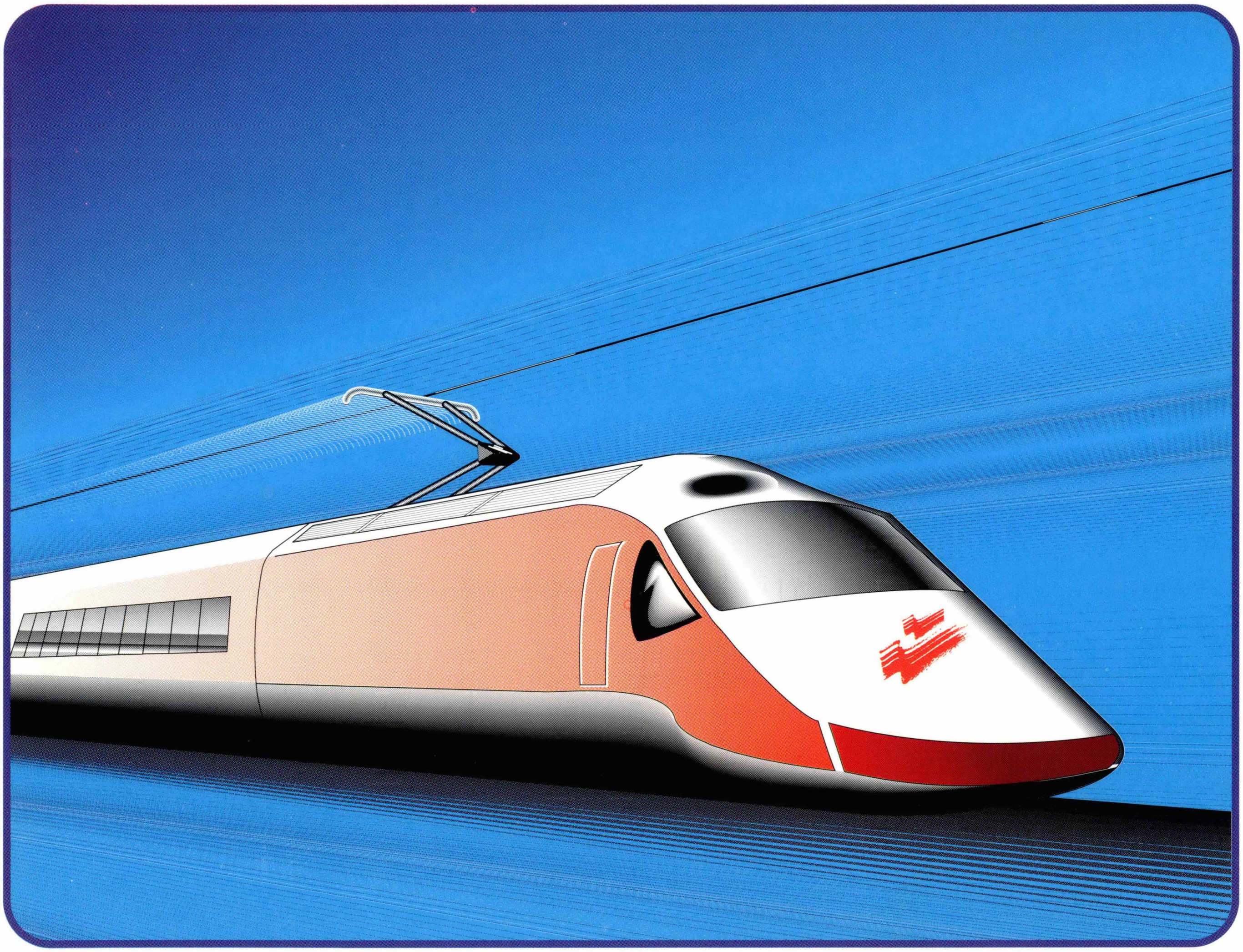
U. S. Department
of Transportation

**Federal Railroad
Administration**

Safety Relevant Observations on the TGV High Speed Train



Moving America
New Directions, New Opportunities

July 1991

Foreword

New intercity high-speed rail technologies may become an operational reality in the United States in the next few years. This report presents an initial safety review of one such technology, the French train known as the Train "Grande Vitesse" (TGV). The TGV has been selected as the franchisee for operation in the "Texas Triangle." The other system, the German Intercity Express (ICE), considered in the franchise application process is the subject of a companion report.

High-speed rail technologies are designed and built to suit a particular operating scenario. Three steel-wheel-on-rail systems, each designed for a different application, have thus far been the subject of safety relevant observations: the Swedish X2000, the French TGV, and the German ICE. These new technologies may require a whole new look at our present safety requirements. For example, existing regulations and statutes, as applied to high-speed rail, may have to be adapted to the unique existing foreign technology. Also, foreign standards must be evaluated with regard to applicability to U.S. practices, expectations, and history to ensure that the safety levels experienced in Europe and Japan are achieved in the United States. Lastly, any foreign designs, construction, and operations that are changed to meet specific U.S. customer applications must be evaluated further to determine the impact of the changes vis-a-vis both the foreign and U.S. safety assurances needed. This responsibility rests with the Federal Railroad Administration, U.S. Department of Transportation, which is charged with ensuring the safety of rail systems in the United States under the Federal Railroad Safety Act of 1970, as amended.

The Federal Railroad Administration is consciously trying to avoid placing itself in the position of impeding the development of new technology. We strive to work closely with all parties interested in promoting a more efficient and effective guided ground transportation network in the United States. Our early "system" safety assessments are intended to alert both ourselves and a system's developer to any safety issues that need attention prior to full implementation.

The future prospects of "Moving America" on high-speed electric, intercity, guided ground transportation have never looked better. Many new technologies are evolving to accommodate the varied market and operating needs that Americans on the move will need in the future. We are excited about these developments and hope you are also.

Gilbert E. Carmichael
Administrator

Acknowledgement

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Several individuals collected information for and wrote significant portions of this report: Arne J. Bang, Donald Gray, Mark S. Lindsey, Bill O'Sullivan, and Joseph W. Walsh of the FRA and Michael R. Coltman, Robert M. Dorer, William T. Hathaway, and Raymond A. Wlodyka of VNTSC. The editor responsible for combining the writing styles of the many authors was Robert L. Gaumer of EG&G Dynatrend Incorporated.

The excellent cooperation of the French National Railways (SNCF); the TGV builder, GEC Alsthom; the TGV North American agent, Bombardier Incorporated; and the consortium leader for Texas TGV, Morrison Knudsen Corporation, in supplying information before, during, and after the FRA delegation's visit to France enabled the authors to understand the technology at the level necessary for writing the report. In particular, the authors would like to express their gratitude to Monsieur Paul Monserie, Vice President of International Affairs of SNCF, for his personal attention in the numerous meetings between the FRA delegation and SNCF.

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Background

This report describes the background leading up to the development of the train grande vitesse (TGV) system, the French high-speed technology; the technology itself in some detail; and the potential U.S. applications. This document also reviews Federal Railroad Administration (FRA) regulations that may be applicable to the design of this train relative to any potential U.S. application.

This report uses information provided by the train operator in France, the French National Railways (SNCF); the train manufacturer in France, GEC Alsthom; the TGV franchise holder for North America, Bombardier Corporation; and the consortium proposing the TGV technology for application in Texas, Texas TGV, led by Morrison Knudsen Corporation. Information was also gathered from independent sources and during a series of briefings hosted by SNCF, including site visits to TGV production, maintenance, and operational facilities, and a ride on TGV Atlantique equipment for over 500 km (310 mi) at speeds up to 300 kmph (186 mph), during February 1991.

Proposed U.S. Applications

The Texas TGV consortium, based on the TGV high-speed rail technology, has been selected as the franchisee for operation in one area of the United States: the "Texas Triangle," Houston to Dallas and Ft. Worth to Austin and San Antonio. Further application of TGV technology may be proposed for other U.S. operations in the future.

The Texas High-Speed Rail Authority (THSRA) was created by the Texas High-Speed Rail Act of 1989 in part as a result of a study by the Texas Turnpike Authority (TTA). In this study, the TTA found that "high-speed rail for Texas is an economically sound and socially responsible option for increased mobility and business activity." Since its inception in 1989, THSRA has formulated procedures and an aggressive timetable for bringing a high-speed rail facility to Texas. A request for proposal was issued in September 1990.

On January 16, 1991, TGV Texas submitted a proposal to THSRA to provide high-speed rail service between Houston, Dallas, Ft. Worth, Austin, and San Antonio in four phases using TGV technology. This proposal offers an ultimate system of 950 route km (590 route mi) of dedicated double track with operating speeds up to 320 kmph (200 mph); it also includes 32 km (20 mi) of single track between the Dallas-Ft. Worth Airport and Ft. Worth.

On May 28, 1991, THSRA granted Texas TGV a franchise to finance, construct, operate, and maintain a high-speed rail facility.

Development of the TGV

SNCF has a long history of research in high-speed rail operations from both the track and equipment perspectives. During the 1960s, this research was primarily based in laboratories and theoretical analyses. In 1967, SNCF conducted low axle load, high-speed trainset feasibility tests with a turbine powered rail car, the TGS, at speeds up to 251 kmph (156 mph). Then in the early 1970s, intensive experimental and test programs to verify designs were undertaken.[1]

Vehicles used during this testing phase included a prototype of the TGV Sud-Est consist called TGV-001. The TGV-001 was turbo powered, featured an articulated trainset, and was used to study high-speed rail constraints and possible solutions prior to production. Areas such as high-speed dynamic stability of trucks and air drag reduction were investigated with this prototype. As early as 1972, the TGV-001 had attained a speed of 318 kmph (198 mph). By 1978, when this consist was retired from service with the first deliveries of TGV Sud-Est consists, it had completed over 455,000 km (283,000 miles) of reliability test runs, with 80,000 km (50,000 mi) at speeds between 200 and 300 kmph (125 and 186 mph).[2,3]

In 1972, tests were also initiated with another turbine powered vehicle, the RTG-01. These tests concentrated on high-speed trucks and disc braking systems. In 1974, yet another vehicle, the electric railcar, Z-7001, was tested. The tests emphasized the current collection system and mechanical transmission issues with body-mounted traction motors.[4]

SNCF developed grade separated, dedicated dual track lines for its high-speed rail operations. Grade separation is utilized to eliminate dangerous at-grade conflicts and increase right-of-way security. Because of the higher kinetic energies of the high-speed trains, dedicated use of the lines permits the use of steeper vertical grades than would be possible with slower passenger or freight train operations. The TGV Sud-Est line has vertical grades as high as 3.5 percent (3.5:100). SNCF's use of steeper grades is also considered a plus, as it reduces route miles, earth work, and civil structures costs.

The first TGV line, the TGV Sud-Est, has been operating since 1981 at a maximum speed of 270 kmph (168 mph). The service has been very successful and has experienced steady increases in ridership. Planning for the TGV Atlantique, the most advanced TGV technology currently in revenue service, began in 1978, and construction started in 1985. TGV Atlantique revenue service commenced on the West Branch in 1989 and on the Southwest Branch in 1990. The Atlantique version included the following TGV technology advancements: three-phase synchronous traction drives, a unique pneumatic secondary suspension system over the articulated car attachment, and a computerized communication system for the train that includes maintenance information.[5] Figure 1 shows a typical TGV Atlantique consist.

To date, SNCF has transported over 160 million people on the two operating TGV lines with an impeccable safety record. No passenger fatalities have resulted from TGV operations on the dedicated high-speed lines. However, a TGV operator and one passenger were killed when a TGV Sud-Est train, traveling on a non-high-speed line, struck a highway truck carrying a 59 tonne (65 ton) press. The truck crossed the track at an unapproved location. SNCF philosophy is that at-grade highway crossings are inappropriate for high-speed train operation.

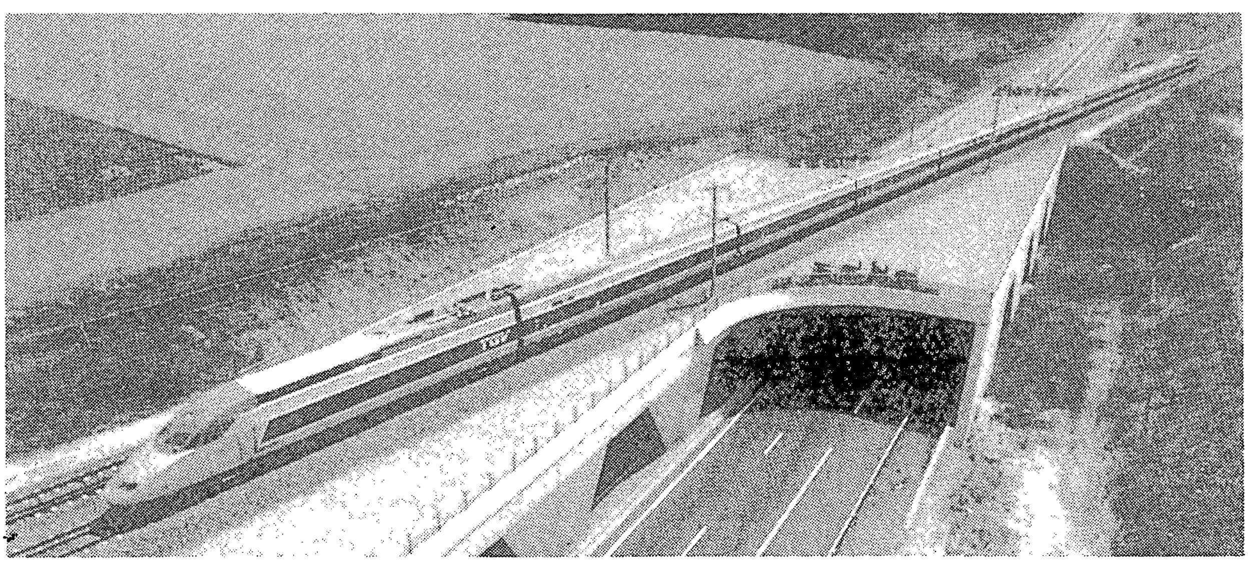

Figure 1 - Typical TGV Atlantique Consist[6]

System Description

Specifications

The TGV track and vehicle components have been specially designed as parts of a unified system to provide a safe, reliable, and economically viable high-speed intercity service.

Track Structures

SNCF builds new track alignments for high-speed operation using premium components throughout. Table 1 summarizes a number of the track specifications proposed for the Texas TGV system.

Table 1 - TGV Texas Track Specifications[7]

Distance between track centers	15 ft 0 in	(4.6 m)
Gage:		
Minimum	4 ft 8 in	(142.2 cm)
Normal	4 ft 8 1/2 in	(143.5 cm)
Maximum	4 ft 8 3/4 in	(144.1 cm)
Width of subgrade	46 ft 0 in	(14 m)
Nominal height of catenary contact wire	16 ft 9 in	(5.1 m)
Minimum ballast thickness under ties	14 in	(35 cm)
Distance between concrete tie centers	23 1/2 in	(60 cm)
Maximum curve super elevation	7 3/32 in	(18 cm)
Maximum cant deficiency:		
Standard	3 in	(75 mm)
Exceptional	4 in	(100 mm)
Minimum horizontal curve radius:		
Standard	15,600 ft	(4,750 m)
Exceptional	14,500 ft	(4,400 m)
Vertical curve radius:		
Nominal	57,700 ft	(17,600 m)
Exceptional for summits	51,800 ft	(15,800 m)
Exceptional for sags	43,300 ft	(13,200 m)
Maximum variation of super elevation in spirals within 31 ft:		
Nominal	1/5 in	(.56 mm/m)
Exceptional	1/4 in	(.67 mm/m)
Variation of cant deficiency in spirals:		
Nominal	1 1/4 in/s	(30 mm/s)
Exceptional	2 in/s	(50 mm/s)
Maximum gradient	5%, 5:100	
Spiral length for minimal curve radius	1,000 ft	(300 m)
Separation between successive transitions	500 ft	(150 m)

Note: Primary dimensions are in English units, as listed in the Texas TGV proposal. Metric units are adjusted to reflect more accurately the true metric equivalent.

Ballast - Texas TGV proposes to use the American Railway Engineering Association (AREA) no. 3, i.e., 25 to 50 mm (1 to 2 in), granite, traprock, or quartize ballast. Ballast depths of 355 mm (14 in) will be used on a 203 mm (8 in) subballast layer. SNCF uses ballast shoulder widths of approximately 500 mm (20 in), which it considers wide enough to prevent lateral shifting of the track. Occasionally, a wider section is used in curves than is used on tangent track.

Ties and Fasteners - SNCF uses twin block concrete ties in a standard ballast section at a center spacing of 600 mm (23.6 in) to support the rail. Wood ties are still used at some turnouts because of their better resilience to shock loadings. Nabla fasteners are used to provide lateral and longitudinal restraint. The rail is isolated from the tie with elastomeric pads. These pads reduce noise and tie wear. The twin block tie is thought to be more resistant to lateral motion than a single block tie; however, it may not be as resistant to longitudinal motion. Gage and precise rail cant angles may be more difficult to control for twin block than for mono block ties; however, SNCF officials have stated that they have not experienced any of these problems. Twin block ties may provide some maintenance advantages in terms of spot replacement. The ties and fasteners are shown in Figure 2.

Rails - The rails are high-strength, head hardened steel manufactured to achieve high surface quality and straightness. An International Union of Railways (UIC) 60 or equivalent U.S. rail section, comparable to AREA 132 lb/yd rail, will be used for the Texas application. Of particular concern is the straightness at the rail ends, which tend to become curved during the roller formation process. The rail is plant welded into 440 m (1,440 ft) strings, which are then field welded to provide continuous welded rail (CWR).

SNCF normally establishes a rail neutral temperature of between 20° and 32° C (68° and 90° F), based on the ambient temperature variations experienced in France. Lower neutral temperatures increase thermally induced longitudinal loads during the hot season. If not controlled, these loads can lead to track buckling. Conversely, the rail neutral temperature must not be too high compared to the coldest winter temperatures to reduce tensile forces, which if large enough can cause broken rails. Concrete ties with direct fixation fasteners, a full ballast section with wide shoulders, and careful track maintenance practices are also important in controlling longitudinal stress and buckling.

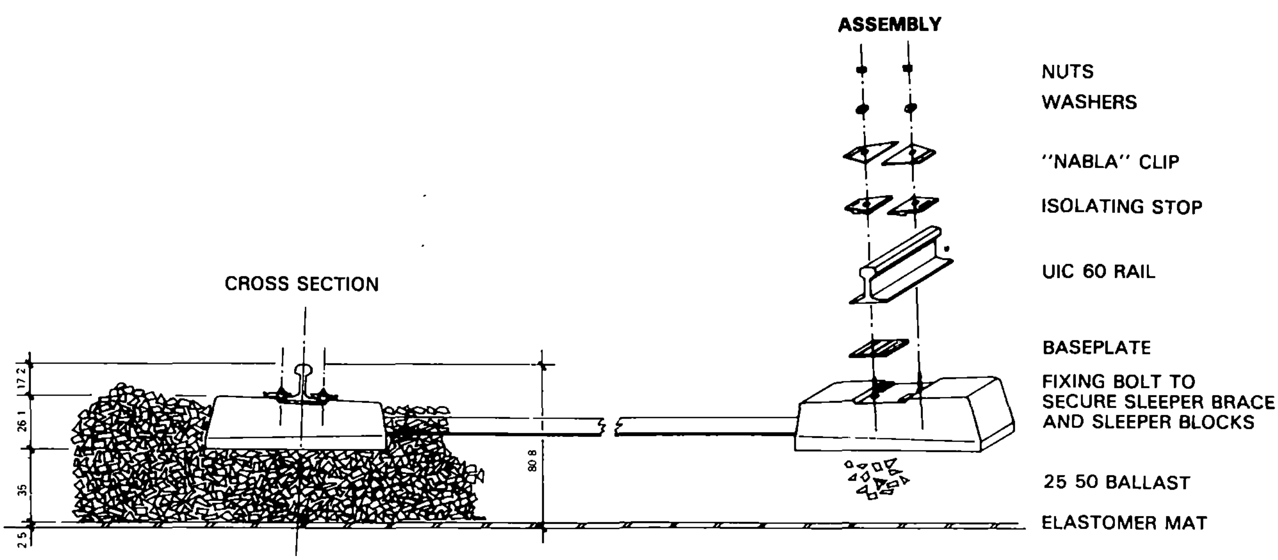

Figure 2 - Ties and Fasteners[8]

Turnouts - SNCF has specially designed turnouts for high-speed operations. An important feature of these turnouts is the moveable point or swing nose frog (see Figure 3). It eliminates much of the impact and poor ride quality associated with frogs at high speed. The other important feature of a high-speed turnout is the maximum curvature in the diverging leg. Because turnouts have no super elevation, the curves must be shallow for high speed. The number of a turnout is related to the angle of the diverging rail. The larger the number, the smaller the diverging angle. For the Texas TGV application, a no. 65 turnout is planned for speeds up to 225 kmph (140 mph) on the diverging leg. A no. 46 turnout will be used for low-speed turnouts, for speeds up to 160 kmph (100 mph). Normal AREA no. 10 turnouts will be used in yards and storage areas.

Right-of-Way - The right-of-way typically used by SNCF and proposed for Texas has a minimum width of 31 m (100 ft). To reduce wear and achieve an acceptable ride quality,

Figure 3 - Swing Nose Frog[9]

SNCF has used track with very shallow curves, with minimum radii of 4,420 m (14,500 ft), 0°, 23'. Vertical curves are even shallower, with minimum radii of 15,800 m (51,840 ft) for summits and 13,200 m (43,300 ft) for sags.

Figure 4 shows typical track and structures cross sections of SNCF TGV right-of-way. Noted in the figure is the right-of-way fence. SNCF fences the entire TGV dedicated

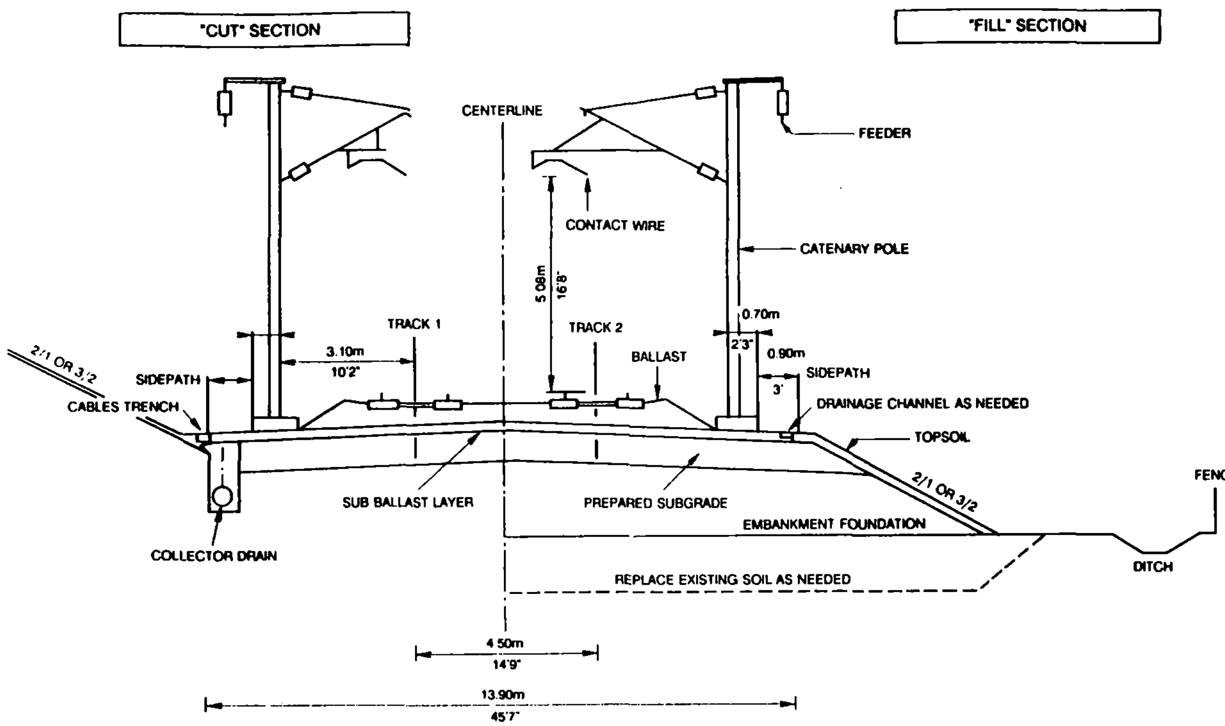

Figure 4 - SNCF TGV Typical Track and Structures Cross Sections

right-of-way. Texas TGV also proposes to fence the entire right-of-way. In many cases, special berms and walls were built to contain noise or protect the track from intrusions from adjoining parallel right-of-ways, including conventional rail lines.

Vehicles

Texas TGV proposes to operate a fixed consist with a power car at each end and eight articulated cars in the middle. Figure 5 shows the layout of the consist and the proposed seating arrangement. Table 2 lists a number of important parameters defining the trainset appearance and performance.

Vehicle Structure - The TGV combines high strength and stiffness with low structural weight. The low weight is important for braking performance and for reducing dynamic loading of the track structure. The power cars use a stressed girder type frame with a substantial underframe. Each power car is enclosed by a nonstructural hood, which provides streamlining for high-speed operations and access to the machinery. A protective steel frame consisting of four collision posts is provided in front of the cab. This structure extends from the underframe up to the bottom of the windshield and into the structural members around the windshield. The main structural underframe extends approximately 0.6 m (2 ft) in front of the protective shell.

The TGV has an energy absorbing structure supported by four collision posts in the nose of the power car. The honeycomb structure can absorb 2 million J, or 1.475 million ft-lb, of energy. This structure is designed to protect the operator during a frontal impact; it would absorb the energy of an

Table 2 - Trainset Parameters

Maximum operating speed		320	kmph	(200	mph)	
Acceleration	0 - 80 kmph	0.576	km			52 s
	0 -160 kmph	2.96	km			123 s
	0 -320 kmph	23.6	km			408 s
Deceleration - emergency: Maximum 4.32 kmph/s (2.70 mph/s)	320 - 0 kmph	4.38	km			98 s
Deceleration - operational: 1.2 km/s (0.75 mph/s)	320 - 0 kmph	11.91	km			266 s
Total train weight (loaded)		418	tonnes	(461	tons)	
Axle loading: Power car and trailing cars		17	tonne/axle	(18.7	ton/axle)	
Unsprung mass:						
Power car		2,150	kg	(4,740	lb)	
Trailing cars		2,100	kg	(4,630	lb)	
Total train length		200	m	(656.3	ft)	
Power car length		2,215	cm	(872	in)	
Power car truck center spacing		1,400	cm	(551.2	in)	
Transition car length		2,184.5	cm	(860	in)	
Transition car truck center spacing		1,870	cm	(736.2	in)	
Trailing car length (articulated)		1,870	cm	(736.2	in)	
Truck base		300	cm	(118	in)	
Wheel diameter		91.4	cm	(36	in)	

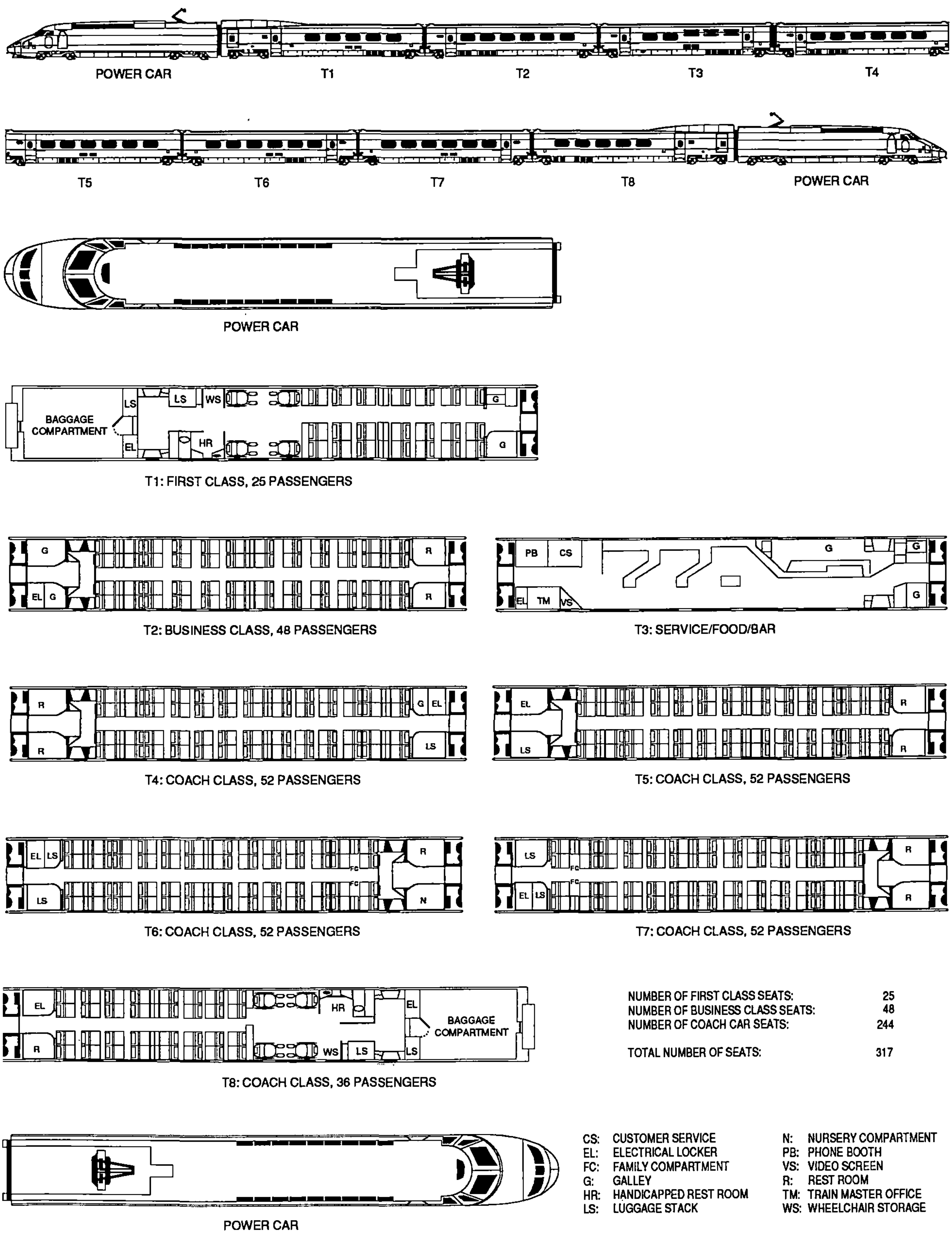

Figure 5 - Layout of Texas TGV Consist[10]

impact with a 500 kg (1,100 lb) object at 320 kmph (200 mph).

Much more important to the crash management of the TGV are the intercar connections, especially the articulated car attachments. SNCF stated that these are designed to deform during severe collisions, reducing the peak longitudinal accelerations. The attachments do not allow override. This is critical in collision energy management, as the mass of the entire train must be considered, not just the individual cars. In addition, the attachment is designed to allow the longitudinal forces to be transmitted through the underframes and side sills, which are designed for large loads.

Longitudinal loads are specified at several locations and heights for the TGV cars. The largest load is at the level of the underframe. Other defined points include the lower edge of the windows and the top of the car.

Inspections

SNCF has reported the following TGV Sud-Est (Paris to Lyons) inspection procedures:

- Continuous performance monitoring of critical components through the train diagnostic and reporting system
- Inspection of vital safety functions every time the train is turned in Paris
- Safety systems and current collection, including roof inspection every 3,000 km (1,864 mi)
- Comfort systems - every 9 days
- Running gear - every 18 days
- Traction motors, automatic couplers, and filters - every 36 days
- Axles and batteries - every 72 days

Shop visits (a more detailed inspection process) occur as follows:

- Limited visit - 2 days every 4.5 months (SNCF has indicated that the interval may be extended to 6 months because of favorable operating experience.)
- Limited general visit - 3 days every 9 months
- General visit - 4 days every 18 months

Aesthetic operation (repaint exterior and refurbish interior) is being performed every 8 years.

Modularization of equipment allows more efficient maintenance; modules are serviced on the basis of distance, time in service, and degradation of design values.

In 1988, failures causing delays of over 10 minutes occurred 3.2 times per million train-km (5.14 per million train-mi).

In some cases, the inspection intervals for the TGV Atlantique equipment are longer than those for the Sud-Est because of technological advancements. TGV maintenance officials will continue to adapt the inspection procedures on both lines, based on experience and further advancements.

Passenger Cars

Construction

The proposed Texas TGV trainset consists of a 1-8-1 configuration: eight passenger cars with one power unit at each end. Adjacent passenger cars are articulated over a common truck. The end of each of the transition cars (i.e., the first and last passenger cars) that abuts a power car has one "full" two-axle truck. Figure 6 shows side and top views of a typical passenger car exterior.

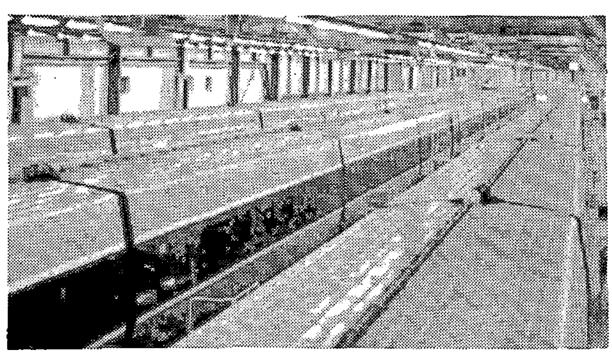

Figure 6 - TGV Atlantique Passenger Car Exterior (Side and Top)

The primary passenger car structure is of high-strength, low-alloy steel and is designed for a service life in excess of 30 years. The car body consists of a stressed skin shell with integrated roof and side structures joined to an underframe without center sills. Compressive loads are transferred from the end structure to strengthened side sills. The side sills form a floor-level border structure that resists side impact. One end of the car body is equipped with a support ring which frames the intercar doorway. This support ring serves as the body bolster and primary structure connecting the truck with the car. A cantilevered extension located at the opposite end of the car transfers the end-of-car loads, through an articulated joint, to the support ring on the adjacent car. Figure 7 shows the passenger car truck with the support ring in place. The vehicle structure will be manufactured in accordance with the following codes and standards:

Welding code - AWS D1.1 or CSA W59.1

Structural steel bars and plates - ASTM A 6 and ASTM A 588

Hot and cold rolled steel sheets - ASTM A 606, Type 4, and ASTM A 568.

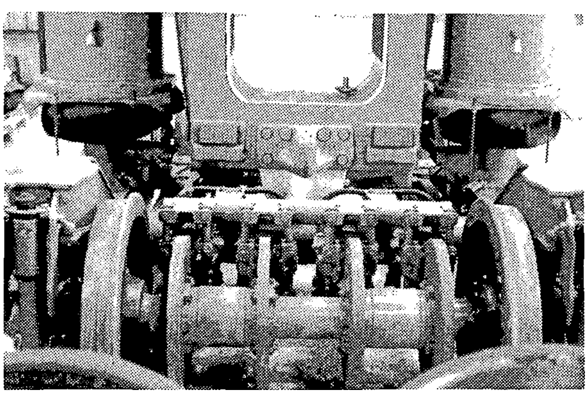

Figure 7 - TGV Atlantique Passenger Car Truck with Support Ring

Passenger cars for the SNCF TGV lines are manufactured at La Rochelle in southwestern France and sent to Belfort, France, where they are coupled to the power cars and functionally tested before being sent to SNCF for service.

Interior Arrangement

Passenger car configurations for the Texas TGV include first class, business class, and coach. Figure 8 shows a typical TGV Atlantique first class passenger car interior. Each configuration includes vestibules, overhead storage racks for small carry-on luggage, and rest rooms. Galleys are included in first class and business class cars. Baggage compartments and provisions to accommodate wheelchair users shall be included in first class and designated coach cars. A food and stand-up bar service car is also included.

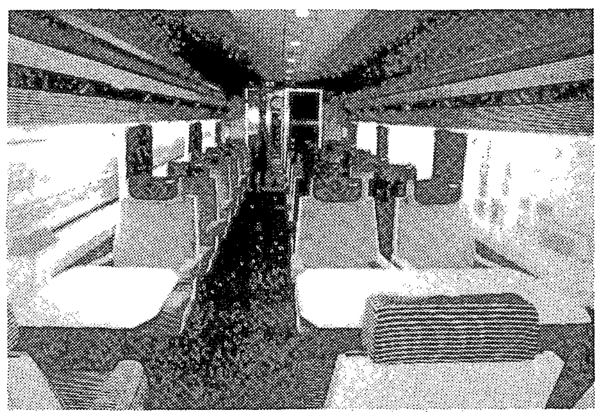

Figure 8 - TGV Atlantique First Class Passenger Car Interior[11]

Crashworthiness

The passenger cars have floor-mounted non-swiveling reclining padded seats with aircraft type fold-out tray tables. The seats do not have restraining belts. The overhead storage areas are open, smooth continuous racks without bulkheads or other longitudinal restraints. The interior is well contoured with no loose equipment. The minimum design longitudinal load requirements for the cars, based on UIC Leaflet No. 566 standards, are as follows:

- 2,000 kN (449,500 lb) compressive at the underframe
- 400 kN (89,900 lb) compressive at the window sill
- 300 kN (67,400 lb) compressive at the roof attachment

Access/Egress and Emergency Equipment

Each of the cars has two side doors, at one end, for normal station platform access. The doors are the sliding-plug type, pneumatically actuated with single-point door panel suspension. A pneumatically actuated bottom footstep is activated along with the door opening. The normal door/footstep sequencing is microprocessor controlled and interlocked with the power unit to prevent opening the doors while the train is in motion. A manual override handle permits the doors to be opened in emergencies. In Texas, the first and last car in each consist will be accessible to wheelchairs.

On the SNCF TGV, four emergency windows are located in the passenger compartment of each car. These windows have horizontal bars which must be removed before breaking the safety glazing. The windows are broken with a small hammer with a sharp point located on the interior wall of the car adjacent to the window. Each car has a battery powered emergency lighting system in case of loss of normal system power. Portable fire extinguishers and an emergency tool kit are also provided in each car. An emergency alarm button is located at each end of the car so that passengers can alert the operator of the train to a possible problem. Aisles and passageways are clear of obstructions and permit free passenger movement through the cars and train. However, the luggage is not sufficiently secured to prevent it from moving and potentially hitting passengers or blocking egress routes if the vehicle tilts or overturns during a collision or derailment.

Power Car

Car Body

The SNCF TGV power car body is a welded assembly of high-tensile strength, corrosion protected steel panels and structural members. Figure 9 is an exterior view of the power car. Components are stamped, cut, or bent from steel panels that vary in thickness from about 3 mm to 1 1/4 cm (1/8 to 1/2 in), depending on the application. After assembly, the body surface is faired smooth and painted with two-part polyurethane epoxy paint. The roof panels are also welded, being assembled from extruded hollow aluminum panels. Pantograph and other high-voltage component mounts are welded to the roof panels. Dynamic brake resistors are mounted inside a separate rooftop enclosure near the front of the power car.

The sides contain long louvers which serve as air inlets for equipment cooling and as inertial filters to remove large dust particles from the input air.

Figure 9 - TGV Atlantique Power Car Exterior[12]

The body nose is fiberglass reinforced plastic. Future versions of the TGV, such as the Trans-Manche Super-Train [TMST] (the cross-channel service between Paris and London) and the Spanish AVE, will feature rounded corner areas in the body nose, a change from the sharper corners now in service. The forward part of the body incorporates a shock absorber structure assembled from aluminum honeycomb.

Pneumatic piping is integrated into assemblies and installed as units in the center of the main deck.

The wiring and piping are integrated into harnesses which are installed in trays in the car body. The tray holding the power conductors is mounted in the center of the car below the floor, and the tray with control cables is mounted just below the roof. Modular construction is used as much as is practicable, and the layout is designed to allow removal of major components (e.g., transformers, inverters). Equipment is mounted in the center of the car to permit access to the cab from the trailing cars via two passageways, one on each side of the equipment racks. Enclosure doors are hinged longitudinally so that they can swing up and out within the confines of the car to allow access to the equipment racks.

Roof Equipment

The roof equipment on the TGV Atlantique includes two pantographs, one for 1.5 kVdc and the other for 25 kVac. Except for the Tours bypass used in mixed traffic, all high-speed lines in France are electrified with 25 kVac. The roof equipment also includes the switches, circuit breakers, lightning arresters, and high-voltage feedthroughs for routing the input power into the equipment area. The ac feedthrough leads directly to the primary portion of the power transformer; thus the 25 kVac cannot be exposed anywhere in the body. The roof equipment also includes a power sensor which senses the magnitude and type (ac or dc) of the power applied to the pantograph. The output of this sensor is used to interlock the power system so that the wrong power supply cannot be applied to the power electronics systems. The dc equipment and the sensor will not be required in Texas, where 25 kVac will be the only power supply voltage used. Therefore, each power car will have only one pantograph.

Control Cab

The operator's control station is securely mounted only to the floor. It is attached to other parts of the body by silicone rubber bushings which hold it in place without conducting noise to the cab. The back bulkhead of the cab is also held in place with a silicone rubber gasket to limit noise transmission into the cab. Access to the cab is either from the trailing car sections or through one of two side doors located just behind the operator's cab, see Figure 10. The exterior access area contains steps and hand holds for the operator.

Figure 10 - Exterior Access to TGV Atlantique Power Car

Equipment

Batteries used to control dynamic braking when there is no catenary voltage are mounted below the main deck in open, pull-out trays. A cab air conditioner is also mounted under the floor area forward of the batteries. Air brake valves and controls are mounted under the floor toward the rear of the car.

Traction motors are hung from the car body frame and connected to the gear boxes through cardan shafts, thus reducing the unsprung mass of the truck. The motors are also safety hung by non-load-bearing shackles attached to the body frame.

Power car wheels on the TGV Atlantique are reprofiled approximately every 400,000 km (248,000 mi), i.e., approximately 12 months of operation. The wheels have an average service life of 1.2 million to 1.5 million km (745,000 to 932,000 mi). SNCF feels that the following factors contribute to this long service life:

- Axle loads of 17 tonnes (18.7 tons)
- Minimal tread braking
- Low unsprung masses
- Significant operation in the lower speed, i.e., 220 to 270 kmph (137 to 168 mph), regime
- An effective anti-slip protection system
- An optimal wheel profile
- Flange lubricators, one for each direction of travel
- Wayside rail lubricators at a few specific locations
- Improved axle bearings

Steps taken to reduce the weight of the power car include constructing the equipment enclosure deck with metal grating rather than solid steel, and locating on the transition cars the two inverters that provide the three-phase, 480 Vac trainline power.

Power Distribution and Electrification

Traction power electrification on the TGV Atlantique is supplied from redundant traction power substations connected to either a 220 kV or 400 kV utility grid. These substations are connected to the utility grid by three-phase, high-voltage feeder lines entering the high-voltage switch yards where primary power protection (lightning arresters, switch gear, circuit breakers, over/under voltage protection) is included. A single phase of each feeder is normally connected to one single-phase 25 kV traction transformer. Because the power distribution network is an important part of system performance, each substation is functionally redundant. There are two fully rated traction transformers, but only one is connected at any time. A network of interconnecting switch gear and catenary fault protection allows isolation of failed components or track sections without disrupting high-speed operations. Phase breaks, consisting of short unenergized sections, are located approximately midway between substations. These locations permit a train to transit from one substation catenary to another without bridging the catenaries because adjacent substations are not necessarily in phase.

The traction catenary system proposed for the Texas TGV is the same as that used on the TGV Atlantique. Figure 11 shows a close-up of the TGV Atlantique catenary. It consists of a constant tension catenary system made up of a contact wire suspended from a messenger wire by "dropper" wires at approximately 6 m (20 ft) intervals. The contact and messenger wires, fixed at the center point, are routed via roller systems to weights at each end. The weights maintain a constant tension on these wires through the operational temperature range, and limit the contact wire sag between the rigid support points.

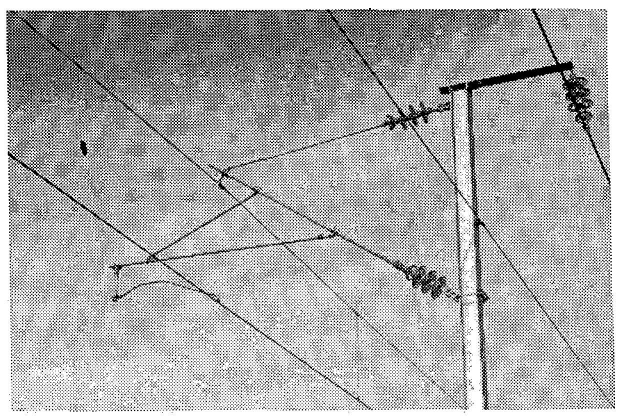

Figure 11 - Close-Up of TGV Atlantique Catenary

Traction power feed from the substation to the catenary system is described as 2 x 25 kV, but can be visualized as a center tapped 50 kV system with the center tap connected to the rails. The catenary is connected to one 25 kV output of the substation, and a negative feed line is connected to the other. In France, the catenary and negative feed line are then connected to single-phase autotransformers at approximately 15 km (9 mi) intervals, which in some cases are reduced to 5 km (3 mi). Similar intervals of 13 to 16 km (8 to 10 mi) are listed in the Texas TGV franchise application. This design supplies 25 kV propulsion power between the catenary and the rails, but it also provides some important system benefits. First, the system currents for the 50 kV distribution system are reduced by 50 percent from those flowing in a 25 kV system. This reduces line losses and permits longer substation spacing. Second, except for the trackage between the train and the closest autotransformer, most of the return current flows through the negative feed line instead of the rails. This minimizes effects on the signal system, and reduces ground current problems. The combination of power factor control in the propulsion system and the 2 x 25 kV electrification system allowed SNCF to install only four substations in the high-speed segments of the TGV Atlantique line, which has a cumulative length of 280 km (174 mi). For the Texas application, the consortium plans to install 12 substations with approximately 88 km (55 mi) spacing. Six of these will be rated for 35 MW and the other six for 65 MW.

Power Collection

Each TGV Atlantique power car is fitted with two pantographs (see Figure 12), one for the 25 kV, 50 Hz ac power collection and the other for the 1,500 Vdc power collection. On the 25 kV high-speed lines, only one pantograph, on the trailing power car, is engaged during high-speed operations. Primary 25 kVac power is routed to the other power car via a high-voltage cable that runs the length of the train. If the pantograph gets tangled in the catenary system, the current collector bow will break away. A pressurized pneumatic line, integral to the pantograph assembly, serves as a pantograph monitor. In the event of pantograph damage, the pneumatic line will fracture, and the resultant loss of air pressure will trigger retraction of the pantograph arm.

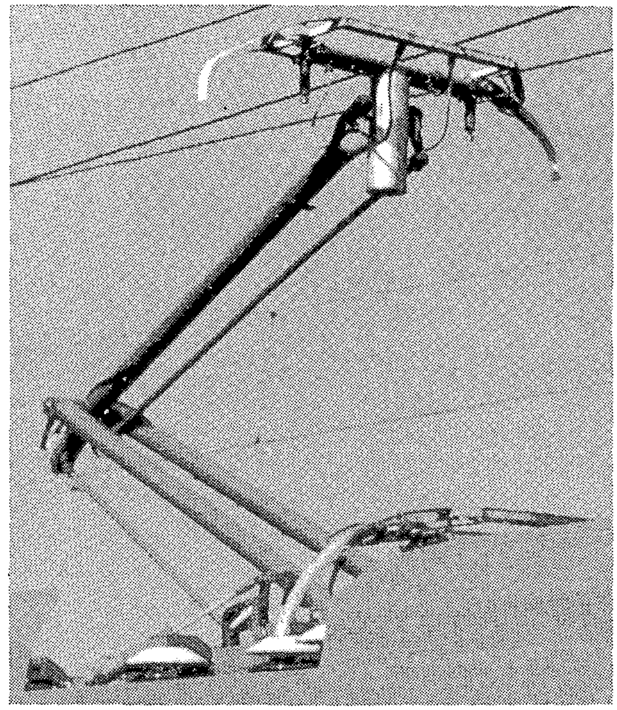

Figure 12 - TGV Atlantique AC Pantograph[13]

Propulsion

For propulsion, TGV Atlantique uses four inverter-driven, ac synchronous traction motors in each power car. There are two inverters per truck, one for each motor; they are connected in series with a dynamic brake resistor during braking. Both inverters are required for truck operation; failure of one inverter also disables its companion inverter on the same truck.

For dc operation, the 1,500 Vdc is supplied to the inverter circuitry through a dc-dc chopper. However, this mode is not required for U.S. operations, and the power car supplier (GEC Alsthom) will modify the vehicles and circuitry to remove it.

For ac operation, the 25 kV is reduced through the transformer to supply the traction power system via four individual secondary windings. These windings, two per bogie, are connected to mixed diode/thyristor phase controlled rectifier bridges, which convert the ac voltage to a variable voltage dc for the inverters. Filters in parallel with each secondary winding attenuate the harmonics and provide power factor control. These filters are computer controlled to regulate the degree of filtering according to system loading. The inclusion of power factor control is beneficial because it lowers the line currents and allows reductions in the size of wayside power and distribution system components. The transformer on the TGV Atlantique is mineral oil cooled. However, silicone oil cooling will be used for the TMST (cross-channel tunnel) TGV, and no problem is seen with using silicone oil cooling in the United States.

Power Conditioning - The inverters used on TGV Atlantique are "naturally" commutated. That is, the counter electromagnetic force (CEMF) of the traction motors is used to commutate the inverter thyristors. Because the traction motors do not develop enough CEMF to commutate the inverter at low speeds, a forced commutation circuit is implemented. This forced commutation scheme requires use of a rotor position sensor to synchronize the application and removal of power according to the spatial relationship of the rotor with respect to the stator. As the motor speed increases, the stator counter EMF also increases until, at a speed of approximately 61 kmph (37 mph), the motor CEMF is high enough for commutation and the inverter is switched to the natural commutation mode. A benefit of synchronous motor propulsion systems is that the motors can operate at a high power factor by using rotor excitation for power factor control.

The inverters develop three-phase line voltages which vary from 0 to 1,246 Vac and provide a phase current of 588 A. Inverter/motor frequency is varied from 0 to 133 Hz over the speed range of 0 to 300 kmph (186 mph).

Traction Motors - TGV Atlantique traction motors are ac synchronous and are rated for 1,100 kW rms (1,475 hp) at 4,000 rpm, corresponding to a train speed of 300 kmph (186 mph). The hourly rating is 1,300 kW (1,740 hp). The motor is designed and tested for an overspeed of 5,000 rpm, giving a 25 percent safety factor at rated speed. The motor weight, 1,450 kg (3,190 lb), is 110 kg (242 lb) less than the dc motor used on the TGV Sud-Est line, yet it develops twice the power. SNCF has been able to double the tractive power of a trainset, with only a 30 kg (66 lb) weight increase per motor-axle. This change has reduced the number of traction motors required for a TGV train from 12 on the Sud-Est to 8 on the Atlantique.

The motors have vacuum impregnated, Kapton teflon insulated wire stator windings. Rotors have a forged alloy steel shaft on which wound, rotor-pole, coils are fastened. These rotors are excited by a dc current supplied to carbon brushes and routed through stainless steel slip rings to the rotor coils. Note that the dc current is continuous and uncommutated, and thus does not cause the commutator wear, brush wear, and flashover found in conventional dc traction motors. Rotors also include a squirrel-cage-type damper winding to assist in reliable stator current commutation at low speeds. The rotor position sensor, used in the forced commutation mode, consists of a notched steel disc on the rotor and stationary sensors on the stator.

The motors are axially cooled by fan forced air entering through duct work at the non-drive end of the motor, passing through the motor in an axial direction and exiting at the drive end. Motor sections are cooled by air passing through ducts in the stator assembly, through the gap between the stator and rotor, and around the rotor coil assemblies. There are no air ducts integral to the rotor assembly. The motor bearing on the drive end is lubricated and cooled by the reduction gear oil, while the two bearings on the non-drive end (a thrust bearing and a roller bearing) are grease lubricated. Temperature monitors included within the motor enable the control system to disable a motor if it overheats.

Auxiliary Power - All auxiliary motors are ac asynchronous. There are five inverters and two battery chargers in each power car. The inverters support the motor driven components (pumps, fans, etc.), and the battery charger maintains the dynamic brake excitation batteries. Hotel (non-propulsion) power for TGV passenger cars will be supplied from a 1,500 Vdc line, two 500 Vdc lines, and two three-phase 480

Vac, 60 Hz lines. The 1,500 Vdc trainline is fed by each power car and is used for the train's heating equipment. Each of the 500 Vdc lines is fed from one of the power cars. They are also used to supply battery chargers and low-voltage power and to feed inverters located on the transition cars, which provide the three-phase 480 Vac trainline power.

Trucks

Motorized Trucks

The TGV power trucks are designed to be lightweight and stiff so they will be stable throughout the operating speed regime. The truck has two side frames with a central transom and is shown in Figure 13.

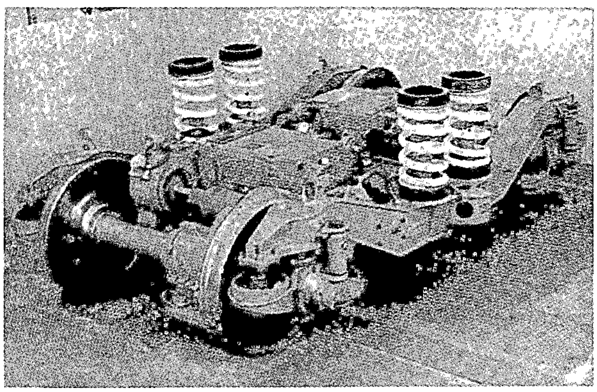

Figure 13 - TGV Atlantique Motorized Truck[14]

The primary suspension uses both metal-rubber and helical coil springs. Vertical motion is absorbed by the helical coil springs, as well as by the resilient components. The lateral motion is absorbed by resilient components, and the assembly is equipped with an anti-pitch damper. The secondary suspension consists of coil springs in series with elastomeric pads. The truck is equipped with one transverse, two vertical, two anti-hunting dampers.

The car body is attached to the truck trough with a double-hinged vertical pin mounted in resilient bearings. The traction motors are mounted on the car body to reduce the unsprung mass and provide high-speed stability.

Non-Motorized Trucks

The non-motorized TGV truck has two side frames and two transoms which support the disc brakes. The truck is shown in Figure 14. The primary suspension is a link arm type which allows decoupling of the vertical and lateral or guidance functions. Dampers are provided between the linkage and the truck frame.

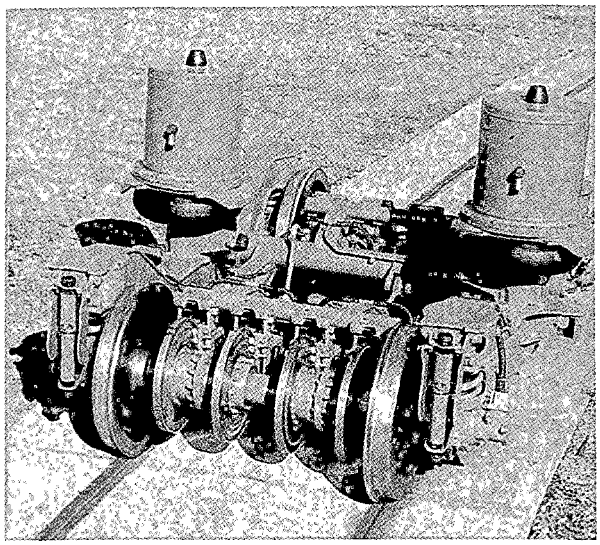

Figure 14 - TGV Atlantique Non-Motorized Truck[15]

The secondary suspension is provided by two pneumatic springs and associated air reservoirs. The use of articulation and low vertical and transverse stiffnesses substantially reduces truck to car body vibrations. In addition, the variable stiffness secondary eliminates the need for vertical and transverse dampers. The conventional dampers are replaced with four longitudinal dampers between the car bodies, one at each corner. The car body to car body relative displacements act as the dampers to vertical and transverse truck to car body motion. The cars also have an anti-roll bar acting across the secondary suspension, limiting car tilt.

Each truck also has anti-hunting dampers to improve the stability margin at high speed while allowing low-speed curving. The truck to car body attachment is through two link rods and a balancing arm for maximum decoupling of the truck motions.

The transition car does not have an articulated connection with the power car and therefore has body-to-truck vertical and transverse dampers, as well as a more direct truck to car body connection. This results in a poorer ride in the compartment over this truck, which for the Texas application will be a baggage room. On the Atlantique line, this space is a special lounge area for groups.

To avoid truck hunting, the self-excited lateral instability of a truck at high speed, the TGV trucks are designed to be stable at speeds beyond the operating speed limit. To provide a margin of safety against instability, the TGV utilizes special rotational dampers, and each truck has accelerometers that can detect the onset of hunting behavior. The operator would be notified of the condition, and would then slow down until the hunting stopped and presumably would call for inspection and maintenance of the truck assembly at the earliest opportunity.

Braking System

The braking system on the TGV Atlantique consists of rheostatic, pneumatic, and electro-pneumatic braking components. The pneumatic braking elements meet the applicable UIC standards. Air operated disc (for cars) and tread (for power cars) brakes are controlled via commands transmitted through the trainset via a brake pipe complemented by an electro-pneumatic train line for fast response of the braking equipment throughout the train.[16] Each truck's braking elements contain independent controls with redundancy of vital automatic controls, such as the wheel anti-skid control systems. Brake tests, once initiated by the operator, are automatically assisted through computer controls, the necessary data processing network, and remote sensors such as pressure sensors in the brake actuators. Microprocessors to complete these various braking diagnostics and applications are used extensively in the TGV Atlantique braking system. In particular, the anti-skid system utilizes both primary and secondary backups, with automated transfers, if failure occurs to ensure availability and monitoring of this critical element.

The rheostatic braking system on the TGV Atlantique is considered fail-safe and is relied on, because of battery operation, for signal spacing calculations. Although in normal situations the rheostatic brakes are energized by the catenary, independent batteries for each driving truck are available as a backup power source in the event of catenary failure. Resistor grids mounted in the roof enclosure of the power car are used to dissipate the braking energy. Power is not fed back into the catenary. When operating with battery backup, the rheostatic braking systems are supplied 72 V from the batteries, but are able to operate on as little as 48 V. Battery voltage below 48 V is considered a braking system failure for that driving truck, and the train operator is alerted via the control console. Each driving truck has an independent rheostatic braking system complete with separate batteries and resistor grids.[17]

Friction brakes consisting of four non-ventilated discs per axle are located on all non driving axles. The higher-speed operation of the TGV Atlantique necessitated a more efficient braking system than the system used on the TGV Sud-Est. In addition to the non-ventilated discs, the TGV Atlantique uses a higher-performance material for the disc, i.e., a high elastic limit steel alloy and fritted metal (sintered) linings, rather than cast iron discs. These sintered metal disc pads allow higher energy dissipation and reduced sensitivity to moisture. Friction brakes on the driving trucks consist of brake shoes that apply force to the tread of the wheels.[18]

A new braking technique including carbon fiber discs and linings is now being tested for possible application on future TGV versions.

Parking brakes for the TGV Atlantique are springs that apply pressure to one axle's brake shoes per driving truck. To release these brakes, other than through special maintenance procedures, air must be provided by the train's brake pipe. This parking brake system is designed to hold a fully loaded TGV Atlantique consist on a 5 percent (5:100) grade with an adverse 100 kmph (62 mph) wind acting on the consist. SNCF feels it is unnecessary to have hand or parking brakes on any other cars of the consist, as the consist cannot be "uncoupled" except in a maintenance facility and under controlled conditions.[19]

The train operator controls the brakes under normal conditions. The operator controls acceleration and deceleration of the consist (via rheostatic braking) via the braking position of a wheel on the console called a traction controller. Its rotation controls the intensity of the function. A separate control available to the operator sets the brakes on all cars in the consist via the brake pipe and electro-pneumatic system. When the operator uses this brake, valve blending is automatic via interaction of the various control computers. This system minimizes braking force dynamics and maximizes rheostatic braking, thereby minimizing brake disc wear on passenger cars and wheel wear on power cars.[20]

Automated inspection and diagnostic systems support the operator in monitoring, operating, and testing the braking system. Before each run of a TGV Atlantique trainset, the operator tests the brake pipe for continuity and the friction brakes for a successful set and release. The automatic train stop system is also checked prior to each run for correct operation. During operation, the brakes are monitored approximately once a minute, and their status, by car and truck, is relayed to the train operator via the computer screen located on the operator's console. The anti-skid systems are automatically checked every time the train stops. The operator is expected to monitor the automated system that displays the status of the braking system during a run and to respond appropriately to exceptions as they occur. Speed reduction tables are used to reduce maximum operational speed for various combinations of brake failures. At one corner of the TGV single consist table, failure of four friction and four rheostatic truck braking systems requires the train operator to initiate an emergency application of the brakes to stop the train. At the other extreme of the table, one passenger car truck's friction brake and one power car truck's rheostatic braking system are allowed to fail without any operational speed reductions. In France, a run can be initiated with this level of inoperative brakes.[21]

If the operator exceeds the maximum speed permitted by the signaling system, the automatic train stop system will initiate an emergency braking action. The stepped limits are as follows: 300, 270, and 220 kmph (186, 170, and 137 mph), with a 15 kmph (9 mph) overspeed allowed, and 160 kmph (100 mph), with a 10 kmph (6 mph) overspeed allowed. In addition, a speed limit of 80 kmph (50 mph), with a 10 kmph (6 mph) overspeed allowed, is incorporated in the automatic train stop system in certain instances, such as switch protection.

If the operator brakes within the control restrictions, the train will stop with at least one block buffer between it and the occupied track. In the worst case of an emergency application, e.g., where a speed of 169 kmph (105 mph) is maintained into a 35 kmph (22 mph) speed monitoring block, the one block buffer will be largely used up, but the train will stop short of entering the zero-speed block. Once an emergency braking action is initiated, the operator cannot intervene or reset the system until the train comes to a complete stop. Figure 15 shows the projected braking curve from 300 kmph (186 mph) and the stepped speed limits employed on the TGV Atlantique.[22] Note: An absolute stop is not enforced by the automatic train stop system for the stop shown in Figure 15; only a reduction to below 35 kmph (22 mph) is enforced. However, when the 80 kmph (50 mph) stop is utilized for switch protection, an absolute stop is enforced by the automatic train stop system at the beginning of the 35 kmph block.

The TGV Atlantique does not have an emergency brake valve for passengers to operate. SNCF feels that such a brake valve may not be the safest solution to the problem, as it would produce the unnecessary risk of trains being uncontrollably stopped in tunnels or other potentially unsafe areas. The emergency handles located in the cars do alert the operator and crew immediately to the location of the alarm. Operating procedure

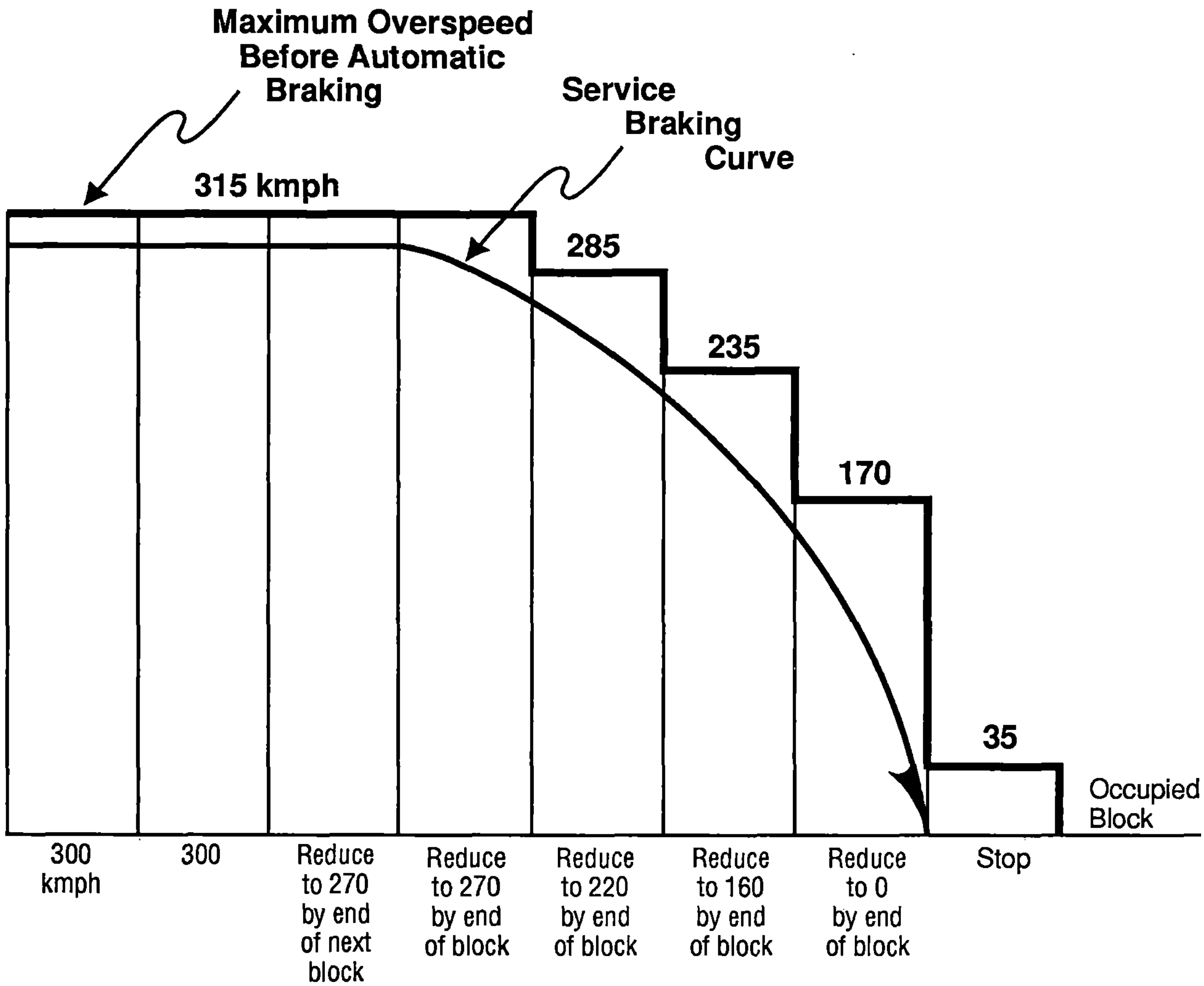

Figure 15 - TGV Atlantique Braking Curve from 300 kmph

is for the crew to ascertain the problem and develop the best response.

Under normal loads and conditions, the emergency braking distance of a TGV Atlantique trainset from 300 kmph (186 mph) to 0 is 3,500 m (11,483 ft). Under less than ideal conditions, i.e., one rheostatic truck braking system and one friction truck braking system not functioning, low adhesion, and maximum passenger loading, the stopping distance is 4,500 m (14,764 ft). Maximum service braking and emergency braking rates are the same. However, during emergency braking, the driving truck anti-skid systems automatically apply sanding at speeds greater than 30 kmph (19 mph). Sanders are located on the first and last axles of the consist. The signal system is designed to allow for stopping distances of 8,000 m to 10,000 m (26,248 to 32,800 ft) from 300 kmph on level track to reduce the rate of braking required under normal operations.[23]

Computer Control

SNCF has determined that the maximum speed for operator perception of wayside signals is 220 kmph (137 mph). This fact along with stopping distances of up to 4 to 5 km (2.5 to 3.1 mi) for operation at 300 kmph (186 mph) dictate the necessity of a cab-based information system with reliable advanced information about the status of the route for both the operator and automated systems. Figure 16 shows the TGV Atlantique operator's desk.

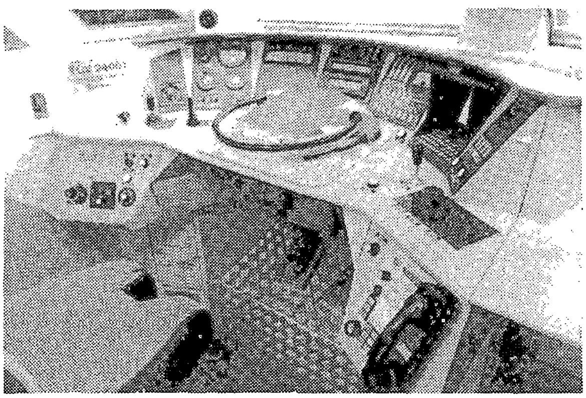

Figure 16 - TGV Atlantique Operator's Desk[24]

The train operator controls the TGV Atlantique consist relying on input received from the cab signal system. Normally the operator is alone in the cab. Vital information for the cab signal system is received via ac audio-frequency coded track circuits; up to 18 channels are available for this purpose. No insulated joints are necessary for this type of installation, and interference from return traction power currents is minimized. Information from the track circuits includes the speed limit of the current block and the speed required by the end of the following block. Block lengths are approximately 2,000 m (6,560 ft) and are marked on the wayside. The speed of the train is displayed by a linear analog needle; the cruise control speed set by the operator is shown by a rotary analog display. In addition, the operator's computer display screen can display the current speed of the train via a bar graph. Additional information such as absolute stopping points and pantograph up or down commands are received via 10 m (32.8 ft) inductive loops placed at certain locations in the center of the track.[25]

As previously mentioned, TGV has an automatic braking system that stops the train when the operator exceeds the speed limit. However, to date there have been no interventions by this system as a result of operator error or inattention on the TGV Atlantique line. The last stop by the automatic surveillance system due to operator error on the TGV Sud-Est was in 1985. The automatic surveillance system, which checks for operator response as well as speed limit conformance, can be overridden, in the event of a failure, if at least one other crew member is present in the cab.[26]

On the TGV Atlantique line, there are various forms of intrusion detection systems that are tied to the signaling system. On most bridges over the high-speed lines, the catenary is protected by wires that detect objects that breach the bridge's guardrail and drop on the wire and through to the track. These sensors then relay this information on the signal system, resulting in a stop command for that area. There are also other detection systems parallel to the track in areas with potential hazards, e.g., falling rocks. These systems are also tied into the signaling system. Figure 17 shows a typical catenary protection installation.

A more advanced train control system is planned for the TGV Nord. This system dramatically increases the amount of data that can be transmitted via the track circuits and allows for more precise monitoring of speeds. The stepped speeds used on the TGV Sud-Est and Atlantique for individual blocks will be modified, and speed reduction within a block is more precisely monitored via a continuous speed curve rather than step functions. Thus, shorter block lengths can be used to provide the same level of protection to a stopped train (or other obstruction). These changes will effectively increase the potential capacity of TGV lines; the four minute headways of the TGV Atlantique could be reduced to three minutes.

The dispatching on the TGV Atlantique is controlled from one central location. Routing of TGV trains is computer supported with manual overrides available if desired by the dispatcher or required by an emergency situation. Routing is normally predetermined based on an accepted operating plan.

This central location also controls electric power for the high-speed line and can cut power at any point on the catenary at any

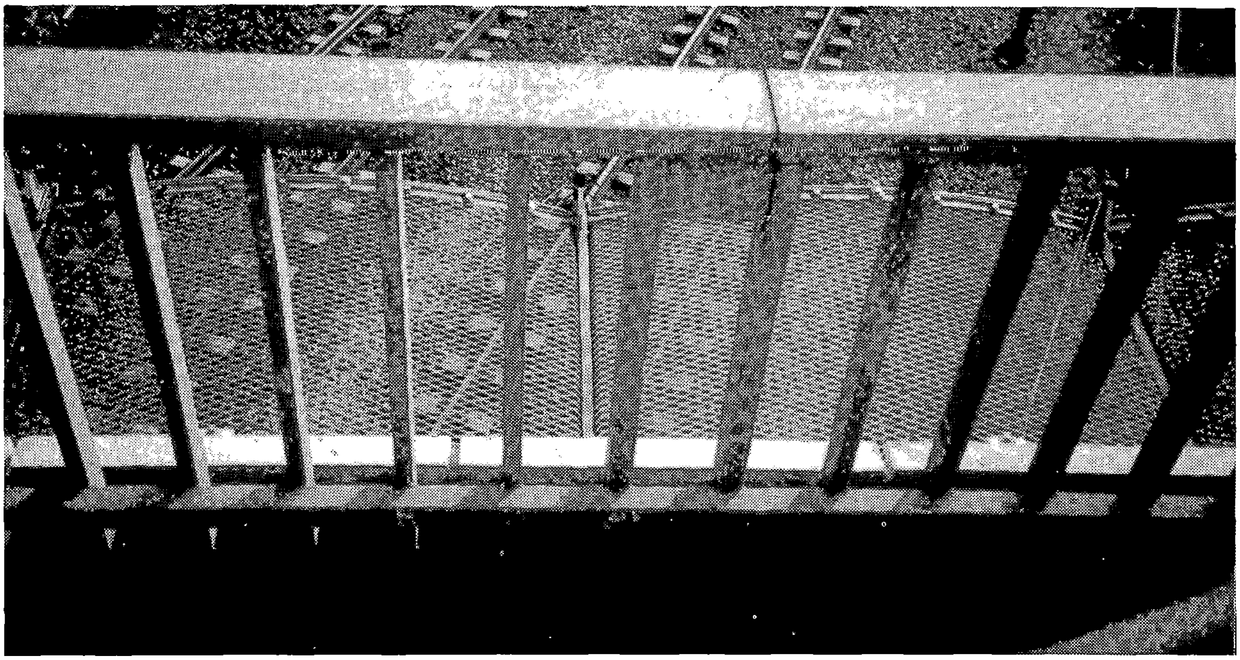

Figure 17 - TGV Atlantique Catenary Protection System

time by de-energizing the power section in which the point is located. Hot bearing detectors are located every 40 to 50 km (25 to 31 mi) along the high-speed line, with output directed to the central dispatching center for analysis. Bearing temperature history and rate of rise is tracked in addition to absolute temperatures.

On board the TGV Atlantique, a data processing network called TORNAD links the various microprocessors (18 computers) in the train operator's cab, the traction motor control, and the cars. The system is based on a pair of two strand wires (which replaces 100 train cables on the TGV Sud-Est). Both control and monitoring equipment are interfaced through this network. The network is looped from one end of the consist to the other and reconfigures automatically to maintain the data link if a section of the loop fails or a piece of equipment on the loop fails. The anti-skid system, braking system monitoring, and automatic door control are all connected via this network. In the future, SNCF plans to provide the ability to pass this information to the wayside via a radio-based data link to enhance maintenance planning and consist status at the central control facility. The radio link will also allow for remote control of train preparation tasks, such as raising the pantograph, turning on lighting and air conditioning systems, locking doors, and setting destination displays. Software and hardware security includes error checks inserted into the data transfer between various computers and watchdog functions with disconnect capabilities. The main computer in the operator's cab is backed up by a separate standby unit.[27,28]

Upon boarding the TGV Atlantique, the operator keys into the TORNAD network to check items such as train lighting, air conditioning, door-closing mechanisms, and passenger information systems. This network also monitors the braking system and cab signal self-diagnostic system and records any failures found. There is a pull-down folding ladder available for the operator to conduct a roof inspection when needed. Access to the roof is safety interlocked with the power supply. The ladder cannot be released from its clamps without a key. The key is inserted in the power control panel and cannot be removed unless both pantographs are down. Neither pantograph can be raised unless the key is in place in the power control.

During a run the TORNAD system provides real-time status to the operator of on-board equipment, announces faults if they occur, and presents computerized troubleshooting of failures to determine the correct remedial action.[29]

Vehicle-Track Interaction

For the maximum speed at which the TGV commonly operates, 300 kmph (186 mph), wheel-rail interaction obviously assumes pronounced importance for safety and passenger comfort. Given SNCF's qualitative standards for supporting track and vehicle suspension systems for dedicated high-speed service, shock and vibration limits related to passenger comfort are reached long before critical safety limits are approached. Nevertheless, in light of the loads applied to the track by high-speed vehicle operation and the response of these vehicles to the negotiation of track imperfections, the four rolling stock derailment modes, any one of which can be operative at a given moment, need to be considered in order to see the margin of safety built into the TGV system.

Track-caused derailment of any kind of flanged-wheel-on-steel-rail type vehicle on main line track, low speed or otherwise, can usually be traced to one or more of the following sources:

- Track panel lateral shift (buckling)
- Rail rollover or gage widening
- Wheel climb
- Vehicle overturning

Track Panel Shift (Buckling)

Resistance to track panel shift is a function of the inherent lateral stability of track at a given location. The factors that affect lateral track stability are ballast density, gradation and the amount of material present, cross tie design and spacing per unit length of track, train speed, and the torsional restraint (in the horizontal plane) of the rail-cross-tie fastening subsystem. Additional factors that affect lateral stability of curved track are super elevation, cant deficiency (the amount of additional super elevation that would be required for a specific curve to be transited at some target train speed with the effect of centrifugal force exactly canceled by super elevation), and radius of curve. This combination of interactive factors has become, over the last 60 years, a focal point of research in the general field of track stability mechanics, and has engaged the attention of investigators worldwide, including those from SNCF.

Based on research that has been virtually continuous since the 1950s and has been strongly oriented toward the evolving TGV concept, SNCF has adopted numerous standards for derailment avoidance. They are discussed in the following paragraphs.

For lateral track shift, in 1967, SNCF's then principal track investigator, Andre Prud'homme, derived the following relationship, which is used to determine the maximum allowable lateral axle load applied to the track by a given vehicle type as a function of its static vertical axle load:

$$L = 0.85\ (10 + 0.33P)$$

where

L is the lateral axle load in kN

P is the vertical axle load in kN

This formulation, which is widely applied in Europe, yields a conservative value of L, but even so, maximum lateral TGV axle loads actually measured by SNCF were, in general, not more than 57 percent of the Prud'homme criterion. During the 515 kmph (320 mph) run on May 18, 1990, the maximum lateral load measured was 32 kN (7,200 lb) on a 15,000 m (16,500 yd) radius (0°, 6.6') curve. Track super elevation was not given for this instance. This criterion is equally conservative when compared with the measured lateral resistance of dual-block concrete tie track:

135 kN (30,000 lb) for stabilized track

90 kN (20,300 lb) for non-stabilized track

Such low axle loads at high operating speeds result from track designs that incorporate large-radius curves and modest cant deficiencies. This, in turn, reflects the philosophy for the TGV of treating the vehicle and track as interdependent elements of a single system.

Rail Rollover or Lateral Translation

Rail rollover/translation is influenced by the effectiveness of the rail-tie fasteners. TGV track incorporates the Nabla clip fastener, the characteristics of which are evident in Figure 2. The rail-tie fastening systems used with concrete cross ties, dual block or mono block, restrain the rail from translation, rollover, and longitudinal creep.

Under optimum tightening conditions, the toe load for the Nabla fasteners on each side of the rail base proposed for Texas is 11 kN (2,500 lb). This effect compares favorably with "... a longitudinal restraint of 2.4 kips per tie per rail ..." recommended for "two-block" concrete cross ties in Chapter 10 of the American Railway Engineering Association Manual for Railway Engineering. The typical ballast gradation employed in TGV track - no particles smaller than 25 mm (1 in) or larger than 50 mm (2 in) - in the consolidated condition offers restraint to creep in the direction of the track axis of tie blocks subjected to the force of thermally loaded rail of about 12 kN (2,700 lb) per tie.

Wheel Climb

It has been stated that wheel climb derailment may occur when the forward motion of the axle combines with wheel and rail profiles, surface conditions, and interactive forces to permit the wheel flange to roll, with creepage or slip, up onto the head of the rail. The maximum ratio of lateral (L) to vertical (V) force (L/V) on any individual wheel is used in evaluating the tendency for wheel climb derailment to occur.[30]

The maximum L/V ratio recorded with a revenue TGV trainset at 280 kmph (174 mph) was 0.39, which is well below the conservative upper limit of 0.8[31] that has been operative in the United States until recently. Current thinking in the industry tends toward an increase in this value, but this has not yet been authoritatively reported in the literature.

Vehicle Overturning

The interactive elements for vehicle overturning include vehicle weight, track super elevation, the location of the vehicle's center of gravity, and the centrifugal force generated at a given speed (and perhaps the effect of cross winds). TGV vehicles generate relatively low lateral forces. This condition coupled with a low center of gravity suggests that vehicle overturning is virtually impossible without the type of track misalignment defects associated with track buckling. Past experience shows that TGV track is unlikely to buckle under normal circumstances. Thus, vehicle overturning may be dismissed as a safety concern.

Because the only known contemporary standard, in these terms, in the United States requires immediate reduction in train speed when 3.9 m/s^2 (0.40 g) lateral or vertical car body acceleration is exceeded, it can be concluded reasonably that the interactive vehicle-track forces generated by the TGV high-speed operations on track dedicated to this service are benign and not a threat to system security.

Track Geometry Measurement Systems

The acceptability of track conditions for high-speed operations is determined by several levels of track inspection. SNCF operates several track geometry measuring cars called Mauzin cars. These cars measure the track geometry based on approximately 10 m (33 ft) chords. The car uses three contacting shoes and eight axles to measure gage, profile, alignment, cross level, and twist. The sample rate is about 46 cm (18 in), and data can be collected at speeds up to about 160 kmph (100 mph). Using a 10 m (33 ft) chord, track irregularities of long wavelength are attenuated. SNCF has developed an on-line procedure which processes data from short cord measurements to produce a long wavelength defect chart as if the chord were 30 m (98 ft). Irregularities of this wavelength have great significance to ride quality and safety at high speed.

Long wavelength track alignment variations can induce car body yaw motion when traversed at high speeds, and long wavelength track surface variations can induce car body bounce and roll when traversed at high speed. As the speed of the vehicle increases, the excitation frequency associated with track geometry variations of a particular wavelength also increases, while the frequencies to which the vehicle is sensitive remain nearly constant. Consequently, as the vehicle speed increases, the longer track variation wavelengths become associated with the frequencies which can excite vehicle dynamic responses.

In addition, SNCF operates a special car which is similar to a standard revenue TGV car. This car has accelerometers at various locations on the car body and trucks and is used to locate track irregularities which cause ride quality and safety concerns. This car can easily find long wavelength irregularities that would be missed in processing the Mauzin car data. Limits in two categories are operative:

- Defect put under observation:
  - Truck acceleration
    - 2.5 m/s^2 (0.25 g)
  - Car body acceleration
    - 1.2 m/s^2 (0.12 g)
- Special track inspection required:
  - Truck acceleration
    - 6.0 m/s^2 (0.61 g)
  - Car body acceleration
    - 2.2 m/s^2 (0.22 g)

The Mauzin car data are also processed statistically, looking for summed deviations from 300 m (985 ft) moving averages, to determine long-range maintenance requirements.

Finally, a "sweeper" train is run every morning before revenue operations commence at 160 kmph (100 mph) to make sure that maintenance forces or vandals have not left equipment or obstacles on the track.

Safety Issues

FRA Regulations

The Federal Railroad Safety Act of 1970, Section 202(e), gives the Federal Railroad Administration (FRA) jurisdiction over "all forms of non-highway ground transportation that run on rails or electromagnetic guideways, including . . . any high-speed ground transportation systems that connect metropolitan areas..." This authority covers the proposed construction of an TGV rail system in Texas.

FRA standards and guidelines with which the TGV system design and realization must comply are summarized here. Regulations that can be applied virtually intact, i.e., without extensive modification, such as radio (voice) operation, operating rules, alcohol and drug restrictions, and site specific requirements, are not covered in this report.

Part 210, Noise Emission Compliance

This part prescribes minimum compliance regulations for enforcing the Railroad Noise Emissions Standards. Exterior noise from the TGV is muffled by concrete barriers or tree hedges between the track and populated areas. All of the bridges and viaducts are ballasted to reduce the noise from the elevated structure.

Measurements to confirm compliance with this section are needed.

Part 213, Track Safety Standards

This part is divided into six subparts and an appendix which defines maximum allowable operating speeds for curved track:

A. General
B. Roadbed
C. Track Geometry
D. Track Structure
E. Track Appliances and Track-Related Devices
F. Inspection

The objective of this discussion is to determine the extent to which the Texas project would conform to Federal requirements. The approach is to compare what is known today about TGV track in France and the track safety standards proposed for construction and operation of the TGV system in Texas with applicable sections of Part 213.[32] None of the subparts presents any conditions that cannot be easily attained with current TGV technology. It would be useful to look at an example. Since the dynamics of vehicle-track interaction at high speed are strongly affected by the state of track geometry, certain parameters of Subsection 213.63, Track Surface, are compared with similar SNCF (TGV) standards.

It is difficult to directly compare the SNCF alignment and surface (longitudinal rail profile) values with those in the Federal track standards because the measurement bases of the two countries are different. However, some reasonable approximations can be made, see Table 3.

The SNCF 10 m (33 ft) chord and one-half the length of the U.S. 62 ft chord can serve as comparable, though not exact, measuring bases for correlating the two sets of numbers for alignment. The values cited in Table 3 for U.S. Class 6 track represent allowable deviation from a hypothetical mean, which coincides with one-half the peak-to-peak SNCF values shown in Figure 18. For a very long defect, a mid-chord measurement with a 31 ft chord is about one-fourth the measurement with the 62 ft chord; however, it is only one-half for a short (random) defect.

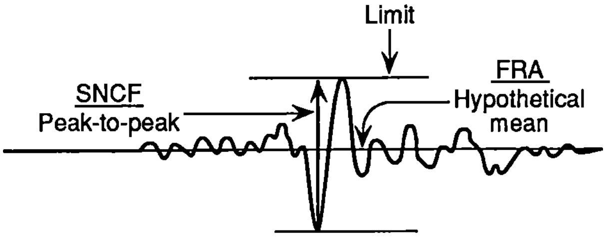

Figure 18 - Peak-to-Peak SNCF Values

Table 3 - Alignment and Track Surface

	U.S. Class 6	SNCF Comfort
Alignment:		
Type of measurement	18.9 m (62 ft) mid chord	10 m (33 ft) mid chord
Maximum defect (tangent/curve)	12.5 or 9.5 mm ($^1/_2$ or $^3/_8$ in)	6 mm peak ($^1/_4$ in peak)
Track surface:		
Type of measurement	18.9 m (62 ft) mid chord	12 m (39 ft) base
Maximum defect	12.5 mm ($^1/_2$ in)	5 mm peak ($^3/_{16}$ in peak)

This process cannot be applied to the track surface parameter because of the French reliance on a 12 m rather than a 10 m chord to measure this defect. However, Table 3 clearly shows that the values employed by the two railroad administrations are very similar.

A fair conclusion is that track built and maintained to TGV standards will come very close to complying fully with the requirements of Part 213. However, Part 213 represents minimum safety standards which are likely to require supplemental regulations in the future to provide the level of safety and comfort essential in high-speed train operation.

Part 221, Rear End Marking Device

This part requires a minimum of one marker, in the red-orange-amber color range, with an intensity between 100 and 1,000 candela to be located at least 1,220 mm (48 in) above the top of the rail. Further, the marking device must be FRA approved as described in Part 221, Appendix A. Alternately, if a locomotive (i.e., a TGV power car) is operated at the rear of the train, as would be the case with the TGV, the power car headlight illuminated on low beam is an acceptable marking device.

TGV trains currently operate with two red rear end markers, each with a minimum intensity of 15 candela. The markers are positioned 1,670 mm (65.7 in) above the top of the rail.

Full compliance with Part 221 could be achieved by either replacing one or both of the existing markers with an FRA approved unit which provides the required intensity, or by operating with the rear power car's headlight illuminated on low beam.

Part 223, Safety Glazing Standards - Locomotives, Passenger Cars, and Cabooses

This part requires locomotive cabs and passenger cars to be equipped with glazing material which has been certified, by the glazing manufacturer, to meet the following minimum impact requirements:

- FRA Type I Material - for use in windshields and other "end facing" locations - must withstand impacts from a 10.9 kg (24 lb), 20.3 cm (8 in) x 20.3 cm (8 in) x 40.6 cm (16 in) object at a velocity of 48.3 kmph (44 ft/s) and a 22 caliber, 40 g (.09 oz) bullet at a velocity of 1,053 kmph (960 ft/s).
- FRA Type II Material - for side windows - must withstand impacts from a 10.9 kg (24 lb), 20.3 cm (8 in) x 20.3 cm (8 in) x 40.6 cm (16 in) object at a velocity of 13.2 kmph (12 ft/s) and a 22 caliber, 40 g (.09 oz) bullet at a velocity of 1,053 kmph (960 ft/s). Additionally, passenger cars shall have a minimum of four emergency opening windows.

The TGV power cars have 28 mm (1.1 in) thick windshields that must withstand impacts from a 1.0 kg (2.2 lb) hollow cylindrical mass 9.7 cm (3.8 in) x 9.4 cm (3.7 in) in diameter at a velocity of 483 kmph (440 ft/s). Although this impact requirement represents a kinetic energy level more than nine times that for the FRA Type I requirements, it is not known whether the existing TGV windshield glazing material will satisfy the FRA Type I impact requirements.

Side glazing on the TGV power cars include forward oblique windows with a total thickness of 17 mm (0.67 in) and side windows with a total thickness of 8 mm (0.3 in). Both types of windows must withstand the following series of impact tests: a 0.5 kg (1.1 lb) ball dropped from a height of 2.1 m (6.9 ft) and from a height of 4.0 m (13.1 ft), each 50 times. It is not known whether the existing TGV power car side glazing material will satisfy the FRA Type II impact requirements.

The TGV passenger car side windows are double glazed units with a total thickness of 28.75 mm (1.13 in), including the air gap between the panes. These units must withstand the following series of impact tests: a 0.5 kg (1.1 lb) ball dropped from a height of 2.65 m (8.7 ft) and from a height of 5.5 m (18 ft), each 50 times. Additionally, these units must withstand shock tests per ST 314B, Section 4.1.4.8, and per French Standard NFF 31-129. It is not known whether the existing TGV passenger car side glazing material will satisfy the FRA Type II impact requirements.

Each of the passenger cars is equipped with four emergency windows and therefore complies with this portion of Part 223.

Part 229, Railroad Locomotive Safety Standards

This part contains numerous safety standards for all but steam powered locomotives. This report addresses only those standards that are applicable to the safety requirements of electric locomotives.

General Provisions - The TGV power cars comply with Subsection 229.13, Control of Locomotives, which requires that the propulsion system, sanders, and both air and regenerative braking systems of each locomotive be operable from the controlling unit in remote or multiple control operation. The units also comply with Subsections 229.41, Protection Against Personal Injury; 229.45, General Conditions; and 229.43(b), Venting of Battery Gases. All moving parts and electrical components supplied with over 50 Vac or 120 Vdc power are guarded under locks and located in non-hazardous locations. All batteries are located below the floor and employ a charging system designed to minimize excess gassing.

Braking System - Based on the information available, the TGV power cars appear to comply generally with the braking system provisions of Subsections 229.47 through 229.55. More specific information will be required to determine the degree of compliance with Subsections 229.57, Foundation Brake Gear, and 229.59, Leakage.

Suspension System - The TGV power cars appear to comply with the suspension system provisions of Subsections 229.63 through 229.71. The measured amount of actual uncontrolled lateral motion for the car's wheel sets has not been obtained, but is stated to be within the maximum limits specified under Subsection 229.63.

Electrical System - With the exception of Subsection 229.81(a), Emergency (Pantograph) Pole, the TGV power cars appear to comply with the provisions of Subsections 229.77 through 229.89. Subsection 229.81(a) requires each locomotive operating with an overhead wire pantograph to be equipped with "an emergency pole suitable for operating the pantograph." The TGV power cars do not have an emergency pole. Normal pantograph operation is through pneumatic pressure provided by a main air compressor. The power cars have an emergency air compressor in case the main air compressor system fails.

Cabs and Cab Equipment - With the exception of Subsections 229.121(b) and (c), Locomotive Cab Noise, and 229.125(a), Headlights, the TGV power cars appear to comply with the provisions of Subsections 229.115 through 229.131.

Subsection 229.121(a) limits the sound level exposure for a continuous noise in a locomotive cab to an 8-hour, time-weighted average of 90 dB(A). The noise information provided for the TGV power car indicates an average level of 78 dB(A) at 300 kmph (186 mph). The TGV design of the trailing cars limits noise to 70 dB(A) in the passenger compartment at 320 kmph (200) mph. Both of these levels are well below the limit. However, additional information is required to determine compliance with the combined noise and short-term sound level limits addressed in Subsections 229.121(b) and (c).

Subsection 229.125 (a), Headlights, requires each lead locomotive to have a headlight that produces an intensity of at least 200,000 candela. The TGV power cars have two headlights and one white marker light. The combined intensity of the existing headlights is between 24,000 and 36,000 candela. Therefore, for the power car to comply with this subsection, at least one of the existing headlights would have to be replaced with a unit which produces an intensity of at least 200,000 candela.

Part 231, Railroad Safety Appliance Standards

This regulation defines hand brakes, hand holds, sill steps, and similar items considered necessary for safe operations.

The TGV has four parking brakes per consist. It has hand holds on the power car and on the interior of the passenger car doors. Each passenger car door has sill steps.

TGV's compliance with this regulation should be judged in terms of how the train is operated relative to the safety intent of specific sections of the regulation.

Currently, the TGV does not comply with the requirements of Part 231, which appear to be inappropriate for high-speed passenger equipment. Absent repeal of the Safety Appliance Act, after which regulatory relief would be available under the Federal Railroad Safety Act of 1970, the only relief potentially available for the TGV and other high-speed equipment is through an exemption proceeding under section 117 of the Rock Island Railroad Transition and Employee Assistance Act. Such proceedings are complex, and there is no assurance that meaningful relief will result.

Part 232, Railroad Power Brakes and Drawbars

This regulation applies to the inspection, test, and operation of air brake systems and components. Also included are rules for drawbars and end of train devices. An appendix to this part includes definitions of terms; specifications for general, service, and emergency brake requirements; and notes delineating modifications and exceptions. This rule covers air brake systems only; rheostatic/dynamic braking is not addressed. This rule also refers to conventional air brake systems; therefore, some requirements, e.g., piston travel, are not applicable to the disc brake system installed on the TGV.

Part 232.1, Power Brakes: Minimum Percentage - This regulation specifies the minimum percentage of air brake systems on a train which must be available before the train can be dispatched. The TGV system either meets or is able to meet these requirements.

Part 232.2, Drawbars: Standard Height - The TGV is assembled and operated as an integral unit train. The consist is not generally coupled or uncoupled except at maintenance centers, and they are not intended to couple with vehicles of different configurations. This section is not applicable to the TGV system.

Part 232.3, Power Brakes and Appliances for Operating Power-Brake Systems - This section refers to the appendix titled "Specifications and Requirements for Power Brakes and Appliances for Operating Power-Brake Systems for Freight Service." It is specific to freight cars. The TGV has a computer assisted electro-pneumatic braking system which controls the brake system pressure, on a per-axle basis to regulate braking with anti-skid control. The TGV block system length is designed to accommodate the braking system performance.

Parts 232.10 to 232.17, Rules for Inspection, Testing, and Maintenance of Air Brake Equipment - These sections delineate requirements for inspection, test, and maintenance. To the extent that the TGV system has operational or functional similarities to conventional brakes, the TGV either meets or can be enhanced to meet these requirements.

Part 232.19, End of Train Device - Although this section is applied only to freight trains, hard-wired, end-to-end communication between power cars of the TGV allow it to meet the requirements of this section, without the need for a radio with a unique identification code.

Part 236, Rules, Standards, and Instructions Governing Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances[33]

This review covers the general aspects of the TGV Atlantique cab signal system that has been proposed as a possible option for the Texas application.

For the most part, these regulations have evolved over the years for a railroad system composed largely of slow - 96 kmph (60 mph) or less - freight trains. The need to accommodate complex and slow speed switching moves may run counter to the type of restrictions that should be imposed for operation of higher-speed trains - up to 320 kmph (200 mph).

Many elements of the TGV high-speed rail signaling and train control system are similar in operation to some installations in the United States. Subsystems that employ methods or designs similar to those accepted in the United States include the track circuit design and operation, the train detection method, the cab signal transmission via the rails, and the mechanical relay based interlockings.

Subpart A, Rules and Instructions: All Systems - Most of these regulations define characteristics needed for some of the basic building blocks of any signal and control system for a railroad. Thus they are broad based and general, and the new system will be able to comply with them before design and installation through minor changes, such as the type of grounding and switching mechanisms used and the color and format of line side signals, if any, and cab signals. Unlike any current system in the United States operating above 127 kmph (79 mph), which uses both line side and cab signals, no line side signals are used on either the TGV Atlantique or Sud Est lines, except for the Tours bypass used in mixed traffic. However, it does not appear that the lack of such signals is prohibited by the regulations.

Subpart B, Automatic Block Signal Systems - Requirements in this section relate directly to the specific design of block lengths and associated signal control circuits. The TGV should fully comply with these requirements where they are relevant to its operations. SNCF design requirements on this subject appear to be as restrictive as the provisions of this subpart.

Subpart C, Interlocking - Requirements in this section relate directly to the specific design of interlocking and the associated signal control circuits. The TGV should fully comply with these requirements where relevant. SNCF design requirements on this subject seem to be as restrictive as this subpart.

Subpart D, Traffic Control Systems - Requirements in this section relate directly to the specific design of the traffic control systems and associated signal control circuits. The TGV should fully comply with these requirements where relevant. SNCF design requirements on this subject seem to be as restrictive as this subpart.

Subpart E, Automatic Train Stop, Train Control, and Cab Signal Systems - The requirements in this section pertain to the general specifications of an automatic train stop system and cab signaling systems. Issues addressed include how and when automatic train stops occur, audible warnings, and the necessary tests.

The automated train stop feature and the train control and cab signaling systems of the TGV Atlantique appear to meet most requirements of this section and in many cases exceed them. Potential design issues are minor, such as the need to provide a separate or isolated power supply for the automatic train stop system.

Other possible issues are, for the most part, related to operational procedures and definitions. For example, Section 236.512 requires the use of the words "proceed at restricted speed," while SNCF's automatic train stop system ensures that the speed does not exceed 35 kmph (22 mph). Likewise, Section 236.567 does not allow for normal speed operation without automatic train stop, while SNCF does not impose any speed restriction if only the speed control is not functioning as long as the on-board cab signal and deadman control (VACMA) are both working. If the VACMA is not working, operating speed is limited to 70 kmph (43 mph) unless a second crew member is in the cab. If the on-board cab signal is not working, the operator is required to run by sight at a maximum speed of 30 kmph (19 mph) and to stop at all block markers and ask for authorization from the control center to proceed to the nearest passenger transfer facility.

Subpart F, Dragging Equipment, Slide Detectors, and Other Similar Protective Devices - The requirements in this section address the stopping distance needed for high-speed installations. The TGV Atlantique signal system appears to fully meet these requirements.

Subpart G, Definitions - This section is not relevant to compliance discussions.

Potential Additions or Modifications to Part 236 - A major area not covered by Part 236 is software, hardware, and firmware design and operational regulations for microprocessors utilized in vital sections of the signal and control system. A definition of what constitutes vital versus non-vital elements in microprocessors is needed along with adequate separation standards for these elements. Also, some form of design standards, and validation and verification methodology are needed along with test requirements for installation, periodic inspections, and modification checks for these types of systems and components.

The TGV Atlantique system relies heavily on microprocessors for operation and maintenance. Some of these microprocessors are unrelated to vital safety functions and are a concern only from a reliability point of view. However, the microprocessors utilized in the automatic train stop, cab signaling, and braking for both pneumatic and rheostatic test and control functions are important from a safety perspective.

Although, as noted earlier, SNCF appears to have applied accepted principles in the design and testing of the systems and components, the FRA does not have a regulation in this subject area with which to judge the safety of these systems. In the short term, an analysis of the French methodology, including recommendations about equivalent existing U.S. or international standards or recommended practices, may be appropriate. The FRA could also require positive verification that all vital elements of the signal and control system are indeed fail-safe or fault tolerant and that possible failure modes of the control system have been integrated with the emergency preparedness plans.

FRA Guidelines

Providing adequate fire protection in a rail vehicle requires that the four phases of a fire be addressed: fire prevention, fire detection, fire containment, and fire suppression. The existing FRA fire safety guidelines, contained in FRA Docket No. RSPC-84-1, Notice 3, are titled "Guidelines for Selecting Materials To Improve Their Fire Safety Characteristics." These guidelines provide performance criteria for the flammability and smoke emission characteristics of the construction materials. Also addressed is the containment phase. At present, the FRA guidelines do not address the detection and suppression phases of a fire. In addition to the FRA guidelines, local authorities may invoke the National Fire Protection Association Standard 130, "Fixed Guideway Transit Systems." This standard provides requirements relative to the fire safety and emergency preparedness aspects of rail system design and operation.

The TGV car builder has addressed the fire prevention, fire containment, and fire suppression issues. The TGV materials selected comply with the European (French) fire safety standards. Comparison of these standards with the FRA guidelines for materials selection is not possible at this time. However, the TGV project in Texas should require that the vehicle materials comply with the FRA guidelines.

FRA guidelines address containment of a fire in the occupant compartment through selection of materials which do not propagate fire. The TGV materials may or may not contain the fire in the occupant compartment. Containing fires in TGV vehicles is currently addressed through specification of fire walls and doors at the end of each car.

Although the TGV has no fire detection system in the cars (fire detection is provided in the power car), fire suppression is addressed through the placement of two fire extinguishers in each car with additional extinguishers in the gallery area.

Other Areas of FRA Interest

In addition to regulations and guidelines, the FRA has areas of jurisdiction and interest. Three of these areas are discussed here.

"Americans with Disabilities Act (ADA) of 1990"

Enacted by the 101st Congress and signed by the President in July 1990, the ADA is built on the Rehabilitation Act of 1973, Civil Rights Act of 1964, and Section 504 of the Rehabilitation Act. The ADA considers it discrimination when a provider of intercity rail transportation fails to have at least one passenger car per train that is readily accessible to and usable by individuals with disabilities, including wheelchair users. Single-level passenger cars, like the TGV, shall:

- Permit entry by wheelchair users.
- Have space to park and secure a wheelchair.
- Have a seat to which a wheelchair user can transfer, and a space to fold and store the wheelchair.
- Have a rest room that is accessible to wheelchair users.

The TGV Atlantique provides wheelchair accommodation and a handicapped washroom on the first class car. In Texas, wheelchair access will be provided on the two end cars.

Occupant Compartment Appointments

There are several potential hazards in passenger cars that could result in injuries to passengers and employees. These hazards involve luggage securement, seat securement, loose equipment, exposed sharp edges, lack of padding, hand holds for standing, and inadequate lighting. All SNCF TGV passenger cars adequately address each of these issues except luggage securement.

Emergency Preparedness

Intercity rail operators must be prepared to respond to accidents, and must have the personnel and equipment needed to respond effectively. The emergency preparedness capabilities noted on the TGV vehicle inspection include the following:

- A small hammer provided at existing emergency exit windows to break the designated glass windows
- Emergency access (side door) for rescue personnel from outside the vehicle
- Capability for the operator to communicate with patrons
- Emergency lighting: full lighting for five minutes, downgraded to limited lighting for duration of battery, approximately one-and-one-half hours
- Emergency stop signaling to the train operator

Potential Regulatory Issues

The FRA's existing regulations do not contemplate railroad operations in excess of 176 kmph (110 mph). Those regulations have been developed over decades in response to safety problems not solved by industry standards and practices. Accordingly, they address specific issues discretely and do not treat whole railroads as integrated systems. That approach, which has proven entirely satisfactory thus far for conventional railroads, as evidenced by the remarkable safety record of the railroad industry in the last decade, appears to be in need of some modification for application to new high-speed railroads, such as the TGV, that are designed and operated as integrated systems having a significantly higher order of interdependent subsystems than conventional railroads.

Integrated, highly interactive, fault-tolerant systems such as the TGV invite regulatory treatment as a system. For example, the signal system, the on-board microprocessor network, the speed control system, and the braking systems for the TGV are so interdependent and interactive that the safety of any component of those subsystems can be fully understood only in the context of the whole system. Yet, this is very difficult to achieve in a set of rules of general applicability, each of which governs one of those subsystems.

There is now no standard for fault-tolerant systems. How many components of such systems and what kinds of them may fail before a train is prohibited from leaving the terminal? How many components of such a system and what kinds of them may fail en route before a train is required to stop or proceed only at restricted speed to the nearest repair point?

Similarly, there is now no standard for the reliability of the computer hardware and software on which these systems rely.

Moreover, many safety issues pertaining solely to passenger service have not been addressed by regulation. Instead, because Amtrak is the sole provider of intercity rail passenger service, those issues have been dealt with separately in the context of the special relationship between Amtrak and the FRA. (The Secretary of the U.S. Department of Transportation is a member of Amtrak's Board of Directors, appoints two of them, recommends candidates for the other positions to the President, holds all of Amtrak's preferred stock, and holds security interests in virtually all of Amtrak's equipment and real property.) With new providers of intercity rail passenger service entering the market, it is highly desirable that passenger safety issues now be dealt with through rules of general applicability. It is clear that some additions to and modifications of some of the existing rules are needed.

There are no regulations at all pertaining to seat securement, luggage securement, equipment securement in dining cars, fire-retardant materials, fire detection and suppression, emergency egress, and emergency training for passenger crews - all issues for which the FRA and Amtrak have worked out practical solutions. The FRA cannot rely on attaining and maintaining the same sort of relationship with the management of each new high-speed rail system as the FRA has with Amtrak.

The FRA's track safety standards offer a somewhat different case in point. They now do not permit rail passenger operations at speeds above 176 kmph (110 mph). Amtrak operates at speeds up to 200 kmph (125 mph) on the Northeast Corridor under a waiver. It seems undesirable to entertain a waiver petition every time a new high-speed service is contemplated. An amendment to the regulation setting standards for high-speed passenger service seems to be in order.

A review of the power brake rule also seems appropriate. There is now no standard for the types of vital braking systems on which high-speed trains typically rely. The safety record of the TGV strongly suggests that dynamic braking of the sort used on the TGV is very safe.

Crashworthiness also merits new attention. Should high-speed trainsets such as the TGV be required to meet the buff strength standards of conventional American railroading? Should there instead be some standard requiring controlled crushing to protect occupants of these trainsets? Should collision posts be required? Should there be an applicable anti-climb standard?

Clearly, all of these subjects and the potential regulatory issues (in areas such as emergency preparedness, fire safety and equipment, and guideway inspection standards), many of which are quite complex, will take considerable time to address.

In addition, items not addressed in this technology-oriented report, such as environmental issues and personnel qualifications and training, will be the subject of other potential regulatory issues to be investigated in the future.

Soon, the FRA will issue new regulations with which any high-speed rail system must comply on certification of locomotive operators and event recorders.

Summary

Several design features of the proposed Texas TGV system render it unique to the customary intercity passenger train designs found in the United States: intercar articulation (except at the power cars), an integral fixed train consist, intercar connections designed for deformation in collision energy management, a power car at each end, synchronous traction motors, electro-pneumatic braking with independent anti-skid control (each truck), and emphasis on minimized unsprung weight on power cars, as well as trailing cars. The system approach is clearly in evidence in examining the TGV design tradeoffs considered and evolving as new generations of the TGV are produced.

Use of a horizontally mounted wheel at the train operator's console for speed control as well as rheostatic braking is very different than the independent lever-type controls more familiar to the U.S. scene. Operator comfort and function have been attended to in a well designed cab that will meet or exceed U.S. industry practice. Noise control is particularly evident in use of the silicone rubber bushings and gaskets to isolate the cab from the rest of the power car.

In the Texas application, each of the two power cars shall have a single pantograph with only one pantograph, normally on the trailing power car, in use at any one time. Operating at 320 kmph (200 mph) makes this necessary because of the dynamic interaction between the pantograph and the catenary. This results in the need to have 25 kVac power routed to the opposite end power car via a trainline bus.

Considerable operating data are available about TGV operations in France: almost 10 years on the 270 kmph (168 mph) Sud-East (Paris-Lyon) line and almost 2 years on the new 300 kmph (186mph) Atlantique line. During this period, no passenger fatalities have occurred. This can be attributed, in large measure, to very high-speed operation only on dedicated, grade-separated lines. In addition, automated inspection and diagnostic systems and the automatic train control system ensure system and operator compliance with the TGV's design limitations on braking.

With stopping distances of up to 4.5 km (2.8 miles) for operation at 300 kmph (186 mph), as in the TGV Atlantique, a cab-based operator information system is essential. Vital information for the cab signal system is provided by ac audio-frequency coded track circuits that do not require insulated joints. The information received informs the operator of the proper operating scenario for the train's present location. Additional information on site-specific locations, such as absolute stopping points and pantograph up or down commands, are received from inductive loops in the center of the track at certain locations. Protection from right-of-way intrusion is also provided through the signaling system in the form of a stop command initiated by objects breaching overpass bridge sides or intrusion of vehicles, rocks, etc. from wayside areas. An even more advanced train control system is envisioned by the time of system application in the United States. This will no doubt be patterned after the TGV Nord (the French portion of the cross-channel service between Paris and London).

For the speeds at which the Texas (or other U.S.) TGV will commonly operate, 320 kmph (200 mph), the problem of acceptable wheel-rail interaction will be governed as much by passenger comfort as by safety considerations. Passengers can be expected to perceive shock and vibration long before critical safety limits are approached. Nevertheless, precautions must be taken to avoid unforeseen safety hazards that may develop. For example, SNCF, in addition to operating conventional track geometry measurement (Mauzin) cars over TGV lines, operates a special car (similar to a standard revenue TGV car) equipped with accelerometers at various car body and truck locations to locate track irregularities which cause ride quality and safety concerns.

Several TGV system components were not yet finalized for the Texas (or other U.S.) application of a 320 kmph (200 mph) TGV at the time of this review. Actual project development activity, following the franchise award in Texas on May 28, 1991, will necessitate further in-depth safety review by the FRA. As a result of the findings in this report, some necessary modifications to the TGV have been identified. Additional independent research will also be undertaken by the FRA to determine acceptable changes to existing U.S. design practices that will permit operation of these very high-speed trains while maintaining an equivalent degree of safety.

Endnotes

1. "Improved Passenger Equipment Evaluation Program," Train System Review Report. Volume 6, TGV - PSE, U.S. DOT/FRA, Report Number FRA/ORD-80/14.VI (March 1978), p. 3.
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