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| 16. Abstract<br><p>The Federal Railroad Administration (FRA) is concerned with safety the of high-speed rail technology proposed for possible application in the United States. This report, one in a series of reports pertaining to high-speed rail technologies, presents an initial review of the German high-speed train, the Intercity Express (ICE).</p> <p>This report utilizes information provided by the train operator in Germany, the German Federal Railway (DB); the train manufacturer consortium leader, Siemens AG; other members of the consortium in Germany, Krauss-Maffei, ABB, and Knorr Bremse AG; and the consortium that proposed the ICE technology for application in Texas, Texas Fastrac, Incorporated. Information was also gathered from independent sources and during a series of briefings hosted by DB during February 1991, including site visits to ICE production, maintenance and operational facilities, and a ride on ICE equipment at speeds up to 280 kmph (174 mph).</p> <p>This report describes the background leading up the development of the ICE system, the potential U.S. applications, and the technology in some detail. This document also reviews FRA regulations that may be applicable to the design of this train relative to any potential U.S. application.</p> |                                                      |                                                                                                                                             |           |
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# Foreword

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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 German train known as the Intercity Express (ICE). In Texas, the ICE and the French Train à Grande Vitesse (TGV) were considered for operation in the "Texas Triangle." (The TGV, which was granted the franchise for Texas in May 1991, 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 safety issues that have come to our attention during our initial review of a new technology.

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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The excellent cooperation of the German National Railway (DB); the train manufacturer consortium in Germany, Siemens AG, Krauss-Maffei, ABB, and Knorr Bremse AG; and the consortium proposing the ICE technology for application in Texas, Texas FasTrac, Incorporated, in supplying information before, during, and after the FRA delegation's visit to Germany enabled the authors to understand the technology at the level necessary for writing the report.



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# Background

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This report describes the background leading to the development of the Intercity Express (ICE) system, the German high-speed train technology; the potential U.S. applications; and the technology in some detail. 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 utilizes information provided by the train operator in Germany, the German Federal Railway (DB); the train manufacturer consortium leader, Siemens AG; other members of the consortium in Germany, Krauss-Maffei, ABB, and Knorr Bremse AG; and the consortium that proposed the ICE technology for application in Texas, Texas FasTrac, Incorporated. Information was also gathered from independent sources and during a series of briefings hosted by DB during February 1991, including site visits to ICE production, maintenance, and operational facilities and a ride on ICE equipment at speeds up to 280 kmph (174 mph).

## Proposed U.S. Applications

ICE based high-speed rail technology has been proposed for application in one area of the United States: the "Texas Triangle," Houston to Dallas and Ft. Worth to Austin and San Antonio.

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 coming into existence in 1989, THSRA has formulated procedures and an aggressive timetable for bringing a high-speed rail facility to Texas. A request for proposals was issued in September 1990.

On January 16, 1991, Texas FasTrac submitted a proposal to THSRA to provide high-speed rail service between Houston, Dallas, Ft. Worth, Austin, and San Antonio with three lines using ICE technology. The third line is presented as a possible future route that would complete the triangle by providing a direct link between San Antonio and Houston. This proposal offers an ultimate system of 1,038 route km (645 route mi) of dedicated double track with operating speeds up to 320 kmph (200 mph).

On May 28, 1991, THSRA granted the franchise to finance, construct, operate, and maintain a high-speed rail facility to a competitor, Texas TGV. However, the ICE technology may be proposed for other U.S. operations in the future.

## Development of the ICE

The German Federal Ministry of Transport (BMT) and DB have been promoting and developing an integrated and transit time-sensitive railroad network over the last 20 years. During the same period, the Federal Ministry of Research and Technology (BMFT) has been promoting research and development in the operation of high-speed trains. Between 1972 and 1989, BMFT has spent over 500 million DM on railroad technology. Research for high-speed operation has focused on vehicle track interaction, novel drive and braking technologies, consist aerodynamic drag reduction, track structures, components and foundation engineering, operation control dynamics, safety of microprocessors, power technology, and environmental issues.

In 1984, a new class of locomotive, the synchronous, three-phase ac drive 120, was introduced on the DB network. The 120 class locomotive set a speed record of 265 kmph (165 mph) in October 1984. In 1985, the Intercity Experimental (ICEexperimental), the ICE prototype, started an extensive high-speed operation

test program; it reached a speed of 317 kmph (198 mph) on existing DB track. In 1988, the ICE experimental set a speed record of 406 kmph (252 mph) on a new line designed for high-speed operation.<sup>2</sup> Since then, the ICE experimental trainset has undergone a variety of tests on various lines in Germany and is still being used for various research projects. The ICE revenue vehicles are currently being delivered for the Hannover-to-Munich service inaugurated in June 1991. Figure 1 shows an ICE/DB consist.

By 1991, through an aggressive program of right-of-way construction and upgrading, DB had over 500 km (311 mi) of 220 kmph (137 mph) track and 400 km (249 mi) of 250-to-300 kmph (155-to-186 mph) track.<sup>3</sup>

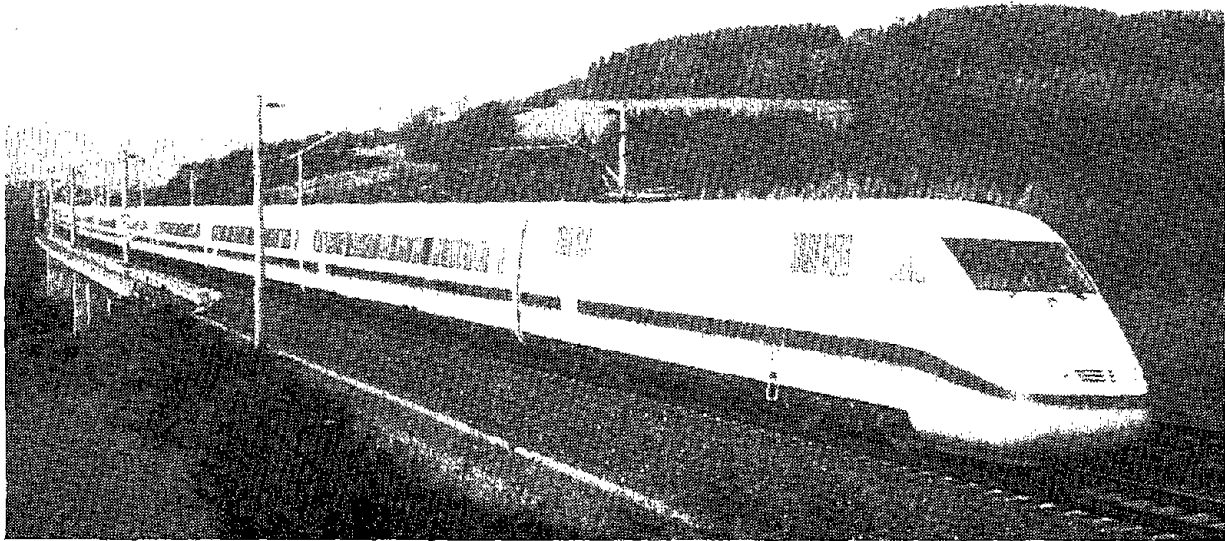


Figure 1 - ICE/DB Consist

# System Description

## Specifications

The ICE track and vehicle components have been specially designed to provide a safe, reliable, and economically viable high-speed intercity service.

### Track Structures

DB built new track alignments and upgraded several older lines to provide high-speed service in special corridors. The new track alignments were laid out using premium components throughout, including extensive tunneling and innovative structures. Table 1 summarizes the track specifications that Texas FasTrac proposed.

**Ballast** - Texas FasTrac proposed to use standard ballast at depths of 300 mm (11.8 in) under the ties. Ballast shoulder widths proposed were about 500 mm (19.7 in), which DB considers wide enough to prevent lateral shifting of the track. Texas FasTrac also anticipates using slab track for certain applications. Two types were considered: the Rheda-type and track-on-asphalt. The

Rheda-type section has special prestressed concrete ties mounted on a concrete bed, positioned, and then fixed in place by a poured concrete grout that surrounds the ties. The track-on-asphalt section requires a special prestressed concrete tie with an adzing strip, which adheres to the asphalt bed.

Slab track has both advantages and disadvantages. The primary advantage is that it is very stable and should reduce the need for routine maintenance. It does, however, cost more and increases wayside noise by about 3 dB(A).

**Ties and Fasteners** - DB uses mono block concrete ties in a standard ballast section at a center spacing of 600 mm (23.6 in) to support the rail. The ties are type B70 W and are about 2,600 mm (102 in) long, very similar to the concrete ties used in the United States. A "W" type clip fastener is used to provide lateral and longitudinal restraint. The rail is isolated from the tie with elastomeric pads. These pads reduce

Table 1 - ICE/Texas Track Specifications<sup>4</sup>

|                                           | <u>Ballast Track</u> |               | <u>Slab Track</u> |               |
|-------------------------------------------|----------------------|---------------|-------------------|---------------|
| <u>Gradient:</u>                          |                      |               |                   |               |
| Maximum on-line                           | 1.50%                |               | 1.50%             |               |
| Maximum station                           | 0.15%                |               | 0.15%             |               |
| Exceptional case                          | 4.00%                |               | 4.00%             |               |
| <u>Radius:</u>                            |                      |               |                   |               |
| Standard design                           | 7,170                | m (23,500 ft) | 7,170             | m (23,500 ft) |
| Minimum                                   | 4,320                | m (14,200 ft) | 4,030             | m (13,200 ft) |
| <u>Vertical curve:</u>                    |                      |               |                   |               |
| Standard design                           | 26,000               | m (85,000 ft) | 26,000            | m (85,000 ft) |
| Minimum summit                            | 16,000               | m (52,000 ft) | 16,000            | m (52,000 ft) |
| Minimum sag                               | 14,000               | m (46,000 ft) | 14,000            | m (46,000 ft) |
| <u>Super elevation:</u>                   |                      |               |                   |               |
| Standard                                  | 100                  | mm (3.94 in)  | 100               | mm (3.94 in)  |
| Maximum                                   | 180                  | mm (7.09 in)  | 200               | mm (7.87 in)  |
| <u>Cant deficiency allowed:</u>           |                      |               |                   |               |
| Standard                                  | 70                   | mm (2.76 in)  | 70                | mm (2.76 in)  |
| Maximum                                   | 100                  | mm (3.94 in)  | 100               | mm (3.94 in)  |
| Minimum distance between centers of track | 4.40                 | m (14.5 ft)   | 4.40              | m (14.5 ft)   |
| Width of embankment (on-line)             | 13.40                | m (47.0 ft)   | 12.90             | m (45.2 ft)   |

wayside noise and tie wear. A cross section of the track proposed for Texas is shown in Figure 2.

**Rail** - The rails are high-strength, i.e., 900 N/mm<sup>2</sup> (130,535 lb/in<sup>2</sup>), head hardened steel manufactured to achieve high surface quality and straightness. Texas FasTrac planned to use an International Union of Railways (UIC) 60 or equivalent U.S. rail section, which is comparable to the American Railway Engineering Association (AREA) 136 lb/yd rail. Straightness at the rail ends, which tend to become curved during the roller formation process, has to be monitored closely. The rail is then plant welded into 440 m (1,440 ft) strings, which are field welded to provide continuous welded rail (CWR).

**Turnouts** - DB 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 operations. The number of a turnout is related to the angle of the diverging rail—the larger the number, the smaller the diverging angle. For speeds up to 160

kmph (100 mph) on the diverging leg, a no. 42 turnout will be used. For speeds up to 130 kmph (80 mph), a no. 26.5 turnout will be used. For low-speed turnouts, less than 95 kmph (60 mph), normal AREA numbered turnouts 14, 12, 9, and 7.5 will be used, depending on the application.

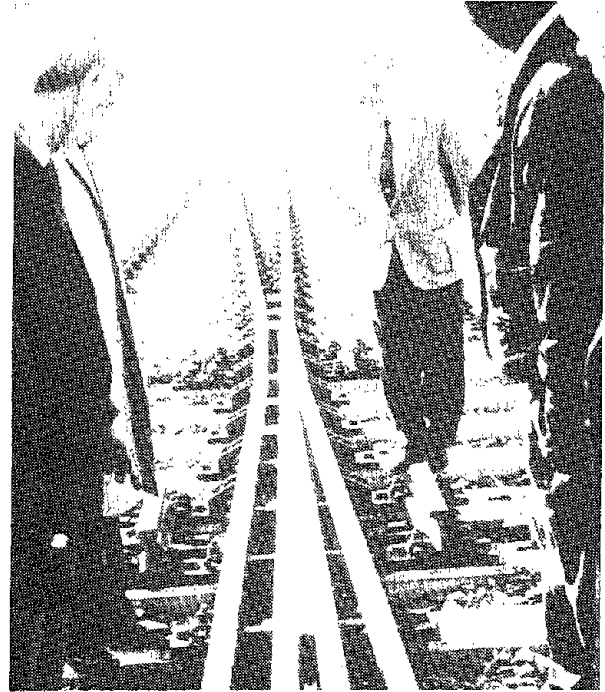


Figure 3 - DB Swing Nose Frog

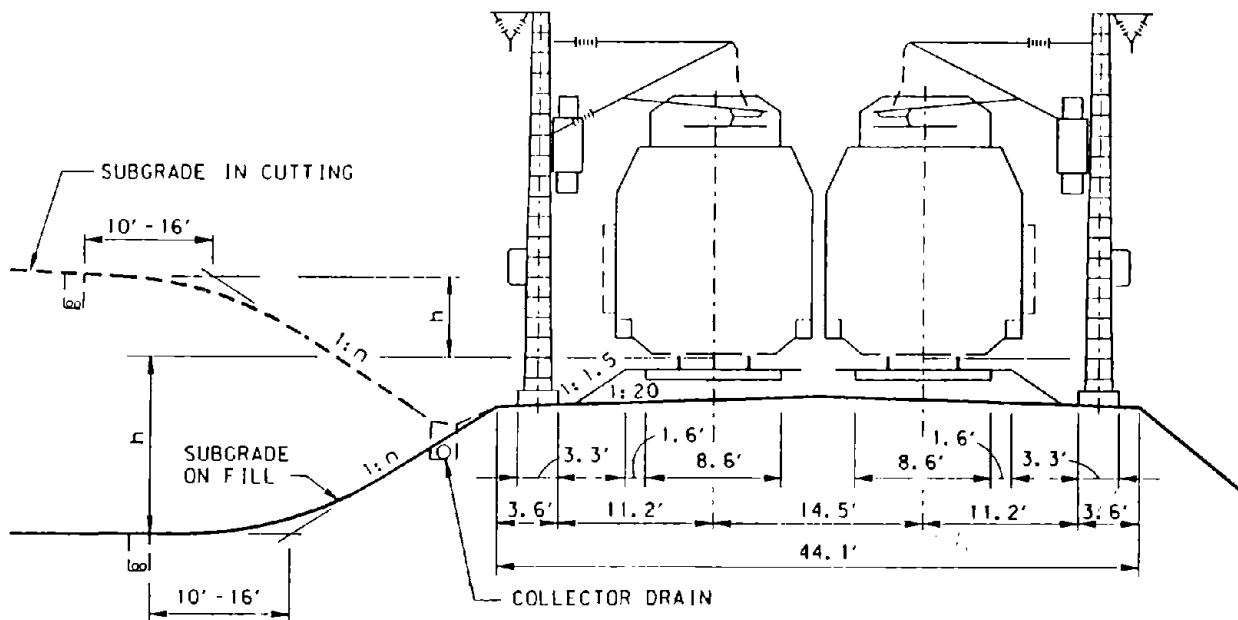


Figure 2 - ICE/Texas Track Cross Section

**Right-of-Way** - The right-of-way typically used by DB and proposed for Texas is approximately 31 m (100 ft) wide. To reduce wear and achieve an acceptable ride quality at 320 kmph (200 mph), DB lays out the track with very shallow curves: minimum radii of 4,320 m (14,173 ft) ( $0^\circ, 24'$ ) for ballast track, and 4,030 m (13,222 ft) ( $0^\circ, 26'$ ) for slab track. The difference between the two track types is the allowable super elevation: 180 mm (7.09 in) for ballast track and 200 mm (7.87 in) for slab track. A maximum of 100 mm (3.94 in) unbalanced super elevation is allowed for either construction type. Vertical curves are even shallower with minimum radii of 16,000 m (52,000 ft) for summits and 14,000 m (46,000 ft) for sags. Because of the physical constraints of the relatively long stiff trucks and close vehicle shrouds at the intercar connections, the ICE train cannot negotiate curves with radii less than 150 m (492 ft), or about  $11^\circ, 30'$ .

Figure 4 shows a typical cross section of the right-of-way planned for Texas. The basic width of the track section is the ballast section width: approximately 13.4 m (44 ft) for tangent track. Curves are slightly wider with ballast sections of 13.7 m (45 ft). A zone is defined from the track centerline

extending 3 m (10 ft) where no solid objects may be stored. Track centers are 4.4 m (14.5 ft) apart. The approximate train envelope is also shown in Figure 4.

In general, DB does not fence the right-of-way. There are no grade crossings in the high-speed sections, and overpasses have special fixtures to reduce the possibility of intrusion. DB stated that fencing was not used to allow better access for emergency vehicles. However, in many cases, special berms and walls were built to contain noise.

Texas FasTrac noted the need for complete grade separation and fencing for high-speed lines; however, fencing details for the right-of-way were not included in the proposal.

#### **Consist**

Texas FasTrac proposed to operate a fixed consist with a power car (locomotive) at each end and, initially, seven cars in the middle, providing 378 seats. Table 2 lists some of the trainset specifications. The power cars have been sized for up to 14-car trains, providing 840 seats.

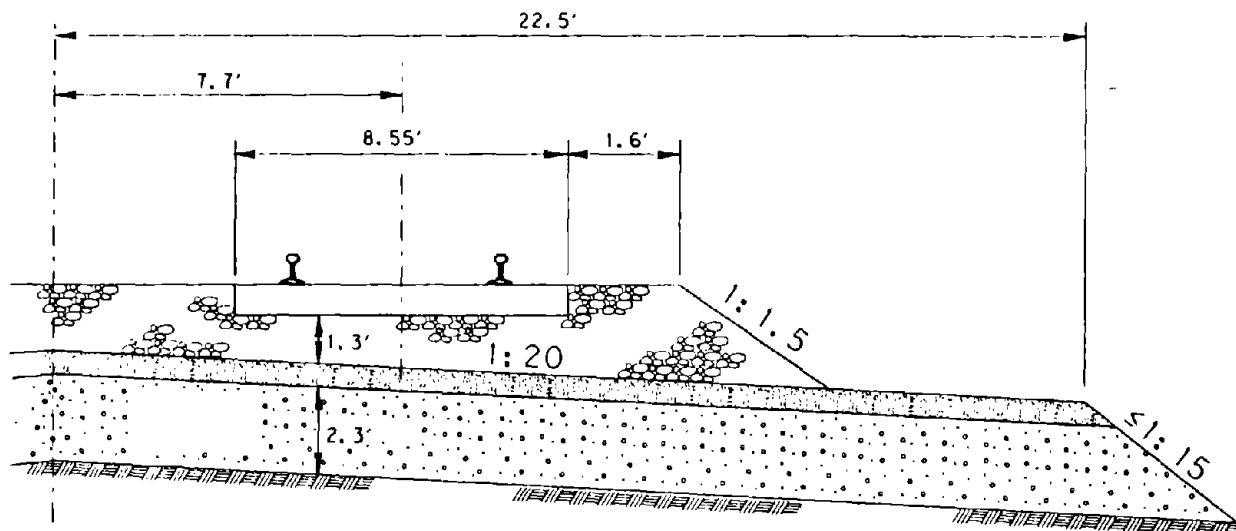


Figure 4 - ICE/Texas Right-of-Way Section

**Consist Structure** - The ICE 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 car uses a self-supporting monocoque structure to provide the high torsional and bending stiffnesses required. The body consists of the underframe, operator's cab with rear wall, sidewalls of the engine room, roof, doors, and rear end wall. The car is designed to allow a 15 kN (337,100 lb) longitudinal compressive load along the coupler. Special access is provided for the electrical and pneumatic equipment. A center aisle allows easy access to all components. The operator's cabin is isolated from the electrical compartment by an insulated wall, which helps reduce noise in the cabin. The cabin is sealed and air conditioned to reduce the discomfort

associated with the many tunnels in the DB application.

The passenger car body structure is large aluminum extruded profile component construction. The floor, sidewalls, and roof profiles are manufactured as single pieces over the length of the car and then welded together, providing a very light, stiff tubular carrier.

The intercar connections of the ICE trailing cars 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. The couplers allow the longitudinal forces to be transmitted through the underframe, which is designed for large loads.

Longitudinal loads are specified at several locations and heights for the ICE passenger cars. The largest load is at the coupler,

**Table 2 - ICE/Texas Trainset Specifications**

|                                    |                                       |                       |
|------------------------------------|---------------------------------------|-----------------------|
| Maximum authorized speed           | 320 kmph                              | (200 mph)             |
| Operating speed                    | 300 kmph                              | (186 mph)             |
| Design speed                       | 352 kmph                              | (220 mph)             |
| Maximum tractive effort            | 360 kN                                | (80,900 lb)           |
| Continuous power rating            | 9,600 kW                              |                       |
| <u>Maximum deceleration:</u>       |                                       |                       |
| Emergency (no dynamic)             | 320 kmph (200 mph) - 0                | 1.30 m/s <sup>2</sup> |
| Operational (comfort limited)      | 320 kmph (200 mph) - 0                | 0.50 m/s <sup>2</sup> |
| Dynamic regenerative only          | 320 kmph (200 mph) - 16 kmph (10 mph) | 0.30 m/s <sup>2</sup> |
| Total train weight                 | 507 tonnes                            | (559 tons)            |
| <u>Axle loading:</u>               |                                       |                       |
| Power car and trailing cars        | 18 tonnes                             | (20 tons)             |
| <u>Unsprung mass:</u>              |                                       |                       |
| Power car                          | 2,220 kg                              | (4,900 lb)            |
| Trailing cars                      | 1,800 kg                              | (3,970 lb)            |
| Total train length                 | 226 m                                 | (741.5 ft)            |
| Power car length                   | 2,056 cm                              | (809.40 in)           |
| Power car truck center spacing     | 1,145.5 cm                            | (451 in)              |
| Passenger car length               | 2,640 cm                              | (1,039 in)            |
| Passenger car truck center spacing | 1,900 cm                              | (748 in)              |
| Truck base                         | 250 cm                                | (98 in)               |
| Wheel diameter                     | 104 cm                                | (40.95 in)            |

which is designed for a compressive load of 1,500 kN (337,100 lb) and a traction load of 1,000 kN (224,730 lb). Other defined points include the lower edge of the windows and the top of the car, both at 300 kN (67,420 lb).

### ***Inspections***

The ICE/DB has on-board diagnostics which continually monitor the status of vehicle equipment. Any failures are communicated to the Hamburg maintenance facility so they can be repaired expediently before the train is dispatched on its next trip. Trains are also cycled through a self-test procedure prior to being dispatched, increasing the likelihood of the train completing its scheduled run. Upon entering the maintenance area after some runs, the train passes through an inspection area where wheels are ultrasonically inspected for flaws and profiles are checked.

The scheduled maintenance/inspection intervals proposed for the Texas application are as follows:

- Type L - Daily running gear check
- Type N - Weekly follow-up checks
- Type F1 - Monthly inspection  
60,00 km (37,500 mi)
- Type F2 - 4 month inspection  
240,000 km (150,000 mi)
- Type R - 20 month overhaul  
1.2 million km (750,000 mi)

Table 3 lists the DB inspection levels at the Hamburg maintenance facility.

## **Passenger Cars**

### ***Construction***

The primary passenger car structure is fabricated from weldable aluminum alloys and is designed for a service life of 30 years. The car body underframe consists of two longitudinal side sills, a floor plate, and lateral cross members. The floor plate provides the necessary support and guidance rails for suspending the required electrical and pneumatic equipment

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**Table 3 - ICE/DB Inspection Levels**

|                                                                            |                                                                                                                                                                     |
|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Every trip                                                                 | Running gear safety inspection, including checking wheels and brakes, flushing sanitary tanks, replenishing on-board supplies, and completing any necessary repairs |
| Every 2 days                                                               | Washing of the complete trainset                                                                                                                                    |
| Every 3 days                                                               | Ultrasonic, mechanical, and optical inspection of wheels                                                                                                            |
| Every 2,000 km (1,250 mi)                                                  | Running gear inspection - 1 hour                                                                                                                                    |
| Every 2,000 km(1,250 mi)<br>or 6 days (whichever occurs first)             | Power car inspection - 1 hour                                                                                                                                       |
| Every 60,000 km (37,500 mi)<br>or 40 days (whichever occurs first)         | In-depth 8-hour inspection                                                                                                                                          |
| Every 240,000 km (150,000 mi)<br>or 6 months (whichever occurs first)      | A more in-depth 8-hour inspection than the 60,000 km inspection                                                                                                     |
| Every 1.2 million km (750,000 mi)<br>or 2.5 years (whichever occurs first) | Overhaul of equipment at Nürnberg                                                                                                                                   |

beneath the floor. The car body shell (sides and roof) consists of a series of extruded profiles (stiffened panel sections) which are welded together. Lateral reinforcement at the roof is provided by hoops attached to two upper longitudinal girders. The ends of the car body consist of bulkheads fabricated from aluminum plate and extruded profiles, and include the support frame for the double bellows "gangway" between adjacent cars (see Figure 5). Figure 6 shows a typical exterior of an ICE passenger car.

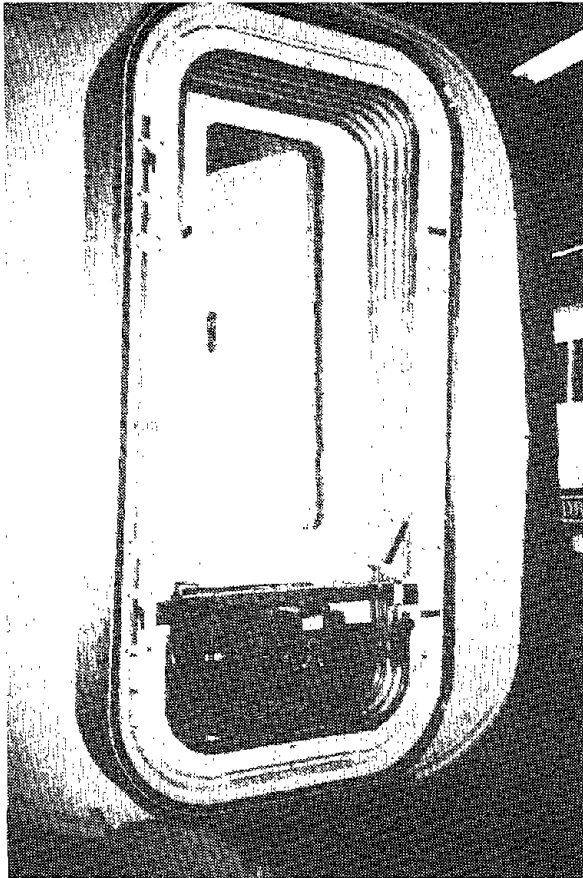


Figure 5 - Double Bellows at Rear of Power Car

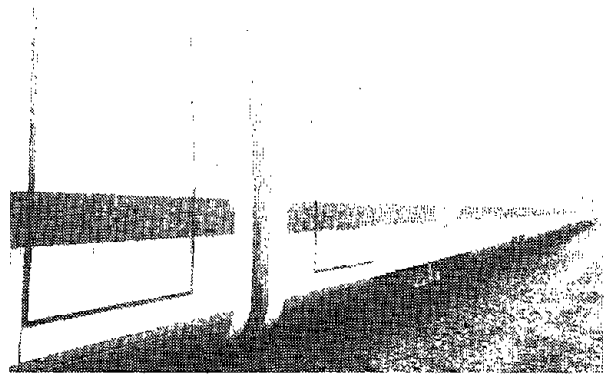
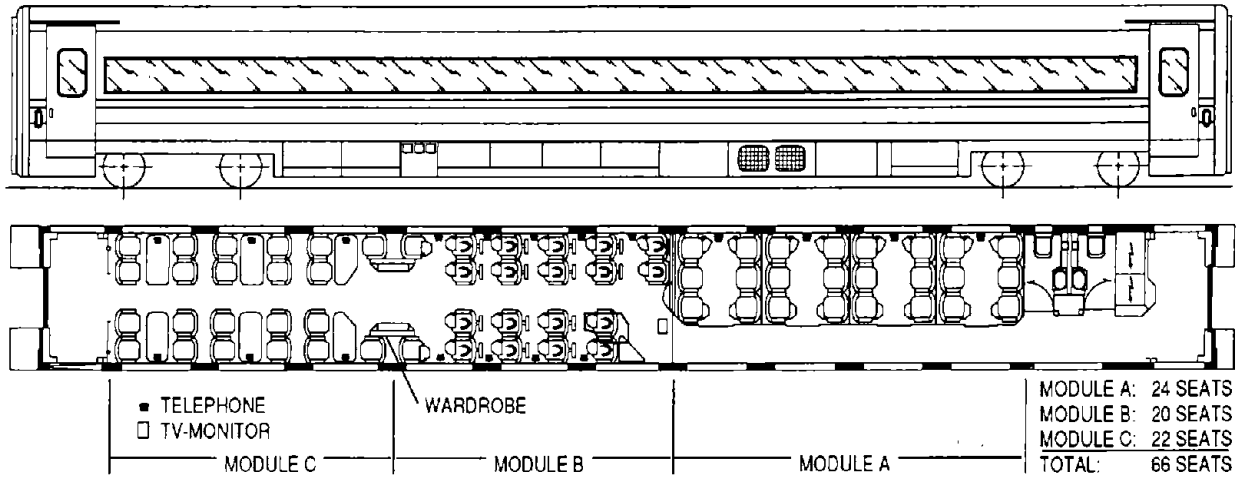


Figure 6 - ICE/DB Passenger Car Exterior

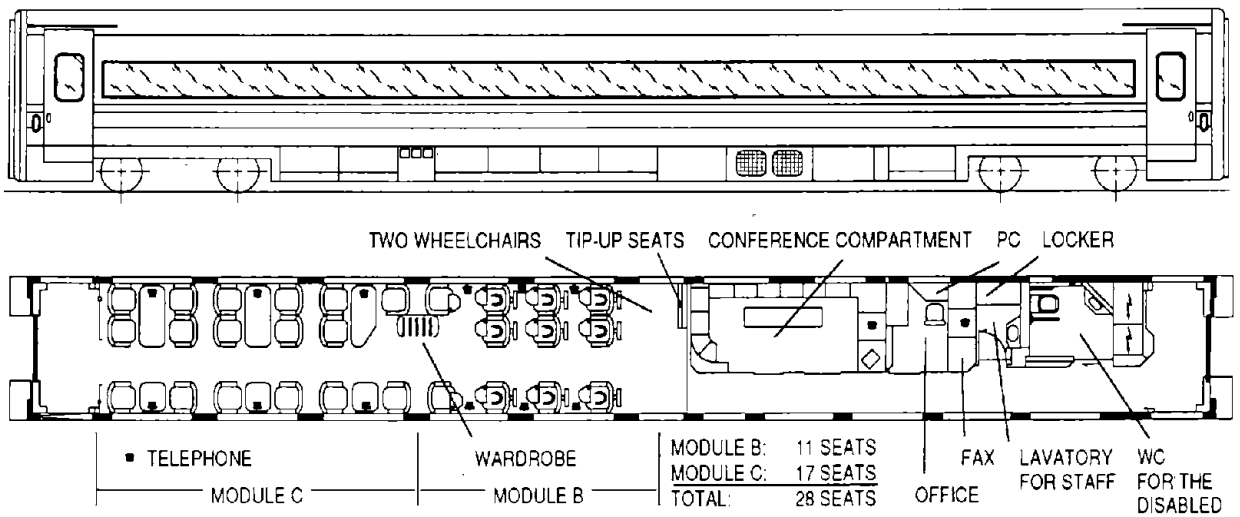
### ***Interior Arrangement***

The proposed ICE/Texas trainset included two passenger car seating configurations and a restaurant car (see Figure 7). Both passenger car configurations included vestibules, overhead storage racks, rest rooms, and automatic double sliding safety-glass corridor doors between the vestibule and passenger area at one end of each car. The first class car configuration included a separate conference compartment, an office area, and provisions for handicapped passengers with wheelchairs. A floor-mounted, free-standing open wardrobe was to be provided near the center of each passenger car. The coach passenger car configuration included four six-seat enclosed compartments with manual sliding steel/safety glass entrance doors. The restaurant car design included a kitchen and both seated and stand-up (self-service) eating areas. Figure 8 shows a typical interior of an ICE/DB first class passenger car.

### Coach Class ICE Passenger Car



### First Class ICE Passenger Car



### Restaurant Car

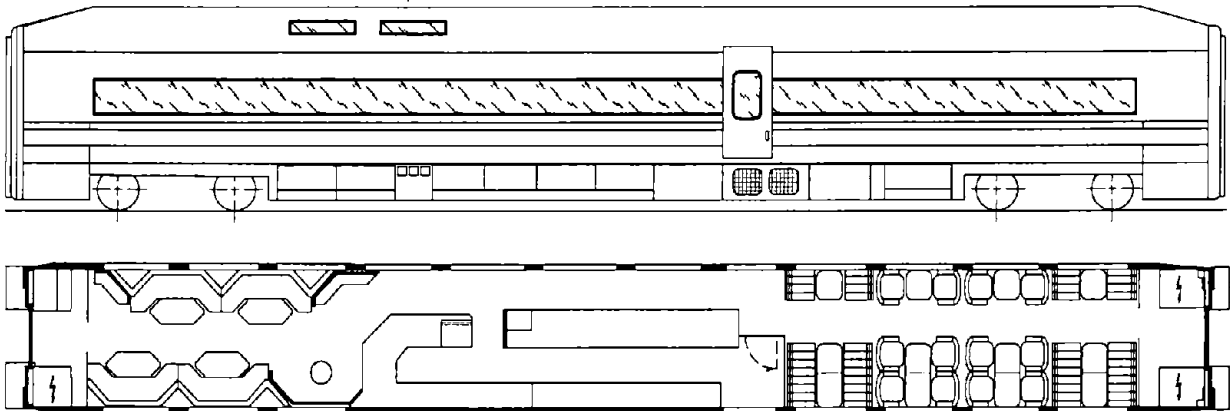
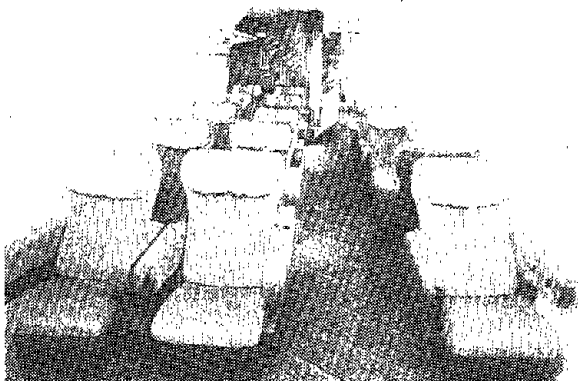


Figure 7 - Layout of ICE/Texas Consist



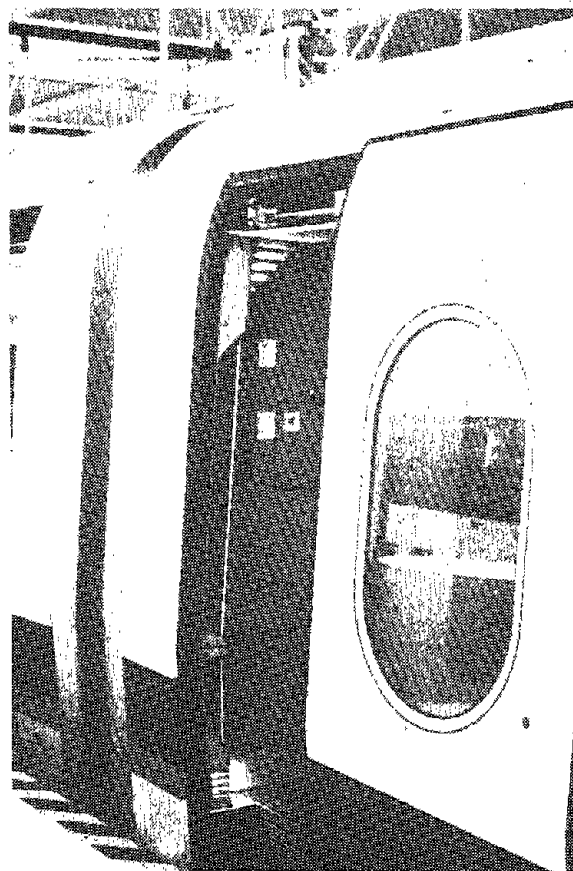
**Figure 8 - ICE/DB First Class Passenger Car Interior**  
***Crashworthiness***

ICE/DB passenger cars have both swiveling and non-swiveling floor-mounted reclining padded seats. The seats do not have restraining belts. The overhead storage rack floors are inclined to resist lateral movement of stored items. The rack design also incorporates bulkheads, spaced approximately 2 m (80 in) apart, which provide additional luggage restraint in the fore and aft directions. The car interior is well contoured with no loose equipment. The minimum design static longitudinal load requirements for the cars based on UIC standards are as follows:

- 136 tonnes (150 tons) compressive through the couplers
- 27 tonnes (30 tons) compressive at the upper girder

***Access/Egress and Emergency Equipment***

Each ICE/DB passenger car has four entrance/exit doors, one at each outer corner of the car (see Figure 9). The doors are the swing-sliding type, electro-pneumatically actuated with speed-dependent closing and locking features. Pneumatically actuated bottom footsteps are activated along with the door opening. During an emergency, the doors can be manually unlocked and opened. Each of the four doors has a removable emergency window. The restaurant car has two exit doors located near the center of each side of the car (one in the kitchen area). Each of these doors has one emergency window.



**Figure 9 - ICE/DB Plug Door**

All cars have fire alarm sensors in the passenger compartments, vestibules, rest rooms, equipment lockers, and areas below the floors. These sensors are integrated with a train-wide fire alarm system which can also control the closing of car ventilators and doors between cars. Emergency ceiling lighting is provided in each car in event of loss of normal system power. Aisles and passageways are clear of obstructions and permit free passenger movement through the cars and train. The passageway between adjacent cars is fully enclosed with outer and inner "wave" bellows.

**Power Car**

Table 4 contains a partial listing of the ICE/Texas power car specifications.

**Table 4 - ICE/Texas Power Car Specifications**

|                                        |                                                                               |
|----------------------------------------|-------------------------------------------------------------------------------|
| Overall length                         | 20.50 m (67.26 ft)                                                            |
| Body width                             | 3.07 m (10.07 ft)                                                             |
| Traction motors                        | 1,200 kW                                                                      |
| Traction power transmission            | 600 A at 25 kV, 60 Hz                                                         |
| Transformers                           | 3,480 kVA rms, 5,120 kVA peak                                                 |
| Rectifier                              | 7,600 kVA                                                                     |
| Maximum tractive effort                | 400 kN starting<br>375 kN at 92 kmph (57 mph)<br>130 kN at 250 kmph (155 mph) |
| Acceleration rate                      | 0.45 m/s <sup>2</sup> (1.48 ft/s <sup>2</sup> )                               |
| <u>Adhesion:</u>                       |                                                                               |
| Power                                  | 0.25                                                                          |
| Brake                                  | 0.19                                                                          |
| <u>Grade capability:</u>               |                                                                               |
| Seven car trainset                     | 80 kmph continuous on 6% grade                                                |
| New wheel diameter                     | 1,030 mm (40.5 in)                                                            |
| Worn wheel limit                       | 950 mm (37.0 in)                                                              |
| <u>Diameter differential limits:</u> * |                                                                               |
| All wheels (new)                       | 0.10%                                                                         |
| Same axle (new)                        | 0.03%                                                                         |
| <u>Operational limit:</u>              |                                                                               |
| Same bogie                             | $\Delta \leq 3 \text{ mm (.12 in)}$                                           |
| Different bogies                       | $\Delta \leq 10 \text{ mm (.39 in)}$                                          |

\*Because the traction motors can operate with wheel diameter difference limits maintained by DB, no restrictions to accommodate the propulsion system are required in Germany.

## Car Body

The ICE/DB power car body is a welded assembly of high-tensile, corrosion protected steel and is designed to UIC safety requirements. It consists of the main frame, cap, sidewalls, and rear walls. These are built as steel frame sections with plating welded on. Stainless steel is used for cab plates, but corrosion protected steel is used for other structural components. Non-structural parts, such as roofs, doors, etc., are aluminum alloy. Forward fairing and sidewall covers for underfloor equipment are fiberglass reinforced plastic. The unit has been built with smooth, flush surfaces to minimize noise. Stress, weight, and aerodynamic analyses were performed continually throughout the design phase to preclude adverse impacts resulting from design modifications. Figure 10 shows the exterior of an ICE/DB power car.



**Figure 10 - ICE/DB Power Car Exterior**

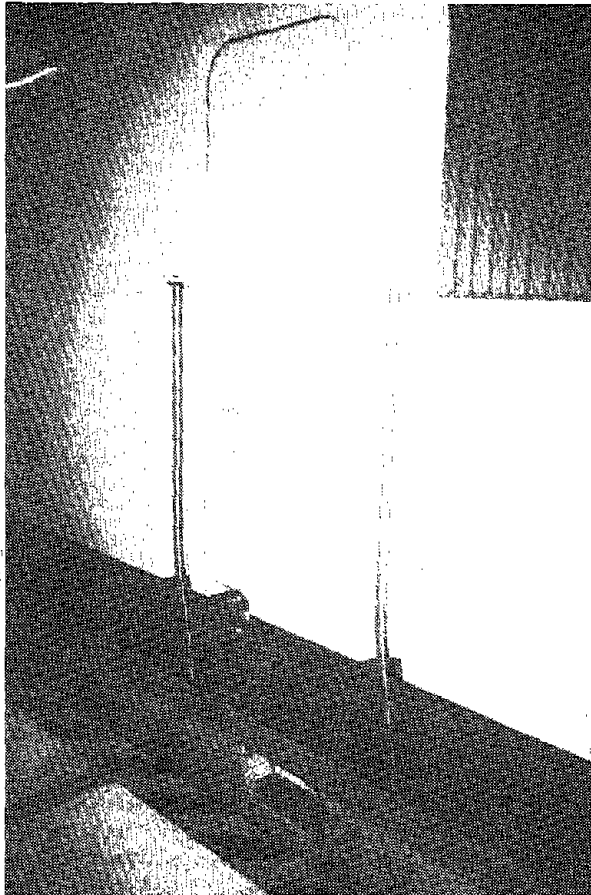
## Roof Equipment

Roof-mounted components are held to a minimum on the ICE/DB; only the pantograph and its protective devices are on the roof. All high-voltage switching and

protection equipment is mounted in an enclosure within the power car equipment bay.

### **Control Cab**

The ICE/DB operator's cab is air conditioned and pressurized to protect the cab occupants from pressure changes when meeting trains or when operating in tunnels. The cab has been designed to meet the requirements specified in UIC Directive 651. Equipment in the unit body is mounted along the outer walls, leaving a center aisle available for access to the cab. Access to the cab is either from the adjoining passenger car through a door at the rear of the power car, or through either of two side doors located just behind the operator's cab (see Figure 11).



**Figure 11 - Exterior Access to the ICE/DB Power Car Equipment**

The power car equipment area is a closed volume, and is cooled by a separate, filtered ventilator which regulates the temperature

and keeps the equipment area free of dust. Modular construction is used as much as is practicable with major enclosures bolted to the power car underframe. Equipment can be removed through removable roof sections. Pneumatic brake piping and power cables are routed under the equipment bay floor. Lower-voltage and control wiring is in racks near the top of the car.

The transformer is mounted between bogies, under the power car floor, in a rectangular aluminum tank. It is oil cooled, with mineral oil, Shell DIALA D liquid, or equivalent. Transformer oil is pumped to forced air cooled heat exchangers mounted in the power car body. The oil cooling systems are redundant so that the power car may continue to operate if one of the cooling systems fails. The transformer has been designed in accordance with International Electrotechnical Commission (IEC) Publication 310 and German Standard 0532.

The power car includes batteries for critical control system power. These are mounted in enclosures under the power car floor.

### **Power Distribution and Electrification**

Traction power for the ICE/DB is supplied by the DB power network, which is independent of the German industrial utility grid. DB generates its own power and thus can accept regenerated braking energy from its trains without penalty. The ICE would have been able to operate in Texas with or without utility acceptance of regenerated power.

In Texas, the proposed substation and distribution system was based on the design used by DB and incorporated commercial power equipment of companies participating in the Texas program. Catenary power was to be supplied from a 138 kV, 60 Hz utility grid, and then transformed to 25 kV at traction substations spaced at approximately 50 km (31 mi) intervals. Sixteen substations were proposed for the Texas network.

Texas substation design was standardized to include a pair of transformers, rated at 20 MVA, each connected to both tracks on one side of the catenary distribution

system. The design included circuit protection on both the high-voltage and low-voltage sides. Disconnects and tie breakers can isolate a failed component while maintaining power in the total catenary system. Each substation transformer was to carry only 50 percent of rated load in normal operation. Therefore, the Texas design required only one spare high-voltage transformer as a standby for the entire system.

The catenary system is classified by the German railways as Re 250, and is rated for speeds to 280 kmph (174 mph). It has been designed according to German DIN and DIN VDE standards, and has been tested to 350 kmph (217 mph) by the manufacturer, ABB-Henschel. The system supplied for the Texas application would have been the same as that to be supplied by ABB-Henschel for the French TGV in Spain. Aluminum alloy is used wherever possible for poles, supports, cantilevers, etc. Phase breaks (unenergized neutral sections) are located where trains will transit line segments powered by different phases of the utility distribution network. Figure 12 is a typical catenary installation for a DB high-speed line.

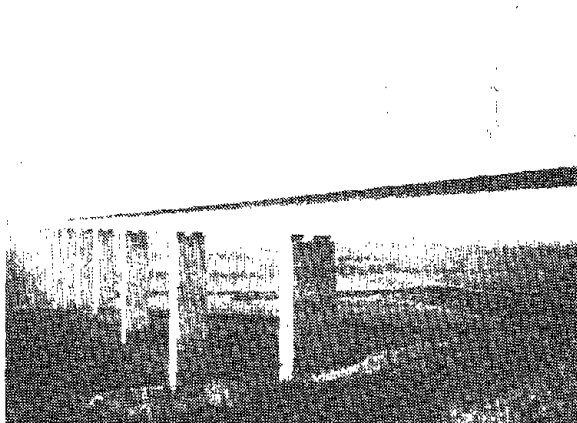


Figure 12 - DB Catenary Installation

The copper or silver-copper alloy contact wire is designed to supply 800 A under continuous operation after a cross-sectional reduction, due to wear, of 20 percent. Although line currents would be lower at 25 kV, the same contact wire used in Germany was to be used on the Texas system. The DB design goal for contact wire life is 2 million pantograph passes, and pantograph

carbon collector strips are expected to travel 50,000 km (31,250 mi) before being replaced.

Traction return currents are routed through the running rails and an interconnected ground system. The ground system consists of a 240 mm<sup>2</sup> (0.37 in<sup>2</sup>) negative feeder installed on the support poles and bonded to the rails at intervals. In tunnels, the return system includes a reinforcing bar grid installed in the tunnel walls above the contact wire, "switching lines" installed in each side of the tunnel walls about 1.5 m (5 ft) above the rail top, and the tunnel bonding grid itself, which is also bonded to the traction return current rails.

### **Power Collection**

Power pick-up for the ICE/DB is via a roof-mounted pantograph from the catenary. Each power car has a pantograph, and the pantographs of both power cars are used for power collection up to a rated speed of 280 kmph (174 mph). At higher speeds, such as 320 kmph (200 mph) in Texas, the catenary/pantograph dynamics preclude two-pantograph operation. Thus, only one power car will have a raised pantograph. Power to the other car will be routed through the train via overhead cables from the power car with the pantograph, according to the original design applied in the ICE experimental train. Figure 13 shows an ICE/DB pantograph.

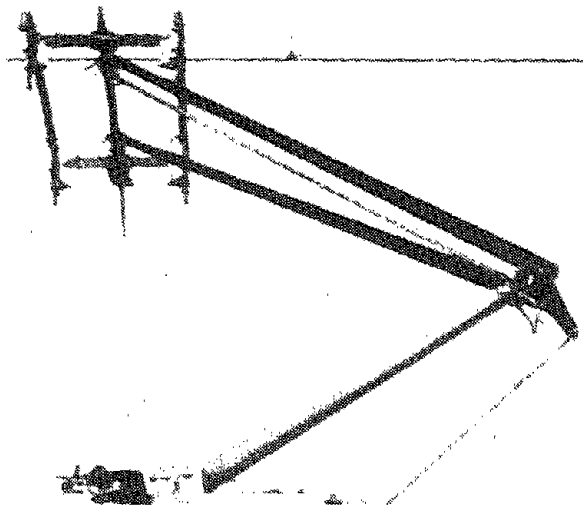


Figure 13 - Pantograph on ICE/DB Power Car

Power from the pantograph is routed directly through the roof to a cabinet which encloses the high-voltage switch gear, including the high-voltage switch, circuit breaker, and filter choke. For 25 kV, 60 Hz operation, the cabinet would be slightly larger than that on the ICE/DB. The circuit breaker that was specified for the Texas application is an industrial design which is rated for 25 kV, but ruggedized for railroad operation. It is also being used for 25 kV applications in a high-speed locomotive being built for operation in Spain.

From the switch gear cabinet, the high voltage is routed to the main traction transformer, where it is stepped down to levels needed for traction and auxiliary power. The transformer has seven secondary windings, four for traction power and three for auxiliary power. The transformer for the Texas application would have been a rewound version of the present transformer designed to accommodate the change to 25 kV, 60 Hz from the 15 kV, 16 2/3 Hz used in Germany. A similar transformer, to be used at 25 kV, 50 Hz, has already been designed for application in Spain. AC voltages from the traction windings are converted to dc for the traction power inverters through four-quadrant ac-to-dc controlled rectifier converters.

### ***Propulsion***

The ICE/DB uses inverter-controlled, three-phase asynchronous (induction) ac traction motors for propulsion and regenerative/dynamic braking. The inverters are pulse width modulated (PWM) variable voltage, variable frequency using gate turn-off (GTO) thyristor technology. GTO thyristor inverters are now the state-of-the-art in traction power systems, as they use thyristors which can be turned off at their gate with relatively simple turn-off circuitry. GTO thyristor inverters are lighter, more efficient, use fewer power electronic components, and generate less electromagnetic noise than the outmoded conventional auxiliary thyristor forced commutated inverter.

***Power Conditioning*** - The four-quadrant converter provides complete power flow control to and from the supply (or dynamic brake resistors) without contactors in either direction of travel. GTO modules in the converter, featuring both thyristor turn-on and turn-off control, also provide power factor control. The high power factor achieved by the converter circuit reduces system costs because power supply and distribution system components can be rated for lower currents. The four-quadrant converter uses dual-converter stages for forward and reverse power flow. These are incorporated in single modules, so only two modules are required for each single-phase, four-quadrant converter system.

The dc voltage from the four-quadrant converters is routed through harmonic filters to three-phase PWM inverters, which supply the variable voltage and variable frequency excitation required by the traction motors. The inverters develop the ac excitation for the motors from the 2,800 Vdc output of the converters, and provide an output that varies from 0 to 2,200 Vac at frequencies from 0 to 130 Hz. The GTO power modules used for the traction current inverters are identical to those used in the four-quadrant converter. DB has found that module standardization reduces the number of designs required and is more effective in terms of supply and maintenance.

The power modules are enclosed in hermetically sealed containers of a freon evaporative bath. Liquid freon, evaporated by the hot semiconductors, condenses on the top surface of the enclosure, where it releases its heat and returns to the semiconductor area to continue the cooling cycle. Hermetically sealing the freon in the chamber reduces the environmental risk of freon release to the atmosphere and keeps the circuitry clean. Heat released by the freon is carried away by forced air cooling of the heat sink fins at the top of each power module. Modules are not designed for any shop maintenance or adjustment, but are replaced when they fail. Failed modules are returned to a maintenance facility, where the freon is removed and stored for reuse.

The module is then opened and repairs completed.

**Traction Motors** - Traction motors are four-pole induction (asynchronous) squirrel cage construction with rectangular copper bars. They are rated for 700 kW rms, 1,078 kW peak at 2,050 Vac rms (2,200 V peak). At a maximum frequency of 130 Hz, they provide a peak of 2,805 Nm (2,069 ft-lb) torque at a maximum speed of 3,670 rpm and 3,216 Nm (2,372 ft-lb) at 2,077 rpm. The operating power factor ranges from 0.8 to 0.9. The stator magnetic circuit is laminated steel with two-layer insulation class H vacuum impregnated cores. The rotor is a squirrel cage construction of copper bars brazed to end rings. Temperature sensors are included to monitor winding and bearing temperatures.

Motors are forced air cooled by air ducted to the non-drive end of the motor and exited through grated vent openings on the drive end. The stator is cooled by the air flow through channels in the back of the laminated stator core, the unwound parts of the stator, and the gap between rotor and stator. The rotor is cooled by air forced through two rows of longitudinal ventilation holes in the rotor assembly. Drive-end motor bearings are cooled with gear oil circulated through the reduction gear box. The bearings on the non-drive end of the motor are grease lubricated.

**Auxiliary Power** - Auxiliary power for the power car and passenger cars is supplied from auxiliary windings of the main transformer. The power car is supplied by an 885 V winding and a 200 V winding. The 885 V is rectified, filtered, and then converted to three-phase ac for driving the power car's motor loads by GTO inverters. Auxiliary motors for blowers, compressors, etc. are also three-phase induction motors supplied by two auxiliary variable voltage, variable frequency converters.

The 200 V output supplies low-voltage auxiliary loads and a thyristor controlled converter battery charger, which maintains the charge on a 100 A/h battery. Critical safety-relevant loads are powered by the battery through regulated dc or inverter-driven ac loads.

A third auxiliary transformer winding is used to supply passenger car hotel power from the power cars via two 1,000 V, 50 Hz bus bars, one from each power car. Each car is connected to only one bus bar at a time. The second is a standby, which is used if the first fails. Non-critical loads are de-energized if the train is forced to operate from only one bus.

## Trucks

### Motorized Trucks

The DB/ICE power trucks are designed to be lightweight and stiff so they are stable throughout the operating speed regime. Each truck has two side beams connected to two end transoms, forming a closed rigid box frame. The inboard transom has a flange to support the traction bar which transmits the tractive and braking efforts from the truck to the body. The transom also has slots for support of some of the braking rigging. The truck assembly is shown in Figure 14. Great effort has been made to reduce the unsprung mass of the wheel sets. Through use of a special transmission arrangement, the traction motors, gearing cardan drive, and disc brakes are all suspended from the car body and the truck frame, not from the axles.

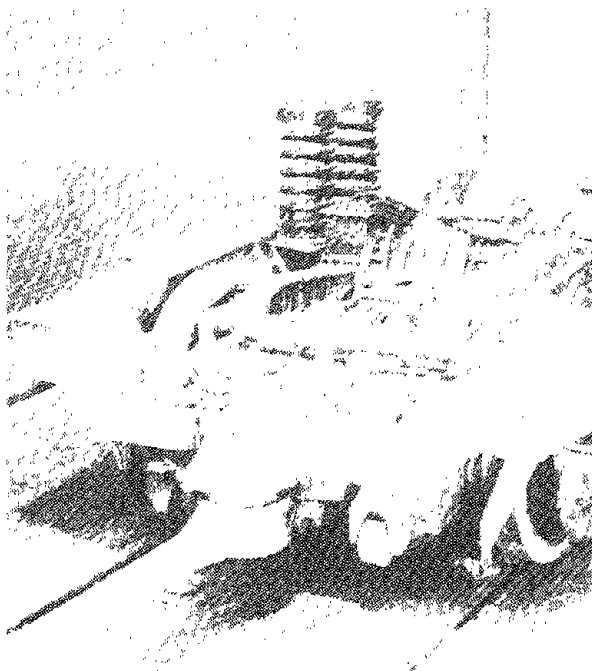


Figure 14 - ICE/DB Power Car Truck

The primary suspension consists of a pair of metal coil springs at the journals. Vertical motion is absorbed by the coil springs. The lateral motion is also absorbed by these springs, which are designed to cushion impacts from rail irregularities. Tractive and braking forces are transmitted from the axle boxes to the truck frames through longitudinal rubber bonded joints that allow vertical and lateral motion of the axles.

The secondary suspension consists of four groups of flexi-coil springs mounted on the side beams of the truck. These allow lateral motion of the truck under the power car body up to cushioned stops, resulting in less lateral stroke for the pantograph. Tractive and braking forces are transmitted from the truck frames to the body through one longitudinal bar per truck with rubber bonded joints at both ends. The bar is attached to the inboard transom and the car body cross member that supports the transformer.

The truck has vertical hydraulic dampers in parallel to the primary springs. In addition, there is a damper in parallel with the secondary springs and a horizontal damper on each side between the body and the truck to reduce roll, sway, yaw, pitch, and bounce. Two yaw dampers per truck prevent truck hunting, the self-excited lateral instability of a truck at high speed. Finally, a horizontal damper between the drive unit and the power car decouples the drive unit from the truck and suppresses undesirable lateral oscillations.

#### ***Non-Motorized Trucks***

The non-motorized ICE/DB truck is equipped with an H-shaped flexible frame. This truck is shown in Figure 15.



Figure 15 - ICE/DB Passenger Car Truck

The primary suspension consists of coil springs in parallel with hydraulic dampers. The secondary consists of sets of two coil springs on each side between the bolster and a spring attachment which is connected to the side frame through a pendulum arrangement. Rubber-metal spring elements are introduced between the spring attachment and the springs for noise control.

The car body is attached to the bolster through lateral fully supporting side bearings in combination with a rubber-bedded center pin. The bolster is equipped with hydraulic dampers to absorb bolster cross motions.

The truck has mechanical ride stabilizers through the friction moment in the lateral side bearings. Torsion bars between the bolster and truck frames help to steer the bolster and to prevent longitudinal oscillations of the truck from reaching the car body.

Because truck hunting must be avoided, each ICE truck has accelerometers to detect the onset of hunting behavior, which, if detected, is then controlled by special dampers.

#### **Braking System**

The ICE/DB braking system consists of electro-pneumatically and pneumatically controlled friction disc brakes, dynamic regenerative brakes, and electromagnetic rail brakes. The electromagnetic track brakes are designed for possible retrofit to eddy current brakes in the future.

The service braking rate for an ICE consist is  $0.5 \text{ m/s}^2$ . With all braking systems activated, the ICE could achieve a braking rate of more than  $1.4 \text{ m/s}^2$ , but the rate is limited to  $1.3 \text{ m/s}^2$  to reduce potential for injuries to passengers caused by such sudden braking.<sup>5</sup> UIC code requires an emergency rate of  $0.85 \text{ m/s}^2$ ; however, this value is only for speeds up to 200 kmph (125 mph). With only the friction discs operating, the ICE can achieve a braking rate of  $0.9 \text{ m/s}^2$ . A rate of  $0.7 \text{ m/s}^2$  is used to compute required stopping distances.

The braking system is computer assisted. Braking tests are automated, and all braking systems are continuously monitored with the information presented to the operator via one of two available computer screens at the operator's console. Reductions in braking capability are entered into the system by the operator and then automatically compensated for in terms of maximum speed permitted by the automatic train control system. Brake monitoring is also tied into the consist maintenance monitoring system. Thus, any braking component failures or operational problems will be included in the information relayed via a data radio link to the ICE's maintenance facility prior to the train's arrival.

The operator can run the train under full automatic control. A second option is to use the automatic speed control by selecting a speed and letting the power and propulsion system automatically maintain that speed via various microprocessor controls tied into the power and braking systems. Another option is to use the brake valve that initiates blended braking between dynamic regenerative and disc braking. The blending is done automatically, again with microprocessor assistance, and is programmed to favor the more energy efficient and less maintenance intensive dynamic regenerative braking and to maintain jerk-free interaction between the various braking systems. If dynamic regenerative braking is not available (because the power grid will not accept power or the system has failed), no blending would occur, and a 100 percent disc brake application would result. In an emergency, the operator also has available a brake valve directly connected to the brake pipe and can initiate emergency braking independent of all the automated or powered systems. All the automated braking functions interact with the anti-skid systems located on each car of the consist. These systems are designed to ensure maximum braking while avoiding wheel skidding.

The friction disc brakes are controlled electro-pneumatically with the option of

straight pneumatic control in emergencies where the other system may have failed. The driving axles on current production power cars have two non-ventilated discs, and each car axle is equipped with four ventilated discs for friction braking. The non-ventilated discs on the power cars are cast alloy steel with sintered metal linings similar to those used on the cars of the TGV Atlantique. Each axle in the consist has its own brake cylinder.<sup>6</sup>

The car discs are cast iron with organic pads for 250 kmph (155 mph) service speed and 280 kmph (174 mph) maximum speed. A second production set of ICE cars, equipped with discs and pads similar to the power cars, is planned for higher speeds, up to 300 kmph (186 mph).

The hand brake on each car acts separately through a caliper independent of the pneumatically operated brake caliper on a brake disc on one axle in one of the two trucks.<sup>7</sup> The parking brakes on the power cars are spring loaded disc pads that only release when air is supplied to the brake cylinder.

The electromagnetic track brake is mounted on each side frame of the car trucks. Its purpose is to provide a retardation force independent of wheel-rail friction. This brake is used only during emergency braking, as it is not adjustable and is subject to considerable wear. This braking concept is the same as the concept currently used on Intercity (IC) trains throughout Germany.

The ICE experimental train was equipped with eddy current brakes instead of the electromagnetic track brakes. Although there have been some instances of rail heating and signal system interference with the eddy current brake, DB hopes to retrofit all ICE vehicles with eddy current brakes after these technical issues have been fully addressed. Although eddy current brakes will provide the same emergency braking role as the electromagnetic track brakes, the eddy current brakes can also be controlled and thus used for service braking. Because they are non-contact brakes, wear should be negligible. This

retrofit would also decrease the wear experienced by the disc pads, as eddy current braking would become a preferred braking method along with regenerative braking.<sup>8</sup>

The ICE does not have an emergency brake valve for passengers to operate. DB 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 areas. The emergency handles located in the cars do alert the operator and crew immediately to the location of the alarm. Operating procedure is for the crew to ascertain the problem and develop the best response.

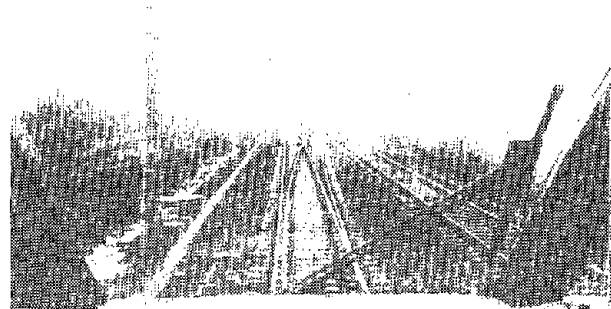
### ***Dynamic Regenerative Brake Operation***

During braking, the traction motors, acting as induction generators, regenerate the train's kinetic energy into electrical energy. The inverters then supply that power to the four-quadrant converters via the dc link. The converters continue the regeneration process by converting the energy from dc power to ac and transferring that power back to the ac line through the transformer windings, again in either forward or reverse direction of train motion.

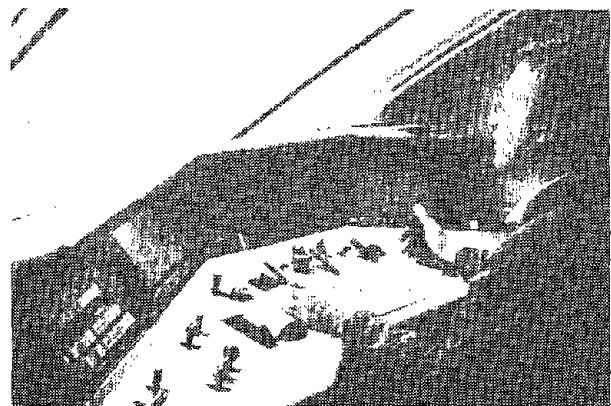
The train does not have dynamic brake resistors on board; it relies on regeneration into the ac grid. Although DB uses this method of braking in Germany, it may not be used in the United States. The power car builder, Krauss-Maffei, is prepared for this possibility because regeneration is also restricted in Spain. For the Spanish application, Krauss-Maffei has equipped its locomotives with dynamic brake resistor grids that are forced air cooled and mounted in an enclosure within the locomotive equipment area. The ICE resistor enclosure would be smaller than that required for the Spanish high-speed locomotive, and internally mounting the resistors within the power car precludes any aerodynamic effects.

## **Computer Control**

The ICE/DB train is highly automated. Computers and microprocessors involved in the vital safety-critical information and control elements of the automated control system were designed based on fault-tolerant methodology. Figure 16 shows the view from the operator's cab in the ICE power car, and Figure 17 shows the operator at the console.



**Figure 16 - View from Operator's Cab**



**Figure 17 - Operator at the Console**

Three operational methods are available: (1) fully automated speed control; (2) manual selection of speeds, allowing the speed control to meet the set speed; and (3) full manual operation utilizing control system information on the console for guidance. Before every run, the operator keys in the train identification number, maximum speed, train length, and status of the braking systems. If the train is operated manually, the automatic train speed monitoring systems are still active. The alerter system will start controlled braking of the train anytime the operator fails to touch the foot pedal or hand reset for more than 24 seconds. An alarm sounds and

flashes, and the operator has 5 seconds to respond. If no response is made, controlled braking is automatically initiated.

Under manual control, on-board calculated monitoring speed curves are used to control speed. These curves represent the use of the emergency braking rate. The nominal speed curves are also calculated on board, utilizing a lower operational braking rate. If the train's speed exceeds the nominal speed curve, the operator is warned of the overspeed. However, if the train's speed reaches the monitored speed limit, the speed control system initiates an emergency application of the brakes. During constant speed sections of the nominal speed curve, the monitoring speed is 8.75 kmph (5.5 mph) above the nominal speed.

All braking and control systems on board the train are monitored frequently for their operational state. This information is made available to the operator and in some cases is relayed wayside via data radio links for maintenance purposes. Various passenger comfort systems such as lights and air conditioning can also be turned on (or off) remotely.

A fiber optic communications cable runs the length of the ICE consist. This link is used for operations (from power car to power car for propulsion coordination and on all cars for braking control), voice communications (passengers to crew, crew to operator, etc.), and maintenance, inspection, and diagnostic systems (brake test, component failures, etc.). The cable is looped and networked so that a failure at any point can be addressed by rerouting communication messages.

For transmission of vital information between wayside and train, inductive loops, 300 m (984 ft) long, are laid inside the track. These loops are crossed every 100 m (328 ft), and each crossing is detected and noted by the train. Because of the higher data transmission capacity of the inductive loops, the large amounts of information necessary to accomplish continuous automatic train control can be transferred to and from the train. Information is transmitted from the wayside to the train at 36 kHz and from the train to wayside at

56 kHz. Data exchange between the train and wayside can occur every 14 seconds.

This type of communication system between wayside and train was first introduced in Germany in 1965. Improvements, including shortened loops, have been made over the years. This system meets the ORE A46 recommendations and is also installed on trains used in Austria and Spain.<sup>9</sup>

Because all the necessary information for safe train operation is transmitted via the inductive loop system, wayside signals are generally omitted. However, they are installed at interlockings and stations for use by maintenance and other trains that are not equipped to receive and transmit information to and from the inductive loop, and for emergency purposes where backup manual operations would not be adequate during failure of the inductive loop system. These wayside signals have three aspects and in some cases additional limiting information, such as a speed limit or routing.

High-speed lines are separated into block sections that are marked by reflectorized signs with unique numbers. These markers serve as target points for manually (radio) controlled trains under failure conditions.

The wayside and train computers used to transmit, receive, and manipulate data for control purposes operate on a two-out-of-three basis. Three computers operate in parallel. If two of the three do not agree, the information is not acted on, and the system reverts to a non-automated control mode.

Safety-relevant information sent from the wayside to the train includes the distance to the next required stopping point, the braking curve to be utilized, and the traveling direction. The control equipment on board the train uses this information to determine where the train should be on the curve relative to the stopping point, and then determines the speed needed at that point. Thus, the actual train speed to be achieved and the necessary braking or power commands are determined via on-board logic. The speed control loop resides totally on the train. Actual train

speed and direction are monitored via redundant pulse generators (16 pulses per revolution). An acceleration meter is also on board to check the logic sequence of the pulse generator output to avoid misinterpretation during slide conditions.

Other information sent from the wayside to the train that is necessary for effective train control includes target speed in 5 kmph (3.1 mph) increments, target distance, line gradient, and civil speed restrictions. Items such as gradient and civil (i.e., related to track parameters) speed limits, although not directly considered safety relevant in transmission to the train for automatic operation, are utilized by wayside elements in computing the braking curve and next required stopping point, both of which are considered safety relevant. Each train on the line receives wayside information at least once every second.

Safety information sent from the train to wayside locations includes address confirmation (and correction if necessary), data about the train's braking capabilities, and details such as the train number and train length. The operator must input any changes in the braking capability of the train into the on-board control unit, which then transmits the updated information to the wayside control elements. Information that is not subject to change is only transmitted when the train enters a new central control area.

Each train has an event recorder that records important operating parameters, including speed, location, and brake applications.

Audio-frequency track circuits are used to ensure safe route control and to monitor the track for broken rails. Although the required interlocking functions could be served by mechanical relays, DB uses SIMIS, a microprocessor-based interlocking control system developed by Siemens. DB has used this system in parts of its operations for the past 6 years. SIMIS elements are utilized as functional modules with the same requirements as the mechanical relays that they replace. The

geographic method (where each module interfaces only with adjacent modules) is used for interlocking requirements to facilitate modification of an interlocking plant if changes are needed. This design method requires modification of only the new module and the elements it connects to.

Each SIMIS unit consists of two identical SIMIS-C elements. One element is active, and the other is in standby mode. Each element has two identical microprocessors that have the same configuration and software. Each microprocessor operates continually to check the other. If the results do not agree for the on-line SIMIS-C element, it is switched off and separated completely from the network, the other parallel SIMIS-C takes over, and an alarm message is sent to maintenance personnel. The parallel processing and comparing is a safety feature, and the hot standby (i.e., no startup delay) of an identical system improves system reliability. As noted earlier, all areas with turnouts are protected by wayside signals, both as an emergency backup method of getting information to trains and for use by trains with non-automatic controls.<sup>10</sup>

Interlocking related software has three sections: the basic organization, the special railway appliance, and the station specific software. The basic organization software replicates the traditional aspects of any interlocking and is the same for all railway applications. The special railway appliance software handles system unique aspects, such as type of signal, communication protocol, and dual-gage use. The station specific software includes all the unique aspects of a particular station, such as names and numbers of track elements and their interaction with other track elements in the station.

ICE train operations are monitored from a central control point, but regularly scheduled traffic is handled automatically at a decentralized level. Only when disturbances occur does the central control intervene.

## Vehicle-Track Interaction

In its proposal to THSRA,<sup>11</sup> Texas FasTrac stated that the values defining vehicle-track interaction would be based on the ICE technology. The design of modern high-speed track/train systems seeks to minimize the magnitude of forces operative at the wheel-rail interface.

### Curve Design

New track constructed in Germany for ICE service relies on very long-radius curves, minimal values of cant deficiency, and low-mass vehicles to reduce the effect of centrifugal forces developed during high-speed curving. Specifications for curved track proposed for Texas are listed in Table 5.

Curve radii approximating the minimum value shown in Table 5 are rare, though not unknown, in conventional U.S. railroading. "Standard design" curves are even more rare. An interesting point is that track design is being driven by system requirements, not by the topography of the region through which a route will pass. However, adherence to this philosophy must remain flexible to minimize construction costs. The terrain in southeast Texas, though, generally would lend itself to economical construction of long-radius curves.

The standard design and cant deficiency values are well within the range defined by the current Federal track safety standards. For the special-case situation, however, the maximum design standard of 180 mm (7.09 in) substantially exceeds the safety standard threshold of 152 mm (6.0 in).

The relationship between curvature, super elevation, and train speed proposed for ICE/Texas was approximately equivalent to

$$R = \frac{4V^2}{3(E_a + E_u)}$$

(cant deficiency)

where:

R = the radius in yards

V = train speed in mph

E<sub>a</sub> = actual super elevation in inches

E<sub>u</sub> = unbalanced elevation in inches

For a case where V equals 322 kmph (201 mph), the maximum operating speed proposed for Texas, and the combined E values equal the sum of the limits authorized in the safety standards, 152 mm + 76 mm (6 in + 3 in), the minimum curve radius is 5,418 m (17,777 ft), or a curve of approximately 0°, 9'. Thus, if the target curved-track running speed is 322 kmph (201 mph), no curve in the Texas alignment can have a radius less than 5,418 m (17,777 ft) without a waiver of compliance with §213.57(a) and (b) of the safety standards. The standard design curves having a minimum radius of 7,170 m (23,500 ft) would clearly conform to today's track safety standards. However, as shown above, the expected minimum curve radius is indeed less than this value. The literature currently available does not clearly describe the circumstances under which "special-case" shorter radius curves and/or super elevation exceeding 152 mm (6 in) would be needed.

Table 5 - ICE/Texas Curved Track Specifications

|                                                                |         |             |           |
|----------------------------------------------------------------|---------|-------------|-----------|
| <u>Radius:</u>                                                 |         |             |           |
| Standard design                                                | 7,170 m | (23,500 ft) | (0°, 15') |
| Minimum                                                        | 4,320 m | (14,200 ft) | (0°, 24') |
| <u>Super elevation (maximum, standard, and special cases):</u> |         |             |           |
| Standard design (as installed)                                 | 100 mm  | (3.94 in)   |           |
| Standard cant                                                  | 70 mm   | (2.76 in)   |           |
| Total standard deficiency                                      | 170 mm  | (6.70 in)   |           |
| <u>Design cant:</u>                                            |         |             |           |
| Special-case design (as installed)                             | 180 mm  | (7.09 in)   |           |
| Special-case cant deficiency                                   | 100 mm  | (3.94 in)   |           |
| Total special-case design cant                                 | 280 mm  | (11.03 in)  |           |

### ***Curving Forces***

Long-radius curves and low vehicle weight create relatively small forces at the wheel-rail interface, even at high train operating speeds. However, the literature does not estimate the force that ICE/Texas trains would have produced. It was stated that the high-speed track in Texas would not have been subjected to lateral wheel loads exceeding those predicted by the highly conservative Prud'homme criterion:<sup>12</sup>

$$L = 0.85(10 + 0.66V)$$

where:

V = static vertical wheel load

L = maximum allowable applied lateral load

(both values in kN)

This same source posited a static vertical wheel load in Texas for an ICE-type power car (most severe case) having a static axle load of 186.3 kN (41,890 lb), which yields a track lateral load limit of 60.8 kN (13,600 lb). This means that the track must be able to contain, without inelastic horizontal deflection, an applied load of this magnitude. No data have been supplied that indicate how Texas FasTrac track designs would have behaved under these loads. However, tests of ICE equipment in Germany of the MD 52-350 truck operated at 300 kmph (186 mph) yielded the following data:

- Maximum lateral load of the wheel sets equals 26 kN (5,800 lb).
- Vertical dynamic load wheel forces equals 23 kN (5,200 lb).

For the test case, the lateral load limit was 40.5 kN (9,100 lb). This value can be compared with the essentially similar figure cited by Montagne<sup>13</sup> of 46 kN (10,300 lb), which is applied to the design of TGV track in France. It is not known why DB test personnel would set a lateral load cutoff at 40.5 kN for test purposes, as test conditions are usually more rigorous than conditions encountered in revenue operations. Texas FasTrac recommended a 60.8 kN value. Nevertheless, it is extremely unlikely that ICE-type equipment would produce lateral loads near the safety limit in normal high-speed operation.

The Texas FasTrac discussion recognizes that the ORE B65 RP8 definition of a safety coefficient to guard against wheel climb derailments limits the L/V ratio to 1.2, but then goes on to say that "test results at high speeds show the following maximum values:

- L/V less than 0.75 at 365 kmph (227 mph) in curves of 6,500 m (21,300 ft) radius
- L/V less than 0.30 at 400 kmph (250 mph) on tangent track"

It appears that elevated L/V values would not have been a problem for the ICE-type equipment in Texas.

### ***Ride Quality***

Ride quality, as perceived by passengers within the car body, is expressed as vertical and lateral acceleration maxima not to exceed 2.5 m/s<sup>2</sup> (0.255 g). This is a surprisingly high, though not unsafe, value for modern high-speed trains operating on new, dedicated track.

### ***Track Geometry Measurement Systems***

Texas FasTrac proposed to inspect the track structure for a number of geometry related defects by using several different procedures.

The first inspection process proposed was patrolling: a visual inspection that is particularly useful during construction or major maintenance phases, as well as during periods of extreme weather such as hot spells or flooding. These inspections would have noted gross defects and deteriorations.

The next inspection procedure was to be performed by a track geometry vehicle that measures track gage, alignment, profile, cross level, twist, and curvature. The technique proposed for Texas and currently used by DB is a 10 m (33 ft) chord based measurement system. However, DB is currently designing and building a new inertia-based track geometry measurement system. This system detects critical small amplitude, long wavelength irregularities which may act in combination with other perturbations to cause an unsafe condition

or unacceptable ride quality. DB plans to use geometry measurements to evaluate the expected vehicle performance through approximately 30 specially defined transfer functions. These transfer functions describe the response of specific vehicle types to certain critical geometric excitations, and can differentiate between the response to repeated small irregularities and single, isolated irregularities. DB feels strongly that maintenance be conducted only on track in need of correction because vehicle performance (i.e., tolerances) is so sensitive to wavelength and amplitude.

DB plans to use two additional specialized tests: ultrasonic rail inspection and rail surface inspection. The first of these, which is proposed for twice a year, inspects for internal rail head defects that could result in rail breaks. The other test looks for small short-wavelength surface irregularities, including corrugations, engine burns, scaling, irregular welds, and short-wavelength surface irregularities. All of these defects contribute to poor ride quality, a reduced life span for the track components, and increased noise. These surface problems would be corrected by using conventional rail grinding trains. For the high-speed lines, rail corrugation depths exceeding 0.05 mm (0.002 in) would be ground flat.

DB also uses a specially instrumented power car called a reaction car, which measures wheel forces, lateral and vertical accelerations, and lateral truck accelerations. These measurements are used in combination with the classical geometry measurements to evaluate track quality.



# Safety Issues

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## **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 ICE rail system in Texas.

FRA standards and guidelines with which the ICE 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.

DB erects wooden and steel barriers between the guideway and populated areas to limit exterior noise emissions. Many of the bridges and viaducts are ballasted to reduce the reflected noise from the elevated structure. DB applies special treatments to slab track surfaces to reduce noise. At 320 kmph (200 mph), the ICE consist emits no more noise than a conventional IC train emits at 200 kmph (125 mph).

### ***Part 213, Track Safety Standards***

It is impossible to directly compare the minimum track safety standards in Part 213 with the track standards used by DB, which might be proposed for U.S. application, because the measurement bases are intrinsically different.

Each of the Federal track safety standards fits into one of two categories: procedural instruction or specification of permissible track parameter dimensions. The ICE is not expected to have any difficulty complying

with any of the procedural track safety standards relevant to its high-speed operations. However, given today's information, easy compliance with track parameter dimensions is less likely. For example, none of the available literature indicates that track constructed in Texas using ICE/DB track geometry criteria will meet all of the requirements of FRA Class 6 track, although intuition indicates that it would comply. This literature includes extensive descriptions of the important aspects of the ICE concept obtained by a U.S. delegation that recently visited DB facilities in Germany. However, some of these descriptions are in German and have not yet been translated. Oral presentations given by specialists during this visit clearly indicate that the way DB technicians measure track geometry parameters and the way they treat data is quite different from the methods and measurements specified in the U.S. standards - not better or worse, just different. The extent to which ICE/DB track geometry and evaluation technology would be applied to any U.S. operation is also vague, as the franchise application was virtually silent on the issue. The section of this report titled "Vehicle-Track Interaction" discusses some elements of a qualitative track analysis approach advocated by Texas FasTrac. These are performance-based specifications, though, and cannot be compared with any section of Part 213.

The uncertainty suggested by these comments should not be interpreted as serious reservation about the ultimate safety of the track designs proposed for use in Texas, but merely as indicative of the need to study this subject further.

### ***Part 221, Rear End Marking Device***

Part 221 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 122 cm (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 is operated at the rear of the train, as would be the case with the ICE trains, a locomotive headlight illuminated on low beam is an acceptable marking device.

Details concerning the existing ICE rear end markers are not currently available. However, full compliance with Part 221 could be achieved by either replacing 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***

Part 223 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 be equipped with a minimum of four emergency opening windows.

The ICE power cars (locomotives) are equipped with laminated 24 mm (0.94 in) thick windshields that comply with UIC Leaflet No. 651. The side windows are glazed with two sheets of 8 mm (0.31 in) thick safety glass. Detailed impact testing requirements are not currently available for either the windshield or the side window glazing. It is therefore not known whether the existing ICE power car glazing material

will satisfy either the FRA Type I or Type II impact requirements.

All passenger car configurations have four emergency windows, one in each of the four entrance/exit doors located at the outer corners of the cars. These cars therefore comply with this portion of the safety glazing requirements. The restaurant car has only two emergency windows, each in one of the two exit doors near the center of each side of the car. Therefore, two additional emergency windows would be required for the restaurant car to fully comply with this portion of Part 223. Additional information concerning the existing side window glazing materials, including impact testing requirements, is not currently available, although it has been requested. It is therefore not known whether the existing ICE passenger car side glazing material will satisfy the FRA Type II impact requirements.

***Part 229, Railroad Locomotive Safety Standards***

Part 229 contains numerous safety standards for all but steam powered locomotives. This part addresses only those standards which are applicable to the safety requirements of electric locomotives.

***General Provisions*** - The ICE 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 power car in remote or multiple control operation. More information is needed to determine full compliance with Subsections 229.41, Protection Against Personal Injury; 229.43(b), Venting of Battery Gases; and 229.45, General Conditions.

***Braking System*** - Based on the information available, the ICE power cars appear to comply generally with the braking system provisions of Subsections 229.47 through 229.55. More specific information is required to determine the degree of compliance with Subsections 229.49, Main Reservoir System; 229.55, Piston Travel; 229.57, Foundation Brake Gear; and 229.59, Leakage.

**Suspension System** - More specific information is required to determine the degree of compliance of the ICE power cars with the suspension system provisions of Subsections 229.63 through 229.71.

**Electrical System** - Based on the information available, the ICE power cars appear to generally comply with the electrical system provisions of Subsections 229.77 through 229.89. Additional information is required to determine the degree of compliance with Subsections 229.81(a), Emergency Pole, and 229.89, Hand-Operated Switches.

**Cabs and Cab Equipment** - Included in this area are the provisions for slip/slide alarms, speed indicator accuracies, cab noise levels, cab and headlights, snowplows, horns, and sanders.

The ICE propulsion control system effectively controls slip/slide. Speed indicators on the ICE appear to be within the required accuracy. The ICE design, which seals the cars, significantly reduced the noise and pressure pulses associated with entering or exiting tunnels or passing other trains. The operator's cab is also sealed, air conditioned, and sound insulated, providing a quiet environment where noise is limited to less than 70 dB(A). The ICE design for the trailing cars limits noise to 67 dB(A) in the passenger compartment at 320 kmph (200 mph). The cab provides a good view of the track, and the seat is well secured. However, the intensity of the existing headlights do not appear to comply with the 200,000 candela minimum required under Subsection 229.125(a).

With the exception of Subsections 229.121 (b) and (c), Locomotive Cab Noise, and 229.125(a), Headlights, the ICE power cars appear to comply generally with the provisions of Subsections 229.115 through 229.131. However, additional information is needed to determine the degree of compliance with each of these items.

### **Part 231, Railroad Safety Appliance Standards**

The ICE 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 Act of 1970, the only relief potentially available for the ICE 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 ICE disc brake system.

**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 ICE system either meets or is able to meet these requirements.

**Part 232.2, Drawbars: Standard Height** - The ICE system is assembled and operated as a unit train. Power cars are 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 ICE 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 ICE has a computer controlled electro-pneumatic braking

system which controls the brake rate, hence braking system pressure, on a per-axle basis to regulate braking with anti-skid control. The ICE block system length is designed to accommodate the braking system performance. If the ICE operates on dedicated track, the requirements of this section may not be applicable.

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

**Part 232.19, End of Train Device** - Hard-wired, train-lined, end-to-end communication between the power cars allows the ICE to meet the requirements of this section without a radio with a unique identification code. The ICE either meets or can be enhanced to meet this regulation.

**Part 236, Rules, Standards, and Instructions Governing Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances**<sup>14</sup>

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 300 kmph (186 mph).

However, certain elements of the ICE high-speed rail signaling and train control system are similar in operation to some installations in the United States. Subsystems that employ concepts or designs already accepted in the United States include the track circuit design and operation, the cab signal transmission via inductive loops (transit applications in the United States), and the use of microprocessors for some elements of automated speed control and 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 used, the switching mechanisms used, and the color and format of line side signals, if any, and cab signals. Unlike the current systems in the United States operating above 127 kmph (79 mph), which use both line side and cab signals, the ICE uses line side signals only for vehicles that do not have cab signals or during emergencies and only in interlockings or locations of potential route conflict. 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 ICE should fully comply with these requirements where they are relevant to its operations. The design of the ICE automatic train control system will permit programming of block lengths to whatever is required. The DB design requirements on this subject appear to be as restrictive as the provisions of this subpart. The interaction between the "computer" block lengths via the inductive loops and the traditional track circuits may require further analysis. The interface of ICE equipment with traditional signaling, if applicable, would also require further analysis.

**Subpart C, Interlocking** - Requirements in this section relate directly to the specific design of interlocking and the associated signal control circuits. The ICE should fully comply with these requirements where relevant. The DB design requirements on this subject appear 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 ICE should fully comply with these requirements where relevant. The DB design requirements on this subject appear 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. The automated speed control and train stop features of the ICE appear to meet most of these requirements and in many cases exceed them. Most of these requirements appear to be met and in many cases exceeded by the automated speed control and train stop features of the ICE. 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, Subsection 236.512 requires use of the words "proceed at restricted speed."

**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 ICE signal system appears to fully meet this subpart.

**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 needed are design standards, validation and verification methodology, testing requirements for installation, periodic inspections, and modification checks for these types of systems and components. Additionally, consideration should be given to developing standards for ensuring computer

redundancy for vital systems, and methods for ensuring the integrity of transmitted data.

The ICE 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 speed control, train stop, cab signaling, and braking for both pneumatic and electromagnetic test and control functions are important from a safety perspective.

Although, as noted earlier, DB appears to have applied accepted principles in the design and testing of the systems and components, the FRA has no regulation in this area to judge the safety of these systems. In the short term, an analysis of the German 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 fail-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 ICE car builder has addressed each of the four phases of fire protection. The materials selected comply with the European or German fire safety standards. Comparison of these standards with the FRA guidelines for materials selection is not possible within the scope of this report. However, any ICE application in the United States should require that the vehicle materials comply with the FRA guidelines.

Each ICE vehicle has a fire detection system with sensors in the passenger area and underfloor equipment area. Additionally, each car contains two fire alarm boxes, one at each entrance area. The fire alarm system also provides for switching off the ventilation and air conditioning, thereby minimizing the spread of fire and smoke.

FRA guidelines address containment of a fire in the occupant compartment through selection of materials which do not propagate fire. The ICE materials may or may not contain the fire in the occupant compartment. Containing the fire in ICE vehicles is currently addressed through the specification of fire walls and doors at the end of each car. Undercar power units and other equipment in coach passenger cars are in separate compartments, and joints and partitions are sealed. Finally, electrical power cables are in pipes under the floor.

Each ICE vehicle occupant compartment contains a fire extinguisher.

In summary, the existing ICE vehicle adequately addresses the four phases of a fire, and the existing level of fire safety would have to be maintained in any transfer of the ICE from Germany to the United States.

## Other Areas of FRA Interest

In addition to the FRA regulations and guidelines, the FRA has areas of jurisdiction and interest. This section provides a discussion of three of these areas.

### ***"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, the 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 individuals who use wheelchairs. Single-level passenger cars, such as the ICE, 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 ICE vehicle inspected provides for wheelchair users. The number of wheelchair places needed on a particular vehicle would have to be determined.

### ***Occupant Compartment Appointments***

There are several potential hazards in railcars 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. The ICE adequately addresses each of these issues except luggage securement. In addition, the

vehicle exterior doors are locked at speeds above 5 kmph (3 mph), and the rubber profiles on the doors will reverse the doors if they meet an obstacle while closing.

### ***Emergency Preparedness***

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

- Emergency window exits: four pop-out windows in the vestibule
- Emergency access (side door) for rescue personnel from outside the vehicle
- Capability for the operator to communicate with patrons
- Emergency lighting in roof arches that is activated automatically and will last for four hours
- Emergency stop signaling to the train operator



# Potential Regulatory Issues

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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 ICE 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 ICE 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 ICE are so interdependent and interactive that the safety of any component of those subsystems can be fully understood only in 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 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 handled 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 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 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 systems typically rely.

Crashworthiness also merits new attention. Should high-speed trainsets such as the ICE 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

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Three contemporary high-speed train designs have been reviewed during the past year: the Swedish X2000, the French Train à Grande Vitesse (TGV), and, now, the German InterCity Express (ICE). Each was designed and built to specific operational requirements: the X2000 for operation on existing freight/passenger service lines, the TGV for operation primarily on new dedicated right-of-ways, and the ICE for operation on "new" or upgraded lines capable of carrying very high-speed passenger and fast freight trains. The design features of each of these systems offer opportunities for potential application in the United States.

These technologically advanced train systems could significantly improve intercity passenger service in the United States. However, each of these systems is constructed to foreign rather than U.S. standards. Will constructing these trains to U.S. standards jeopardize the very attributes that made them successful in Europe, or can these trains be made to fit U.S. standards with little sacrifice in performance? This question will be the subject of further studies.

The ICE, as noted in this report, can accommodate a range of traffic conditions with its two power cars and up to 14 trailer cars, as the train consist can be varied as necessary. The equipment uses advanced technology; innovations include three-phase asynchronous traction motors, regenerative braking, microprocessor controls, operator cabs with LCD displays, on-board fiber optic data transmission, computer-aided monitoring and diagnostics, pressure resistant cars and operator cabs, and an electronic passenger information system. Emphasis on systems engineering is evident throughout the ICE. Lessons learned over several years on the InterCity Experimental train have been applied to the InterCity Express now operating between Hamburg and Munich.

A typical ICE/DB train consist has two power cars, one at each end to facilitate turnaround; four 48-seat first (business/tourist) class cars; one service car with accommodations for the handicapped, including a toilet and space for two wheel chairs; a conference room; two crew compartments and a telephone booth; one restaurant car; and six second (economy) class cars. The car body structure is extruded aluminum supported by side sills with cross members. The two-axle trucks are fabricated steel with center-mounted steel springs, four disc brakes per axle, and an electromagnetic track brake which may later be replaced by an eddy current brake. The train uses separate trailing cars, allowing ready adaptation to seasonal or route dependent needs and rapid replacement of a defective car with another car instead of a whole train unit. A transit type coupling with an integrated trainline of high-voltage and low-voltage bus bars and fiber optic data transmission cable connectors is used to join the cars.

To achieve its high operating speeds, the ICE is restricted to very shallow horizontal and vertical curves, requiring extensive use of tunnels. To ensure comfort of passengers and crew in the many tunnels, the passenger cabins are pressure resistant.

The ICE has an on-board diagnostics system for easy inspection and detection of malfunctioning components. This system monitors vehicle status and can communicate failures to the nearest maintenance facility so its personnel can prepare for the train's arrival in advance. A self-test program prior to train dispatch helps ensure reliable service. Periodically, the entire train is passed through an ultrasonic and wheel profile inspection.

The ICE Class 401 power cars use the latest electric drive equipment: three-phase induction motors supply power from static converters. The static converters permit operation in either of two modes: motoring

or regenerative braking. Microcomputer technology is used extensively throughout the train and fiber optic conductors are used for reliable data transmission between the individual cars. The operator's cab is air conditioned and pressurized, and uses a standard tractive power and braking lever control console design. The trainset can be operated using either the tractive power/brake (operator) control or automatic speed control. The brake controller provides a common lever for all three braking systems, which are employed automatically in an optimum manner. The continuous automatic train control (ATC) system is based on redundant microcomputer technology and has an inductive train protection function integrated within.

Traction power for the ICE is provided by a conventional substation and distribution system that feeds a high-speed catenary of 25 kV, 50 Hz. Substations are nominally spaced at 50 km (31 mi) intervals. Power pick-up is via two pantographs (one per power car) at speeds up to 280 kmph (174 mph). At higher speeds, the pantograph/catenary dynamics permit use of only one pantograph; power to the other power car is provided by a high-voltage trainline.

The ICE braking system relies on three different systems: electrodynamic or regenerative braking of the asynchronous three-phase drive, four axle-mounted disc brakes per axle, and electromagnetic rail brakes in the trailing car trucks with the option of eddy current brakes. The regenerative braking system has priority and is assisted by the disc brakes as necessary; the electromagnetic track brake is for emergency use only. Brake control is provided by a microprocessor-aided operator's brake in conjunction with an automatic, electro-pneumatic pre-regulated compressed-air brake.

Only limited operating data are currently available for the ICE, as revenue operations did not begin until June 2, 1991, with trains between Hamburg and Munich via Frankfurt and Stuttgart. If the ICE is chosen for an application in the United States, the FRA will have to conduct a more in-depth safety review. This preliminary review has enabled researchers to identify some likely necessary modifications to the ICE.

# Endnotes

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1. ICE, High-Tech on Rails. Hestra-Verlag (1991), pp. 33, 45, 46.
2. Ibid, p. 33.
3. Ibid, p. 36.
4. Franchise Application to Finance, Construct, Operate, and Maintain a High-Speed Rail Facility in the State of Texas. Volume 2. Texas FasTrac, Inc. (January 16, 1991), Table 5.2.1.3.1-1.
5. Discussions with DB, Siemens, Krauss-Maffei, and Knorr-Bremse AG officials, Hamburg, Munich, and Nuremburg, Germany (February 24-27, 1991).
6. ICE, High-Tech on Rails. Hestra-Verlag (1991), pp. 80, 81.
7. Ibid, p. 82.
8. Discussions with DB, Siemens, Krauss-Maffei and Knorr-Bremse AG officials, Hamburg, Munich, and Nuremburg, Germany (February 24-27, 1991).
9. Franchise Application to Finance, Construct, Operate, and Maintain a High-Speed Rail Facility in the State of Texas. Volume 2. Texas FasTrac, Inc. (January 16, 1991), pp. V-254 through 257.
10. Ibid, pp. V-275 through 283.
11. Ibid, pp. V-254 through 257.
12. Ibid.
13. Montagne, S., "Five Year's Experience With French High Speed Track," Rail International (October 1988).
14. Code of Federal Regulations, Transportation 49, Parts 200 to 399 (Revised October 1, 1990).

