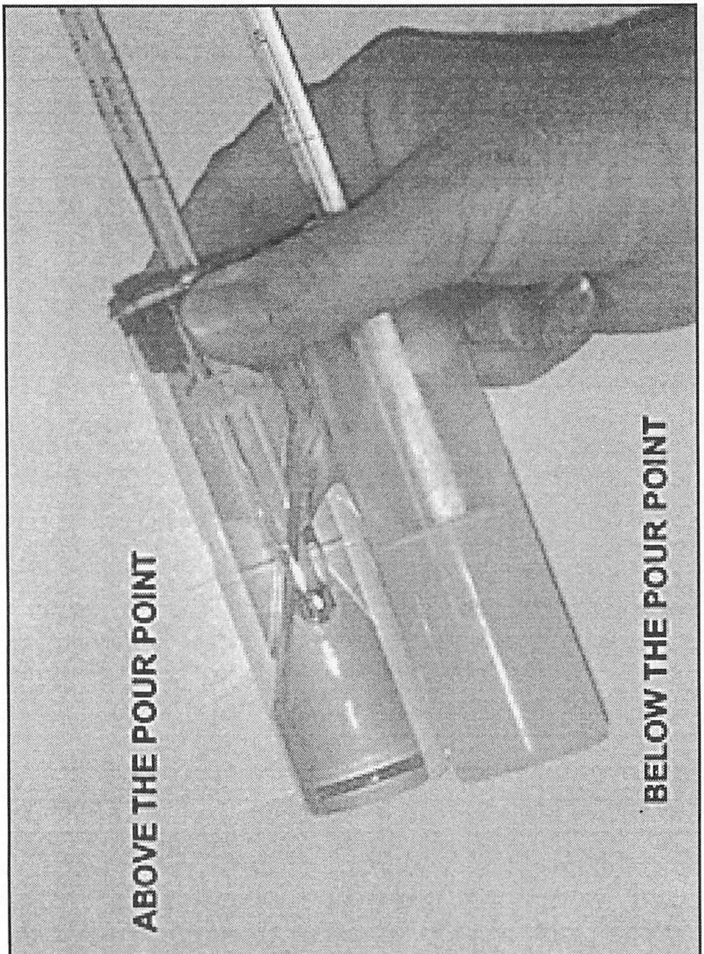


Figure 4

CFPP APPARATUS

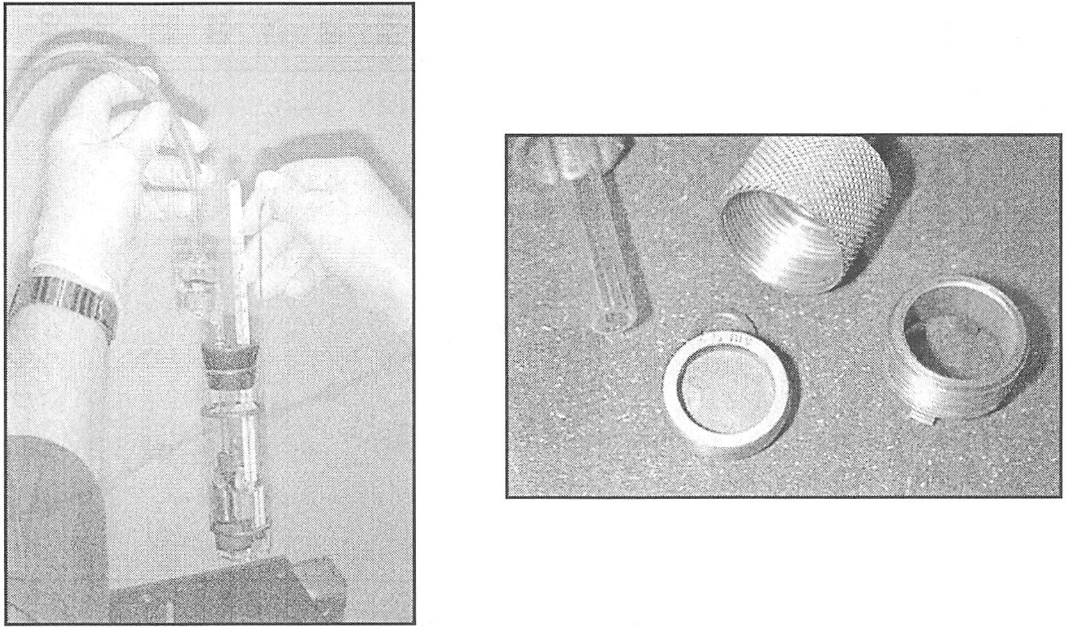


Figure 5

KEROSENE BLENDINE
EFFECT ON POWER

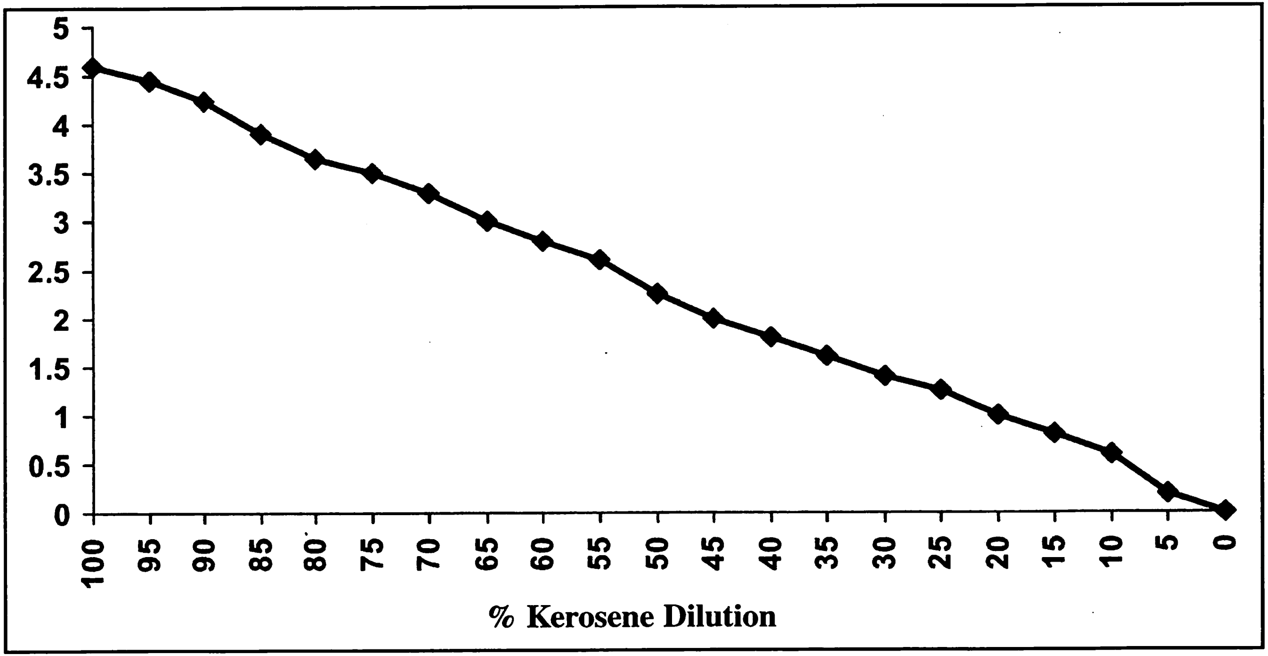


Figure 6

KEROSENE BLENDINE
EFFECT ON POWER

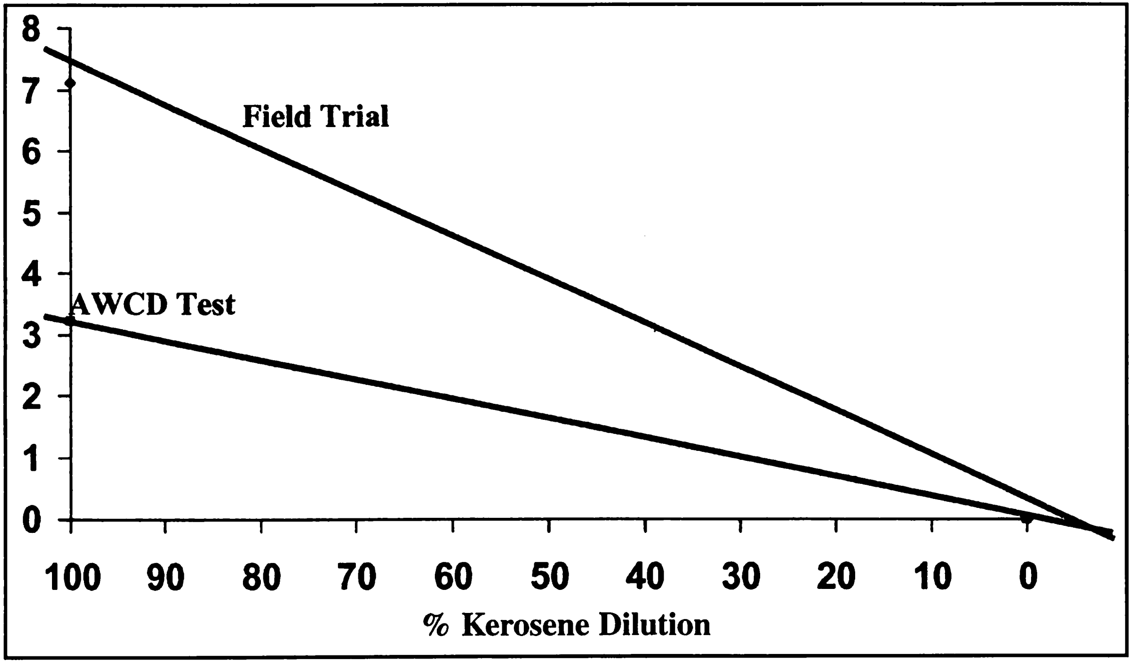


Figure 7

KEROSENE BLENDING
EFFECT ON SCUFFING BOCLE TEST

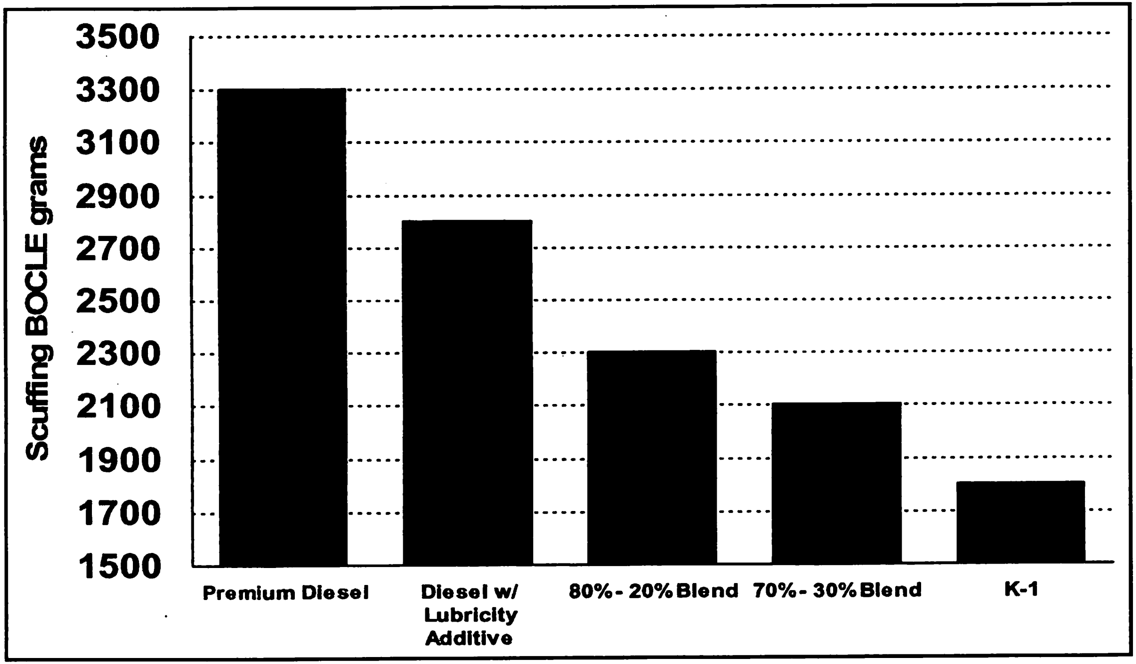


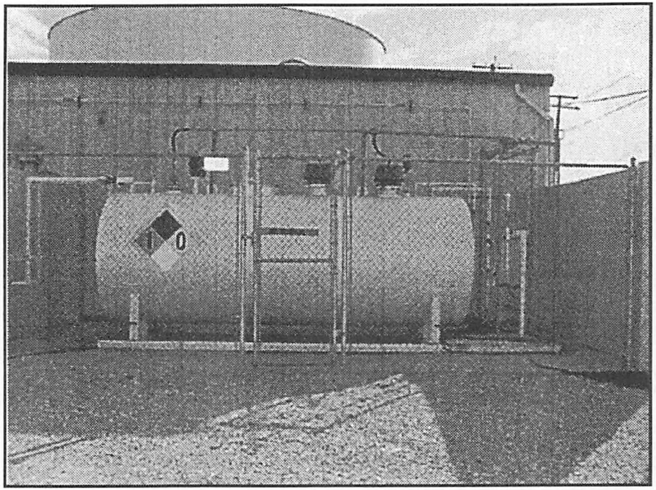
Figure 8

LOW TEMPERATURE OPPERABILITY BENEFITS

ADDITIVE TYPE	TREAT RATE, PPM	TYPICAL BENEFIT
CLOUD POINT	200-2000	3-4°C (5-7°F)
LTFT	50-2000	8-12°C (15-25°F)
CFPP	100-2000	15-20°C (25-35°F)
POUR POINT	100-300	30-40°C (50-70°F)

Figure 9

METHANOL/ISOPROPYL ALCOHOL ADDITIZING SYSTEM



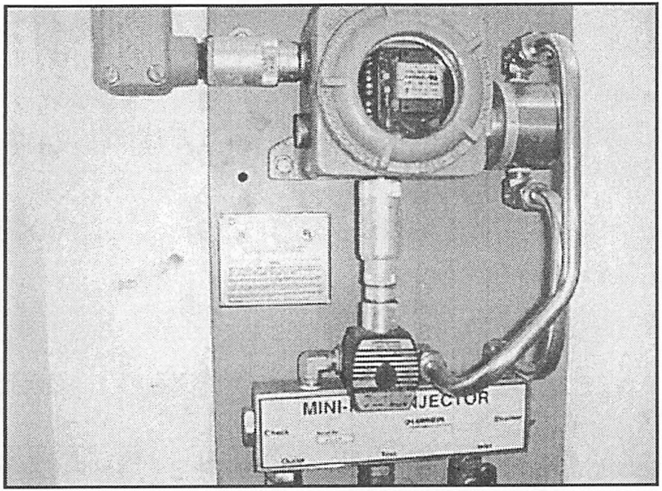


Figure 10

DRAG REDUCING AGENT

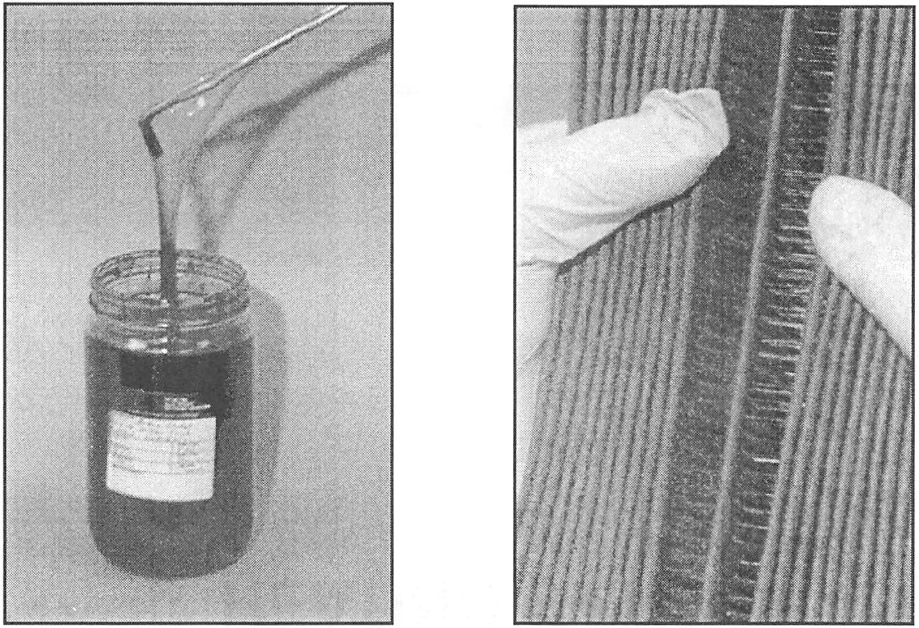
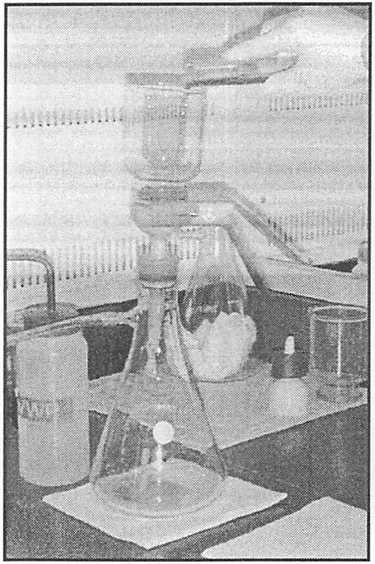


Figure 11

FILTRATION APPARATUS & HEATING BATH



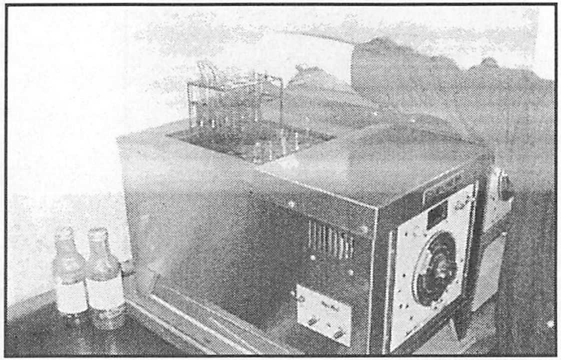


Figure 12

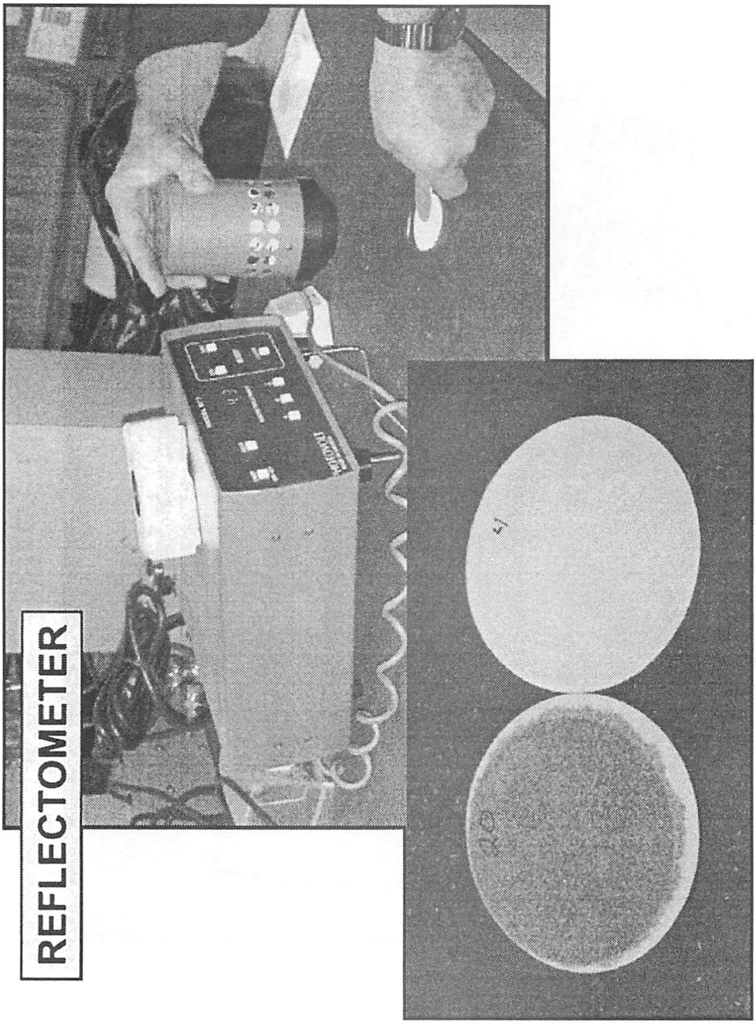


Figure 13

SINGLE CYLINDER ENGINE TEST STAND

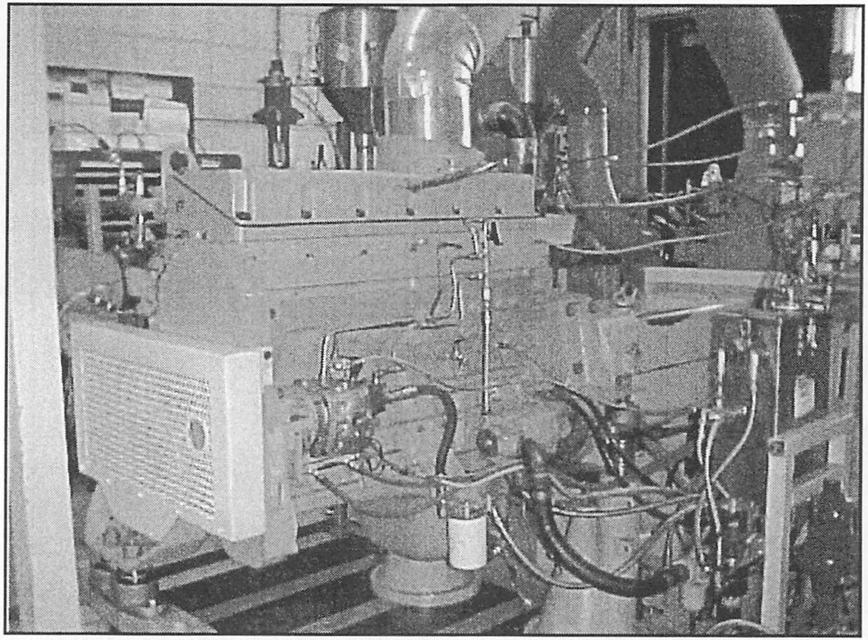
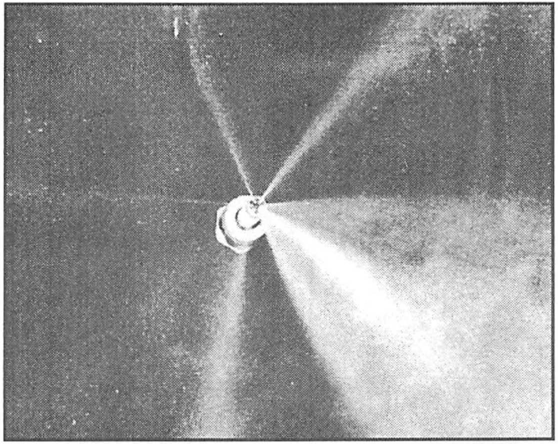
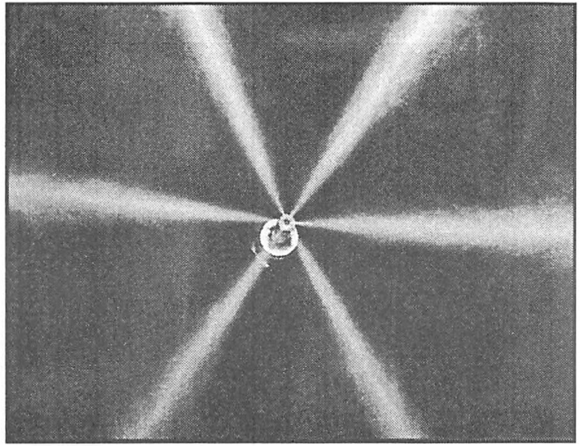


Figure 14

INJECTOR SPRAY PATTERNS



POOR SPRAY PATTERN

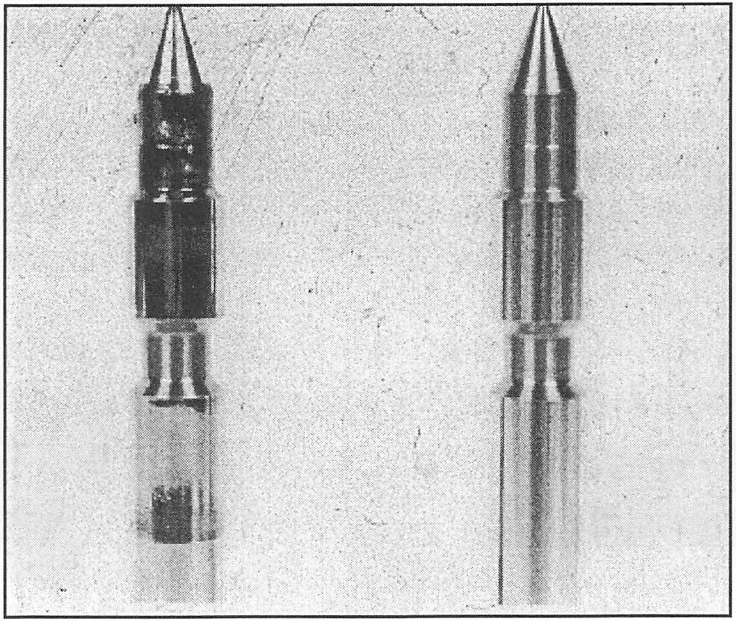


GOOD SPRAY PATTERN

Figure 15

CUMMINS L-10 INJECTOR CARBONIZING TEST

Injector with Carbon Deposits



Clean Injector

Figure 16

CUMMINS L-10 INJECTOR CARBONIZING TEST

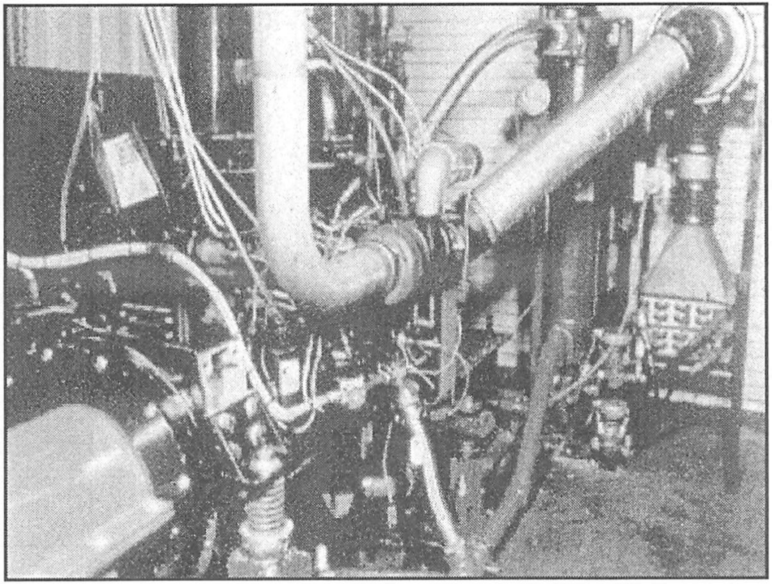


Figure 17

ORION TEST KIT

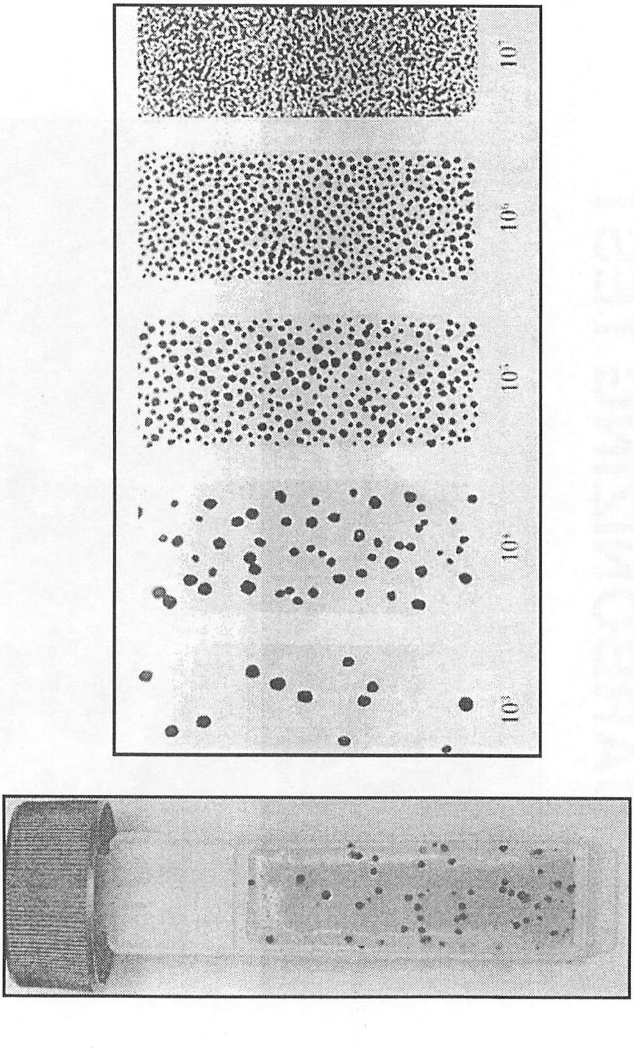


Figure 18

NACE CORROSION TEST

TM-01-86

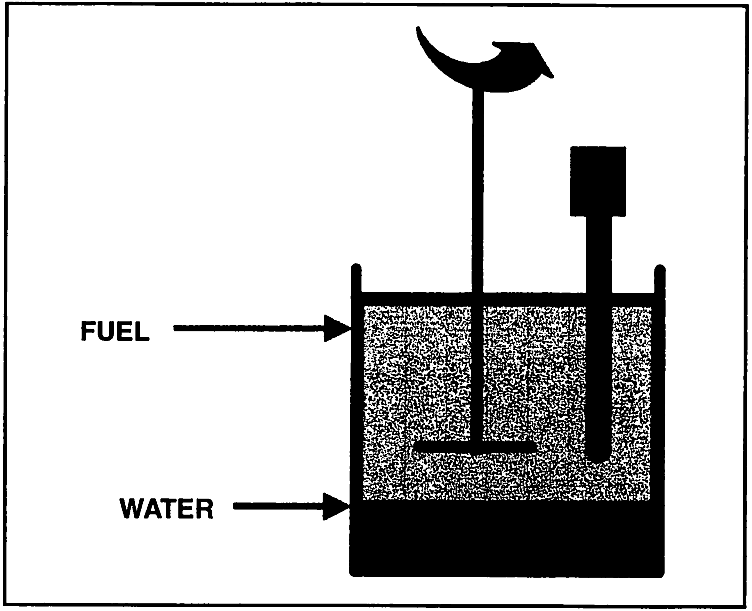


Figure 19

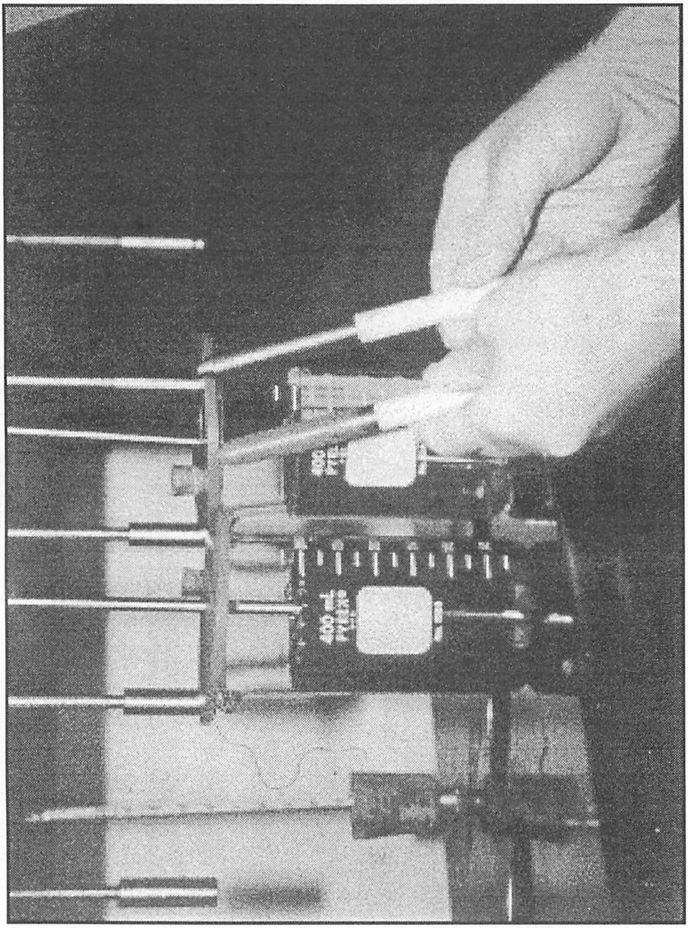


Figure 20

COMPARISON CHART

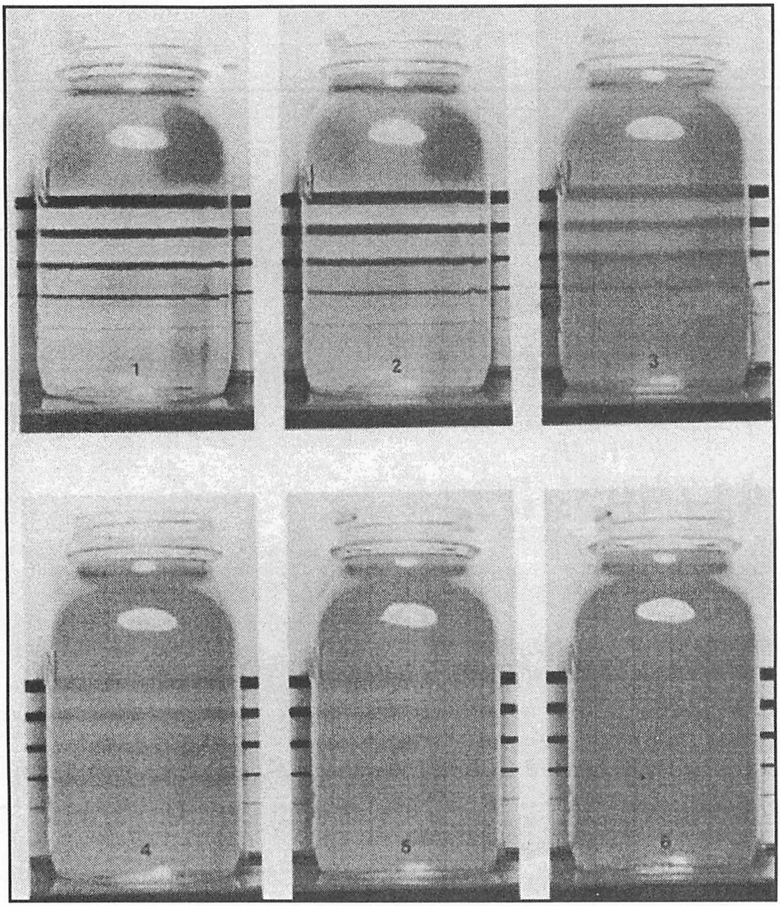


Figure 21

REPORT OF THE COMMITTEE ON DIESEL ELECTRICAL MAINTENANCE

WEDNESDAY, SEPTEMBER 26,2001
9:00 A.M.

Chairman
BOB REYNOLDS, CHAIRMAN
Manager Loco. System
Canadian Pacific Railway
Calgary, Alberta

Vice Chairman
DAVE PERKINS
Electrical Project Manager
Montana Rail Link
Missoula, Montana

Pre-Convention Presentation: Southern & Southwestern Rwy. Club

July 20, 2001
Ponte Verda, FL

COMMITTEE MEMBERS

R. Bartels	Mgr.-Electrical Systems	Via Rail Canada	Montreal, PQ
D. Becker	Design Engineer	Electro Motive Divn.	LaGrange, IL
R. Doletina	Gen'l Foreman - Mech.	Florida East Coast	Miami Springs, FL
J. Estes	Manager-Electrical	Union Pacific RR	No. Little Rock,
K. Gazarov	Mgr-Electrical Engineering	CSX Transportation	Jacksonville, FL
K. Gilbert	Director-Loco. Sales	Alstom	Montreal, PQ
D. Haffner	Superintendent	Amtrak	Chicago, IL
B. McCaffery	Mgr-Transp. Products	Natl. Electric Carbon	Wilmington, DE
T. Nudds	Acct. Mgr.	ZTR Control Systems	London, Ontario
S. Olson	Reg. Sales Mgr.	Wabtec Ray Elect.	Alpharetta, GA

PERSONAL HISTORY

Bob Reynolds
Manager Locomotive Systems
Canadian Pacific Railway

Bob was born in Montreal in 1951. He received a diploma in electronics technology from Dawson College in Montreal. After graduating he began work as an electronics technician with the Canadian Pacific Railway in 1972. His first position was working on the track geometry car, operating and maintaining various electronic instrumentation and computer equipment. He joined the Communication and Signal section in 1976 performing equipment tests on a variety of new equipment developed at that time.

In 1981 he joined the Mechanical department as an electronics specialist in the equipment engineering group. Since that time he has been involved with improvements and modifications to electrical and electronics equipment on the locomotive fleet. In recent years he has prepared specifications for new locomotives and worked with locomotive builders to ensure new orders met technical requirements and reliability standards.

Bob transferred to the new CPR headquarters office in Calgary in 1997, where he lives with his wife Mary and their three boys Andrew, Matthew and David. Bob was promoted to Manager Locomotive Systems in November 2000. His hobbies are electronics and hiking in the Canadian Rockies.

I. DIAGNOSTICS AND PREDICTIVE MAINTENANCE

Prepared by
Dean Becker
Electro Motive Division (EMD)

Locomotive troubleshooting is an ongoing activity associated with locomotive maintenance. As locomotives increase in performance and use state-of-the-art technology, methods of troubleshooting have become more sophisticated and complex. Maintenance personnel familiar with older locomotives may find the maintenance activities of the newer locomotives to be quite formidable. To counter this trend, EMD has developed a computerized diagnostics package that works along with maintenance personnel. Together, locomotive problems are systematically diagnosed in a quick, straightforward manner.

While quick problem solution is a worthwhile endeavor, preventing a problem from occurring provides even greater value to the maintenance community - and to the overall railroad. Predictive maintenance techniques can prevent many equipment failures. Repair work can be scheduled to fit in with the logistics of running a railroad. This helps the railroads avert road failures. An understanding of the common wear-out modes of locomotive equipment makes this task more scientific than clairvoyant.

These two elements of locomotive maintenance have been joined by a new element: remote monitoring. Now, important maintenance information can be obtained without having to get onboard a locomotive - or even knowing its location. Diagnostics can be done without bringing the locomotive into a shop. Similarly, some preventative maintenance efforts can be done remotely. In essence, remote monitoring is an enabling technology that increases the effectiveness of diagnostics and predictive maintenance.

Remote monitoring, diagnostics and predictive maintenance form a triad of opportunity for the maintenance community. Any of these elements, by themselves, provides value to the locomotive. When used together, they tend to overlap in coverage and provide even greater value. This paper describes each of these elements and how they can operate together.

Remote Monitoring

In today's information society, we are used to getting information and data in quick and straightforward ways. We read the newspaper, go to the library, and in recent years, log into the Internet. A wealth of information can be found conveniently on most any subject.

This trend has been extended to locomotives through the techniques of remote monitoring. This system brings information and data from locomotives right to the desktops and offices of people that need it most. Details from one or many locomotives are now available for quick, convenient use.

This type of information has tremendous potential for the railroad community. A locomotive's fuel tank can be checked to determine if refueling is necessary. A dirty filter can be scheduled for change-out (before it leads to major performance disruptions). Up-to-date duty cycles of a locomotive fleet are available. Locomotive operation can be viewed in real time (e.g., as heavy train ascends a steep grade). Indeed, remote monitoring provides a multitude of information for both the maintenance and operations segments of the railroad.

Remote monitoring has been set up so that each locomotive is accessed as a separate Internet site. Users simply log onto any computer that has Internet access, and then navigate to the desired locomotive information. Although various levels of communication technology are at work, they are largely transparent to the user. Remote monitoring has been designed to be IP-centric. It is as simple as connecting to a favorite web site.

Just *how* is this information obtained? Actually, there are several technologies that can be used to transmit the data over the distance between the locomotive and the user. These methods will be described in a moment, but it is important to realize that the feature that makes remote monitoring so straightforward is that these technological methods are in the background and the users of the system don't have to be experts on new and changing technology.

One of the technologies used by remote monitoring is cellular telephone. Both CPDP and CSC technologies are supported. This technology works well in regions served by cellular telephone, but not at all when the locomotive goes outside the covered territories. For most locomotives, excursions into remote areas are usually temporary.

Short-range radio communication is another technology used in remote monitoring. A wireless local area network (LAN) is such an implementation where locomotive information is broadcast over a short distance - such as a railroad yard.

Most locomotives already have some sort of radio, and this hardware has the potential to communicate other information. The technique is called "data over voice". It is not used in today's remote monitoring since various hardware interfaces would need to be developed for each type of radio (whereas cellular telephone and wireless LAN hardware are widely available). Nevertheless, this concept is still valid and could be developed.

In the future, EMD is planning to add satellite communication to the list of technologies. This approach would reduce the size of the region not covered.

Diagnostics

One of the drawbacks of today's information society is having too much information, or more commonly, not being able to extract the truly useful information from the mountains of apparently useful information we encounter. EMD's diagnostics tool, EMD ASSIST ™, addresses this drawback while assisting maintenance workers in tracking down the reason behind a reported locomotive problem. It helps quickly identify the source of the problem - which improves the locomotive's availability, and it finds the root cause of a problem - which prevents repeat failures due to ineffective troubleshooting efforts.

The diagnostics tool is an intelligent software package that helps maintenance workers track down the root cause of a reported problem. It can be installed on a PC or laptop computer. A laptop computer is preferred since the diagnostic process operates in an interactive manner and it is convenient to do the work nearby the locomotive. The tool uses standard Windows techniques such as pull-down menus and functional icons.

The diagnostics process begins by selecting a particular locomotive and entering the reported problem. Then, the fault archive records of that locomotive are downloaded into the computer. It is possible that some of this information is already in the computer from previous sessions. After getting things set up, a question appears on the computer screen and the worker responds with an answer. The diagnostics tool uses this answer to generate a follow-up question. The process repeats itself until the root problem is identified.

The tool uses case based artificial intelligence and Bayesian neural network articial intelligence to define the locomotive. When a fault message is entered, an array of possible root causes is shown along with a corresponding probability that it is the correct root cause for the symptoms identified. These possibilities and the answer to the question determine subsequent questions. As the process continues, the probability increases on some possible root causes and decreases on others. Eventually, the process converges on the likely root cause.

While using the tool, the computer screen displays several windows of information. The fault window lists possible root causes and their probability. A test window provides a list of questions and the corresponding answers entered-in so far. A test description window contains a new question under consideration. A test result box is present for the worker to provide an answer. The response is entered through a pull-down menu. Questions are phrased objectively to rule out interpretative errors. Many times, answers are as simple as 'yes', 'no', and 'don't know'. After answering the question, the worker selects the green checkmark icon, which signals the tool to process the new answer.

When answering a question, information can come from several places. The answer may be something the worker knows already. Or, it may be something that is part of a fault data pack. Sometimes, the worker may have to make a specific measurement or observation on the locomotive in order to answer a question. If the question is not understood, a 'help' feature provides additional information and links to other documentation sources including service manuals, schematics and parts catalogs.

Some fault conditions are rather obvious and straightforward to diagnose. For example, a fault indicating the traction motor #3 experienced a flashover is quite focused. An accompanying ground relay fault further reinforces the problem. Maintenance attention is directed at the wellbeing of the traction motor, its brushes, and its commutator. Other fault conditions are subtle and complicated to diagnose. In these instances, some of the possible problems are not obvious or intuitive. For example, an undervoltage fault may be caused by a bad radar speed sensor or non-functioning sanders. These types of faults are well suited for the diagnostics tool. Figure 1 illustrates some of the steps in a "TCC #1 INTERNAL RESET - DC LINK UNDERVOLTAGE" fault.

Another feature of the diagnostics tool is its ability to organize the information contained in the locomotive's fault archive. There are thousands of potential messages, and many fault messages have data packs that contain a lot of numeric information. Hence, there is a great deal of information available for use. The diagnostics tool takes this information and organizes it into groups and categories. Furthermore, data packs can be parsed so that the information is presented in a time-sequenced chart. This allows the viewer to spot normal and abnormal trends in the data.

When finished, the tool can generate a record of the work performed. Also, a session can be stored for the future activity.

Predictive Maintenance

Predictive maintenance is the technique that attempts to identify some component or equipment that has worn out to the point where a failure is imminent. Wear-out is a fact of life: filters get dirty, bearings run dry, insulation degrades, etc. In fact, many scheduled maintenance procedures are created just to address this fact. Realizing that items wear out and eventually fail, predictive maintenance techniques have been developed to monitor specific situations so that a potential failure can be detected and corrected before it becomes a road failure.

As seen in Figure 2, wear-out occurs late in the equipments life cycle whereas infant mortality failures occur just after the product is built. Failures of a random type may occur anytime. Predictive maintenance focuses on many of the recognized wear-out patterns and associated failure modes.

Some type of predictive maintenance have been in use for many years. Common examples are: checking the oil level, chemical analysis, and differential pressure measurements across filter elements. In these examples, much of the activity is manual and takes place only when someone takes the effort to do the work.

A few types of predictive maintenance use techniques that must be done when the locomotive is in the shop. These include vibration analysis along with pattern recognition, ultrasonic measurements, and thermography. An example of the ultrasonic analysis appears in Figure 3, which shows the results of the "valve blow" test. The noisy pattern indicates that an exhaust valve is not sealing the combustion chamber.

More recent advances in predictive maintenance make use of newer technology. For example, the coolant level test uses a special water level sensor along with locomotive software. A drop from full to low-level probably indicates a water leak. Other possibilities include special engine control software that can be used to turn off one cylinder at a time while the computer senses a corresponding drop in performance, and special transducers to measure the level of ground current, which can serve as an indication of insulation health.

Maintenance Synergies

Remote monitoring, diagnostics, and predictive maintenance address three important, yet distinct areas of locomotive maintenance activity. Each tool offers the railroad a variety of benefits.

Remote monitoring works well with predictive maintenance. Predictive maintenance determines that some corrective action is required on a locomotive and remote monitoring brings this information to the attention of the right people while there is time to respond to it. Potential failures can be identified before a locomotive comes into the shop, and even while a locomotive is pulling a train. Once a problem is identified, corrective action can be scheduled. An example of this is learning about a water leak and bringing in the locomotive for repair before a major engine failure occurs, and before the situation escalates into a road failure. Remote monitoring also collects locomotive information that is useful for diagnostic analysis. Maintenance workers can begin to troubleshoot problems as soon as the report is received. Remote monitoring can be used to update the fault archive information already stored on the computer. Overall, when the techniques of remote monitoring, preventative maintenance, and advanced diagnostics are used together, locomotive reliability and availability are improved.

Possible Faults	Prob.	Question	Answer
• Change out the VDCL voltage transducer. • Follow the TCC troubleshooting – Fault Code 393 or 499 • Replace the RE VDCL resistor. • Diagnose the ground relay problem – Fault Code 359 • Check the DC Link voltage feedback wiring for intermittent.connections.	25% 25% 25% 12% 12%	Did a ground relay occur at the time of a fault?	No
• Change out the VDCL voltage transducer. • Follow the TCC troubleshooting – Fault Code 393 or 499 • Replace the RE VDCL resistor. • Check the DC Link voltage feedback wiring for intermittent connections.	28% 28% 28% 14%	Is the DCLV (MGV) feedback the incorrect value?	No
• Replace the radar. • Fill sandbox or fix the sander problem. • Fix power supply or its connections. • Problem caused by wheelslip. No action required. • Qualify traction motor RPM sensors. • Inverter software problem.	28% 14% 14% 14% 14% 14%	Are both truck speeds significantly higher than the radar speed (+50%)?	No
• Fill sandbox or fix the sander problem. • Problem caused by wheelslip. No action required. • Inverter software problem.	33% 33% 33%	Are any wheel speeds on one truck significantly higher than on the other truck (+50%)?	No
• Fill sandbox or fix the sander problem. • Inverter software problem.	50% 50%	Are the sanders functioning ok?	No
• Fill sandbox or fix the sander problem.	100%		

Figure 1 Example of Diagnostics Tool with Undervoltage Fault

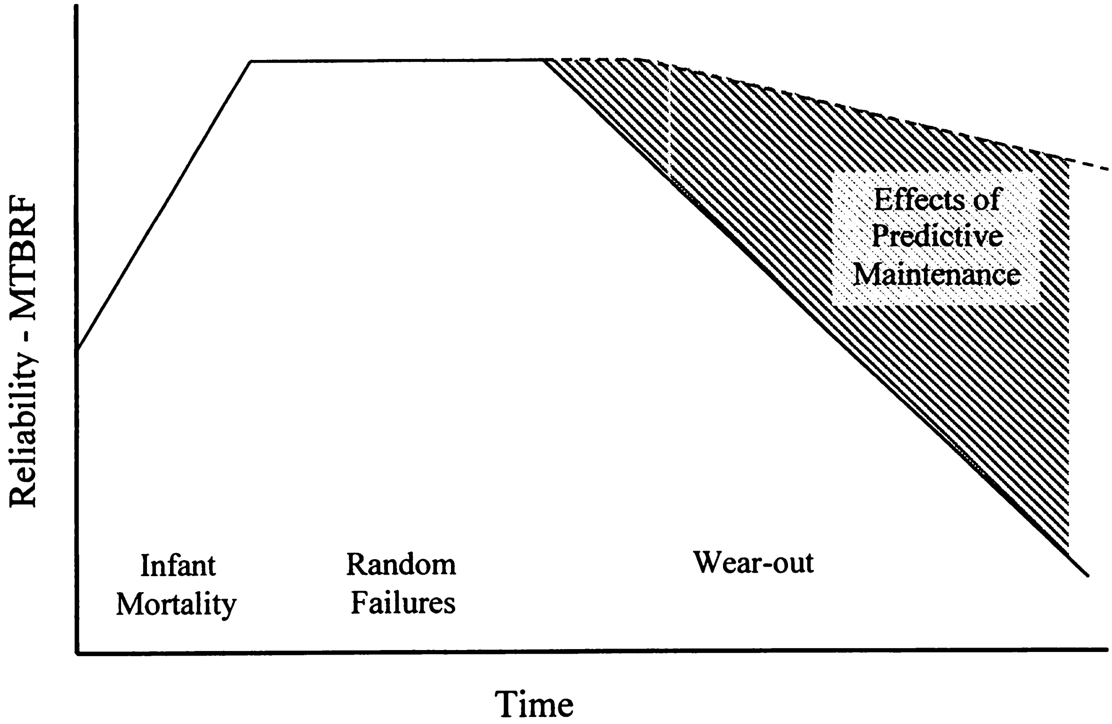


Figure 2 Reliability Chart

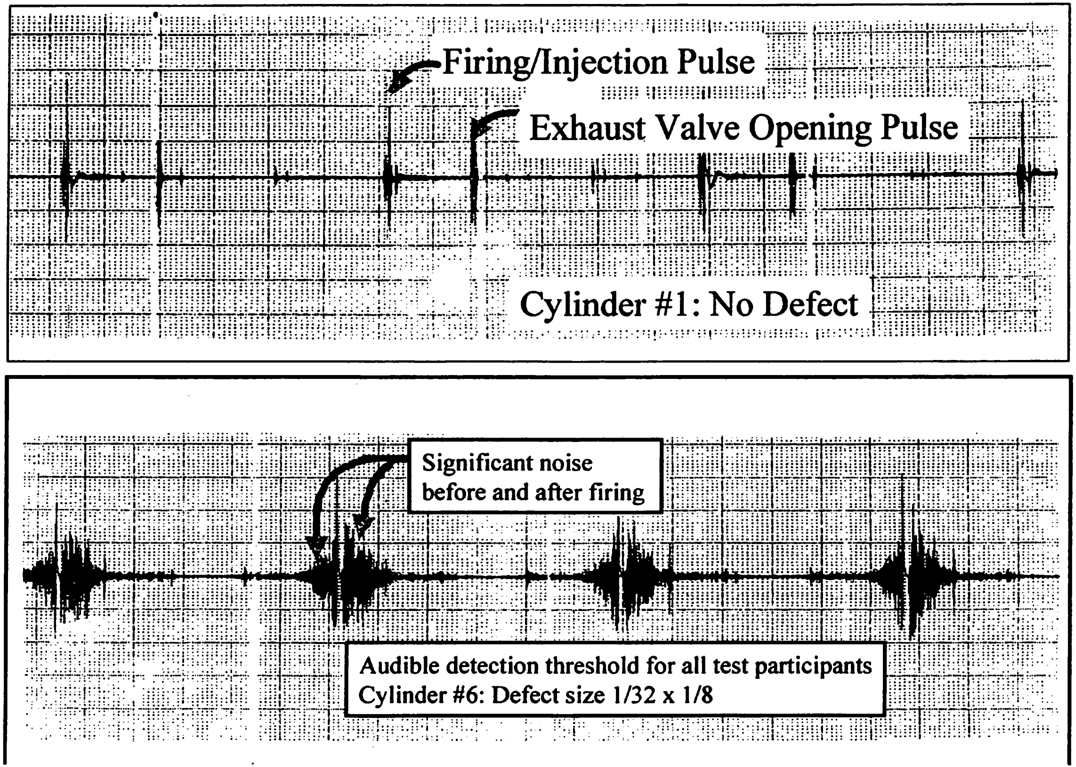


Figure 3 Predictive Maintenance with Ultrasonic Analysis

II. Locomotive Replacement Control Systems

By Stuart Olson
Wabtec Railway Electronics

Presentation Objectives

This paper is intended to assist the reader in making a decision about locomotive control systems. The major emphasis is on replacement systems.

The areas to be covered in this paper are as follow:

- Rebuild or Replace
- Control, Protection and Features
- Maintainability
- Upgrade Ability
- Product Experience
- Design and Start Up Support
- User and Operation Support

Replace or Rebuild Indicators

There are certain indicators present when considering replacement or rebuild of control systems.

- Locomotive built before 1972 (not rebuilt)
- Recent electrical cabinet fire
- Increased troubleshooting man-hours
- Appearance of rail burns
- Wheel slip is a constant problem
- Decreased availability due to frequent non-scheduled shopping
- Business requires additional hauling capability

Rebuild Considerations

There are factors to be considered when thinking of rebuilding the control system.

- Technicians are familiar with the existing system.
- Inventory supports the present equipment.
- Present equipment requires periodic calibration and maintenance.
- Present equipment design is based on traditional relay logic.
- Present equipment design is based on analog circuits.
- Present equipment design uses analog circuit feedback loops.
- Present equipment is approaching end of life cycle.
- Dispatch adhesion (daily pulling power) coil relay 14% - 16%.
- Dispatch adhesion IDAC or WS 10 Module 17% - 18%.
- A complete rewire may be required. Older control systems were applied using wire and insulation that has a generally accepted life of about 15 years. (In some instances the high voltage wiring can be reused.)
- A rewire and installation of rebuilt or remanufactured components will insure a locomotive out of the shop that should perform at a level as good as the base technology used in that control system.

Replacement Consideration

Certain factors should be considered when replacement of control systems are being explored:

- Technician require training.
- Inventory requires adjustment.
- Solid state digital technology (no adjustments required).
- Microprocessors can sample parameters 100 + times/sec.
- Micropressors process data and take action extremely fast.
- Dispatch adhesion (daily pulling power) up to 23% - 24%.
  - Peak adhesion 28% - 32%.
- Instant corrective actions provide exceptional control capability.
- The effect of microprocessor based technology is smooth intuitive control system operating without hunting or wide swings.
- Locomotive availability is significantly increased.
- Costs associated with rebuilding and rewiring are reduced.
  - Wire harnesses are often supplied with replacement systems.
  - Terminations are usually required at one end of the harness.
  - Less components and wiring because logic occurs in software and not hardware.
- Replacement control systems can provide integrated control of other locomotive systems and further reduce material and wiring.

Basic Control

- Main Generator (AC or DC) Excitation Control.
  - Power and Dynamic Braking modes.
  - Includes rate control and throttle control.
- Wheel Slip/Slide Control in Power and DB modes.
- Transition Control where applicable.

Basic Protection

- Main Generator.
  - over current, over voltage, over excitation.
- Traction Motor.
  - locked axle, slipped pinion, over speed, over temperature, motor stall.
- Dynamic Braking.
  - over grid current, blower open or shorted, open grid.

Expanded Control & Features

- Slow Speed Control.
- Battery Charging Control (Voltage Regulation).
- Engine cooling fan and shutter control.
- Load Meter Control.
- Compressor Control.
- Sand Control.
- Hi and Low Idle Control.
- TMCO and automatic power reduction where applicable.
- Ground Relay Reset Control and Lockout.
- Engine Speed Control.
- Isolated and amplified speed signals for ancillary device use.


BOA™
An Excitation/Wheel Slip Control System That Dramatically Improves The Pulling Power of Your Locomotives
Retrofit your older locomotives with a BOA Excitation/Wheel Slip Control System. It provides significant improvements in operating performance and does not require any operator interface to prevent wheel overspeed.
BOA Excitation/Wheelslip System
Advantages Include:
• Increased Adhesion
• Increases Drawbar Pull
• Smoother Excitation Control
• More Efficient Train Handling
• No Probes or Axle Generators
• Solid State Replacement of Load Regulator
• Easy Installation
• Self Diagnostics
ZTR
Control Systems
www.ztr.com
1940 Oxford St. East #1
London, ON N5V 4L8
519/452-1233
8050 State Hwy. 101
Shakopee, MN 55379
(952) 885-8122

- Automatic Main Engine Start and Stop.
- Integrated Event Recorder.
- Integrated Alertness Device.
- Health Monitoring
- Radio/Cellular remote communication capabilities.
- Diagnostics
  - Real time display
  - Alarm and/or fault archive
  - Data packet stored with each alarm/fault.
- Run data accumulation
  - Miles, Hours in each throttle, Total Hours Total KW Hours.
- Operator initiated tests
  - Contactor Test, Relay Test, Fan Test, Transition Test, Load Meter Test, Self Load Test (if applicable).

Expanded Protection

- Main Engine
  - Water temperature
  - High oil temperature
  - Low oil temperature
  - Redundant main engine overspeed
- Control System
  - Faulty sensors
  - Low voltage
  - High voltage
  - Voltage transients

Maintainability

The replacement system must be easy to understand and the installed components of the system must be accessible. Troubleshooting and diagnostics must be easy to perform. The on-board diagnostic features must be easy to use and understand and the extended diagnostic software must be user friendly.

Upgrade Ability

Determine whether any changes can be made after initial installations. Also determine what has to be done if you decide to change, add or modify functions and/or features.

Product Experience

The following questions should be answered satisfactorily.

- Is the replacement system in widespread use?
- Has the replacement system been applied to the same locomotive type or types you are considering?

Contact references and get feedback regarding experiences.

Design and Start Up Support

- Has the sales staff been able to supply you with enough information to make a decision about the system and it's features?
- Will you have application support for the final planning stages after ordering (assistance with schematics and equipment layout?
- Will there be on-site assistance for the initial start up and shakedown run and at what cost?
- What type of training will be provided and at what cost?

User and Operation Support

- What type of documentation will you receive and at what cost? (Manuals, software, operating instructions, etc.)

- What type of training will be provided and at what cost?
- What is the recommendation for spare parts inventory?
- Is there a UTEX program?
- What is the repair turn around time? Where is the service center?

Involving maintenance personnel in the replacement program will insure a clearer understanding and quick acceptance of the system.

Summary

- There are a number of replacement control systems available in the railroad today. Most of the manufacturers have been in business for quite some time and provide reliable products.
- Converting a small group or a fleet of locomotives to a new control system can be full of challenges and very rewarding.
- It is best to review your requirements in great detail to insure you fully understand the impact and scope of your repalcement choice.
- We hope that this report has provided you with some basic insight to help you with your decision.

III. Automatic Shutdown Startup Controls
Fuel Savings Through Technology

Prepared by
Rudy Doletina
Florida East Coast Railway

(Equip all road and switcher locomotives with an automatic shutdown - restart control system).

Automatic Shutdown - Startup Control, offered by four major companies, EMD, GE, ZTR Control Systems and Wabtec Railway Electronics, is a microprocessor technology that can be installed in almost any type locomotive. It reduces engine fuel consumption, resulting in significant fuel savings.

It will also reduce lubrication oil use and exhaust emissions, and will extend locomotive component life by safely shutting down the locomotive engine during appropriate idle periods.

Starting and stopping the engine only as needed insures all locomotive systems are ready for immediate use and maximizes fuel savings.

The fuel reporting and analysis software provides information on total dollar savings and other shutdown and restart statistics.

Statistical data downloads can be retrieved via PC, PCMCIA card, and radio control. It can also be interfaced with an event recorder.

Cost analysis basis

- It is widely accepted, based on duty cycle data, that switcher locomotives are parked at idle in excess of 75% of the time.
- Duty cycle data indicates road locomotives are at idle 50% to 75% of the time.
- At anytime the locomotive is at idle there is a potential for fuel savings using automatic shutdown - startup controls. (Table 1)

Table 2 shows annual fuel savings you can expect calculated on locomotive availability at 95% and no other shutdown policy in effect.

Calculations are based on Idle fuel consumption @ 4 gal/hr, and fuel cost of $1.00 / gallon. Since FEC is still in the preliminary stage, the download reveals on the first quarter, that the average savings are $10,000 per year, per locomotive or 27.4 gallons of fuel per day, per locomotive.

The Canadian Pacific has already implemented an identical system and has recorded total savings of $2,657,762 in fuel cost for 4.3 years for 33 locomotives. See Tables 3-5.

By equipping 75 locomotives with automatic shutdown - startup control, we can project our first year fuel saving of $750,000 or $10,000 per locomotive per year.

Information recorded

The system has an integrated recording function, which operates continually while the system is enabled. It records information and provides the following reports and logs (See Table 6).

- Fuel Statistics (Fuel Report)
- Locomotive Statistics (System Log)
- Events (Extended Log)
- Alarms (Alarm Log and Extended Log)

System overview

This add-on system has the following components:

- Main control unit (MCU)
- Governor assist pump
- EPD override
- Battery current transducer
- Air & H_2O temperature sensors
- Brake Cylinder sensor
- Status lights & sirens
- Download port.

Shutdown functions

The system will shutdown the engine when ALL the following conditions are true:

- Idle for 10 minutes & reverser handle centered.
- Brake cylinder is greater than 30 PSI.
- Engine coolant is greater than 120 degrees.
- Battery charge current is less than 31 amps.
- Battery voltage is greater than 67 volts.
- Ambient temperature is greater than 32 degrees.
- No manual or engine protection shut down.
- Less than 3 system restart attempts.

Restart functions

The system restarts when ONE of the following conditions is true:

- Locomotive is not in idle.
- Reverser handle is not centered.
- Brake cylinder is less than 27 PSI.
- Battery voltage is less than 63 volts.
- Engine coolant is less than 100 degrees.
- Ambient temperature is less than 28 degrees.

System indicators

There are visual and audio indicators to inform operating personnel of the system status. LED's (red and green) and sirens (2) work together. These indicators provide system status.

If the system is unable to shut down or restart the locomotive engine, the system indicators (LED's and sirens) help determine system status.

System available options

Load shedding

Locomotive shut down, the optional load shedding function eliminates repeated, and unnecessary locomotive restarts resulting from a low battery condition (below 63 volts). To conserve battery voltage, the load shedding feature turns off the locomotive headlights 2 minutes after the auto-shut down. Lighting can be restored at anytime by pressing the headlight reset button, located on the control panel. Pressing this button restarts the 2 minute headlight shut down time-out period.

Automatic ground relay reset

The optional automatic ground relay reset function resets the ground relay once following each locomotive auto-reset. Older locomotives commonly use a starting winding in the main generator to start the engine, which occasionally causes the ground relay to trip.

Fan control

The optional fan control feature controls the cooling fans cycle. With this option, the system controls the temperature at which cooling fan contactors pick up and drop out. The fans operate in a start-shared manner in order to keep their startups equal. The actual operating times are recorded in the system log of the download/analysis software.

Low / high idle control

In addition to fan control, low and high idle operation are two other means of controlling engine temperature. Low idle is typically used in above-freezing conditions to increase fuel savings when the system is prevented from being shut down. High idle is used in freezing conditions when maintaining adequate engine temperature is a concern.

Low/high idle operation is enabled 30 minutes after engine startup, and will only occur when the locomotive is in idle with the reverser handle centered. Low/high idle control is dependent on the ambient air temperature. When the ambient air temperature exceeds 40 F (4.4 C), the AUTOSTART system enters summer operation. When the temperature subsequently drops below 32 F (0 C), the autostart switches to winter operation.

The autostart system will enter low idle operation only during summer operation if the water temperature exceeds 140 F (60 C). Low idle is maintained until water temperature drops below 140 F (60 C).

Similarly, the system will enter high idle operation only during winter operation if water temperature is less than 122 F (50 C). High idle is maintained until water temperature drops below 140 F (60 C).

Any operation of the reserver or throttle handle terminates low/high idle operation.

Kilowatt-hour logging

The kilowatt-hour log option tracks the total kilowatt-hours produced by the locomotive engine. These statistics are totaled for the current trip and since the system was installed on the locomotive (lifetime). Use these data, download/analysis software, to compare locomotive maintenance costs against locomotive working time.

Speed & distance recording

With the addition of speed equipment, this optional feature can be used to record and log speed and distance traveled. Up to two additional speed outputs are available with this option:

one 20 PPR output and one 60 PPR output.

Enhanced health monitoring recordings
(e.g. grid or traction motor currents, oil temperature & press-pressure, water inlet/outlet pressures, etc.)

Summary

Automatic Shutdown – Startup Control gives FEC:

- Lube oil usage reduction
- Exhaust emissions reduction
- Significant reduction in re-start exhaust smoke
- Extended locomotive component life
- A shut down policy - active 365 days a year - 24 x 7
- Locomotives in a ready to use state
- Information on general locomotive conditions
- Reports and verification of fuel savings
- Safe, reliable, and automatic operation
- Better shutdown management policy
- Fuel savings of thousands of dollars a year.

Operating Time Spent in Idle	Idle Time Reduction				
	50%	60%	70%	80%	90%
80%	$13,315	$15,978	$18,641	$21,304	$23,967
70%	$11,651	$13,981	$16,311	$18,641	$20,972
60%	$9,987	$11,984	$13,981	$15,978	$17,976
50%	$8,322	$9,986	$11,560	$13,315	$14,980
40%	$6,657	$7,989	$9,320	$10,652	$11,983

Table 1

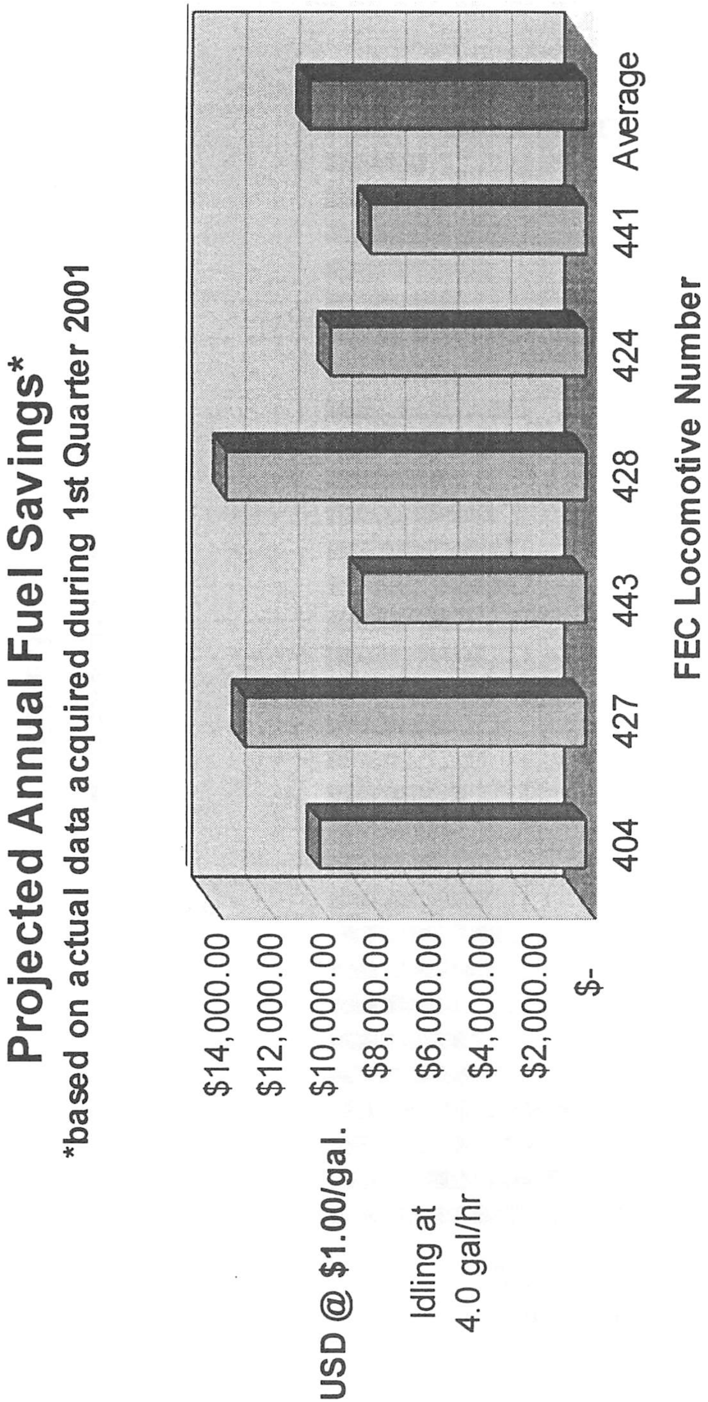

Projected Annual Fuel Savings*
*based on actual data acquired during 1st Quarter 2001
USD @ $1.00/gal.
Idling at
4.0 gal/hr
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$-
404
427
443
428
424
441
Average
FEC Locomotive Number

Table 2

Coquitlam Auto-Stop/Start Lifetime Average Fuel Saved
Average 39.7 gallons per day by each of 33 units

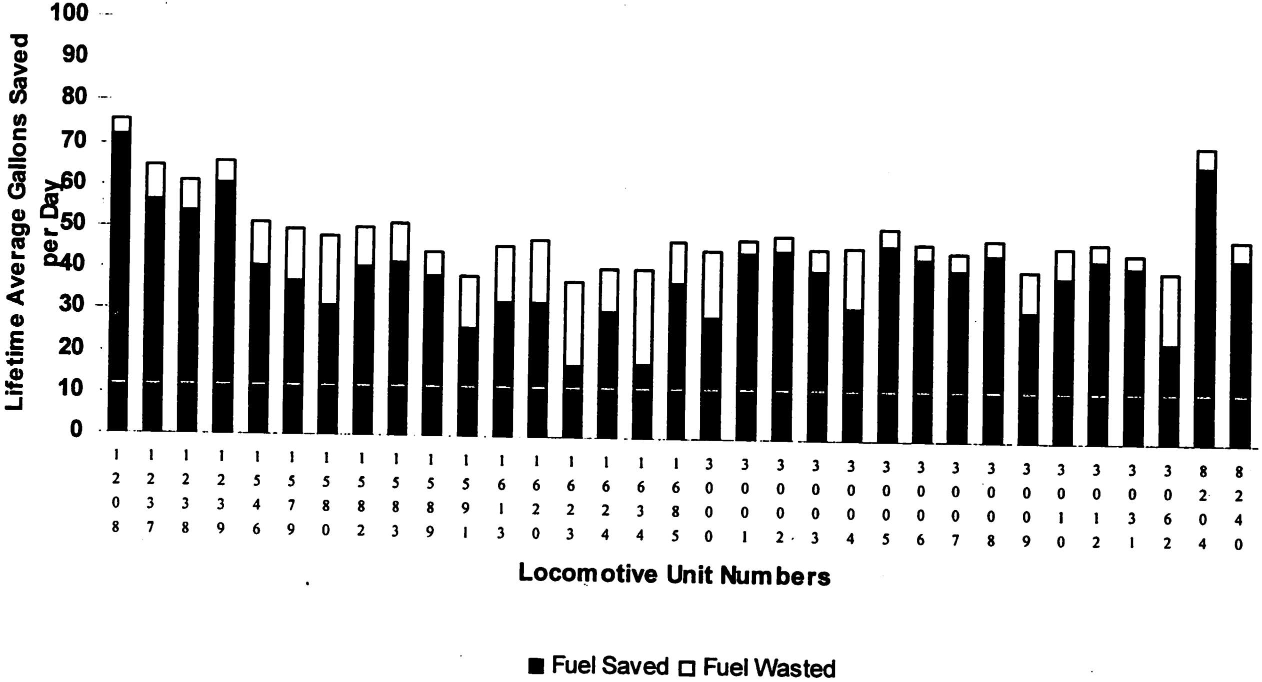


Table 3

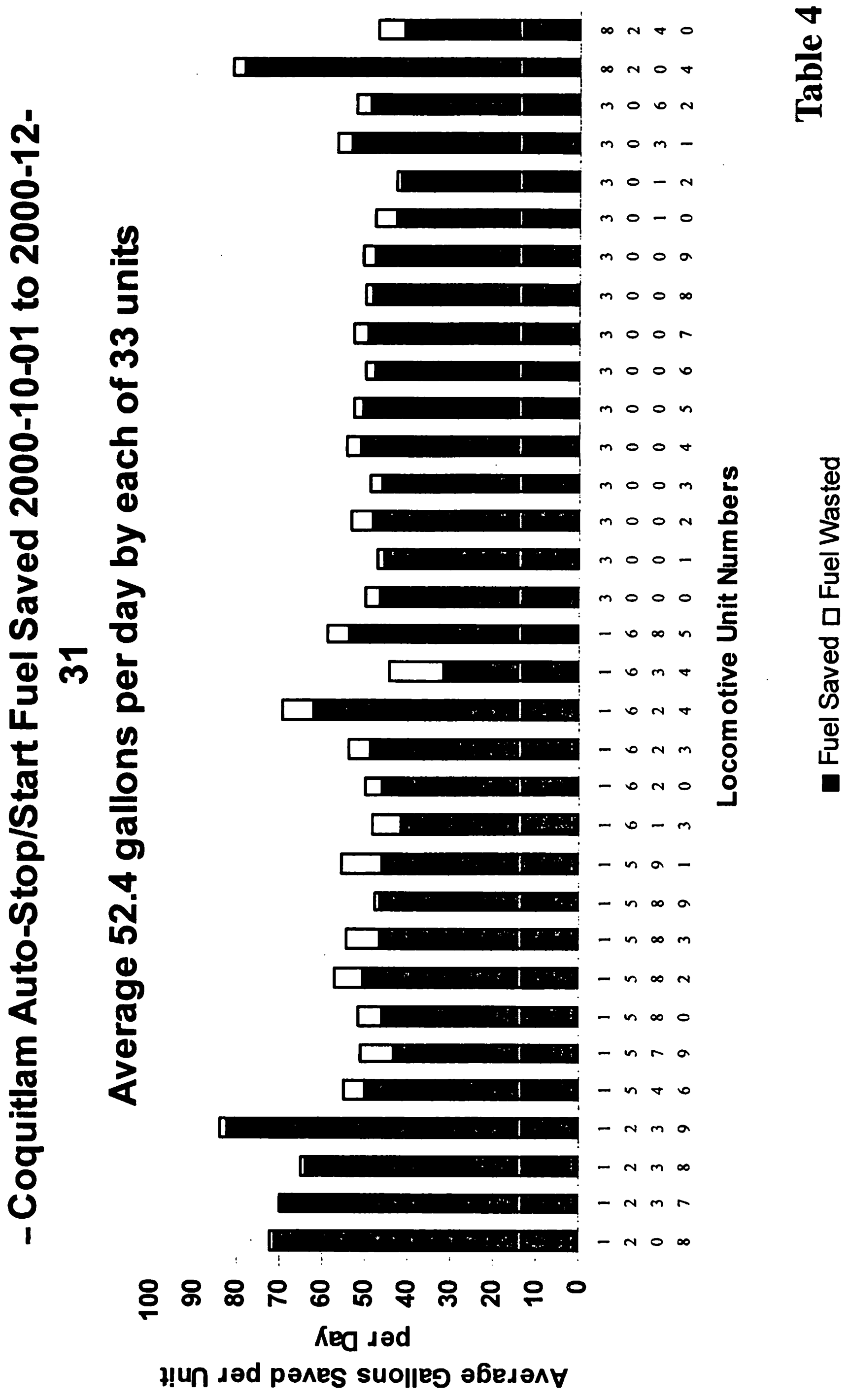

- Coquitlam Auto-Stop/Start Fuel Saved 2000-10-01 to 2000-12-31
Average 52.4 gallons per day by each of 33 units
Average Gallons Saved per Unit per Day
100
90
80
70
60
50
40
30
20
10
0
1208
1237
1238
1239
1546
1579
1580
1582
1583
1589
1591
1613
1620
1623
1624
1634
1685
3000
3001
3002
3003
3004
3005
3006
3007
3008
3009
3010
3012
3031
3062
8204
8240
Locomotive Unit Numbers
Fuel Saved
Fuel Wasted

Table 4

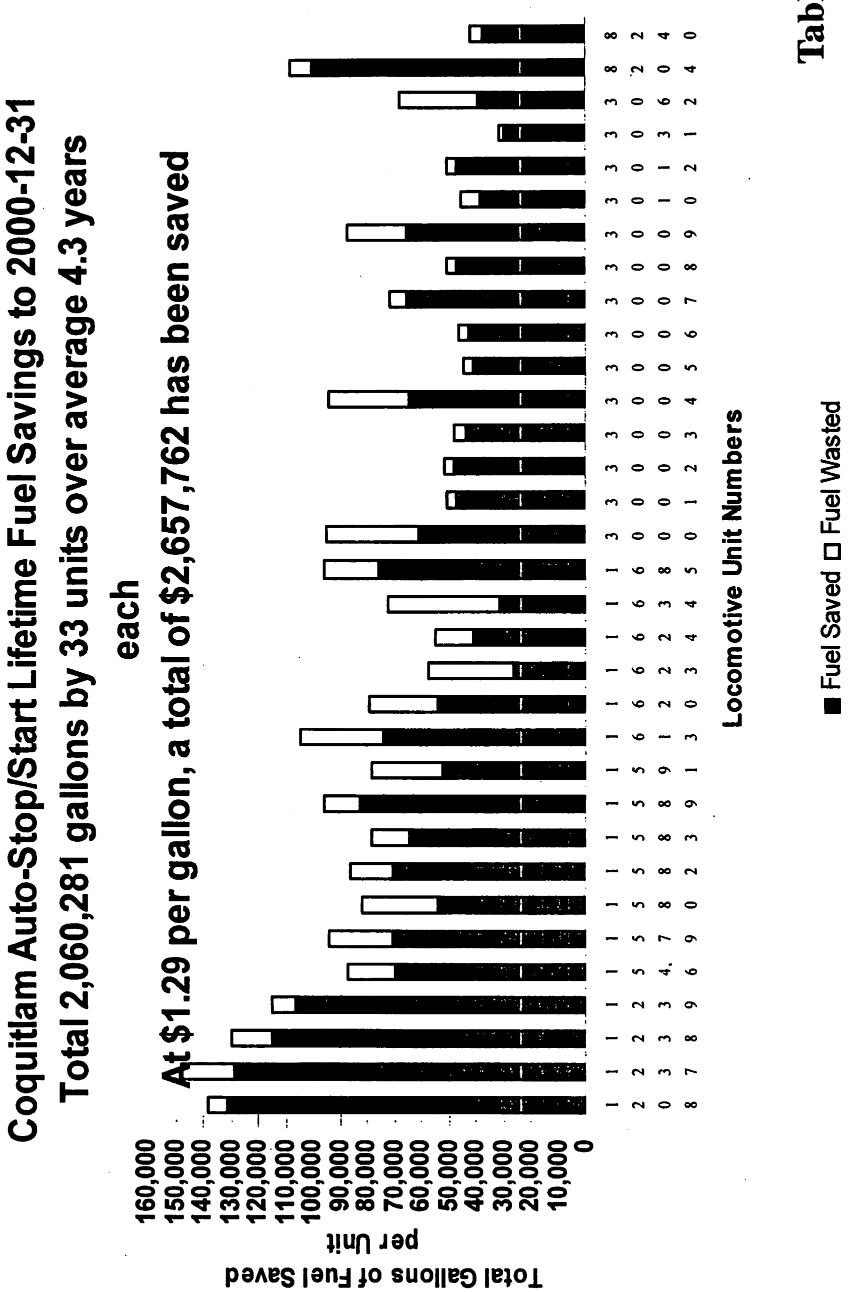

Coquitlam Auto-Stop/Start Lifetime Fuel Savings to 2000-12-31
Total 2,060,281 gallons by 33 units over average 4.3 years each
At $1.29 per gallon, a total of $2,657,762 has been saved
Total Gallons of Fuel Saved per Unit
160,000
150,000
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1208
1237
1238
1239
1546
1579
1580
1582
1583
1589
1591
1613
1620
1623
1624
1634
1685
3000
3001
3002
3003
3004
3005
3006
3007
3008
3009
3010
3011
3013
3032
8204
8240
Locomotive Unit Numbers
■ Fuel Saved □ Fuel Wasted

Table 5

Table 6

AUTOSTART (FECGP38-2)				FUEL REPORT	
COLLECTED ON:		16:28:06	02/06/01	LOCO NUMBER:	00000510
TIME/DATE OFFSET:	+	00:00:00	0 DAYS		

****

LOCO NUMBER	=	00000510	(GP38-2)
COLLECTED ON T/D	=	16:28:06	02/06/01
SYSTEM TIME/DATE	=	15:25:25	02/06/01
FUEL CONSUMPT IN IDLE	=	4.00 gal/hr	
FUEL COST	=	$1.30 dollars/gal	

FUEL SAVINGS	LIFETIME STATISTICS		SHORT TERM STATISTICS	
SINCE TIME/DATE	11:05:37	09/08/00	07:57:10	10/11/00
	SAVINGS	GALLONS	SAVINGS	GALLONS
MANUAL SHUTDOWN	$1297.48	998	$1193.00	918
AUTOSTART SHUTDOWN	$3850.87	2962	$3850.84	2962
UNREALIZED SAVINGS	$409.06	315	$408.44	314
ESTIMATED ANNUAL SHUTDOWN SAVINGS			$22551.26	17347

****

Table 6 (Continued)

AUTOSTART (FECGP38-2) FUEL REPORT

COLLECTED ON:	16:28:06	02/06/01	LOCO NUMBER: 00000510
TIME/DATE OFFSET: +	00:00:00	0 DAYS	

****

THROTTLE	LIFETIME STATISTICS			SHORT TERM STATISTICS		
	HOURS	DAYS	%ON	HOURS	DAYS	%ON
IDLE PARKED	90.2	3.8	5.9	87.9	3.7	5.9
IDLE WORKED	125.5	5.2	8.2	125.3	5.2	8.4
LOW IDLE	171.6	7.1	11.3	171.5	7.1	11.5
HIGH IDLE	0.0	0.0	0.0	0.0	0.0	0.0
THROTTLE 1	39.1	1.6	2.6	39.0	1.6	2.6
THROTTLE 2	36.8	1.5	2.4	36.7	1.5	2.5
THROTTLE 3	23.6	1.0	1.6	23.6	1.0	1.6
THROTTLE 4	14.3	0.6	0.9	14.3	0.6	1.0
THROTTLE 5	6.6	0.3	0.4	6.6	0.3	0.4
THROTTLE 6	4.2	0.2	0.3	4.2	0.2	0.3
THROTTLE 7	2.3	0.1	0.1	2.3	0.1	0.2
THROTTLE 8	15.6	0.6	1.0	15.6	0.6	1.0
DB BRAKING	0.0	0.0	0.0	0.0	0.0	0.0
RUN TIME	1521.4	63.4		1496.9	62.4	

****

Table 6 (Continued)

ENGINE OPERATION	LIFETIME STATTISTICS			SHORT TERM STATISTICS		
SINCE TIME/DATE	11:05:37	09/08/00		07:57:10	10/11/00	
	HOURS	DAYS	%ON	HOURS	DAYS	%ON
TOTAL SERVICE TIME	3628.3	151.2		2839.5	118.3	
OUT OF SERVICE TIME	2108.5	87.9	58.1	1342.6	55.9	47.3
IN SERVICE TIME	1519.8	63.3	41.9	1496.9	62.4	52.7
PERCENTAGES BASED ON TOTAL SERVICE TIME						
ENGINE OFF TIME	990.1	41.3	65.1	970.0	40.4	64.8
ENGINE RUN TIME	531.4	22.1	35.0	526.9	22.0	35.2
PERCENTAGES BASED ON IN SERVICE TIME						
ENGINE LOADING	144.1	6.0	27.1	142.2	5.9	27.0
ENGINE IDLING	387.2	16.1	72.9	384.7	16.0	73.0
PERCENTAGES BASED ON ENGINE RUN TIME						
MANUAL SHUTDOWN	249.5	10.4	16.4	229.4	9.6	15.3
AUTOSTART SHOUTDOWN	740.6	30.9	48.7	740.5	30.9	49.5
UNREALIZED SAVINGS	78.7	3.3	5.2	78.5	3.3	5.2
PERCENTAGES BASED ON IN SERVICE TIME						
ESTIMATED ANNUAL SUTOSTART SHUTDOWN TIME				4336.8	180.7	

Table 6 (Continued)

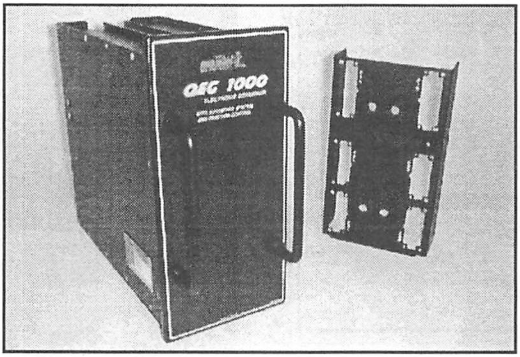
UNABLE TO SHUTDOWN TIMES			ALARM LOG	
REASON	LIFETIME		SHORT TERM	
	HOURS	DAYS	HOURS	DAYS
TOTAL	78.7	3.3	78.5	3.3
BRAKE CYLIN	3.7	0.2	3.7	0.2
DIRECTION	1.4	0.1	1.4	0.1
AMBIENT TEMP	0.0	0.0	0.0	0.0
BATTERY VOLT	0.0	0.0	0.0	0.0
WATER TEMP	8.3	0.3	8.2	0.3
BATTERY CURRENT	68.8	2.9	68.8	2.9
EXTENDED IDLE	33.6	1.4	33.3	1.4
LEAD	0.0	0.0	0.0	0.0

****

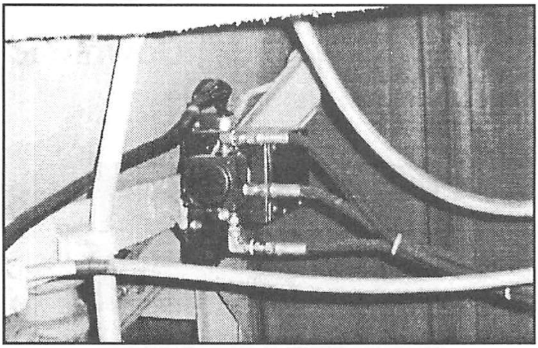
ENGINE RESTART COUNTS

REASON	LIFETIME	SHORT TERM
BRAKE CYLIN	117	117
DIRECTION	117	117
AMBIENT TEMP	0	0
BATTERY VOLT	4	4
WATER TEMP	52	52

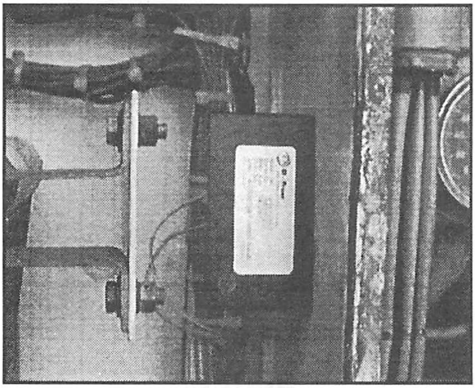
The following photos show the components installed onboard the locomotive.



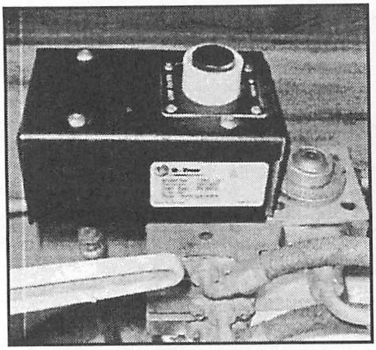
Main control unit



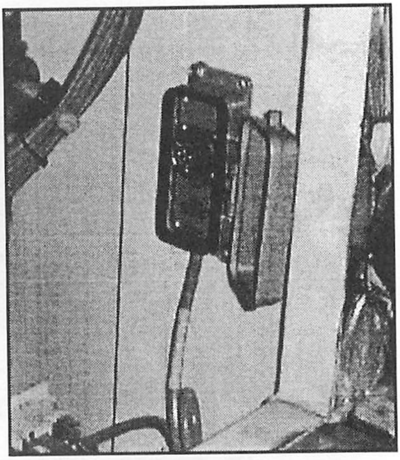
Governor assist pump



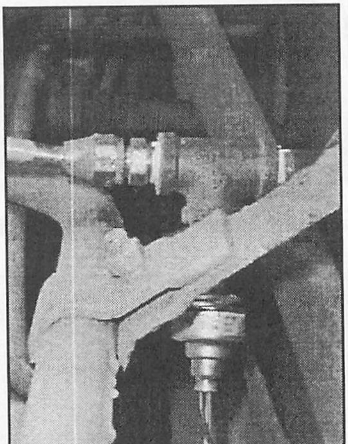
Siren Panel



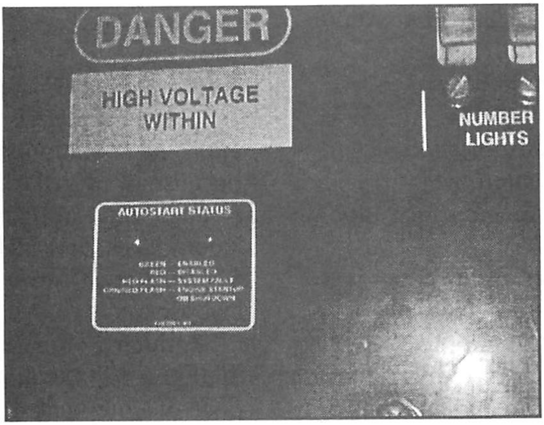
EPD override



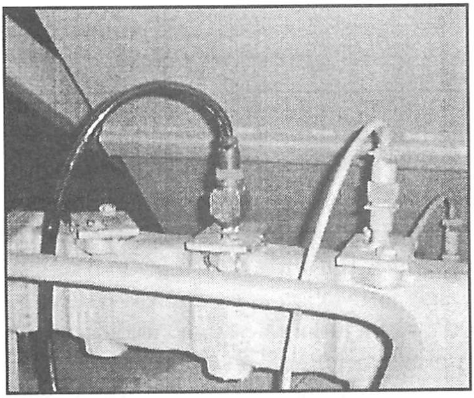
Download port



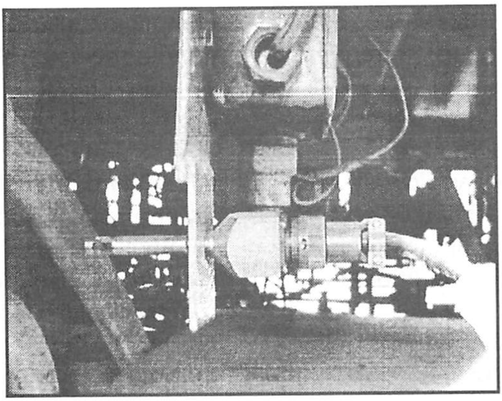
Brake cylinder sensor



Status lights



Water temperature sensor



Ambient air temperature sensor

IV. LOCOMOTIVE ALTERNATIVE AIR CONDITIONERS

Prepared by:
Michael E. Drylie, P.E.,
CSX Transportation
Presented by:
Kar Gazarov, CSX Transportation

The purpose of this paper is to assist the reader in making a decision about locomotive retrofit air conditioning systems. Some factors to consider when making this decision are:

- Low cost
- Cooling capability
- Long life
- Ease of installation
- Maintainability
- What is on the horizon?

Low cost

Standard rooftop (internal inverter air conditioner) retrofit applications have high installation costs ($16,000.00 - including labor). The material required consists of the air conditioner, roof supports, insulation and curcuit breakers. It generally takes 40 man hours to perform this work. If the auxiliary generator requires replacement, cost can skyrocket.

Low cost alternatives are available and are listed below:

- Recreational vehicle air conditioners - $8,500.00
- Companion alternator powered air conditioners - $8,500.00
- Two speed companion alternator powered AC - $9,200.00
- Other types are available at similar costs.

The above cost figures include labor.

Class I railroads are slow to apply air conditioners to their fleet because of overall total cost. With a fleet of 2,000 non-equipped locomotives, an installation cost of $16,000 equals to a $32,000,000 investment.

Reducing the unit cost by $6,000 - $7,000 makes the prospect of equipping the fleet more acceptable to those who are budget conscious.

Cooling capacity

How much cooling is enough? CSX has found that crews are generally happy with any improvement. Through testing various air conditioner types, we found that a single style air conditioner rated at 13,500 BTU will cool a cab approximately 10-15 degrees and an additional 13,5000 BYU (total 27,000 BTU's) unit would cool the cab 20-25 degrees. Internal inverter air conditioners are rated at 30,000 BTU. Single speed companion alternator powered air conditioners (CAAC) provide variable output dependent upon engine speed with a maximum of approximately 24,000-25,000 BTU's and significantly less at lower engine speeds.

Two speed CAAC systems provide a variable output throughout the engine speed range but produce a more flat (constant) output than the single speed systems.

Long life

Air conditioners have traditionally failed due to poor maintenance (filters), inverter failures, and leaks. The maintenance aspect will be covered later. The desired objective is to install a system and forget about it. Today, we are happy with an air conditioner that lasts five years. The goal is to have an air conditioner that is either replaced during standard repairs (eight years) or has such a low cost that it can be thrown away each year.

Previous internal air conditioners have suffered from leaks. CSX experienced about a 10% failure rate over the last 4-5 years. Because of the inverter design some compressor failures caused damage to the inverter, increasing the repair costs. Many older units have components (contactors) with three year life cycles. SIngle speed CAAC systems have high compressor speeds (RPM's) at high notch levels resulting in shortened life cycles. CSX RV style applications have exceeded our expectations on air conditioner life (one failure on 30 locomotives over the last two years). Currently, these air conditioners still require an inverter for power. CSX experience, to date, with inverters has been mixed, with about a 20 percent failure rate.

Changes of installation have been made to attempt to improve the life of the inverter. These changes include power pickup point and a heat deflector on the roof between the air conditioners units. Additionally, changes have been made to the inverter design to include improving the fuse holders. Since the inverter is an expensive component of the installation, it is imperative that its life cycle be extended.

Two speed CAAC systems have been applied for a short time on the CSX. It is too early to tell what the life cycle expectancy will be. Compressor RPM's, have decreased compared to single speed systems. How long the life cycle will be extended is unknown at this time. Testing on the Union Pacific, Florida East Coast and CSX will quickly provide an expected life cycle figure.

Ease of installation

All air conditioners have been installed in less than 40 man hours. Removing the ceiling, cutting a roof hole and replacing the insulation is the bulk of the work. A factor to consider in the future will be replacement time. CSX has experienced replacement times of less than one shift.

Maintainability

The only maintenance items are replacement of brushes and filters. CSX rooftops do not have brushes. Filter replacements need to be done every 92 days. Longer replacement intervals result in clogged filters and necessary air conditioner replacements. CSX does not perform on-board repairs of air conditioners. LED's are used to indicate system health on most applications. Download ports are being considered to assist in the troubleshooting process.

What is on the horizon?

Future developments include utilization of 220 volt - 110 volt on-board generators. CSX is testing auxiliary power units to provide power for many systems. Piggy backing onto the 110 volt system would allow the low cost air conditioners to be installed resulting in much lower installation ($2,500) and replacement costs ($1,000 every other year).

What about companion alternator AC units? Perfecting this design would allow CSX to greatly reduce installation costs and make fleetwide implementation possible. CSX will test hydraulic air conditioners in the near future.

CSX is exploring the above options to ensure cool environments for the crews. Currently, 40% of the fleet is equipped with air conditioning systems. Over the next few years, the number of locomotive equipped with air conditioners will slowly grow. When the decision to equip the fleet is made, CSX will be in position to equip the remaining locomotives quickly with an inexpensive system of long life expectancy.

CONSTITUTION AND BY-LAWS LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION

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 I - Active Railroad Membership shall be composed of persons employed by a railroad company and interested in locomotive maintenance. Membership is subject to approval by the Board of Directors.

Section 2 - Associate Membership shall be comprised of persons employed by a manufacturer of equipment or devices used in connection with the maintenance and repair of motive power, subject to approval of the Board of Directors.

Associate members shall have equal rights with active members in discussing all questions properly brought before the association at the Annual Meeting, but shall not have privilege of voting or holding elective office.

Section 3 - Honorary Membership: Honorary Membership may be issued at the discretion of the President, subject to the approval of the Board of Directors. Honorary Members may not vote or hold elective office; all Honorary Membership shall expire at the end of the current membership year.

Section 4 - Life membership shall be conferred on all Past Presidents. Honorary life memberships shall be conferred on others for meritorious service to the Association, subject to approval by the General Executive Committee.

Section 5 - Dues and fees: Membership dues for individual active and associate membership shall be set by the Board of Directors and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end September 30. Life and honorary life members will not be required to pay dues. 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. A registration fee will be set by the Board of Directors for those attending the annual meeting. Life, life honorary, and honorary members 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. There will be one Regional Executive for each technical committee. Each officer will hold office for one year or until successors are elected. In the event an officer leaves active railroad service, he may continue to serve until the end of his term, and, if they choose, 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 - Board of Directors: There shall be a Board of Directors composed of the President, Vice Presidents, and all Past Presidents in active official railroad service. In the event a member of the Board of Directors becomes inactive, he may continue to serve until the end of his term of office.

Section 3 - General Executive Committee: There shall be a General Executive Committee, composed of the Board of Directors, the Regional Executives, and the Technical Committee Chairpersons.

Section 4 - Secretary-Treasurer: There shall be a Secretary-Treasurer, appointed by, and holding office at the pleasure of the Board of Directors, who will contract for his or her services with appropriate compensation.

Section 5 - Advisory Board - There shall be an Advisory Board composed of at least nine members, who are Senior Mechanical Officers, Assistant Vice Presidents or Vice Presidents. They will be invited by the Board of Directors and serve as ex-officio members of the General Executive Committee without vote.

Article V - Officer, Nomination and Election of

Section 1 - Elective officers shall be chosen from the active membership. The nominating committee, composed of the Board of Directors, 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 - Vacant offices. Vacancies in any elective office may be filled by presidential appointment, subject to approval of the Board of Directors.

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 countersign all expenditures of the Association and 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.

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 Board of Directors.

C. Perform the duties of the Secretary of the Board of Directors, 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 Board of Directors shall be responsible for the following duties:

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 Nominating Committee.

D. Serve as the Auditing and Finance Committee.

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

F. Exercise general supervision over all Association activities.

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

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

I. Those present at any meeting called on not less than thirty days advance written notice, shall constitute a quorum.

Section 5 - There will be one Regional Executive officer assigned to each technical committee. Their duties will consist of:

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. Represent LMOA in their respective regions.

D. Promote Association activities, especially those held within their assigned region and monitor membership activities on those railroads so assigned.

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

Section 6 - Duties of General Executive Committee:

A. Monitoring technical papers for material considered unworthy or inaccurate for publication.

B. Approve topics for the **Annual Proceedings** and Annual Meeting program.

C. Approve the schedule for the Annual program.

D. Administer all Association activities not specifically assigned to the Board of Directors.

Section 7 - The Advisory Board shall act in a consulting capacity. Past Presidents still in official active railroad service shall automatically become members of the Advisory Board.

Section 8 - The Board of Directors are entrusted with all public relation 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 Board of Directors.

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

Section 3 - Committee members will be made up of:

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 discretion of the General Executive Committee, non-railroad personnel may be allowed to participate in committee activities, subject to annual review.

E. All individuals who are on technical committees must be LMOA members in good standing. (See dues and fees, Article 3, Section 5).

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

Article VIII - Proceedings

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.

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 may be amended by a two-thirds vote of the active members present at the Annual Meeting.

DIESEL MECHANICAL MAINTENANCE COMMITTEE
TWENTY YEAR INDEX

4. Stationary and Dynamic Test Procedure for Locomotive Fuel Efficiency Measurement.
5. Personnel training on New Technology.

1990

1. Caterpillar Power in Remanufactured Locomotives.
2. The EMD 710G3A Engine
3. Improving Performance of Traction Motor Friction Suspension Bearings.
4. Fluid Leaks on GE 7FDL Engine.
5. Rebuild of the EMD F3B Fuel Injector.

1989

1. Wheel Axle Gear Wear/Impact on Traction Motor Life.
2. 710 Engine - Operational and Overhaul Update.
3. GE Power Assembly Improvements on Welded Head-to-Liner
4. Assembly Rework Procedures.
5. EMD Engine Oil Leaks. Secondary Air Filtration - Barrier vs. Impingement.

1988

1. Low-idle Operating Costs vs. Fuel Savings.
2. Rebuilding GE's EB Liner.
3. The Extended Maintenance Truck
4. Flange Lubricator Update.
5. Permaspray II - Cylinder Liner.

1987

1. EMD Water Pump Rebuilding.
2. On Board Flange 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 YEAR INDEX

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 Distribution 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 Feedback.
3. Paperless Requisitions.
4. A Practical Application of Bar Coding in the Railroad Industry.

1987

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

by the Airline Industry.

1986

1. The In-House Electronic Requisition System.
2. Electronic Data Interchange.
3. RAILING and Electronic Purchasing.
4. Quality Evaluation 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 Productivity Through Computerized Data.
2. Inbound Material Inspection.
3. Minimize Maintenance Cost Through Material Management Systems.
4. New Ideas In Material Storage Containers.

1982

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

1981

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

SHOP EQUIPMENT AND PROCESSESCOMMITTEE TWENTY YEAR INDEX

2000

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

1999

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

1998

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

1997

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

1996

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

1995

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

1994

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

1993

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

1992

1. Automated Test and Production Equipment
2. Safety Corrective Action Team
3. Automated Locomotive Wheel Shop
4. Cleaning and Surface Preparation with Sodium Bicarbonate Based Abrasive Blasting
5. Trainline Continuity Tester
6. BN - Railroad Power Assembly Shop of the 1990's.

1991

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

1990

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

1989

1. Automated Locomotive Wheel Shop.
2. Laser Guided Material Handling Vehicles.
3. Bulk Rail Lubrication Storage & Fill 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 Technology.

1986

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

1985

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

1984

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

1983

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

1982

1. Tools.
2. Rebuild line for EMD turbochargers.
3. Air brake equipment line.
4. Industrial robots.
5. Automated machines.
6. Safety related items and equipment.

1981

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

DIESEL ELECTRICAL MAINTENANCE COMMITTEE TWENTY YEAR INDEX

cedures.
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 remanufactured D87 Traction Motor Frames (Using D-77 Armature Coils)
3. Locomotive Storage (Electrical).
4. Water Cooling and Refrigerating Methods for Locomotive Cab Application

1982

1. Tests on Traction Motors.
2. Transition 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
EIGHTEEN YEAR INDEX

1990

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

1989

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

1988

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

1987

1. Electronic Fuel Injection Systems.
2. Update on Electronic Governors.
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 Developments.

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 YEAR INDEX

Exposure.
4. Field Experiences with Multi-grade Railroad Locomotive Oils.
5. Conrail Wheel/Rail Lubrication Update.

1989

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

1988

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

1987

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

1986

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

1985

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

1984

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

1983

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

1982

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

1981

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

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