Electric Locomotives for the 1980s

MAX EPHRAIM, JR.

An up-to-date report on electric locomotive developments in the United States is presented in this paper. U.S. manufacturers of electric locomotives are continuing their design and development of electric locomotives for worldwide applications. Although no major electrification projects are being undertaken in the United States, electric locomotives for Mexico, Canada, and South Africa are being designed in the United States. They are being built either in the United States or in associates' plants in other countries. The major question of relative maintenance and capital costs for electric and diesel-electric locomotives is addressed. These relative costs will vary considerably depending on the type of service to which the locomotives are assigned and the quantity of locomotives manufactured.

U.S. locomotive manufacturers are progressing in their electric locomotive technologies, although applications are primarily in foreign countries. The evidence shows that U.S. manufacturers have the electrical and mechanical skills to provide electric locomotives that have the most modern electrical features in significant quantities.

NEW ELECTRIC LOCOMOTIVES MANUFACTURED IN THE UNITED STATES

Amtrak Model AEM-7 Locomotive

National Passenger Rail Corporation (Amtrak) model AEM-7 locomotive (1) is designed specifically for high-speed (200 km/hr) passenger service in the Northeast Corridor (Washington to New York and later to Boston). Figure 1 shows the specifications and arrangement and location of major equipment items. Delivery of the AEM-7 locomotives began in 1980, and the 47th and last unit was delivered in July 1982.

Figure 2 gives the operating characteristics of the AEM-7 locomotive including rail power and tractive effort capabilities. The locomotive is nominally 7,000 diesel equivalent horsepower and uses features proven in European railroad service. This locomotive also includes the first application of a static inverter for supplying three-phase power to passenger cars (head-end power).

Features of the AEM-7 locomotive include the following:

1. High horsepower--7,000 diesel equivalent;
2. High-speed operation to 200 km/hr;
3. Thyristor control power circuits;
4. Multivoltage power capability; can operate on 11,000 volt, 25 Hz, or 25,000 volt, 60 Hz;
5. Separately excited frame-mounted traction motors;
6. Static inverter for train power--625 kVA, 480 volts, 60 Hz, three-phase; and
7. Combination disc and tread air brakes with automatic blending of air and electric dynamic brakes.

National Railways of Mexico Model E60C Locomotive

General Electric is providing 39 E60C locomotives to the National Railways of Mexico for operation on their new 155-mile (250-km) electrified line between Mexico City and Queretaro. Figure 3 shows the general arrangement of this new dual cab locomotive design.

Single-phase power is picked up from the catenary and stepped down by the main transformer and then supplied to the six railway type DC series traction motors by using thyristor-rectifier converters.

Locomotive auxiliaries, including ventilation blowers, control power, and air compressor, are powered by two DC motors. Self-cleaning inertial filters provide air to ventilated components. Ratings, weights, and dimensions are also shown in Figure 3, and tractive effort and speed characteristics are shown in Figure 4.

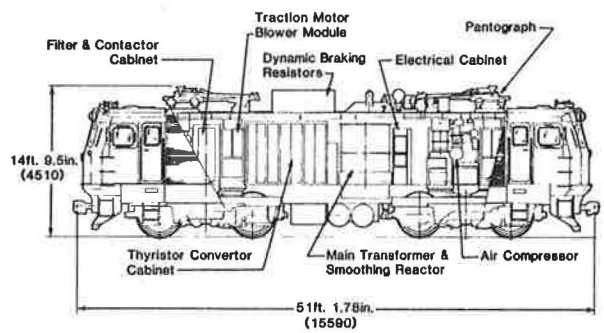
South African Transport Services Class 11E Locomotive

In 1984 Electro-Motive will deliver 30 model GM5FC (Class 11E) locomotives for the South African Transport Services (see Figure 5 for the general arrangement). These locomotives are nominally rated at 3,780 kW at the rail at a speed of 34 km/hr.

The new model GM5FC locomotives are designed for operation on the 25-kV, 50-Hz electrified line between Ermelo and Richards Bay. They are Co-Co type locomotives (i.e., two trucks with three axles on each) with a single cab and are designed to operate on the 3-ft, 6-in. gauge (1,067 mm) track that is the South African standard. These locomotives are designed for 28-T axle loading.

Figure 6 shows the rail power and tractive effort

Figure 1. AEM-7 locomotive.



Track Gauge	4 ft. 8.5 in.	1435 mm
Wheel Diameter	51.2 in.	1300 mm
Bogie Wheel Base	9 ft. 1 in.	2770 mm
Width (max.)	10 ft. 2 in.	3100 mm
Axle Load (max.)	50,160 lbs.	22.75 tonnes
Speed (max.)	125 mph	200 km/h
Tractive Effort at Rail	28,100 lbs.	125 kN
Starting Effort	51,710 lbs.	230 kN

Figure 2. Operating characteristics of AEM-7 locomotive.

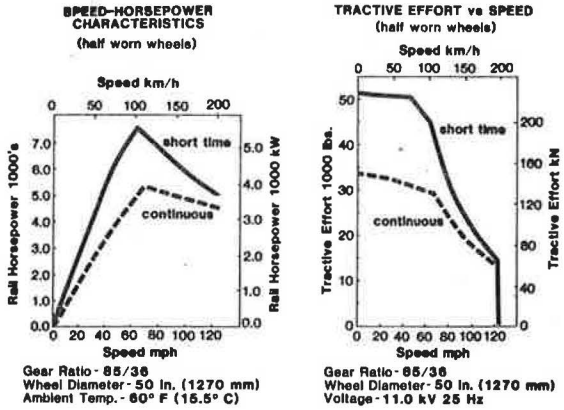
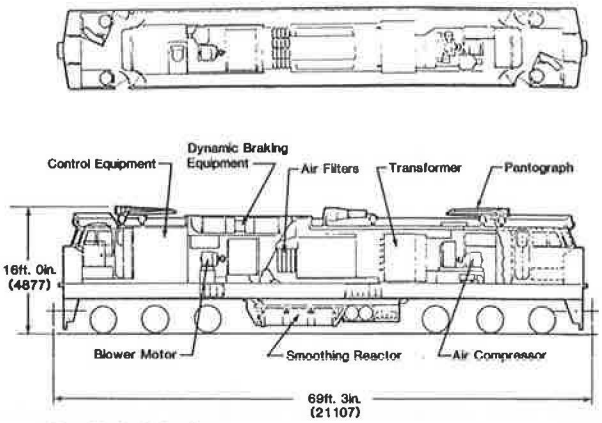


Figure 3. E60C locomotive.



Ratings	Nominal voltage	25,000 V
	Maximum voltage	27,500 V
	Minimum voltage (continuous)	19,000 V
	Minimum voltage (short time)	17,500 V
	Continuous rail power	4,400 kW
	Continuous tractive effort (83/20 gearing, 1016 mm wheels)	365 kN
	Maximum starting tractive effort	520 kN
	Maximum locomotive speed	110 km/h
Weights	Nominal locomotive (locomotive weight subject to manufacturing tolerance of ± 2%)	168,000 kg
	Nominal per driving axle	28,000 kg
	Minimum locomotive	150,000 kg
	Minimum per driving axle	25,000 kg
Wheel Arrangement		Co-Co
Major Dimensions	Length inside knuckles	21,107 mm
	Height over pantograph locked down	4877 mm
	Width over platform	3023 mm
	Clearance under gear case	111 mm
	Minimum radius of curvature (locomotive alone)	80 m
	Track gauge	1.435 m
Capacity	Sand	1.7 m³

Figure 4. Operating characteristics of E60C locomotive.

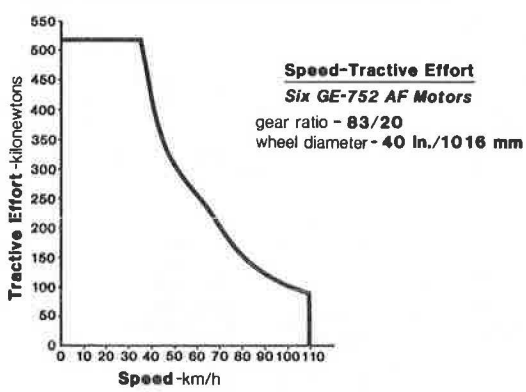


Figure 5. GM5FC locomotive.

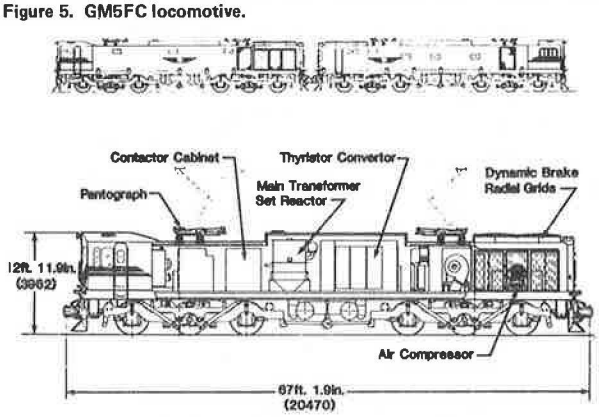
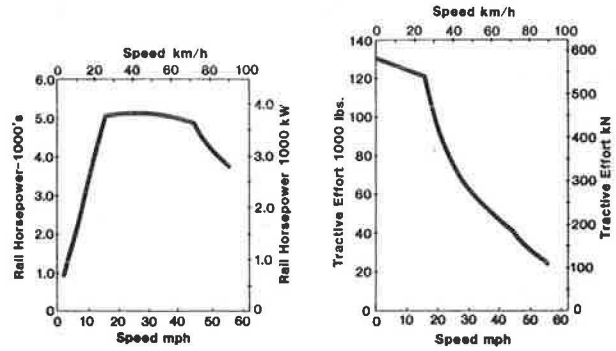


Figure 6. Operating characteristics of GM5FC locomotive.



capabilities. The power transmission uses full thyristor control for the six separately excited motors. Radar is used to measure locomotive speed and provides the input for the controlled creep wheel slip system.

The high-adhesion, three-axle trucks feature a zero weight shift design with intertruck control. Electrical load compensation is provided for weight shift between the two trucks.

Other features include the following:

1. Radar-based adhesion control with controlled wheel creep,
2. AC-powered auxiliaries that use three-phase power from a static inverter,
3. Oil-cooled power devices,
4. Dynamic brake, and
5. Accelerometer and distance meter.

British Columbia Railway Model GF6C Electric Locomotive

In August 1982 General Motors of Canada was given an order for seven locomotives from the British Columbia Railway. These locomotives (Figure 7) will operate on a new 130-km electrified line between Tumbler Ridge and Anzac in the central section of British Columbia. This will be the first 50-kV electrification on an operating line-haul railway in North America.

These locomotives are rated at nominally 3,800 kW at the rail, or the diesel equivalent of 6,000 hp. They include provision for power adjustment between 2,500 kW and 4,400 kW to protect from line overload as required. These locomotives are designed for nominally 65,000 lb (29.5 T) axle loading.

Figure 8 shows the rail power and tractive effort characteristics. The control system is designed so that, in a small speed interval, the traction motor voltage decreases linearly with increased motor current rather than following a hyperbolic curve. The result is a hump in the graph that shows the power at the rail versus locomotive speed.

A standard U.S. high-adhesion, three-axle truck is used with minor modifications. The traction motors feature roller support bearings and separately excited fields. Other features include the following:

1. Radar-based adhesion control with controlled wheel creep,
2. AC-powered auxiliaries that use three-phase power from a static inverter,
3. Oil-cooled power devices, and
4. Dynamic brake.

Delivery of these new locomotives was scheduled to begin in the fourth quarter of 1983.

Figure 7. GF6C locomotive.

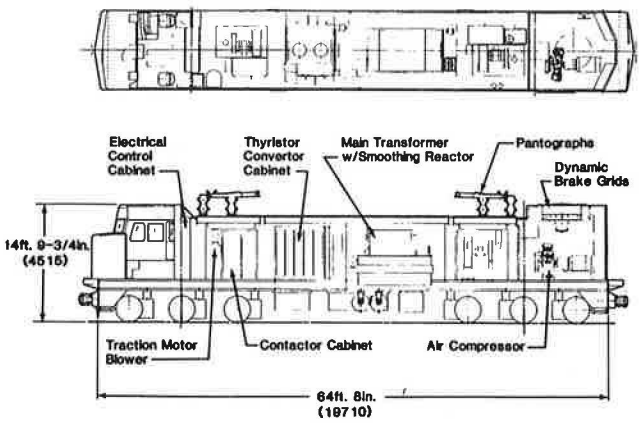
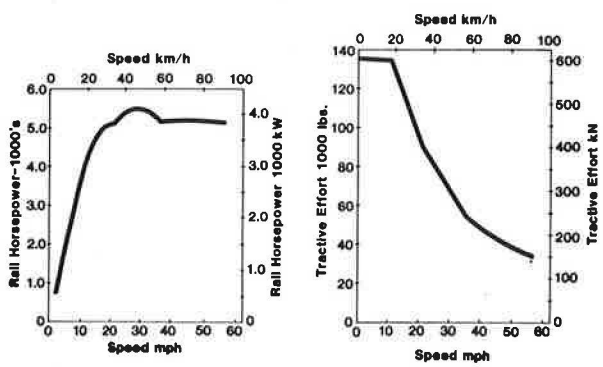


Figure 8. Operating characteristics of GF6C locomotive.



MAINTENANCE AND CAPITAL COSTS

Maintenance and capital costs of electric locomotives are frequently compared with those of diesel-electric locomotives. A clear understanding of tractive effort and power capabilities is important when reviewing such costs. An electric locomotive has the same potential maximum tractive effort capabilities on drivers as a diesel-electric locomotive of equivalent weight.

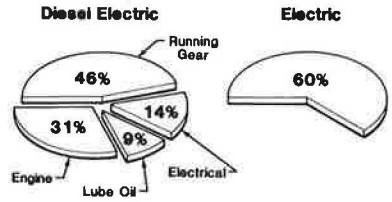
In North America major railroad emphasis is directed toward handling freight, and this normally involves high adhesion requirements over ruling grades. Electric locomotives are not restricted by the output of a diesel engine. They can haul freight trains faster but do not have the capability of achieving higher maximum tractive effort than a diesel-electric locomotive.

A 1981 report released by the Jet Propulsion Laboratories estimated annual maintenance costs of $55,000 in 1980 dollars for a 3,000 hp main line locomotive. This figure is considered a good industry average, recognizing that there is a wide difference between railroads. Note that these maintenance costs apply to U.S. locomotives in heavy-duty freight service. In many countries these costs are reduced considerably because locomotives in general have lighter duty cycles.

The distribution of maintenance costs is estimated as shown in Figure 9. These costs can be summarized as follows:

Item	Percentage of Total
Engine	31
Lube oil	9
Electrical	14
Running gear	46

Figure 9. Distribution of maintenance costs for heavy-duty freight locomotives.



The maintenance cost of a comparable electric locomotive would be approximately 60 percent of the diesel-electric because engine and lube oil expenses are eliminated. This ratio will be applicable for electric locomotives that operate in heavy-duty freight service in North America.

Passenger trains present a different challenge because they require high horsepower to meet high-speed schedules. An AEM-7 electric locomotive is ideal for hauling high-speed passenger trains in the relatively level Northeast Corridor, but because of their light weight [201,000 lb (91.2 T)], they would not be suitable for hauling a coal train up a 2 percent grade.

These differences must be noted when comparing maintenance and capital costs of electric and diesel-electric locomotives. Whereas an AEM-7 locomotive could replace two or three diesel-electric locomotives in high-speed passenger service, it may replace only one four-axle, diesel-electric locomotive in heavy-duty freight service. Capital costs of electric and diesel-electric locomotives must be weighed on the basis of comparative cost per horsepower and comparative cost of tractive effort.

The AEM-7 electric locomotives cost approximately $2.5 million in 1982 dollars. This price includes many special features required for passenger service in the Northeast Corridor. It would require 2.5 or 3 diesel-electric locomotives to replace one AEM-7 electric locomotive in this high-speed service, and the total cost would be about the same or even more than the AEM-7 locomotive. Thus, in the Northeast Corridor, in high-speed passenger service (which does not involve any appreciable grades), one electric locomotive can replace two or three diesel-electric locomotives. If heavy gradients are encountered this comparison no longer holds true.

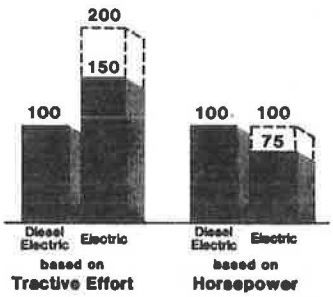
The capital costs of diesel-electric and electric locomotives depend on type of service (i.e., freight versus passenger service and limiting grades and accelerations) and quantity of locomotives built (i.e., standardization of models and special requirements by the railroad).

Throughout North America the primary railroad concern is hauling freight, which involves the hauling of coal and other commodities in heavy drag service over some ruling grade at slow speeds. One six-axle electric locomotive may replace only one six-axle diesel-electric locomotive, although it could, presumably, operate at higher speeds. The use of higher power and higher speeds requires more energy with attendant increased energy costs. This additional power capability, however, cannot be used much of the time due to restrictions on train speed.

Indications are that the relative cost ratio of electric locomotives to diesel-electrics is being reduced. As U.S. builders produce more electric locomotives and gain additional experience, this ratio will be reduced further. With limited information, the following estimates can be made for heavy-duty freight locomotives (Figure 10).

1. On the basis of continuous tractive effort ratings the cost of electric locomotives will be be-

Figure 10. Estimated capital cost for heavy-duty freight locomotives.



tween 150 and 200 percent of that of diesel-electric locomotives.

2. On the basis of power capability the cost of electric locomotives will be between 75 and 100 percent of that of diesel-electric locomotives.

These are estimates; locomotive prices will depend much on customer special requirements. These comparisons, however, should provide input to the question of whether electric locomotives cost more or less than diesel-electrics. The answer will depend on the type of operation involved.

CONCLUSION

Current orders for electric locomotives designed by U.S. manufacturers will ensure their capabilities of meeting U.S. railroad needs if and when electrification is adopted. Maintenance and capital cost information included in this paper should prove helpful when making railroad economic studies.

REFERENCE

1. M. Ephraim, Jr. The AEM-7--A New High-Speed, Light-Weight Electric Passenger Locomotive. ASME, 82-RT-7, April 1982.

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