TECHNOLOGY DIGEST

Timely Technology Transfer

The Maintenance and Reliability of AC Propulsion Systems in Europe

by

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TD93-006

<u>*Summary*</u>

An AAR study of the maintenance and reliability of first generation (conventional thyristor-based) three-phase AC propulsion equipment, used on European mainline locomotives, showed that the performance has been acceptable but not as good as expected. It must improve significantly to meet new European reliability targets. The AAR study also showed that the reliability targets for new European AC locomotives are generally in agreement with those recently proposed for North America.

The maintenance study was carried out over the last four years for fleets of locomotives, incorporating AC propulsion equipment, operated by the German State Railways, the Danish State Railways, and the Norwegian State Railways. These were selected because of the design similarities to the North American mainline locomotives and for their length in service since new.

The European data showed that, while the reliability of the traction motors and inverters was high throughout, the reliability of the peripheral equipment (sensors, control circuit cards, etc.) on the early series of locomotives was not up to expectations. Design modifications to the existing fleet, also incorporated into the later series of locomotives, improved the performance. Service failures of the AC propulsion systems in the Norwegian diesel-electric locomotives accounted for 0.16 failures/locomotive/year. This is marginally better than the target of 0.2 failures/locomotive/year specified in the AAR's "Performance Specification for an AC Traction Motor Equipped Diesel Electric Freight Locomotive". Therefore, it was concluded that the AAR specification targets are realistic, given the improvements expected from the use of the much simplified GTO thyristor-based inverters, and accounting for the difference in maintenance philosophy between European and North American railways.

The AAR specification was developed for a pilot fleet of freight locomotives to evaluate the reliability of AC propulsion systems under North American operating conditions. Economic analysis showed that the economic viability of this technology lies in fleet reduction with a corresponding improvement in reliability.

Association of American Railroads
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August 1993

INTRODUCTION AND CONCLUSIONS

AC traction systems employing modern thyristor-based inverters and 3-phase asynchronous induction motors are now commonly used to power locomotives in Europe. Control system technology for the use of asynchronous AC motors in locomotives has steadily developed over the last twenty years, with much success. This has mainly been brought about by the advent of the high current capacity thyristor, which has made the control of the asynchronous motor highly reliable and less costly. Within the past two years, mainline passenger and heavy haul freight locomotives incorporating this technology have entered service in North America.

The AAR in 1988, at the request of its members, undertook to perform an independent assessment of the then existing and emerging AC traction motor technology. Ultimately this assessment led to the preparation of a performance specification for North American AC equipped freight locomotives. Based on analysis results that showed economic viability lay in fleet reduction, strict reliability targets were included in the performance specification.

Reliability parameters were specified for the propulsion system only, and these were defined by three categories. The first category is Unscheduled Maintenance and the reliability target is 0.2 shoppings per locomotive per year. A shopping is defined as a repair requiring more than 2 hours on a service track or moving to a back shop. The second category is Service Integrity, and the target is 2 failures per locomotive per year for the first million miles of service. A failure is defined as an incident impairing performance by 5% or more. The word performance denotes train schedule performance. The final category is Component Reliability and the target is a maximum of 3 failures per locomotive per year for the first million miles. A component failure is defined as unscheduled replacement of any propulsion system component.

In order to support further economic analysis of AC traction in North America, a preliminary maintenance study was needed. Data for the maintenance study were obtained through face-to-face discussions in 1990 with several European railways, with AC equipped locomotive fleets comparable in power levels and annual mileage to North American equipment. Conversation centered around the railways' maintenance practices and service experience. Additional visits were then made in 1992 to the same European railways to gather up-to-date maintenance data and to request information regarding their present and future reliability targets.

The following conclusions were drawn from the maintenance and reliability study:

- AC propulsion system equipment component failure data and locomotive over-the-road failure data showed that the performance of the basic AC propulsion equipment was acceptable by European standards but not up to expectations.

- Overall locomotive system reliability of early units has not reached acceptable levels, but the failures largely occur in peripheral components not directly related to the AC propulsion system.

- There is little difference in capacity between European and North American AC propulsion system inverters and traction control computers, the main difference being in the transmission system (motors, gearing). European experience at high inverter power levels is useful information.

- Mean Mileage Between Failure (MMBF) for diesel-electric locomotives for the same railways showed fewer failures than electric locomotives. The catenary/pantograph/transformer/convertor is a much "stiffer" power source than the diesel engine/alternator, which may account for some of this difference.

- There is considerable variability in MMBF

Railway	Class	No. of Units	Weight (Tons)	HP	Max Speed (mph)	Wheel Dia (in)	S.T.E. (lbs)	Motors per Inv'tr	Catenary Diesel Engine Info.
DSB	ME EA3000	37 10 (12)	125 88	3300 5360	98 100	43 49	90,000 58,000	6 2	EMD 16-645 E3B 25 kV, 50 Hz
NSB	El 17 Di 4	12 5	70 124	4020 3300	87	43	81,000	2 6	15 kV, 16.67 Hz EMD 16-645 E3B
DB	E 120	65	92	7500	125	49	81,000	2	15 kV, 16.67 Hz

Legend:
S.T.E = starting tractive effort
kV = kilovolts, catenary voltage
HP = horsepower, mechanical power output
Hz = Hertz, catenary AC frequency
EMD = Electro-Motive Division, General Motors Corporation

EXHIBIT 1. KEY EUROPEAN AC TRACTION LOCOMOTIVES - DESCRIPTION

	Series 1 1988	Series 1 1989	Series 1 1990	Series 1 1991	Series 2 1991	Series 2 1992*
Fleet Mileage	1,609,500	1,500,563	1,684,125	739,625	918,438	
No. of Delays	45	53	37	28	13	7
In-route Failures	36	38	32	22	9	2
Miles Between Delays	35,600	28,300	45,500	26,450	70,600	
Miles Between Failures	44,700	39,500	52,600	33,600	102,000	250,000

* First 8 months of 1992

EXHIBIT 2. RELIABILITY OF NSB CLASS El17 LOCOMOTIVES

Railway	DSB		NSB		DB
Fleet/Type	ME (d-e)	EA 3000 (elec)	Di 4 (d-e)	**EL17 (elec)**	E120 (elec)
Mileage/ Unit/year	132,000	105,000	128,000	**186,000**	187,500
Failures/ Unit/year	2.1	2.6	0.54(0.16)	**2.7 (1.0)**	1.0
MMBF*	62,900	40,400	256,000 (800,000)	**68,900 (186,000)**	187,500

* = Mean Mileage Between Failures　　( ) = AC related
d-e = diesel-electric　　elec = electric

EXHIBIT 3. OVER-THE-ROAD FAILURE DATA

	DANISH STATE RAILWAYS	GERMAN STATE RAILWAYS	FINNISH STATE RAILWAYS	AAR SPEC.: SERVICE INTEGRITY	AAR SPEC.: UNSCHED. MAINT.
Annual Mileage	150,000	187,500	125,000	**150,000**	150,000
Failures/ Loco/Year	0.24	0.50	1.00	**2.00**	0.20
Mileage/Failures	625,000	375,000	125,000	75,000	750,000

EXHIBIT 4. FUTURE RELIABILITY TARGETS

values between railways. This is probably due to different maintenance practices, failure definitions, operating practices and utilization, as well as the age and manufacturer of the locomotives in their fleets.

- It is difficult to make a direct comparison between the European reliability data and the North American AC locomotive performance specification because of different operating and maintenance philosophies.

- The main benefit of European maintenance data is that it confirms a high level of traction motor reliability under high mileage/high utilization service. While data for electrical and electronic equipment are less valid, due to the difference in design (conventional thyristor versus GTO thyristor), it does demonstrate the "worst case" performance that can be expected.

- The European railways were not satisfied with the initial levels of reliability of the electronic control equipment, but were generally encouraged by an upward trend in the ensuing years of service.

- The latest European specifications for new equipment contain reliability targets in line with those contained in the AAR specification, indicating the expectation of reliability improvements due to design progress over the last five years.

- Only service experience in North America will satisfactorily resolve the reliability issue. The widespread operation of service prototypes, such as the SD60MAC and the AAR member railroad pilot fleet will provide this experience.

EUROPEAN MAINTENANCE AND RELIABILITY EXPERIENCE

The three fleets of AC equipped locomotives that were the focus of the maintenance and reliability study belonged to the Danish State Railways (DSB), Norwegian State Railways (NSB), and German Federal Railways (DB). Exhibit 1 lists the main attributes of these fleets.

These locomotive fleets, introduced in 1981, were the first AC traction road haul locomotives put into service in their respective countries. There were initial problems, but most have been resolved and reliability has generally improved. The following is an example of the history of the NSB with their fleet of 12 electric locomotives, Class El17.

These locomotives were purchased as a series of 6, followed later by a second series of 6. Most of the initial problems were encountered with the original order. Revisions made in the field with the original order were built into the second series. Statistics were compiled for 1988 - 1990 on the first series of locomotives, and for 1991 on the second series, as shown in Exhibit 2. Partial 1992 data is also included.

These statistics show the reliability improvements after correction of defects. The defects were largely in peripheral equipment and not in major AC traction equipment. The statistics for Series 1 locomotives in 1991 were affected by the first scheduled heavy maintenance of the first unit. The dramatic improvement in reliability can be seen with the introduction of the second series in 1991. This may be taken as typical of the Scandinavian experience with their early units. Exhibit 3 shows over-the-road failure values for several European fleets for 1990 and 1991, as well as a comparison of electric and diesel-electric equipment. The definition of over-the-road failure is that a relief locomotive was required.

The electric locomotive data shows the similarity between the two Scandinavian railways, and some disparity between their units and those of the DB. The diesel-electric locomotive data shows fewer breakdowns and longer mileage between breakdowns than the electric units for the same railway. When looking at the number of failures attributed to the AC propulsion system alone, the numbers look considerably better.

The AC related failures can be compared to the AAR AC Locomotive Performance Specification reliability targets. The first target is 0.2 unscheduled shoppings per locomotive year for the first million miles. This translates to a Mean Mileage Between Failure (MMBF) of 750,000 for failures that are AC propulsion system related. The target for mission failure rate (5% performance loss) of 2 per year would translate into a MMBF of 75,000. The NSB Class Di4 locomotive had a total shoppings MMBF value of 44,600 for AC propulsion system related causes over 31 months.

Included in this study were the European railways reliability targets for their next generation of AC power. These values are shown in Exhibit 4, as well as the targets for the AAR performance specification. The comparison shows that the North American targets, for AC related causes only, look realistic. The difference in operating philosophy can also be seen. The European targets for over-the-road failures compares by type to the AAR unscheduled shoppings target (Service Integrity), but in number more to the mission failure target (Unscheduled Maintenance). North American freight railroads have set a tight unscheduled maintenance target and an over-the-road failure target with more latitude, while the opposite is true in Europe.

European service is typically a single locomotive on tight schedule and any road failure presents problems. North American railroads typically use multiple unit consists where a road failure will not usually mean a stalled train. North American railroads are looking for high availability, keeping locomotives out of the shop and in service. The Europeans typically shop their locomotives daily to inspect them between daytime (passenger) and nighttime (freight) services. However, hot-shot intermodal service is being introduced in North America that utilizes a single locomotive. This should be considered when setting reliability targets. AC traction is well-suited for high speed service as well as high tractive effort.

Note: Contact G. B. Anderson at (312) 808-5824 with questions or comments about this document.