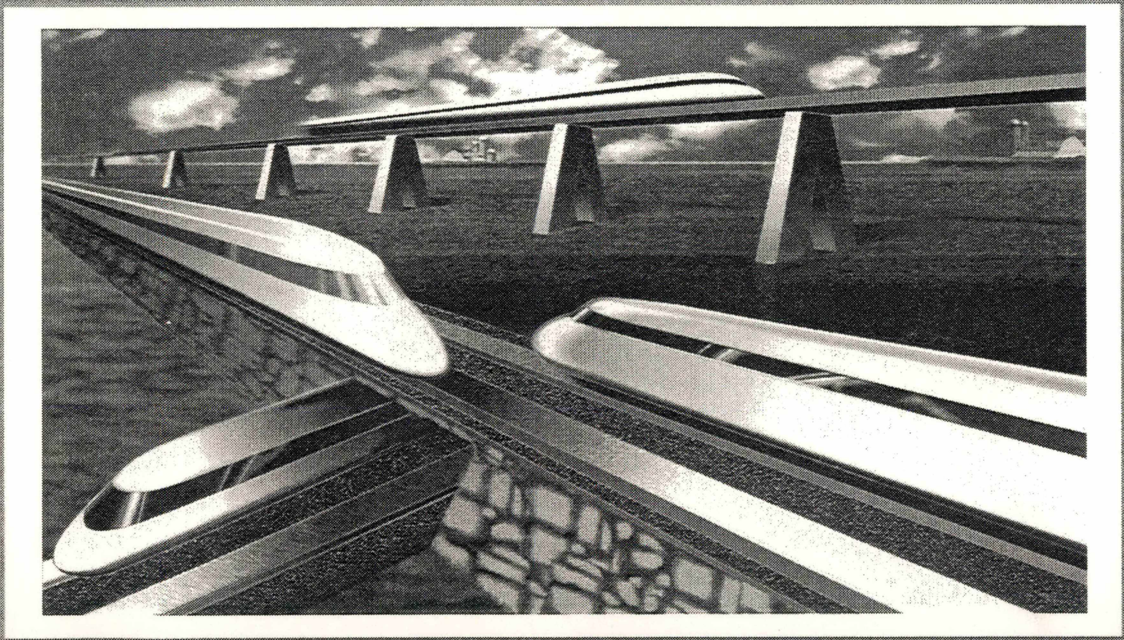
U. S. Department
of Transportation
Federal Railroad Administration

Safety of High Speed Ground Transportation Systems

Office of Research
and Development
Washington, D.C. 20590

Technical Descriptions of Advanced Braking Concepts for High Speed Ground Transportation



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13. ABSTRACT (Maximum 200 words)

The objective of this study is to develop qualitative and quantitative information on the various braking strategies used in high-speed ground transportation systems in support of the Federal Railroad Administration (FRA). The approach employed in this study is composed of two steps: first, build a technical understanding of the various braking strategies, and second, perform a safety analysis for each system. The systems considered in this study include seven operating high-speed rail transportation systems and three existing magnetic levitation systems. The principal technique used in the system safety analysis is Failure Modes and Effects Analysis (FMEA), an inductive approach to identifying system failure modes that depends on a thorough understanding of the system design and operation. Key elements derived from the system safety analysis are the fault-tolerant and fail-safe characteristics of the braking systems. This project memorandum contains proprietary information in both the technical descriptions and the FMEAs which does not appear in the companion volume, "Safety of High Speed Ground Transportation Systems: Safety of Advanced Braking Concepts for High Speed Ground Transportation Systems" (DOT-VNTSC-FRA-95-14; DOT/FRA/ORD-95/09.1). As such, distribution is limited as noted on the cover.

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PREFACE

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) generated renewed interest in establishing high-speed guided ground transportation (HSGGT) service in the U.S.* These initiatives range from traditional rail service (though upgraded to accommodate higher speeds) to advanced technologies such as magnetically levitated (maglev) trains. As part of a comprehensive review of the safety and reliability of the proposed HSGGT systems, this current study of advanced braking systems examines the various strategies used to brake these high-speed vehicles safely, reliably, and efficiently.

This report contains the detailed technical descriptions and system safety worksheets developed to support the study of the safety of HSGGT advanced braking concepts. These descriptions, in part, are derived from proprietary data supplied by trainset manufacturers and operators to support U.S. government investigations related to HSGGT safety and operating practices. This report thus contains proprietary data and is subject to limited distribution. A separate summary report containing the results and conclusions of this study has been published for general distribution.

This work was performed by a team comprising Battelle, TransTech Management, and Booz Allen & Hamilton for the Volpe National Transportation Systems Center under contract #DTRS-57-93-D-00027 Task No. VA 3207. This work is part of a broader program on HSGGT safety being conducted by the Volpe Center in support of the FRA Office of Research and Development.

*High speed is defined as exceeding 200 km/hr (125 mph).

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (k)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	= 1.1 short tons

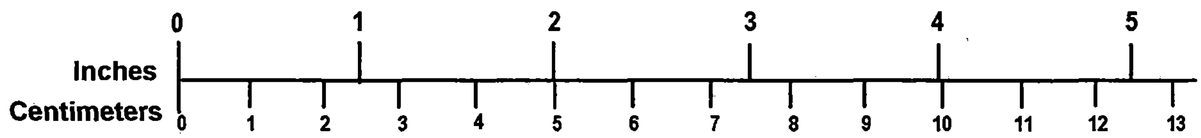
VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures.
Price $2.50 SD Catalog No. C13 10286

Updated 1/23/95

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1. INTRODUCTION

With the passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), there is renewed interest in establishing high-speed guided ground transportation (HSGGT) service in some of the major transportation corridors in the U.S. These initiatives have ranged from traditional (though upgraded) rail service to the advanced technologies such as magnetically levitated (maglev) trains. As part of a comprehensive review of the safety and reliability of the proposed HSGGT systems, this current study of advanced braking systems examines the various strategies used to brake these high-speed vehicles safely, reliably, and efficiently.

Conventional methods for braking rail passenger vehicles operating at "moderate" speeds (<200 km/h, 125 mph) include friction brake systems, either wheel tread or disc brakes, and dynamic brake systems, both converting the train's kinetic energy into heat. In modern transit or intercity trains, these brake systems are "blended" to achieve the desired deceleration rates for ride comfort, efficient train handling, and safety under both service and emergency conditions. As operating speeds increase above 200 km/h (125 mph), the capacity of these conventional brake systems is taxed and other methods of slowing the train must be used, especially during emergency braking situations. With other technologies such as maglev, unconventional brake systems such as reversed thrust of a linear induction motor (LIM) or aerodynamic braking become the "norm" in lieu of friction braking.

The objective of this study is to develop qualitative and quantitative information on various braking systems for HSGGT systems identified by the VNTSC as potential candidates for use in the U.S. These data encompass system safety considerations as well as the technical information describing the braking systems. This information provides sufficient detail to assess the technical and economic feasibility for U.S. applications and to assist the FRA in future rulemaking activities related to high-speed braking of these HSGGT systems.

2. BACKGROUND

2.1 TECHNICAL DESCRIPTION OF BRAKING SYSTEMS

The purpose of this task is to develop detailed technical descriptions of each existing and proposed HSGGT braking system, both foreign and domestic. These descriptions include detailed information in the following broad categories:

- Braking system physical capabilities for both normal service and emergency braking,
- Braking system effects on vehicle, guideway, and other infrastructural components,
- Braking system control and safety features, including control integration, ergonomics, operational status, diagnostics, redundancy, testing, inspection, and maintenance.

Train brake systems must meet three primary criteria in their design, operation, and maintenance:

- Fail-safe characteristics, both on a component and a system level,
- Reliability and redundancy in components and control paths, and,
- Braking capacity to stop the train within the controlled block under the most adverse conditions.

Train braking systems for both freight and passenger service have been developed over the years as an integral part of the train control system, which includes signaling, dispatching, and (in recent years) automatic train control. Since its invention by George Westinghouse in the latter part of the 19th century, compressed air train brake systems have dominated in North American practice. The **straight air brake**, the original form of the Westinghouse design (1869), uses compressed air from the main reservoir supply through direct piping to the brake cylinders to produce the braking effort. With a loss of air pressure (a train separation, for example), brakes could not be applied. The **automatic air brake** (1872), the form common in service today, is designed to apply the brakes when air escapes from the system. In this way, the automatic air brake is more inherently a fail-safe system.

A competitive **vacuum brake** system was developed and is still used by some overseas railroads. In this system, braking effort is produced by exhausting air from the brake cylinders by an ejector on the locomotive. Effective pressures are limited in the vacuum system, where cylinder sizes are large and braking forces relatively low. **Electro-hydraulic brake** systems are also used in some applications, primarily on urban rail transit vehicles.

In the automatic air brake system, each car in the train has auxiliary and emergency air reservoirs which are charged from the main (locomotive) reservoir through the train's main reservoir pipe and/or the train's brake pipe to release the brakes. In freight service, a single pipe (the brake pipe) is used for both charging and control functions. A "triple valve" connected to the brake pipe and reservoirs directs air to the brake cylinder when air pressure is reduced in the brake pipe below that in the auxiliary reservoir, setting the brakes. This reduction in brake pipe pressure is produced by setting the locomotive brake valve into the "service" (or the emergency) position, or by a break in an air hose or pipe. Most modern passenger equipment is "two-pipe" (Figure 2-1), charging the system through the main reservoir pipe and controlling through the brake pipe pressure.*

The need for high braking effort to assure the shortest stopping distances from high speeds led to the development of special brake equipment for high-speed passenger trains. Friction coefficients of metal brake shoes are reduced substantially at higher speeds. Greater brake cylinder pressures and shoe (or pad) forces may therefore be applied at higher speeds without danger of sliding the wheels. Higher brake pipe pressures were used in passenger service with the standard quick-action equipment and the addition of a high-speed reducing valve at the cylinders. Modern brake systems have speed governor control of pressure so that brake shoe force is reduced as speed decreases. This is accomplished by modulating brake cylinder pressures or switching to a smaller-diameter brake cylinder when the speed drops below a given level. In recent years, composition brake shoes or pads have been used in passenger service to provide more uniform friction coefficients over a wide range of speeds.

The Universal Control (UC) brake for passenger service was one of several designs evolved to address the more severe passenger train operating conditions. The use of control and relay valves on each car provided better response to differential pressures than the "triple valve" and allowed graduated release, rather than direct release, of brakes for better train control. The **electro-pneumatic passenger brake** was a next step in passenger train control sophistication. This system includes electro-pneumatic transmission of brake application and release which reduces the serial action time of a purely pneumatic system to nearly zero, eliminating longitudinal draft gear action and "surge." A typical schematic is shown in Figure 2-2.

Friction braking systems for passenger trains include axle disc brakes and/or wheel tread brakes. In high speed service, friction brakes are subjected to extreme thermal and mechanical stresses. Because of this, substantial research and development has gone into improvements in both materials and designs. For medium-speed operations (< 200 km/h, 125 mph), ventilated brake disks are used to moderate temperatures. This results in substantial power losses at high speeds. Non-ventilated alloy steel disks with sintered-metal pads have been used as an alternative on some equipment.

* The European standard UIC Code 546 OR, "High Power Brakes for Passenger Trains," 1-1-80, states under general conditions to be fulfilled that brakes for passenger trains "must only require a single pipe for its operation."

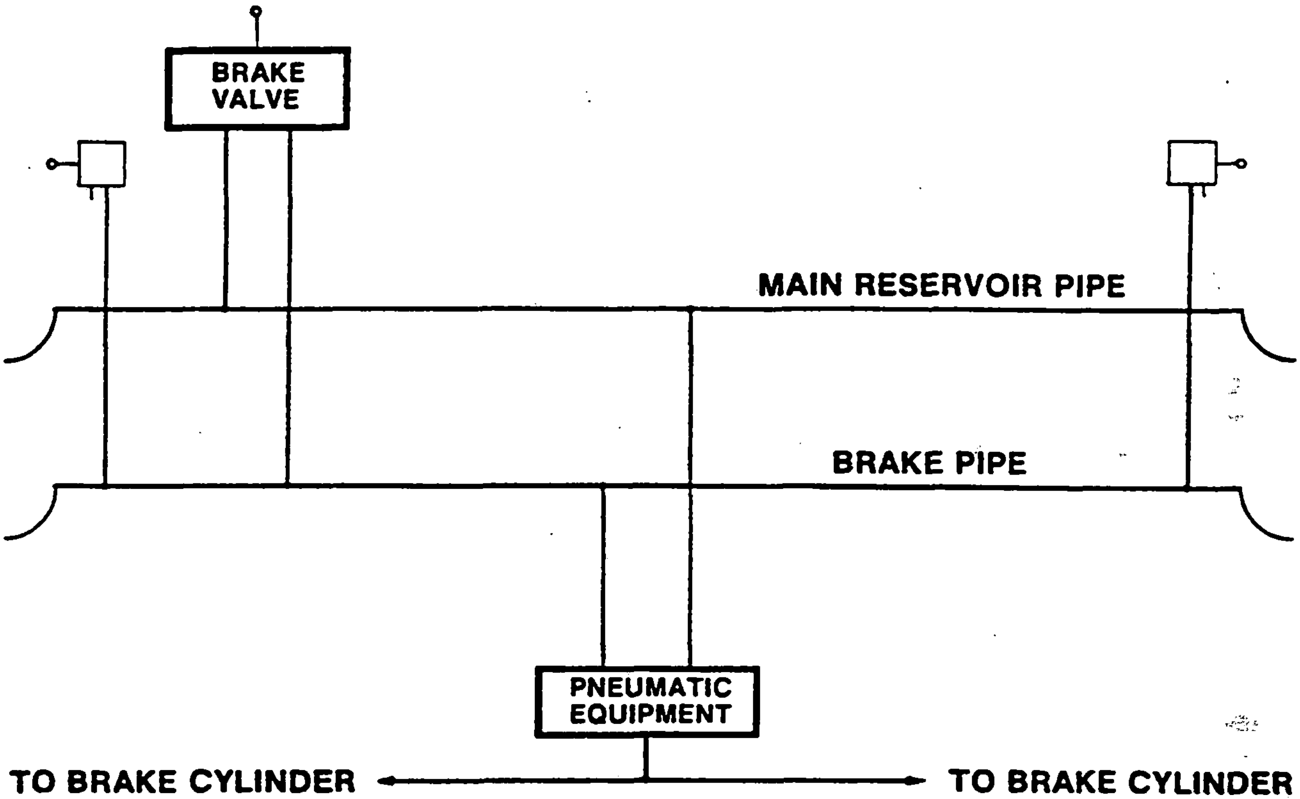


Figure 2-1. Schematic of Typical Automatic Air Brake System (Ref. 1)

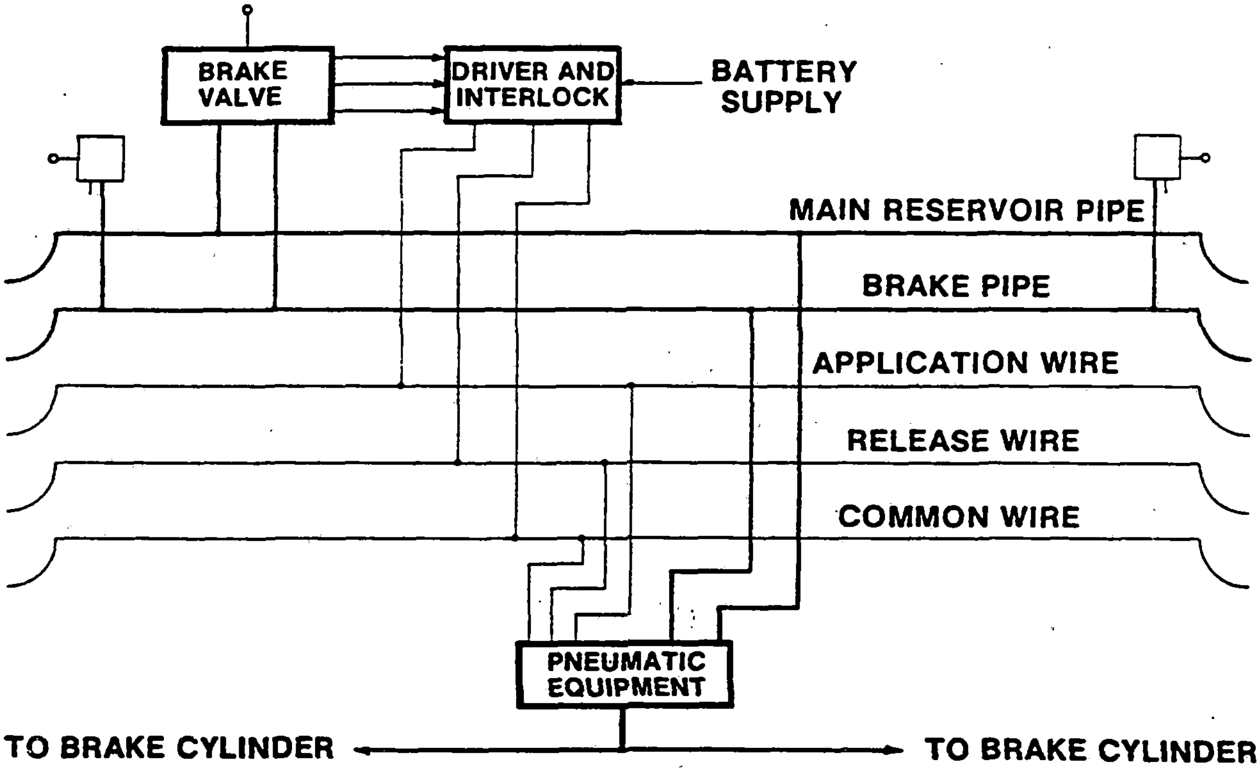


Figure 2-2. Schematic of Typical Electro-Pneumatic Brake System (Ref. 1)

Wheel slip control is also included in modern systems to modulate braking effort as adhesion limits are reached or exceeded. Adhesion is the fundamental limit of the combined friction and dynamic braking capability of a given wheelset. This limit is affected by a number of factors, including truck design (unsprung mass, primary suspension characteristics, load equalization, wheel/rail contact geometry, to cite just a few), vehicle weight, and train speed. Perhaps most importantly, adhesion is affected by rail running surface contaminants such as rain or snow, industrial pollutants, grease or oil from equipment or wayside lubricators, or even wet leaves. Published results of adhesion measurements by the French National Railways (SNCF), Figure 2-3, illustrate these effects.

A model of wheel/rail adhesion versus slip is given in Figure 2-4. The stable side of the curve, known as "creep," includes small relative motion between wheel and rail at the contact patch without gross sliding. The unstable side of the curve leads to gross sliding and a locked wheelset, high surface temperatures, and the formation of wheel flats. To avoid this, brake cylinder pressure must be modulated rapidly to reduce braking torque on the wheelset. The selection of adhesion values on which to base brake system capabilities or signal block distances is generally more a matter of conservative empiricism than measurement. Signal distances are set according to curves relating distance to speed, gradient, and other local conditions for specific trainsets. A typical curve is shown in Figure 2-5 based on tests by the British Railways research department.

Friction brake systems are supplemented by **dynamic** (resistive) or **regenerative braking,** where the traction motors of the locomotives or powered cars are used as generators to convert train kinetic energy into electrical energy. In dynamic braking, the electrical energy is converted to heat in resistor banks and dissipated into the surroundings; while in regenerative braking, the electrical energy is returned to the power grid through third rail or catenary. Generally, greater braking power is available from regenerative systems. If the power system "rejects" the load, however, the regenerative braking is inoperable. High-speed diesel-electric or turbine-electric locomotives would use the dynamic (resistive) braking alternative.

Other auxiliary systems are used on high-speed trains for braking in service or emergency situations. These include **magnetic track brakes** which dissipate kinetic energy through friction to the rails, and **eddy current track brakes** which dissipate kinetic energy through eddy currents in the rails or track structure. The magnetic track brake uses electro-magnets to attract itself to the rail head, dissipating energy through sliding friction between the rail and a wear plate. This technology was developed in the 1930s for use with street cars, mainly for emergency braking. The braking effort available is several times higher at low speeds than at high speeds. Eddy current brakes are suspended about 7 mm above the rail head. When energized from a secure battery backed-up power source, the electro-magnets induce eddy currents in the rail with resulting braking effort. The performance characteristic of the brake is almost speed independent between 200 km/h and 50 to 70 km/h as shown in Figure 2-6. While these auxiliary brakes can reduce wear and maintenance on the friction brake system and are less affected by adhesion limits, they can have adverse effects on rail wear, rail temperature (and possibly track lateral stability), and, due to induced electromagnetic interference (EMI), on track signalling and control circuits.

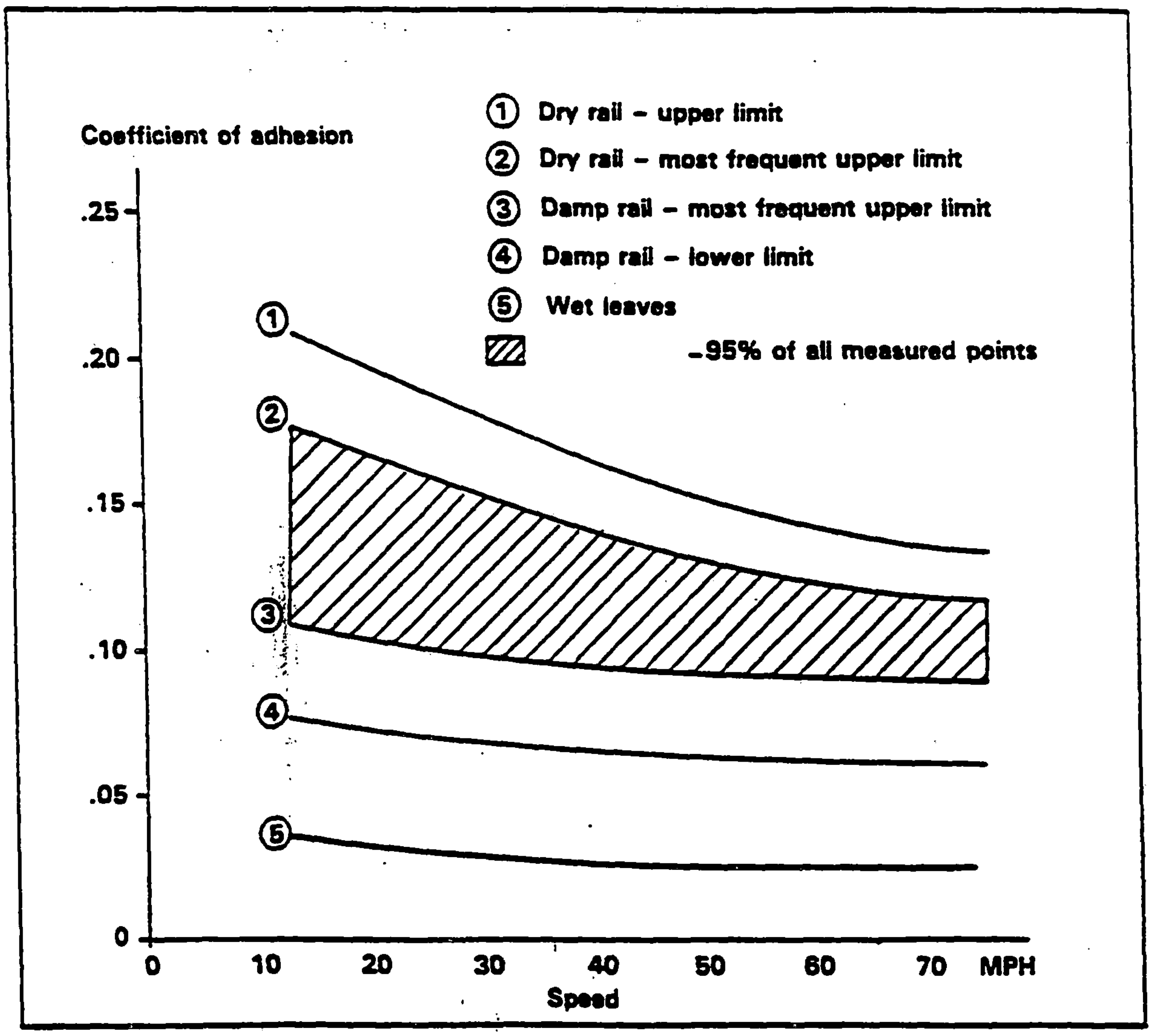


Figure 2-3. Coefficient of Adhesion Versus Speed for Tread Braked Vehicles (Ref. 2)

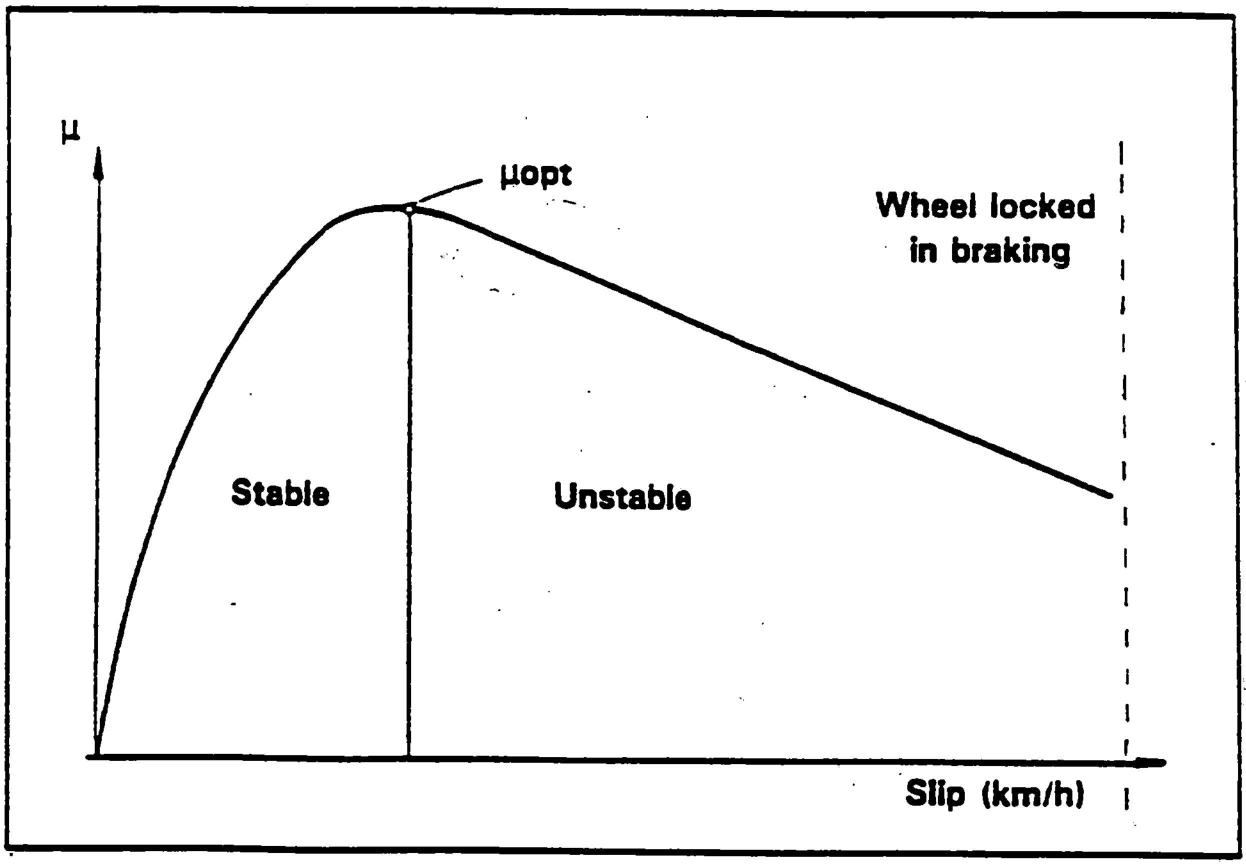
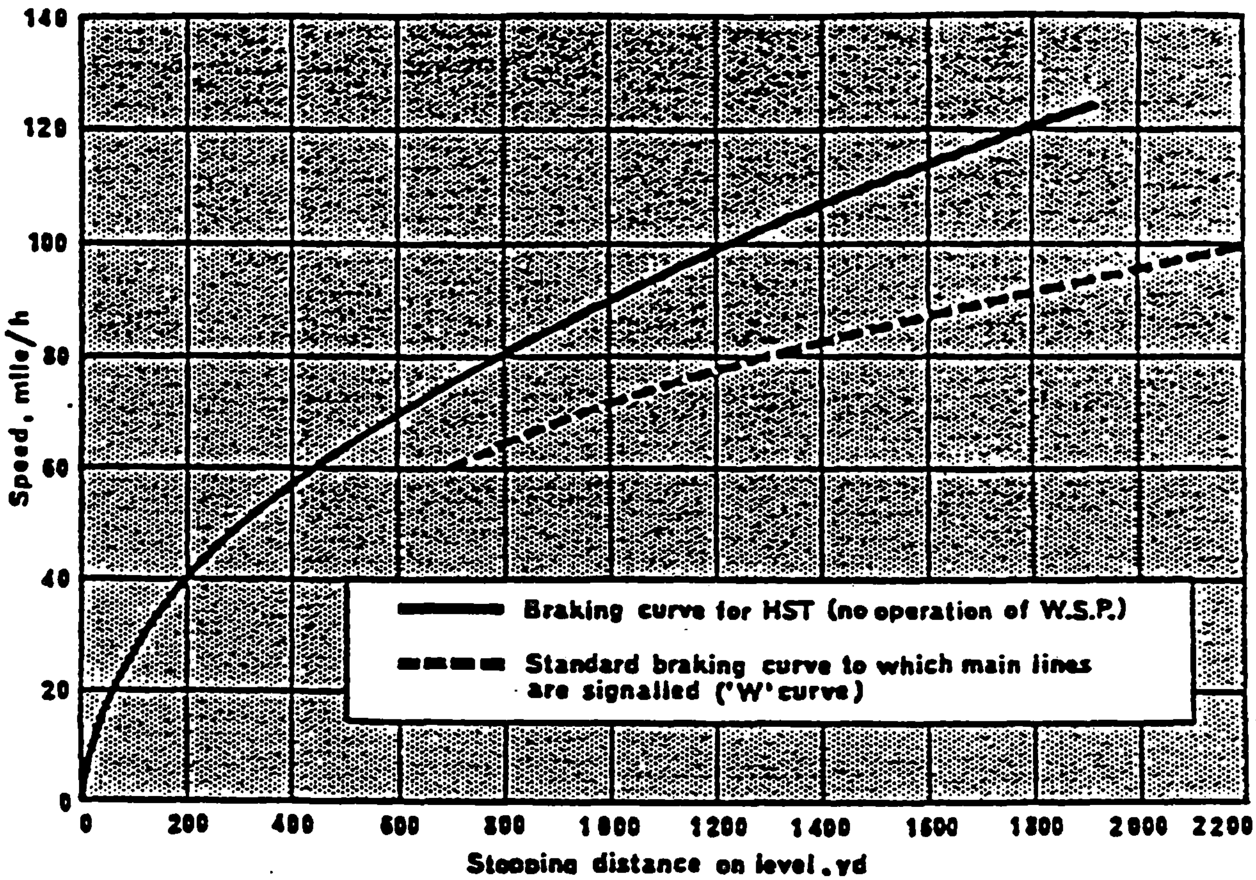


Figure 2-4. Typical Relationship Between Adhesion and Wheel Slip (Ref. 3)



Above *Designed braking performance of the HST at 125 mph is well within the limits set for 100 mph locomotive-hauled trains.*

Figure 2-5. Graph of Braking Performance of BR Intercity 125 Train (Ref. 3)

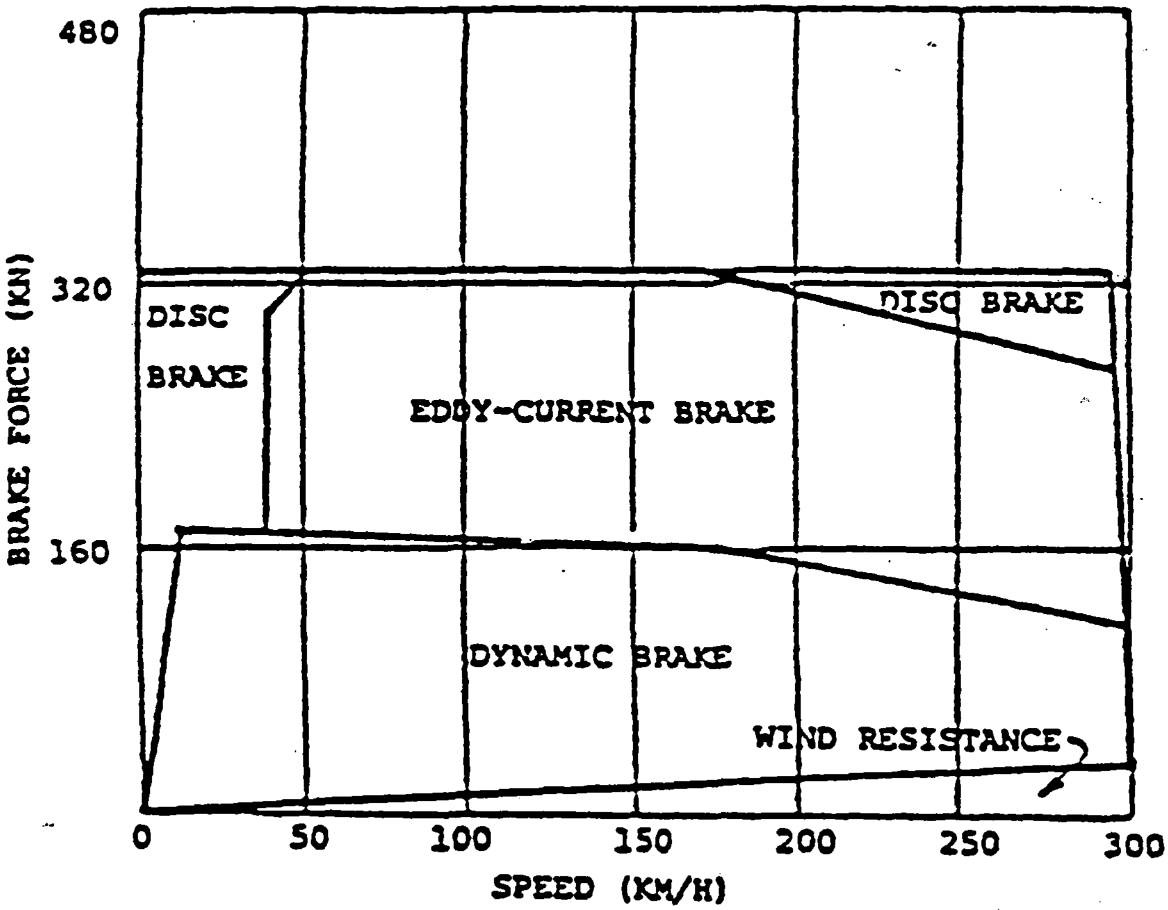


Figure 2-6. Braking Diagram for ICE Train Showing Eddy Current Braking Effort (Ref. 4)

Aerodynamic drag brakes have also been considered for some of the higher speed operations, particularly the maglev systems. Different HSGGT system designers have used different combinations of these systems, blended over the speed regime to provide the designer's best choice of characteristics. In the newer systems, braking functions are computer controlled through the use of a central computer and individual brake system microprocessors to provide efficient, repeatable, comfortable, and (above all) safe stopping distances.

2.2 SYSTEM SAFETY ANALYSIS

The system safety analysis of the high speed rail braking systems is a high-level examination of system failure modes to identify the inherent protection included in the system designs. In general, the failure modes for each trainset are established at a subsystem level for two reasons. First, this level of detail is sufficient for the purposes of this study and second, the available information is insufficient to allow a more detailed examination.

As an example, a braking control system may be considered as a single unit with failure modes described as "fails such that too little braking is commanded" or "fails such that too much braking is commanded". A detailed evaluation of the control system would be required to establish the specific conditions that would lead to these control system failures (or even if those failure modes are possible in some cases). However, examining the system's response to this postulated failure mode can identify the inherent protection (or lack of inherent protection) for the failure mode. This type of result is believed adequate for the purposes of establishing regulatory priorities.

Approach. The system safety analysis used a modified Failure Modes and Effects Analysis (FMEA) approach to identifying important system failure modes. The modifications provide for reporting inherent protection provided by the system design and an indication of the fault-tolerance and fail-safety of each identified failure mode.

The procedure used for identifying failure modes generally followed the logical operation of the braking system strategy and concepts. Failure modes were postulated for each element of the braking system from initiation through application of the braking method. This deliberate, systematic approach to identifying failure modes helps reduce the possibility of omissions in the failure mode list. For each failure mode, the immediate and expected effects (outcomes) of the postulated failure mode were estimated as well as the response of on-board sensors or other equipment, where appropriate. Thus, for each failure mode and effect, the specific design features that mitigate or protect against potential loss of braking capability can be identified by examining the failure mode, effects, and system response.

In addition to the failure modes identified through the above procedure, each braking system was evaluated for the following specific failure modes.

- complete loss of power to the electrical portion of the braking system,
- loss of stored energy (e.g., air pressure) required to apply braking, and
- train operator incapacitated.

Failure Mode Significance. The significance of the failure modes identified in the safety analysis are described in two ways. First, each failure mode was assessed to determine if it was fault tolerant or fail safe, according to the analysis working definitions presented below. Second, if a failure mode was judged to be not fail safe, the failure mode was examined to determine the severity of the failure mode as described below. These two factors determine the importance of the failure mode in the safety analysis results.

Working Definitions. The two key definitions employed in the safety analysis are based on the concepts of fault tolerant and fail safe.

- **Fault Tolerant** is defined as the built-in capability of a system to provide continued (full or limited) operation in the presence of a limited number of faults or failures. As applied in the safety analysis, continued operation means continued train operation with most braking capability intact and, in the absence of subsequent failures, continued train operation does not result in an immediate or subsequent hazard to train operations, passengers, or significant equipment damage.

- **Fail Safe** is defined as a characteristic of a system or its elements whereby any failure or malfunction affecting safety will cause the system to revert to a state that is known to be safe. As applied in the safety analysis, system failing in a safe condition means failures in the brake system such that the train results in a safe condition. Safe condition means the train will come to a full stop without loss of human life, injury to persons, major loss of equipment, or any combination of the three; or full brake capability is retained without additional operator action required to initiate braking. Thus by definition, operator backup for the braking system is not a fail safe condition. This approach permits identification of the operator's contribution to recovering the braking function in the event of failure through the use of severity codes, as described below.

Failure Mode Severity. Since the above definition of fail safe permits a number of failure modes to be designated as not fail safe, the failure mode severity scale shown in Table 2-1 was employed to distinguish among those failures. These severity codes distinguish between three types of failures that are defined as not fail safe.

- Failure modes that result in loss of train-wide braking capability with no means of recovery (codes A1 and B1).

- Failure modes that results in loss of train-wide braking capability, but is recoverable through direct operator action or control (codes A2 and B2).

- Failures modes that result in loss of local braking capability (an axle, a truck, or a car) (codes A3 and B3).

Failure modes that were defined as fail safe, whether they are fault tolerant or not, are considered as having lesser severity.

Table 2-1. Failure Mode Severity Categories

Fault Tolerant	Fail Safe	Severity	Description
No	No	A1	A failure that results in an immediate hazard potentially leading to a catastrophic condition.
		A2	A failure that results in a subsequent hazard, but is recoverable to a safe condition by operator action.
		A3	A failure that results in a subsequent hazard potentially leading to an unsafe condition over time if not corrected.
Yes	No	B1	A permitted or unannounced failure potentially leading to a catastrophic condition.
		B2	A permitted or unannounced failure that results in reduced braking capability, but is operator-recoverable to a safe condition.
		B3	A permitted or unannounced failure that results in reduced, but sufficient, braking capability.
No	Yes	C	A failure that represents a subsequent hazard, however the system remains in a safe condition.
Yes	Yes	D	A failure that represents no significant hazard and results in a safe condition.

The following sections present the results of the system safety analyses for each of the high speed rail and maglev trainsets included in this study. The modified failure modes and effects analysis results tables are presented immediately after the technical discussion of the braking system. The tables identify the failure mode significance in terms of fault tolerance and fail safety and the failure mode severity in terms of the above severity codes.

2.3 CURRENT REGULATIONS

In the United States, railroad brake systems must comply with the Code of Federal Regulations (CFR) as stated in 49 CFR Ch. II Part 232 - Railroad Power Brakes and Drawbars. The salient features of this regulation are as follows:

- Not less than 85 percent of the cars of a train shall have their power brakes used and operated by the engineer (driver) of the locomotive.

- It must be verified that brake equipment is in an operative, safe, and suitable condition for service.

- Each train must be inspected and tested prior to each service use, and a running brake test must be made as soon as train speed permits.

- Emergency braking will always be available no matter what the existing state of the braking system cycle (for example, in service application, or in release). The brake system will function to release an emergency application with the same certainty as a service application.

- Brake equipment must be cleaned, repaired, lubricated and tested within the requirements of the Association of American Railroads (AAR) Standard S-045 in the Manual of Standards and Practices of the AAR.

These requirements, along with other standards of the Association of American Railroads, operational preferences of Amtrak and other potential operating authorities, as well as the requirements and preferences of train operating employees and unions, must be taken into consideration in adapting foreign trainset braking systems to U.S. applications.

3. TECHNICAL DESCRIPTION OF BRAKING SYSTEMS

3.1 AMTRAK METROLINER SERVICE (NORTHEAST CORRIDOR)

3.1.1 General Description of Trainset

The Amtrak Metroliner service on the Northeast Corridor between New York City and Washington, D.C. represents the state-of-the-art in U.S. high-speed rail service. On portions of this route, the Metroliner trains achieve speeds of 201 km/h (125 mph) on a concrete-tie track structure with continuous welded rail (CWR) and direct fixation fasteners. These trains consist in general of an AEM-7 electric locomotive and six Amcoach passenger cars. Express Metroliners with one intermediate stop complete the 362 km (224-mile) trip from Washington to New York in 2 hours 30 minutes. Longer trains are also run with tandem AEM-7s, achieving the 201 km/h maximum speed, but with longer overall schedule times.

The AEM-7 locomotive is based on the standard ASEA Rc-4 locomotive used by the Swedish Railways (SJ). Built by Electro-Motive Division (EMD/GM) with electrical equipment by ASEA (now ABB), the 52 locomotives have been in service since 1980. These 4-axle units, rated at up to 5400 hp (7600 hp short term), have solid-state rectifiers and thyristor control of individual wheelset traction motors to control adhesion and wheel slip. The units run off an 11,000 volt, 25 Hz ac overhead catenary power source.

The original Amfleet coaches were some of the last constructed by the Budd Company and use the standard Pioneer III truck design. Introduced during the late 1970s as the self-powered Budd Metroliner cars were phased out, the design incorporates many of the features of the these older self-powered units. A second procurement, the Amfleet II car, was constructed during 1982. The full trainset (one locomotive and six passenger cars) weighs approximately 366 metric tons (404 tons).

3.1.2 Braking System Design

The braking system of Amtrak's Metroliner trains represents a proven, standard design for an electric locomotive and locomotive-pulled passenger cars operating in a manual block signal system with in-cab signal indications. The braking system on the AEM-7 locomotive consists of dynamic (resistive) brakes, and pneumatically-powered tread and disc brakes (Ref. 5). The coaches are braked by pneumatically-powered axle-mounted disc brakes. The major components of this system are described in the following section.

Major Braking Components

Air Compressor. A single stage, positive displacement rotary (screw-type) air compressor supplies the automatic air brake system of the train. This unit is driven by a 440-volt three-phase electric motor. Output air is filtered and dried, then supplied to the main reservoir.

Dynamic/Resistive Brake. The AEM-7 locomotive uses resistive dynamic braking, where kinetic energy is converted back to electrical energy by the traction motors, then dissipated to the atmosphere as heat through a bank of resistors mounted on the car body roof. Cooling is provided simply by air flow across the resistor bank from forward motion. Dynamic braking capacity is a function of train speed, as shown in Figure 3-1. For typical braking adhesion limits at higher speeds of 0.10 (wet rail) to 0.13 (dry rail), dynamic braking can range from 30 to 39 percent of the available limit at 200 km/h (125 mph), and from 52 to 68 percent of the available limit at 130 km/h (80 mph). A limit of 970 amps is imposed so that the traction motors are not damaged. Below 60 km/h (37 mph), dynamic braking capacity decreases sharply as motor armature speed decreases.

Air Activated Disc Brakes. The AEM-7 locomotive and passenger cars are equipped with conventional automatic air brakes. This provides fail-safe braking and high levels of retardation. On the locomotive, the disc brake units are located on the outboard end of each truck and consist of two discs bolted to one another through the wheel plate. A pair of calipers with brake pads clamp around the wheel rim onto the two discs to provide braking. The discs contribute between 60 to 80 percent of locomotive friction braking.

The Amcoach cars have two ventilated brake discs per axle with standard brake calipers and composition pads. In addition, two wheel tread brakes are used to provide a portion of the friction braking and to "condition" the wheel treads (to reduce surface contaminants, improving adhesion).

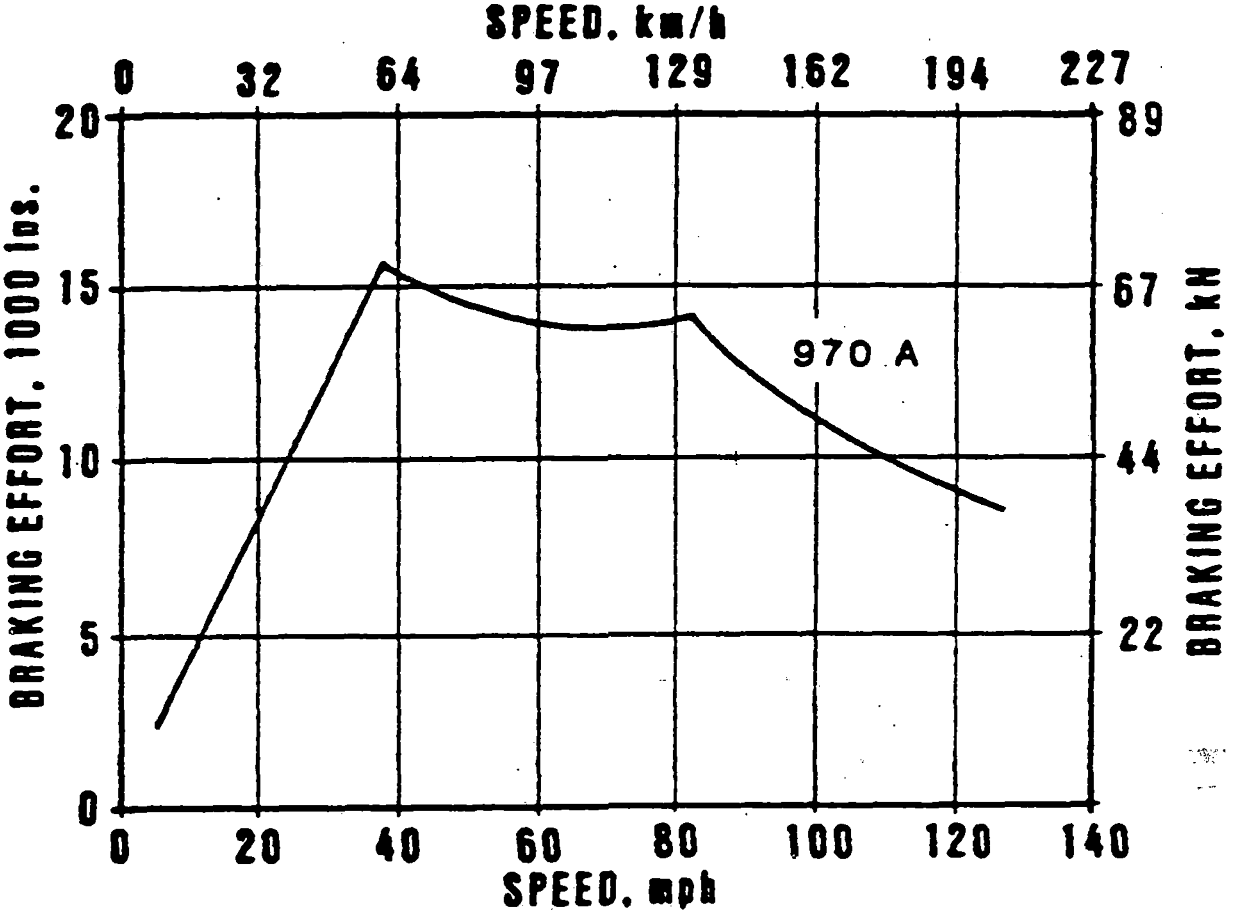
Tread Brakes. On the locomotive, single shoe tread brakes are located at the inboard side of each wheel. These units use cast iron brake shoes to provide the remaining 20 to 40 percent of the friction braking effort and also clean and condition the wheel treads for improved adhesion. As noted above, the passenger coaches also use tread brakes to improve wheel/rail adhesion.

Parking Brake. Standard AAR-approved handbrakes are used on the locomotive and cars. These are configured so that 100-125 lb applied to the handbrake rim will set the brakes to hold the car on a 5 percent grade. Brakes are applied to both axles of one truck.

Braking Control Components

The automatic air brake system on the Metroliner trains consists of a number of subsystems on the locomotive and cars that are optimized to produce smooth and repetitive stops. This is accomplished with the standard Type 26 two-pipe brake system shown in schematic in Figure 2-1. An outline drawing of a typical Type 26 pneumatic system is shown in Figure 3-2.

Locomotive Brake Control Valves. Brake controls in the cab of an AEM-7 locomotive consist of the following components: 1) the **automatic brake valve**, which commands braking of both locomotive and train brakes through reduction in the train brake pipe pressure, 2) the **independent brake valve**, which controls only the locomotive brakes, 3) an **automatic brake valve cutout valve**, 4) an **independent and automatic brake cutout cock**, and 5) an **emergency brake valve**. The Type 26 brake control valve is "pressure maintaining" and will hold the desired brake pipe pressure reduction steady against normal system leakages. The independent brake valve is self-lapping and will hold the locomotive brakes in the applied setting.



Source: Reference 1.

Figure 3-1. Dynamic Braking Performance of the AEM-7 Locomotive (Ref. 5)

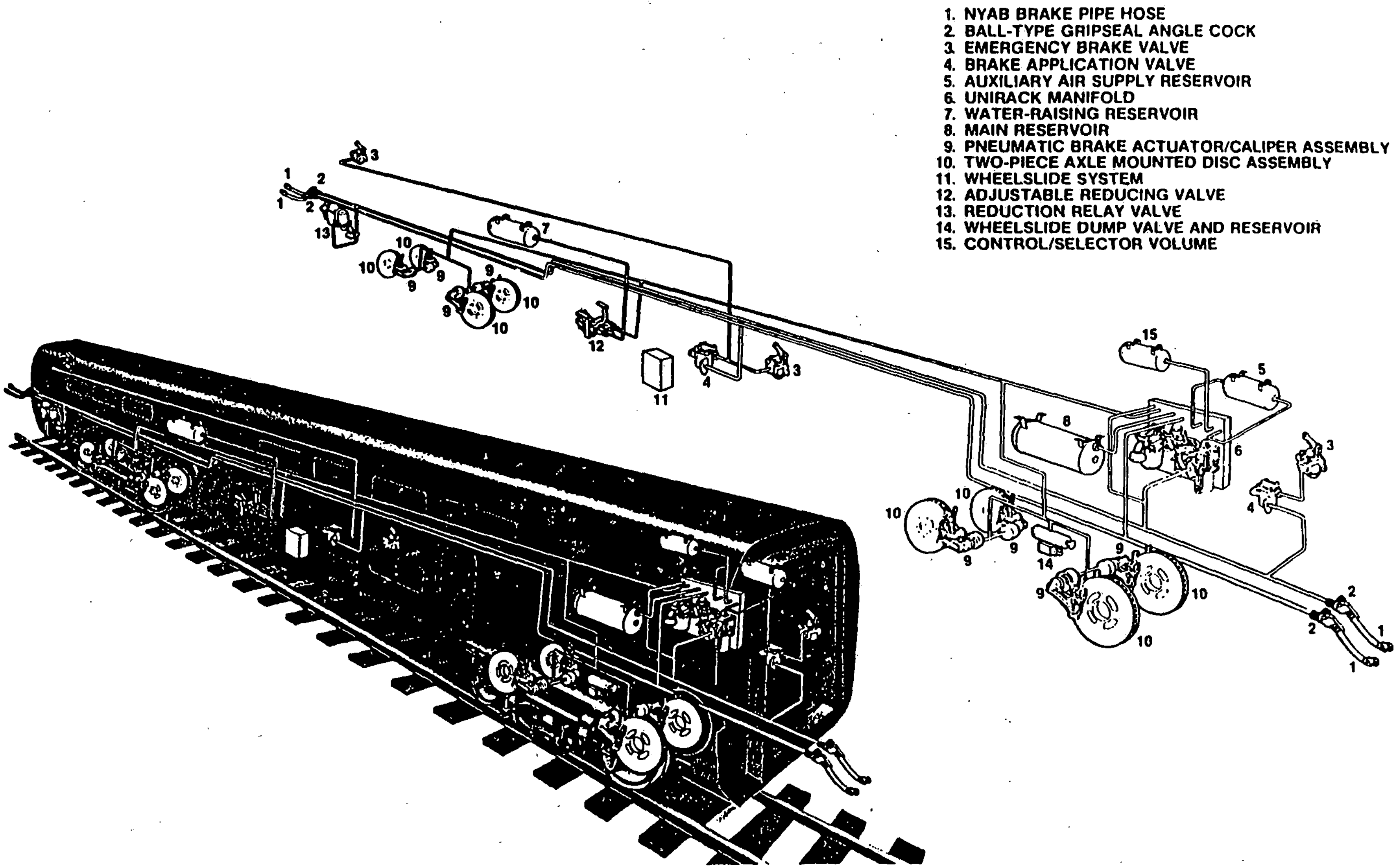


Figure 3-2. Typical U.S. Passenger Train Pneumatic Brake System (Ref. 1)

In addition to the pneumatic brake controls, the locomotive has a dynamic brake control. The dynamic brake is controlled directly by the throttle: forward through ten positions applies traction power, and pulling the throttle toward you past the zero position applies dynamic braking. The dynamic braking is also controlled by the automatic brake valve and is blended with the pneumatic braking, using the dynamic braking to maximum strength, supplemented by friction braking as required. Applying the automatic air brakes disengages throttle power if it is in one of the power positions.

Passenger Car Brake System. The standard Type 26 brake system on the cars consists of a **main reservoir pipe** supplying air to the main **pneumatic control unit** panel and **air supply reservoirs**, and a **brake pipe** providing the basic braking control signal (pressure modulation for brake application or release). A **reduction relay valve** at the opposite end of the car speeds the brake application action. Pressure to the **brake cylinders** is modulated by the **wheelslip dump valve** to avoid loss of adhesion. A **wheelslip protection system**, a WABCO E-5 Decelostat unit, is used to control these valves. A 100-pulse per revolution angular velocity signal from each axle (a gear tooth and magnetic pickup) is analyzed by logic circuits to detect wheel slip. This circuit compares the tachometer signals from the four axles and detects a speed differential (> 2 mph) of the slipping wheelset, reducing brake cylinder pressure at that truck. It also compares the difference in rate of change of rotation speed as the car decelerates in braking. The cars as originally delivered had electro-pneumatic control assist, but this has since been removed. Three **emergency brake valves** and associated **brake application valves** are located on the car for train crew or passenger use in emergencies.

3.1.3 Braking System Performance

Brake test stopping distances for the AEM-7 and Amcoach trainset are listed in Reference 5 as follows in Table 3-1:

Table 3-1. Measured AEM-7/Amcoach Train Stopping Distances

Braking Mode	194 km/h (120 mph)	
Full Service (friction brakes only)	< 1.95 km (6400 ft)	> 2.7 km/h/s (> 1.7 mph/s)
Full Service (friction plus dynamic brakes)	< 1.80 km (5900 ft)	> 2.9 km/h/s (> 1.8 mph/s)
Emergency (friction brakes only)	< 1.49 km (4900 ft)	> 3.5 km/h/s (> 2.2 mph/s)

There are currently no computer-based train brake diagnostic features on the AEM-7 and Amfleet trains. The brake system is monitored in the time-honored way by observing brake pipe pressure.

Since the trainset does not use any novel braking methods, any effects on the infrastructure are those that have been experienced for years by railway authorities running medium-high speed passenger trains.

Table 3-2. Amtrak Metroliner FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Amtrak Metroliner—Northeast Corridor Service (USA)

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Braking Control							
Automatic Brake Valve	Fails on.	Braking occurs above desired level for the trainset, specifically full brakes.	Braking occurs above desired level for the trainset, specifically full brakes.	Operator notified via system monitoring. Must decrease level of braking, if possible, or train stops.	N	Y[1]	C
	Fails off.	Braking is under desired level, specifically no braking available for the trainset via this valve.	Braking is under desired level, specifically no braking available for the trainset via this valve.	Operator notified via system monitoring. Must increase level of braking, which may include using emergency brakes.	N	N	A2
Brake Control Unit (BCU) (Includes electropneumatic valves, pressure transducers, relay valve) Assume one BCU per locomotive.	Signal for too much braking.	Braking occurs above desired level for the trainset.	Rapid decrease in speed beyond level desired	Assume operator has indication of braking level and BCU status. Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested or train stops.	N	Y[1]	C
	Signal for too little braking.	Braking is under desired level for the trainset.	Braking is under desired level for the trainset.	Assume operator has indication of braking level and BCU status. Train does not slow quickly enough. Must increase level of braking requested, probably via emergency brakes.	N	N	A2
	No signal for braking when braking requested.	Braking does not occur at all for the trainset.	Braking does not occur at all for the trainset.	Assume operator has indication of braking level and BCU status. Train does not slow down. Must utilize emergency brake.	N	N	A2
Rheostatic Brake Control Unit (Assume one per locomotive)	Fails indicating higher than actual rheostatic braking effort.	Two stage relay valve holds off more friction braking than it should given the actual rheostatic braking level.	Friction braking is too low resulting in increased stopping distances.	Assume operator is notified of low braking level. Train does not slow quickly enough. Must increase level of braking requested, possibly via emergency brakes.	N	N	A2

Table 3-2. Amtrak Metroliner FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Amtrak Metroliner—Northeast Corridor Service (USA)							Page 2 of 6
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Rheostatic Brake Control Unit (Assume one per locomotive)	Fails indicating lower than actual rheostatic braking effort.	Two stage relay valve does not hold off enough friction braking given the actual rheostatic braking level. This results in too much friction braking being applied for the actual rheostatic braking level.	Friction braking is higher than required . Wheelset Slip Protection may be overworked as a result.	Assume operator is notified of braking effort level. Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested.	N	Y[1]	C
System monitoring	Loss of any signal transmitted to system monitoring.	Full brakes applied by system.	Full brakes applied by system.	If system loses signal, automatically applies brakes.	N	Y	C
Wheelset Slip Protection Control (includes speed sensor) Assume it operates on individual wheelsets.	Fails with output failing to modulate the brake cylinder pressure.	Results in maintaining current brake level, not alleviating wheel slip. Braking applied to wheelset is above desired braking level resulting in wheel slip. This causes excessive wear on wheels and rails.	Over application of brakes on one wheelset causing wheel slide for the wheelset.	Wheelslide indicated to driver. Assume driver can isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3
	Fails with output requesting brake cylinder pressure to be vented, thus keeping the valve open.	Braking applied to wheelset is below desired braking level resulting in reduced or no braking for the wheelset associated with the failed control.	Reduces available braking by the effort of one wheelset.	Assume operator receives indication of lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3
Rheostatic Braking[2]							
Motor Truck							
Catenary Power	Loss of power or decrease in power.	Assume battery back up power is available and initiates.	Battery supplies power and rheostatic braking is still available.	Assume driver has indicators on catenary and battery status and that the battery automatically initiates upon catenary power loss.	Y	Y	D

Table 3-2. Amtrak Metroliner FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Amtrak Metroliner—Northeast Corridor Service (USA)

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Battery	Loss of power or decrease in power.	No effect if catenary available. There will be no backup power for dynamic braking for the truck with the failed battery system.	No effect if catenary available. Friction brakes capable of stopping train.	Assume driver has indicators on battery status. Repair at first maintenance opportunity.	Y	Y	D
Traction Motor (Assume two per truck.)	Does not accept/produce current to dissipate in resistor grids.	Loss of or decrease in rheostatic braking for the motor truck.	Relay valve will allow more or all of requested braking effort to be friction braking.	Relay valve reacts to lower rheostatic braking by allowing more friction braking.	Y	Y	D
	Bearing failure, axle seizes.	Unintentional wheel slide for the motor truck. WSP attempts to alleviate wheel slide.	Unintentional wheel slide for the motor truck. WSP attempts to alleviate wheel slide.	WSP monitored by driver. Failure of motor, assume driver can isolate the wheelset and continue and lower speed or line speed.	N	N	A2
Resistor Grids	Inability to dissipate energy/heat	Loss of or decrease in rheostatic braking for the motor truck.	Assume relay valve will allow more or all of requested braking effort to be friction braking.	Relay valve reacts to lower rheostatic braking by allowing more friction braking.	Y	Y	D
Friction Braking							
Motor Truck							
Air Brake Pipe (ABP)	Fails with Low Pressure (Effects entire brake system)	Brakes applied.	All brakes applied to degree of low pressure failure.	Speed reduction. Computer notifies operator of low pressure.	N	Y[1]	C
Relay Valve	Signal for too much braking	Braking occurs above desired level for the truck.	Rapid decrease in speed beyond level desired. Wheel slide protection prevents wheelslide and maintains braking. Extra wear on brake components and overheating may result.	Operator notified via system monitoring. Must decrease level of braking.	N	Y	C
Relay Valve	Signal for too little braking.	Braking is under desired level for the truck.	Braking effort is too low, increasing stopping distance.	Operator notified via system monitoring. Must increase level of braking.	Y	N	B2

Table 3-2. Amtrak Metroliner FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Amtrak Metroliner—Northeast Corridor Service (USA) Page 4 of 6

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Relay Valve	No signal for braking when braking requested.	Braking does not occur at all for the truck.	Braking does not occur at all for the truck.	Operator notified via system monitoring. May need to utilize emergency braking.	N	N	A2
Disc Brake Actuator, Disc, and Calipers (2 discs/axle)	Fail disc brakes on	One actuator/disc, brake effort is constantly applied equivalent to effort from one disc. Excessive wear on disc and calipers and brakes overheating of brakes is possible.	One actuator/disc, brake effort is constantly applied equivalent to effort from one disc. Excessive wear on disc and calipers and brake overheating is possible.	Operator notified via system monitoring. Assume operator can isolate axle with failed actuator and continue within speed limits required.	N	N	A3
	Fail disc brakes off	One actuator/disc, brake effort not applied, lost braking capability equivalent to effort from one disc.	One actuator/disc, brake effort not applied, lost braking capability equivalent to effort from one disc.	System monitoring indicates lower braking effort than requested. Assume operator can continue at reduced speed.	Y	N	B3
Tread Brake Actuator, Tread Brake (Acts independently on each wheel)	Fail on	Brake effort constantly applied to one wheel. Excessive wear on brakes and overheating of brakes is possible.	Brake effort constantly applied to one wheel. Excessive wear on brakes and overheating of brakes is possible.	Operator notified via system monitoring. Assume operator can isolate axle with failed actuator and continue within speed limits required.	N	N	A3
	Fail off	Brake effort not applied, lost brake effort capability equivalent to effort of one wheel.	Brake effort not applied, lost brake effort capability equivalent to effort of one wheel.	System monitoring indicates lower braking effort than requested. Assume operator can continue at reduced speed.	Y	N	B3
Compressor (1)	Fails on	Pressure builds in the main reservoir and continues beyond normal levels.	Pressure builds in the main reservoir and continues beyond normal levels.	System monitoring notifies operator of compressor running and reservoir pressure. Assume safety pressure relief valve is available on reservoir.	Y	Y	D
	Fails off	May not be able to recharge brake system.	Friction brakes cannot be released once applied.	System monitoring notifies operator of compressor running and reservoir pressure.	N	Y	C

Table 3-2. Amtrak Metroliner FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

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Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Main Reservoir	Fails high pressure	High pressure builds in main reservoir.	Assume pressure relief valve is available on main reservoir.	Assume operator is notified and relief valve operates automatically. Compressor (s) can be shut off to prevent further pressure build up.	Y	Y	D
	Fails low pressure	May not be able to recharge brake system.	Friction brakes cannot be released once applied.	System monitoring indicates low pressure of reservoir and compressor operation. Compressor tries to achieve desired pressure.	N	Y	C
Main Reservoir Safety Valve	Fails open	Air is vented from main reservoir resulting in low pressure in main reservoir. Friction brakes applied.	Air is vented from main reservoir resulting in low pressure in main reservoir. Friction brakes applied or excessive running of compressors or both will result.	Gauges in cab indicate low pressure of reservoir. Assume driver has indicator of compressor operation in cab also.	N	Y	C
	Fails closed	No effect. If a combination of MRS overpressurization and safety valve failing closed occurs, there would be no relief for overpressurization.	No effect. This requires a second failure for this failure to have any impact.	Inspection and maintenance should detect valve failure. Repair at first maintenance opportunity.	N	N	A3
Air Dryer	Fails with air too wet	Wear on components. Contamination and possible corrosion of components.	Wear on components. System contamination.	Maintenance and inspection checks.	N	Y	C
Air Filter	Fails to clean air sufficiently.	Wear on components. Particulates or grit into system.	Wear on components. System contamination and possible line blockages.	Maintenance and inspection checks.	N	N	A3
Main Reservoir Pipe	Fails with low pressure	Pressure is not available to MRP so that once the friction brakes are applied, they may not be able to be released because of the pressure deficiency in the MRP.	Friction brakes may not be released if insufficient pressure is in MRP.	Assume operator is notified in cab of pressure level in MRP.	Y	Y	D

Table 3-2. Amtrak Metroliner FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Amtrak Metroliner—Northeast Corridor Service (USA)							Page 6 of 6
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Brake Supply Reservoir (on each truck)	Fails with low pressure	Pressure insufficient to apply friction brakes for the truck.	Friction brakes unavailable for braking the truck associated with the failed reservoir.	Assume system notifies operator of low pressure and the lack of friction braking on the truck. May have to operate at decreased line speed or apply emergency braking depending on the number of failures.	Y	N	B3
Trailer Coach[3]							
Emergency Braking[4]							
Emergency Valve	Does not vent ABP.	Emergency braking not available. However, crew access to emergency valves can be utilized.	Emergency braking not available. However, crew access to emergency valves can be utilized.	No braking and gauges indicate no venting of the ABP. Crew notified to apply emergency braking via valves in trailer cars.	N	N	A2
Crew and Passenger Emergency Vent Valves (3 per Trailer Car)	ABP not vented when valve operated.	Emergency brake not initiated. Assume driver receives notification of valve operation and can select emergency braking if required. Alternately, other emergency vent valves may be operated.	Emergency brake not initiated. Assume driver receives notification of valve operation and can select emergency braking if required. Alternately, other emergency vent valves may be operated.	Emergency brake not initiated. Assume driver receives notification of valve operation and can select emergency braking if required.	N	N	A2

1. Even though this failure results in the friction brakes being applied, this failure may not be failsafe if it occurs at high speeds.
2. Train can be stopped safely with just friction brakes if rheostatic braking fails.
3. Same as Motor Truck except the Trailer Car has two wheel tread brakes as opposed to single shoe tread brakes on each wheel for the motor car.
4. This section only includes modes of triggering emergency braking because the actual application of the emergency brakes is done via the systems described above.

3.2 X2000 TILTING TRAIN

3.2.1 General Description of Trainset

There is presently a high level of interest in the potential use of active tilt train technologies to overcome the current limits for safe high speed guided ground transport (HSGGT) on existing and proposed corridors in the U.S. operating environment. The X2000 trainset is one of the technologies which has been demonstrated in the U.S. and may be procured by Amtrak for high speed operation on the Northeast Corridor. The system developer, Asea Brown Boveri Traction AB (ABB) of Sweden recently teamed with American partners Raytheon, General Dynamics, and GE Transportation Systems to pre-qualify for the Amtrak bid of 26 trainsets starting in April, 1994.

The X2000 tilting-body train has been under development in Sweden for over ten years, in cooperation with the Swedish National Railways (SJ). Revenue service operations with the train began on SJ's Stockholm to Gōthenburg line in September 1990. A limited number of trainsets are currently in revenue service on three other SJ lines. The trainset order was scheduled for completion in 1994. Two additional proposed X2000 services include Oslo to Bergen in Norway, and Helsinki to Tampere in Finland. In order to increase train speeds on existing corridors and reduce travel times without compromising ride quality, ABB has incorporated advanced (but proven) features in the trainset design:

- An active tilting-body system on the trailer cars (coaches) to improve passenger comfort in curves,
- Self-steering (radial axle) bogies to reduce wheel/rail forces and wear in curves, and,
- Asynchronous ac traction motors on the electric locomotive to reduce weight and increase reliability in traction power,
- Semi-permanent drawbar connections between all cars and locomotive (similar to transit practice),
- Integrated digital electronic controls for power, braking, communications, system diagnostics, and "hotel" functions.

The primary advantage of active-tilt technology is its ability to overcome the constraints of guideway-imposed speed restrictions by rotating the car body to minimize lateral accelerations felt by train occupants and to operate at higher cant deficiencies than would otherwise be possible through compound curves. The active tilt mechanism functions by using a bogie-mounted sensor system combined with accelerometers to constantly monitor underbalanced speed and correct for increased lateral accelerations when entering and exiting curves. A maximum tilt of 8 degrees and effective tilt angles to 6.5 degrees are accomplished by hydraulic rotation of the body of each passenger car. The power car (locomotive) itself does not have a tilting capability.

It is important to note that SJ has invested in substantial upgrading of its signal systems to ensure fail-safe operation and has also engaged in an ambitious program of upgrading its grade crossing safety devices to incorporate train occupancy circuits and full barrier protection. Higher maximum speed limits of 250 km/hr (156 mph) have been achieved in test programs conducted on SJ and the German Federal Railways (Deutsche Bundesbahn, DB) without significant negative effects on train occupants or the wheel/rail dynamics. The current limiting factors to increase speeds on SJ lines are:

- Widespread use of conventional signal and control systems; and,
- Frequency of grade crossings, type of barrier protection, and sensing devices to detect the presence of a train in a fail-safe manner

The X2000 trainset currently in service consists of a locomotive (power car), four trailer cars, and a driving trailer car (cab control car). Weights are as follows:

- Power car - 70 metric tons
- Trailer car - 54.5 metric tons
- Cab control car - 55 metric tons (5 to 6 metric tons additional ballast in winter).

Overall, the nominal train weight is 343 metric tons with a length of 340 m (459 ft). The train is designed for a maximum speed of 210 km/h (130 mph), with a revenue service speed of 200 km/h (124 mph). With a power car at each end, a maximum of 12 trailer cars may be accommodated in one train.

3.2.2 Braking System Design

The braking system of the X2000 trainset used for the NEC demonstration is described in detail in documents provided by ABB Traction Inc., New York Air Brake (NYAB) Engineering, and Amtrak [Ref. 6,7,8,9]. Major components of the brake system are described below.

Major Braking Components

The X2000 trainset which operated on the NEC during the summer of 1993 in tests and revenue service was equipped with the following brake systems. Each major subsystem can be used separately or in combination for speed retardation at those levels prescribed by route-specific requirements. Brake systems are configured differently on the power car, cab control car, and trailing cars as shown in Table 3-3. A description of each major subsystem is provided in the following sections.

Table 3-3. Brake Types on X2000 Trainset

Brake Type	Power Car	Cab Control Car	Trailer Car
Dynamic/Regenerative Brake	√	√	
Air Activated Disc Brake	√	√	√
Air Activated Tread Brake	√	√	
Parking Brake	√	√	
Magnetic (Emergency) Track Brake		√	√

Dynamic/Regenerative Brake. ***Regenerative braking*** is widely proven in both rail and rail transit applications. This subsystem uses the ac traction motor and propulsion system to generate a retarding force on the trainset during braking. When operable, this system can be employed across a broad spectrum of the train's speed range. The regenerative brake on-board the trainset can be used in one of two modes. It can be used as a stand-alone system to control speed or it can be used in conjunction with the friction braking system. In the blended braking mode, additional retarding force is achieved to reduce speed more rapidly.

The train driver (engineer, operator) can set the amount of regenerative braking desired through the speed controller lever (throttle) to make minor speed adjustments. The driver can also use the brake controller, which will apply the automatic train brake through the driver's brake valve (HSM*). This action activates regenerative braking and applies air pressure to the trailing car disc brakes. When the dynamic brake limit is reached, air pressure is applied to the power car disc and tread brakes. The ratio of regenerative to friction braking is controlled by pre-programmed blended braking regimes actuated by the central computer according to a speed profile.

Regenerative braking is a proven technique whose effectiveness is limited only by access to the power grid. Because the NEC is the only electrified HSR corridor currently operational, Amtrak has specified (pre-bid procurement document) that two trainsets must be operable in non-electrified corridors in addition to trains with electric locomotives for use in electrified territory. Non-electrified head end power would likely consist of diesel locomotives using dynamic/resistive and blended braking systems. Conventional dynamic braking systems in the U.S. use the locomotive's traction motors to brake the train and dissipate kinetic energy through large resistive grids located above the locomotive. While dynamic/resistive brake systems are quite reliable and reduce friction brake component wear, they do not offer the additional advantage of regenerative systems by feeding part of the braking power back to the electrified power grid.

* "HSM" is the German acronym for this valve.

Air Activated Disc Brake. All cars (power and trailing cars) are equipped with conventional automatic air brakes. This provides fail-safe braking and high levels of retardation. Compressed air is supplied from a Knorr Model SL-20 screw-type air compressor in the power car through the main reservoir and brake pipes to individual vehicle brake systems. The power car has wheel mounted split friction rings on all wheels serving as disc brakes. (The power car is additionally equipped with tread brakes). All trailing cars are equipped with two axle-mounted discs per axle. These are a ventilated fin design that provide cooling, but reduce the power loss at high speeds compared to the conventional vane design. Each car (including the power car) is equipped with eight SAB Type PB actuators with integral double-acting slack adjusters, and associated caliper foundation rigging.

Tread Brake. The power car is equipped with tread brakes with cast iron brake shoes. These serve primarily as a wheel scrubber to increase adhesion levels and improve tractive effort and braking force. It is an SAB type BFC brake actuator integrated with single action slack adjusters configured with one unit per wheel. Amtrak states that the tread brake units provide approximately 20 percent of the friction braking force for the locomotive when working together with the rest of the friction braking system.

Parking Brake. This system is used in lieu of a conventional hand brake more common to North American equipment. Parking brakes are used on the power car and rear (inboard) truck of the cab control car. The SAB Type PB cylinders are mounted two per truck on the power car, working through the disc brake rigging, and on disc caliper units of the cab car. The units function with coil spring-applied force, air pressure-released. Loss of air pressure enables the spring to clamp the disc pads to ensure fail-safe functioning.

The X2000 units are activated by a magnetic release valve controlled by a switch in the operator console. In addition, the parking brake at each axle can be manually released by means of a handle. According to Amtrak, the X2000 train can be held stationary on grades up to 6 percent. Because HSR corridors are not likely to exceed these actual gradients, sufficient parking brake pressure should be achieved.

Magnetic Track Brakes. Magnetic track brakes supplied on the X2000 provide additional braking and quick response in emergency braking scenarios by achieving higher retardation rates than would otherwise be achievable with the combination of regenerative braking and conventional friction brakes. This subsystem is applied directly to the rail independent of wheel/rail adhesion characteristics in effect.

All trailer cars are equipped with four articulated magnetic track brakes. These are designed with a sealed winding located within each steel frame, where ten floating and two fixed-position cast iron shoes are bolted to the frame. The fixed shoes are located at each end of the frame and are tapered to clean away foreign objects on the rail. Each of ten interior shoes is bolted through vertical slots in the steel frame to allow for some vertical movement to compensate for changes in rail running-surface geometry. The track brake is carried approximately 50 mm (2 inches) above the rail when inactive. Track brakes are actuated by pairs of air cylinders, overcoming return-spring forces, and are electrically energized to generate a minimum 100 kN (22.5 kip) downward force on the rail. Power is supplied for these brakes by the 24 vdc batteries on board the train. At a speed of 194 km/h (120 mph), Amtrak has estimated an average braking rate of 1.53 km/h/sec (0.95 mph/s) due to track brakes alone.

Snow Brake. The snow brake system allows the train operator to make a light application of tread braking force on the power car during adverse weather conditions. This clears the treads and brake shoes of snow or ice, and can improve wheel/rail adhesion. The snow brake function times out after one minute to prevent the tread brakes from being left on unintentionally.

Eddy Current Brake. The European version of the X2000 can be equipped with an eddy current brake. This brake is conceptually identical to the stock brakes supplied on the ICE trainset in Germany for use on Deutsche Bundesbahn (DB). Eddy current brakes operate by dispersing kinetic energy of the train via electrical eddy currents in the rail. These are non-contact brakes which reduce maintenance requirements by avoiding any contact force. Eddy current brakes can, however, cause potential rail heating problems if they are used too frequently over a given track segment.

At decelerations of up to 0.5 m/s^2, 1.1 mph/s (maximum service braking with automatic train control), the train can be brought to extremely slow speeds without any mechanical contact. In low speed ranges, disc brakes are then applied to bring the train to a complete stop.

Braking Control Components

The automatic air brake system actually consists of a number of subsystems optimized to work together. This is accomplished by the following components. An overview of the pneumatic system is shown in Figure 3-3.

HSM Driver's Brake Control Valve. The driver's brake valve (on power and cab control cars) regulates the brake pipe pressure for application and release of disc and tread brakes. The system consists of 1) an electronic brake controller (in both cabs), 2) an HSM brake computer (power car only), and 3) an electro-pneumatic unit (power car only). The controller is activated at one or the other location by a cab switch key, and communicates by current-based signal with the central computer (one at each end of the train set), which in turn controls the HSM computer. The controller has a running position, seven detented service braking positions (Position 1 is a 0.4 bar, six psig, service reduction, Position 7 is "full service" braking reduction), and an emergency (NB) position. In the emergency position, the controller signals the HSM computer to initiate an emergency brake pipe reduction. A special set of electrical contacts de-energize an externally mounted emergency magnet valve, which pilots the emergency brake valve, which in turn vents the brake pipe quickly. This also, through the isolating valve on the pneumatic brake rack, shuts down the brake pipe relay valve cutting out the brake pipe pressure maintaining function.

The HSM computer, mounted on the electro-pneumatic unit, drives two analog converters in response to the driver's commands for braking. One converter controls a pilot pressure to change the brake pipe pressure, while the second modulates the control line pressure (Cv) for

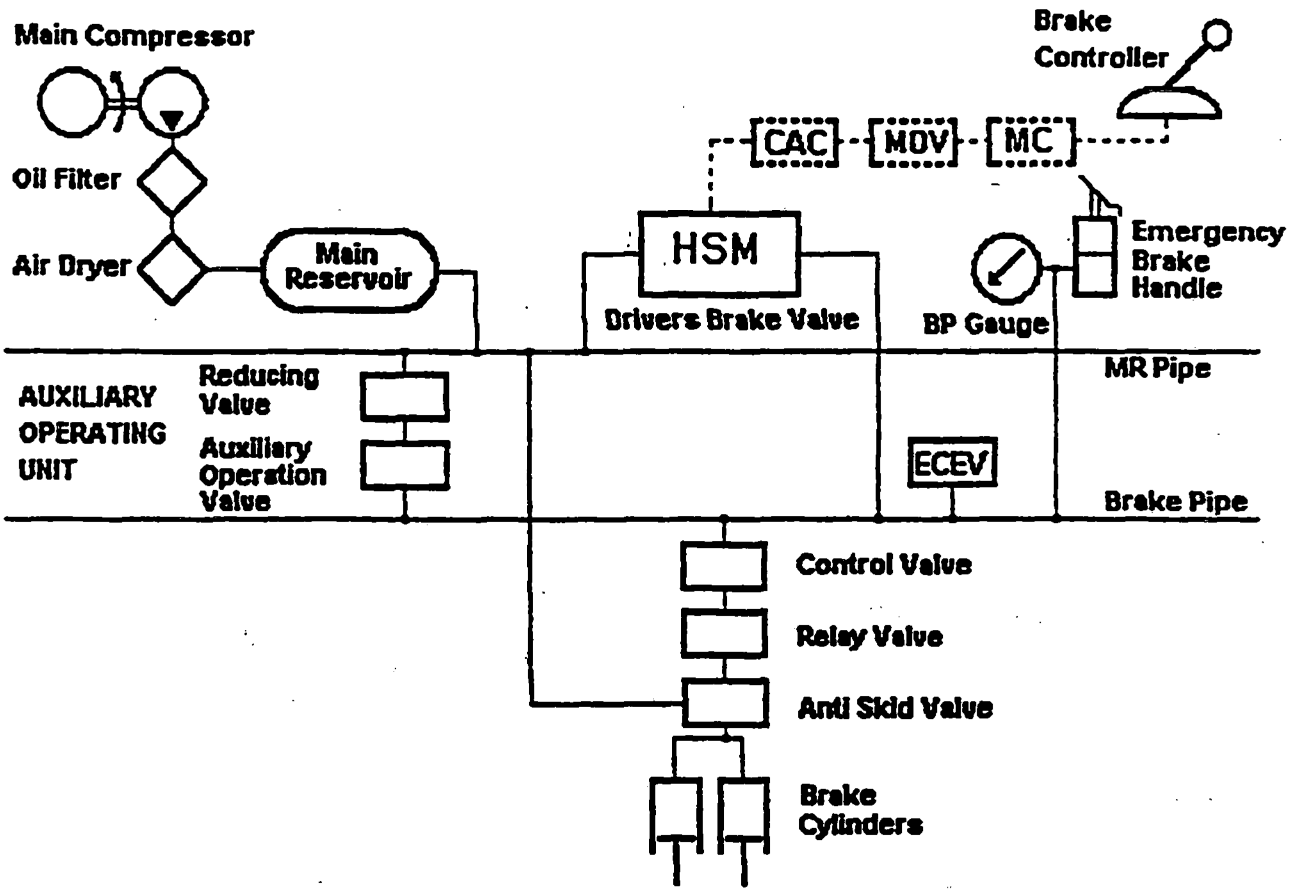

Figure 3-3. Schematic Diagram of X2000 Train Pneumatic Brake System (Ref. 10)

power car friction brake gear. Located in the power car machine room, the electro-pneumatic unit incorporates the following equipment: 1) the analog converters, 2) the **reducing valve** (limiting the pressure in the pre-control reservoir of air from the main reservoir), 3) the **RH2** relay valve (which incorporates the pressure maintaining feature), 4) the **isolating valve** (cutting out the pressure maintaining feature in emergencies), and 5) a **flow indicator** (monitoring main reservoir air flow to the brake pipe).

Two 50 liter air reservoirs, charged by the main reservoir pipe, supply air pressure for each of two DU 111G relay valves and the brake cylinders. Power car brake equipment is shown schematically in Figure 3-4. **Electrically Controlled Emergency Valve (ECEV).** The ECEV, located in the power and cab cars, consists of a normally energized magnet valve, a cutout cock, and a pneumatically piloted emergency brake valve. It vents the brake pipe pressure quickly when the magnet valve is de-energized by signals from 1) the HSM driver's brake valve, 2) the alerter system (Vigilance Control), or 3) the separate emergency brake valve in the cab.

Conductor's Emergency Valve. All trailer cars are equipped with two "conductor's valves" which vent the train brake pipe directly to atmosphere. Activation of these valves will also signal the central computer, which will then initiate the emergency braking sequence.

KEOA/3.8/KSL-EPZ Control Valve. All cars are equipped with the Knorr Type KE control valve to provide quick response to changes in brake pipe pressure or commands from the HSM brake computer to charge, apply brakes, or release brakes on the car. This valve consists of a basic service portion, an EP brake solenoid portion, and a small (four liter) reservoir, which serves as a reference volume for the service portion. The EP brake portion, controlled by the HSM computer, consists of a brake application magnet valve and a brake release magnet valve, charging or venting the brake pipe locally for quick response. Each control valve may be isolated from the brake pipe by a cutoff cock. Each car has a 50 liter air reservoir tank charged by the main reservoir pipe. These supply air pressure to the pre-control (Cv) pipe and the brake cylinders during brake application.

DU111G Relay Valves. All cars are equipped with two relay valves ("step down," or pressure reducing), one per truck, which are piloted by the control valve and supply main reservoir air to the brake cylinders during brake application. The relay valves vent air pressure from the brake cylinders during brake release.

Anti-Skid System. The anti-skid system is designed to prevent wheel sliding during braking, which can cause wheel flats and tread thermal damage, and to maximize wheel adhesion. The system consists of a speed sensor on each axle which detects wheel slip. This signal is computer-processed to modulate brake cylinder pressure through the anti-skid valve on the affected truck. Pressure is momentarily reduced enough to restore full wheelset adhesion. The anti-skid function times out after eight seconds to prevent total loss of braking on that truck. Wheel skid is controlled by slave computers in each trailer car (which also control the tilt system and the doors).

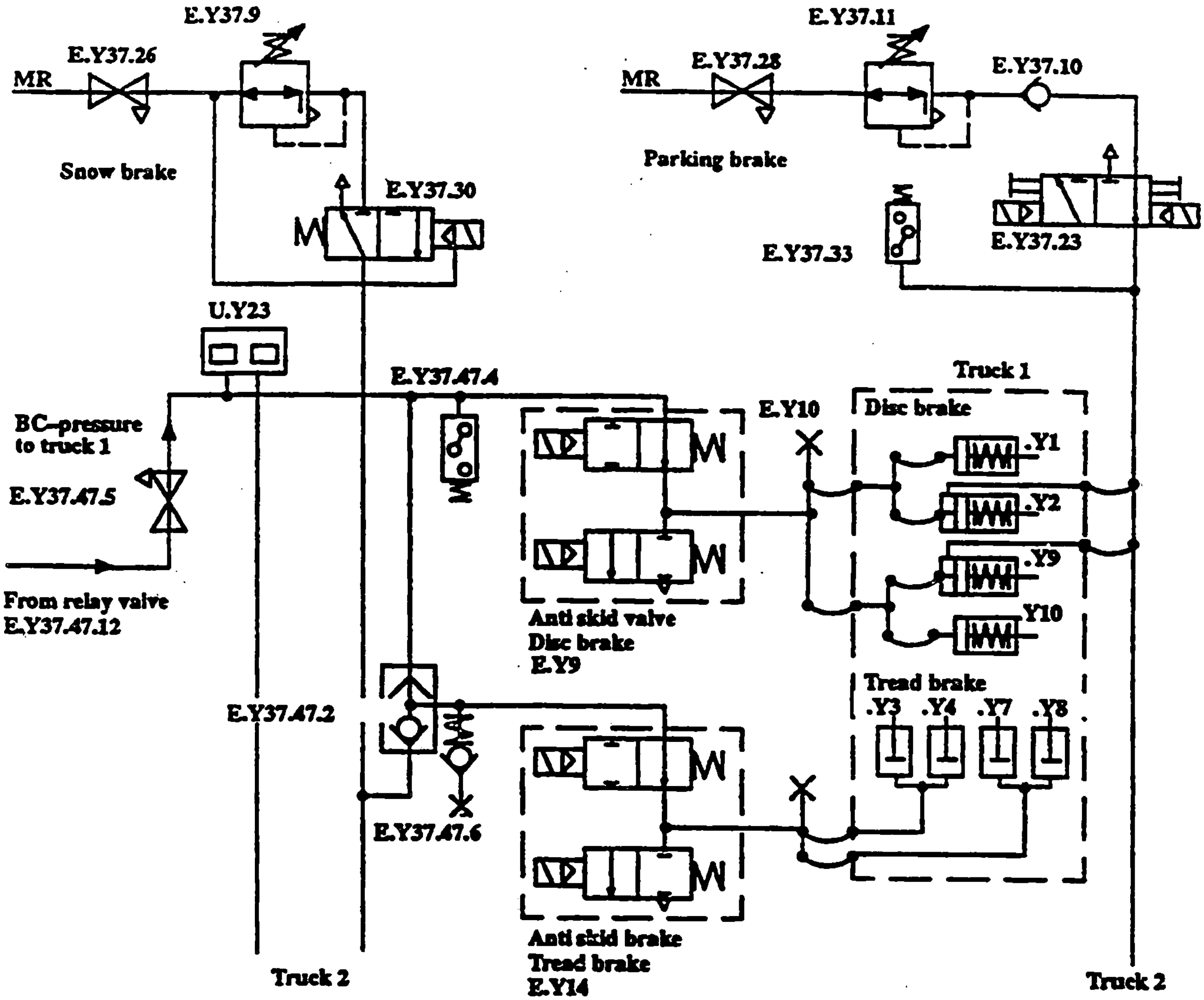

Figure 3-4. Schematic of Pneumatic Brake Equipment on X2000 Trainset Power Car

Brake System Operation

The X2000 braking system is designed for manual operation where the computer controls the "blended braking" sequencing during activation. Fully automatic operation is possible through automatic train control. The Vigilance Control system is used to monitor an operator-controlled train. Finally, manual override capabilities can be used to initiate full service or emergency braking.

Brake subsystems are designed for operation in any of the following three sequences:

- Train Operator - For service application of brakes, the operator may choose dynamic or blended (air plus dynamic) braking, which is automatically controlled by the computer in the power car. In emergency braking, the operator has (in addition to the EB position on the brake controller) an electronic emergency brake button, activating all brakes, plus a backup manual air release valve for the pneumatic brake system. Whenever an emergency braking sequence is started, magnetic track braking is also applied.

- Train Crew (or Passenger) - The train has three emergency brake valves available to crew or passengers in each trailing car. The emergency switch is connected to a brake valve which is connected directly to the brake pipe (BP) system. When this switch is activated, brake pipe pressure is released and emergency braking is invoked. Supply of additional brake pressure is also cut off though a valve such that compressed air intake is removed to the pressure reservoirs. During this sequence, train propulsion is disabled.

- Vigilance Control System, Cab System, and/or Central Computer - The Vigilance Control monitors the operator's activities through his operation of the safety pedal. If its position is not changed within 50 seconds, an alarm sounds. If not acknowledged by position change within five seconds, a penalty brake application is initiated. In Sweden, the automatic train control (ATC) will stop the train if the operator exceeds the allowable speed (plus 10 km/h tolerance), if the operator fails to activate the alerter once per minute, or if grade crossing gates are not down or a vehicle is detected on the track. In U.S. demonstrations, cab signalling penalty results in a full service brake application.

It is important to highlight the significant differences between European and North American operations. In Europe, the X2000 train service braking functions are normally operated using the Automatic Train Protection (ATP) system on board the train, which communicates with train monitoring computers outside the train, locally and with central coordination and dispatching. Swedish National Railroads invested substantial capital on several of its corridors to enable ATP control.

However, the present manual block control system prevalent in the U.S. will not permit ATP operations without substantial redesign and upgrading in the future. Hence, the X2000 is envisioned to function on the NEC, and in other Amtrak corridors, by manual (operator) initiation with computer control assist during a full service or emergency braking regime.

3.2.3 Braking System Performance

Technical Specifications

Prior to the start-up of the X2000 demonstration runs in the U.S., ABB technicians modified the train to ensure compatibility with overhead catenary voltages and Amtrak standards for brake pipe working pressures. Specification pressures are given in Table 3-4 below.

Table 3-4. X2000 Automatic Brake System Pressures for Amtrak Demonstrations

Function	Brake Pipe Pressure	Brake Cylinder Pressure (max.)	
		Power Car Trailer Cars	Cab Control Car
Working Pressure (max.)	1000 kPa (145 psig)	300 kPa (43 psig)	320 kPa (46 psig)
Released	760 kPa (110 psig)		
Full Service/Penalty	600 kPa (87 psig)		
Emergency	Atm. (0 gage)		

The demonstration trainset had its brake pressure system adjusted from 75-80 psig to Amtrak Standard S603 main reservoir pressure of 110 psig to compensate for differences between UIC and Amtrak required stopping distances. This adjustment was necessary to accommodate required stopping distances in conventional operations. The calculated differences in stopping distance for a full service brake application are shown in Figure 3-5.

Specified stopping distances for the X2000 trainset are listed in Reference 11 and follow in Table 3-5:

Table 3-5. Specified X2000 Train Stopping Distances from Different Speeds

Braking Mode	200 km/h (124 mph)	160 km/h (100 mph)	130 km/h (80 mph)
Specification	1.75 km (5742 ft)	1.05 km (3440 ft)	0.70 km (2300 ft)
Full Service	1.45 km (4757 ft)	0.95 km (3117 ft)	0.60 km (1969 ft)
Emergency	1.10 km (3609 ft)	0.65 km (2133 ft)	0.50 km (1640 ft)

Full service braking tests were performed on an NEC track north of Baltimore during the U.S. demonstration project. Results of full service braking are shown in Table 3-6 with dynamic brakes isolated, brakes on one axle of a trailer car disabled (to simulate a full passenger load), and on a descending grade of 0.11 percent.

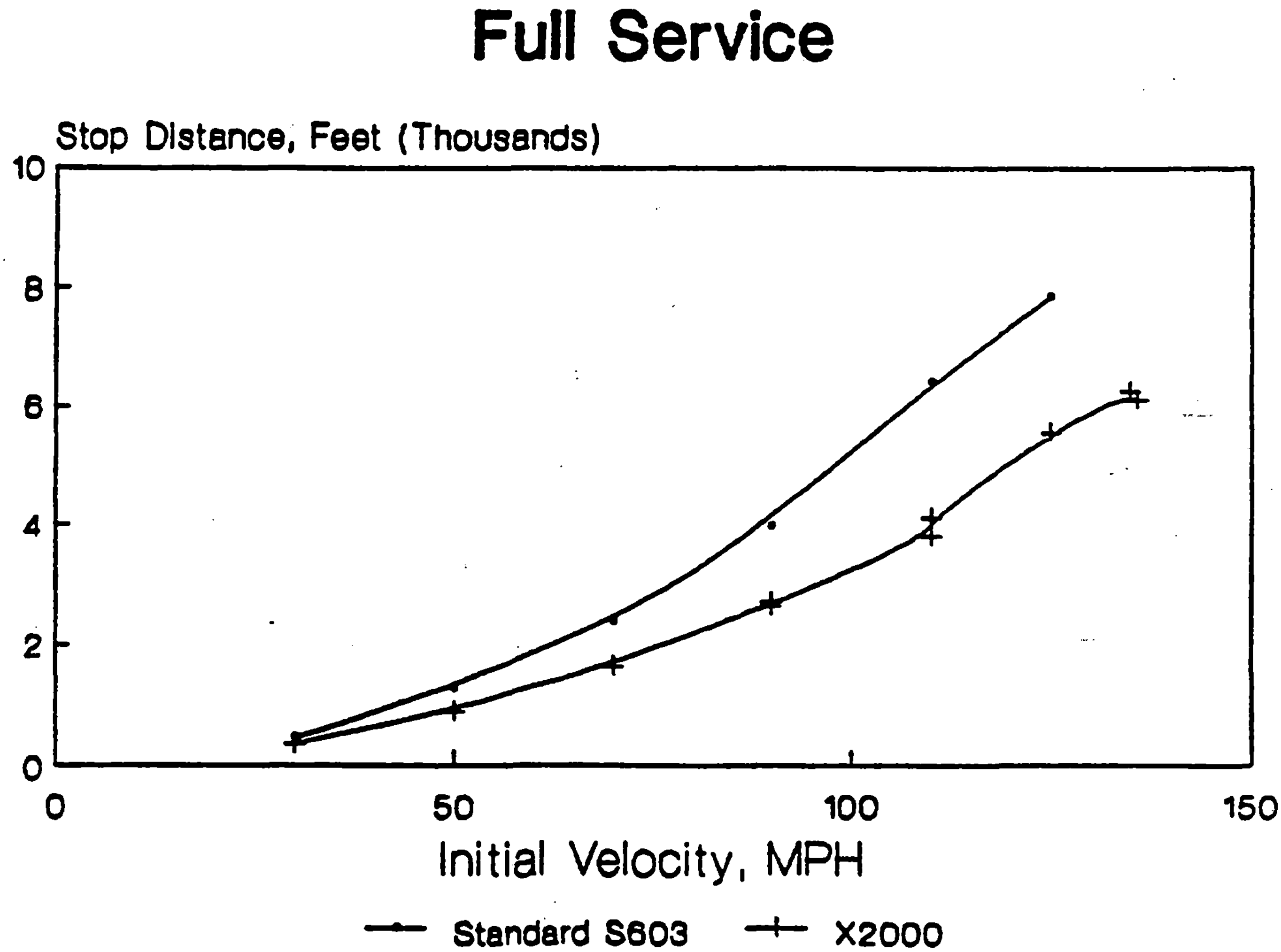

Figure 3-5. Calculated Stopping Distance vs. Speed for X2000 Trainset

Table 3-6. Measured X2000 Train Stopping Distances, Full Service Braking, U.S. Demonstration Tests

Train Initial Speed		Stopping Distance	
(km/h)	(mph)	(km)	(ft)
48	30	0.11	357
80	50	0.27	899
113	70	0.50	1641
145	90	0.83 0.81	2712 2644
177	110	1.25 1.17	4116 3825
201	125	1.69	5549
217	135	1.90	6250
243	151	3.44	11300

From test results supplied by ABB for the X2000 Demonstration train, the anti-skid system was tested on rail where a soap solution of 2 percent and 3 percent was sprayed on the rails in front of each train wheel to determine stopping distance at 72 MPH. The train in these tests consisted of one power car and a cab control car. The adhesion limit in these tests was 6 percent and 8 percent, respectively.

Stopping distances for these tests were:

- Dry 0.47 to 0.50 km (1556-1627 ft)
- 2% Soap Solution 0.56 to 0.59 km (1831-1936 ft)
- 3% Soap Solution 0.59 to 0.73 km (1932-2410 ft)

Soap was used to simulate the affects of poor adhesion introduced by the environment between the wheel and rail. According to ABB, the anti-skid system did not allow any slippage to occur during the tests. However, stopping distances were adversely affected requiring up to 27 percent of additional stopping distance with slippery rail in a full service stopping application.

Diagnostics and Monitoring

System Status Reports. The X2000 driver's cab is equipped with an operator's console which continuously monitors safety-critical activities of the operator. Termed by ABB as "Vigilance Control," this is a logic system designed to extend the "dead man's brake" concept to constantly monitor movements in the safety pedal which controls train operation.

As the operator depresses the safety pedal to the intermediate position, the "Pedal Intermediate Timer" is actuated and an "Acknowledge" light flashes on the console after 50 seconds of operation. After 5 more seconds, an alarm is triggered for the operator to release the safety pedal within 5 seconds. If he/she fails to do so, the central computer initiates penalty (full service) braking. When the brake pedal is released, the timer is re-set to zero for the next sequence.

Alternatively, the same sequence of events takes place when the "Pedal Intermediate" position is defeated by the operator. For this sequence, there is the inverse signal indicator which lights on the console, "Pedal Not Intermediate." When this occurs, the timed "Acknowledge" light goes on after three seconds and the alarm sounds four seconds later if no action is taken. Similarly, the operator must move the safety pedal within six seconds thereafter or penalty brakes are applied.

These sequences repeat whenever the train is in motion except when full service braking has already been initiated. While obviously developed to keep the operator alert, the system has several deficiencies which may not be acceptable:

- The Vigilance Control System can be turned off by closing the ECEV valve located in the cab and trailing car. A negligent or careless operator, crewman, or maintenance worker could defeat this system and render its benefits useless. Access to this capability should be severely restricted for U.S. operations.

- Additional fatigue could be induced on the operator by forcing him to depress the safety pedal approximately twice a minute throughout the run. The Brotherhood of Railway Locomotive Engineers (BRLE) could resist this design feature. However, the benefits of this capability appear to outweigh its deficiencies.

Enroute Indications of Failure. In addition to the above description of the Vigilance Control System, the operator's console employs a rather comprehensive set of fault indicators. The fault indication system gives the operator a variety of visual indications that a fault is occurring through the micro-processor, localized, and central computer diagnostics.

The following functions are monitored continuously:

1) Isolating valve is not energized in regular operation or is energized if the driver's cab is inactive; or it is either closed when energized or open when de-energized

2) Serious faults in the HSM computer are shown by an "HSM Fault" and "HSM Warning" for minor faults

3) Faulty signal in brake controller

4) ECEV valve fails to release when emergency brakes are applied electrically

5) EP control system valve solenoids are activated too long, too short, or simultaneously

6) Feeding maintained for too long

7) Low BP pressure light when the brake controller is in the "Running" position and brake pressure switch releases concurrent with pipe pressures falling below 64 psi

8) BP pressure switch fails to close in emergency braking

9) Incorrect position of any of the BC pressure switches in accordance with the brake controller lever

10) Communication is lost between the cab controller and air compressor computer

11) Brake pipe maintaining function is isolated by driver's panel switch

12) Brake pipe pressure transducer signal output is not being received

13) Auxiliary brakes in use

14) ECEV valve has been manually closed

15) Anti-skid valve is activated longer than eight seconds

16) Pressure switches indicating low BP pressure and emergency brake application conflict

17) Magnetic track brake is not functioning during emergency brake application or is active when emergency braking is not used; or, magnetic brake is not active during emergency braking and vice-versa

18) Fault signals originating from the U/I convertor associated with the bleeding valve

There are two modes of display in the operator console: 1) normal indication, and 2) auxiliary indication when the train is operated in this mode.

A set of software protocols are built into the fault monitoring system to alert the operator of the current status of each safety-critical brake and speed function:

- The emergency brake (EP) from the vigilance control system,
- Constant monitoring of the brake pressure (BP) switch when train speed is five km/hour or greater,
- Status of the "Activate Emergency Brake Valve" indicator and its sister "Feeding Emergency Valve" indicator light in the locomotive cab,
- Indicator light and active train control of the emergency brake originating either from the power or trailing cars.

Inspection and Test Requirements

The standard automatic air brake system leak test (tightness test) may be done using a special switch in the driver cab, providing that the cab is active. This switch deenergizes the isolating valve, cutting off the brake pipe pressure from the main reservoir supply. Brake pipe pressure drop can then be monitored in the time-honored way.

Braking System Effects on Vehicle, Guideway, and Infrastructure

Thermal Effects. During pneumatic braking stop distance tests on the NEC, the temperature of the disc brakes was monitored. Temperatures were measured by using a thermocouple at the end of each stopping test. According to ABB furnished data, disk pad temperatures were not allowed to exceed 752 degrees Fahrenheit and disc temperatures were cooled to at least 250 degrees Fahrenheit before proceeding with the next test. These temperature ranges were supplied by Knorr/NYAB to prevent thermal damage to the wheels or pads.

Test results show a maximum recorded temperature of 277 degrees Fahrenheit. If these results were accurate, there is sufficient thermal margin at running speeds up to 135 MPH in a full service braking application. Thermal crack initiation has been shown by a number of researchers to become pronounced when high surface temperatures are sustained over a long period of time (critical wheel temperature damage to the microstructure can occur in the 900-1100 degrees Fahrenheit range). Since wheel tread braking amounts to a relatively small portion of the total braking power, wheel heating is not anticipated to be a problem. Substantial research and development effort has gone into the design of disc brakes for European high speed trains (Ref. 10, for example). As a result, the disc brake system is well suited for high energy dissipation and high temperature events.

Mechanical Effects. ABB has provided data which indicate brake pad useful life to be approximately 120,000 km (74,400 miles) in service. The complementary expected life for brake discs is 10 times pad life, or 1,200,000 km (744,000 miles).

ABB further states that all discs are replaced at the time of major overhaul together with the wheels themselves. Apparently, wheels and discs are not turned as a regular maintenance activity to prolong their useful economic life. No data were provided on the useful life of magnetic track brakes or their associated lining life.

To the extent that the ratio of dynamic/regenerative to friction braking is increased in blended braking sequences, mechanical wear is proportionately reduced on disc brakes and magnetic track liners. This is one of the primary advantages of regenerative braking. Magnetic track brakes are proportionately most effective in the lowest end of the speed profile, but generate high frictional forces and can possibly subject the rail to damage by wear and heating as speeds increase.

The magnetic track brakes are said not to affect track circuits because dc fields are used.

Table 3-7. X2000 FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden)							Page 1 of 8
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Braking Control							
Central Computer in Power Car (This computer controls the AntiSkid system for the power car and the analog valve)	Fails off.	No effect. There is a central computer at each end of the trainset.	No effect. There is a central computer at each end of the trainset.	Controller sends a signal to both computers at all times so the second computer is always receiving the information, now it sends the control signals.	Y	Y	D
Slave Computer (1 for each trailer car. This computer controls the AntiSkid system for a car)	Fails off.	No wheel slide protection for the car. Wheel slide possible resulting in excessive wear on wheels and rails.	The car with failed computer may experience wheel slide.	Operator has indications from monitoring. Possibly manually isolate failed brakes and continue within speed limits defined for operating with failed brakes.	N	N	A3
Driver's Brake Valve. Consists of Brake Controller (In power car and cab control car), HSM Brake Computer (controlled by central computers - one in each of power and cab control cars), and Electropneumatic Unit.	Signal for too much braking	Braking occurs above desired level for the trainset.	Rapid decrease in speed beyond level desired	Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested.	N	Y	C
	Signal for too little braking.	Braking is under desired level for the trainset.	Braking effort is too low, increasing stopping distance.	Train does not slow quickly enough. Must increase level of braking requested, possibly even emergency braking.	N	N	A2
	No signal for braking when braking requested.	Braking does not occur at all.	Braking does not occur at all.	Train does not slow down. Must utilize emergency brake.	N	N	A2
AntiSkid System (2 valves/truck, 1 each for tread and disc brakes for the motor trucks; 1 valve/truck for the trailer trucks)	Fails with output failing to modulate the brake cylinder pressure.	Results in maintaining current brake level, not alleviating wheel slip. Braking applied to truck is above desired braking level resulting in wheel slip. This causes excessive wear on wheels and rails.	Over application of brakes on one truck causing wheel slide for the truck.	Wheelslide indicated to driver. Assume driver can isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3

Table 3-7. X2000 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden)							Page 2 of 8
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
AntiSkid System (2 valves/truck, 1 each for tread and disc brakes for the motor trucks; 1 valve/truck for the trailer trucks)	Fails with output requesting brake cylinder pressure to be vented, thus keeping the valve open.	Braking applied to truck is below desired braking level resulting in reduced or no braking for the truck associated with the failed control.	Reduces available braking by the effort of one truck.	Assume operator receives indication of lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3
Regenerative Braking System							
Motor Car Trucks							
Pantograph or Catenary power acceptance of load	Load rejected, or power failure	Regenerative braking is unavailable.	Regenerative braking is unavailable.	Operator has indications of failure to accept load. Valve for friction braking on power car is applied immediately and automatically to fulfill the brake demand.	Y	Y	D
Traction Motor (Assume two per truck.)	Does not produce current to return to pantograph.	Loss of or decrease in regenerative braking for the motor truck.	Immediate and automatic application of friction brakes to fulfill brake demand, i.e., supplement for lost regenerative braking.	Computer reacts to lower regenerative braking by allowing more friction braking via the analog valve.	Y	Y	D
	Bearing failure, axle seizes.	Unintentional wheel slide for the motor truck axle. AntiSkid system attempts to alleviate wheel slide.	Unintentional wheel slide for the motor truck axle. AntiSkid system attempts to alleviate wheel slide.	AntiSkid system monitored by computer. Failure of motor, driver must stop and isolate the wheelset and continue at lower speed or line speed.	N	N	A2
Pneumatic Friction Brakes							
Motor Car Trucks							
Air Brake Pipe (ABP)	Fails with Low Pressure	Friction brakes applied for all cars.	Friction brakes applied for all cars.	Speed reduction. Computer monitoring notifies operator of low pressure. Train slows and eventually stops if pressure not recovered via main reservoir.	N	Y	C

Table 3-7. X2000 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden) — Page 3 of 8

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Control Valve (1/car) Will effect disc and tread brakes of the associated car.	Signal for too much braking, fails open	This will result in slowly venting the brake pipe and applying the friction brakes.	The operator can isolate this valve, thus eliminating friction braking for the car, if braking is not requested.	Operator notified via computer monitoring. Either the train will stop, only failsafe, or the operator must decrease level of braking perhaps by isolating the car's friction brakes (control valve) and continuing at a reduced speed, fault tolerant only.	N	Y	C
	Signal for too little braking, fails closed.	Braking is under desired level for the car.	Braking effort is too low, increasing stopping distance.	Operator notified via computer monitoring. Must increase level of braking for the car via regenerative braking, if available, or, more realistically continue operation at a slightly reduced speed if required.	Y	N	B3
Relay Valve (2/car, or 1/truck) Will effect disc and tread brakes of associated truck.	Signal for too much braking, fails open supplying pressure to brakes.	Braking above desired level for the truck. May result in overworking the AntiSkid System.	Unintentional friction braking for the truck associated with the failed valve.	Operator notified via computer monitoring. Must decrease level of braking for the truck perhaps by isolating the car's friction brakes, i.e. the control valve, and continuing at a reduced speed.	N	Y	C
	Signal for too little braking, fails closed not allowing pressure to the brakes.	Braking is under desired level for the truck or unavailable for the truck.	Braking effort is too low or unavailable for the truck, increasing stopping distance.	Operator notified via computer monitoring. Continue operation at a slightly reduced speed if required.	Y	N	B3
Disc Brake Actuator, Disc, and Calipers associated with disc and actuator (2 discs/axle)	Fail disc brakes on	One actuator/disc, brake effort is constantly applied equivalent to effort from one disc. Excessive wear on brakes and/or possible overheating of brakes.	One actuator/disc, brake effort is constantly applied equivalent to effort from one disc. Excessive wear on brakes and/or possible overheating of brakes.	Operator notified via computer monitoring. Operator can isolate car's friction brakes, i.e. control valve, and continue within speed limits required. If not, then excessive wear and overheating is probable.	N	N	A3

Table 3-7. X2000 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden) — Page 4 of 8

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Disc Brake Actuator, Disc, and Calipers associated with disc and actuator (2 discs/axle)	Fail disc brakes off	One actuator/disc, brake effort not applied, lost braking capability equivalent to effort from one disc.	One actuator/disc, brake effort not applied, lost braking capability equivalent to effort from one disc.	Computer monitoring indicates lower braking effort than requested. Assume operator can continue at reduced speed.	Y	N	B3
Tread Brake Actuator, tread shoes (1/wheel) Mostly for wheel conditioning.	Fail tread brakes on	One actuator/wheel, brake effort is constantly applied equivalent to effort from one wheel's tread braking. Excessive wear on brakes and/or possible overheating of brakes.	One actuator/wheel, brake effort is constantly applied equivalent to effort from one wheel's tread braking. Excessive wear on brakes and/or possible overheating of brakes.	Operator notified via computer monitoring. Operator can isolate car's friction brakes, i.e. control valve, and continue within speed limits required. If not, then excessive wear and overheating is probable.	N	N	A3
	Fail tread brakes off	One actuator/wheel, brake effort not applied, lost braking capability equivalent to effort from one disc.	One actuator/wheel, brake effort not applied, lost braking capability equivalent to effort from one wheel's tread brake.	Computer monitoring indicates lower braking effort than requested. Assume operator can continue at reduced speed.	Y	N	B3
Compressor, one/train.	Fails on, pressure switch fails to turn compressor off	Pressure builds in the main reservoir and continues beyond normal levels.	Pressure builds in the main reservoir and continues beyond normal levels.	Computer monitoring notifies operator of compressor running and reservoir pressure. Assume safety pressure relief valve is available on reservoir.	Y	Y	D
	Fails off	May not be able to energize brake system. The result is that the friction brakes cannot be released or may be unavailable.	Friction brakes cannot be released once applied.	Computer monitoring notifies operator of compressor condition, not running, and reservoir pressure.	N	Y	C
Main Reservoir, one/train, 500 liters	Fails high pressure	High pressure builds in main reservoir.	Assume pressure relief valve is available on main reservoir.	Assume operator is notified and relief valve operates automatically. Compressor (s) can be shut off to prevent further pressure build up.	Y	Y	D

Table 3-7. X2000 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden)							Page 5 of 8
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Main Reservoir, one/train, 500 liters	Fails low pressure	May not be able to energize brake system. The result is that the friction brakes cannot be released or may be unavailable. Compressor may try to compensate by running hard trying to reach the desired pressure.	Friction brakes inoperable or excessive running of compressors or both will result.	Computer monitoring indicates low pressure of reservoir and compressor operation. Assume operator can begin compressor operation.	N	Y	C
Air Dryer/Filter	Fails with air too wet	Wear on components. Possible corrosion of components over time.	Wear on components. System contamination and possible corrosion over time.	Maintenance and inspection checks.	N	N	A3
Main Reservoir Pipe (MRP)	Fails with low pressure	Pressure is not available to MRP so that once the friction brakes are applied, they will not be able to be released or reapplied.	Potentially unable to apply friction brakes for entire trainset because brake supply reservoirs may not have enough pressure on their own to apply the friction brakes.	Assume operator is notified in cab of pressure level in MRP. Try to maintain pressure via the main reservoir.	N	Y	C
Brake Supply Reservoir, 1/truck, i.e. 1/relay valve or 2/car, each 50 liters.	Fails with low pressure	Pressure not available to apply friction brakes for the truck with the failed reservoir.	Pressure not available to apply friction brakes for the truck with the failed reservoir.	Computer monitoring indicates low pressure of reservoir. Attempt to refill via MRP and main reservoir.	Y	N	B3
Trailer Car Truck							
Relay Valve (1/car) Will effect disc brakes of associated car.	Signal for too much braking, fails open supplying pressure to brakes.	Braking above desired level for the car. May result in overworking the AntiSkid System.	Unintentional friction braking for the car associated with the failed valve.	Operator notified via computer monitoring. Must decrease level of braking for the car perhaps by isolating the car's friction brakes, i.e. the control valve, and continuing at a reduced speed.	N	N	A3
	Signal for too little braking, fails closed not allowing pressure to the brakes.	Braking is under desired level for the car or unavailable for the car.	Braking effort is too low or unavailable for the car, increasing stopping distance.	Operator notified via computer monitoring. Continue operation at a slightly reduced speed if required.	Y	N	B3

Table 3-7. X2000 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden)							Page 6 of 8
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Brake Supply Reservoir, 1/car, 50 liters.	Fails with low pressure	Pressure not available to apply friction brakes for the car with the failed reservoir.	Pressure not available to apply friction brakes for the car with the failed reservoir.	Computer monitoring indicates low pressure of reservoir. Attempt to refill via MRP and main reservoir.	Y	N	B3
Magnetic Track Brakes							
Trailer Car Trucks							
Batteries (24v) (Assume one battery system per truck)	Loss of power or decreased power available	Decrease or loss of magnetic track braking for the truck.	Decrease or loss of magnetic track braking for the truck.	Computer monitoring should indicate battery status. More reliance on other brake systems if many of these failures occur.	Y[1]	N	B3
Actuators (Air Cylinders)	Fail to engage brake shoes with track	Loss of magnetic track braking for that unit.	Since this is an emergency braking system, other braking systems should be fully deployed to stop train immediately.	Computer monitoring indicates lack of pressurization of magnetic track brakes.	Y	N	B3
Brake Coil/Wiring	Fails to carry current/produce magnetic field	Loss of magnetic track braking for that unit.	Since this is an emergency braking system, other braking systems should be fully deployed to stop train immediately.	Assume only detection is decreased braking. Other systems should be deployed so the effect is slightly increased stopping distance.	Y	N	B3
Brake Shoes (2 stationary, 10 floating)	Fail to make contact with rail	Decreased magnetic braking force for that unit	Effect depends on extent of problem. Loss of contact at one shoe may be negligible, while loss of multiple shoes may require further emergency action.	Assume only detection is decreased braking. Other systems should be deployed so the effect is slightly increased stopping distance.	Y	N	B3
Eddy Current Braking System[2]							
Eddy Current Brake System (Magnetic Coils, switching equip., etc.)	Fail Off	Loss of Eddy Current braking.	ATO senses train not slowing down, increases braking effort in electrodynamic and disc brakes.	Signal in cab?? Unusual wear to disc brakes, result of inspection/diagnostic.	Y	N	B2

Table 3-7. X2000 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden)							Page 7 of 8
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Emergency Braking System							
Driver's Brake Valve	Electronic signal does not initiate braking.	Direct venting of the brake pipe occurs when the controller is in the emergency position and the pressure maintenance function for the brake pipe is disabled.	Emergency braking is still initiated.	Computer indicates the electronic signal error, but braking occurs in spite of the failure.	Y	Y	D
Electric Emergency Brake Button	Fails to signal cab emergency valve to vent the brake pipe.	No effect. This is a backup system to the Driver's Brake Controller.	No effect. This is a backup system to the Driver's Brake Controller.	Computer indicates failure, but emergency braking is still available.	Y	Y	D
Manual Air Release Valve	Fails to directly vent brake pipe.	No effect. This is a backup system to the Driver's Brake Controller.	No effect. This is a backup system to the Driver's Brake Controller.	Computer indicates failure, but emergency braking is still available.	Y	Y	D
Conductor's Emergency Valve (2/trailer car)	Signal not sent to computer to initiate failure.	Brake pipe is directly vented simultaneously.	Emergency braking is still initiated via the direct venting of the brake pipe.	Computer indicates the failure, but emergency braking is still initiated.	Y	Y	D
	Direct venting of the brake pipe does not occur.	Emergency braking is also simultaneously requested electronically via the computer.	Emergency braking is still initiated via the computer signal.	Computer indicates the failure, but emergency braking is still initiated.	Y	Y	D
Crew/Passenger Emergency Valves (3/trailer car)	Fails to directly vent the brake pipe.	One of the two remaining emergency valves in the car must be initiated.	One of the two remaining emergency valves in the car must be initiated.	Brakes will not be applied immediately, indicating to the individual that another valve must be activated.	Y	N	B2
Electrically Controlled Emergency Valve (ECEV)	Fails to directly vent the brake pipe when signalled via the 1) Driver's brake valve, 2) Vigilance control, or 3) emergency brake valve in cab.	If the ECEV is manually closed, the operator is signalled. If it fails, the emergency brakes will not be applied.	No emergency brakes will be applied as a result of this action.	Braking will not occur without further action. The driver has, independent of the brake valve, switches to operate the dynamic and magnetic brakes or the cab emergency brake valve.	Y	N	B2

Table 3-7. X2000 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

X2000 Tilting Train (Sweden)				Page 8 of 8			
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Vigilance Control	Operator fails to respond within specified time to a signal from this safety system or speed limit is exceeded.	Brakes are applied by the system if no response is received within specified time.	Brakes are applied by the system if no response is received within a specified time.	Brakes will be applied, and the train will be stopped.	Y	Y	D

1. Other systems can supply extra braking.
2. Eddy current brakes not available in revenue service. Trucks would be equipped with either eddy current brakes or magnetic track brakes, not both.

3.3 INTERCITY EXPRESS (ICE)

3.3.1 General Description of Trainset

The German InterCity Express (ICE) has been in joint development for over a decade by both the railway industry and the German Federal Railways (Deutches Bundesbahnen). In this development program, two basic objectives were met: test operations at speeds up to 345 km/h (214 mph), and revenue operations at speeds up to 300 km/h (186 mph). These objectives were met by analytical studies (computer simulations of train stability at high speeds, for example), laboratory roller rig experiments, and extensive high-speed running on specially-prepared test tracks. A maximum speed of 407 km/h (252 mph) was actually achieved in tests.

The ICE train is now in service at track speed limits of up to 280 km/h between Hanover and Würzburg allowing start-to-stop schedules between certain cities of 180 km/h or higher. This has been made possible by construction of new high-speed lines (Neubaustrecke, NBS) and upgraded automatic train control equipment on some existing lines. The ICE train consists of two power cars and up to 12 (14 maximum) trailer cars in the standard two-bogie, four-axle configuration for all cars. Weights are as follows:

- Power car - 78 metric tons (86 tons)
- Trailer car - 52 metric tons (57.3 tons)
- Service car - 52.6 metric tons (58 tons)
- Restaurant car - 55.5 metric tons (61.2 tons)

The total train weight is 784 metric tons, 864 tons (two power, one service, one restaurant, and 10 trailer cars) at a length of 357 meters (1171 ft). Current service speed is listed at 250 km/h (155 mph) with a maximum speed limit of 280 km/h (174 mph).

A modified ICE train was tested and demonstrated on Amtrak's NEC trackage during the summer of 1993, reaching speeds of 261 km/h (162 mph) during these tests. Revenue service demonstrations were run as a Washington to New York Metroliner train. The ICE train is expected to be offered by the consortium of Siemens Transportation Systems, Electro-Motive Division (GM) and AEG Transportation Systems as one group in Amtrak's upcoming high-speed train procurement.

3.3.2 Braking System Design

The braking system of the ICE train has been described in several publications [Ref. 12,13,14] and reports [Ref. 15]. Details of the braking system on the ICE train for NEC demonstration was provided by Knorr-Bremse AG through Siemens Transportation Systems, Inc. [Ref. 16]. The salient features of the brake system include:

- Dynamic/regenerative braking, returning kinetic energy to the power grid,

- Computer-controlled priority allocation of braking between dynamic and friction brakes,

- Computer-assisted fault monitoring, diagnostics, and automatic brake test,

- Communications via a fiber optic waveguide train data bus.

Major components of the ICE brake system are described below.

Major Braking Components

The ICE trainset brake control is based on the pneumatic brake pipe complying with UIC standards. Basically, the system uses (in order of preference) three types of braking: 1) regenerative braking, 2) pneumatic/electro-pneumatic friction braking, and 3) magnetic track brakes for emergency braking. There is the option of using eddy-current track brakes instead for both emergency and service braking. These are used in Germany on the ICE-V trainset, but were not included on the demonstration ICE trainset.

Dynamic/Regenerative Brakes. Electrodynamic (regenerative) braking is available on the axles of the power cars, using the ac traction motors as generators to return power to the catenary. Up to 3,300 kilowatts of power can be generated per power car. If the catenary (power system) rejects the load, however, dynamic braking capacity is lost. Microprocessor control of braking uses the dynamic braking preferentially to maximize energy regeneration and gain efficiency in operations.

Air Activated Disc Brakes. All cars (power and trailing) are equipped with a conventional automatic electro-pneumatic brake system. This pneumatic system is designed to provide alone, sufficient braking power to meet both service and emergency braking requirements in case other elements of the brake system fail. Physically, the system includes:

- Two non-ventilated discs (cast steel alloy, sintered metal pads) on each power car axle, with force generated by a double caliper brake cylinder unit for the two discs.

- Four ventilated discs (cast iron with organic composition pads) on each trailer car axle, with force generated by a single caliper and brake cylinder per disc.

Substantial research and development effort has been invested in these high-temperature brake discs to assure reliability under high thermal and mechanical stresses. In addition to the high temperature stability, these disc brakes offer less sensitivity to moisture and more uniform friction coefficients at high speeds.

Magnetic Track Brakes. Electro-magnetic track brakes are used on the trailer car bogies for emergency braking situations. This type of brake has been used by Deutches Bundesbahnen (DB) for more than 20 years, but because of substantial wear it is used only in emergency braking.

Parking Brakes. The parking brake on the coaches consists of a hand brake that actuates a separate caliper on one disc of one axle per car. The parking brakes on the power car function through spring-loading of disc pads by the brake cylinders. These are released by air pressure.

Braking Control Components

The brake system of the ICE trainset consists of a number of subsystems and components optimized to provide reliable control, plus status and diagnostic information. These major subsystems are described below.

Air Supply. Compressed air for the automatic air brake system is supplied by a Type SL20-5 rotary screw compressor in each power car, each of which provides about 2170 litre/minute (76.6 cfm) at a pressure of 10 bar (145 psig) at a rotational speed of 3400 rpm. Each compressor is driven by a three-phase ac motor at about a 22.5 kW power level. One compressor can supply the requirements of the whole train. The compressor has an integrated cooler, and air then passes through a dual chamber air dryer with integrated oil separator. A heating cartridge is mounted on the drain valve to avoid condensate freezing in winter.

The main air reservoir pressure switch is set (for U.S. operation) to cycle between 8.5 bar (123 psig) and 10 bar (145 psig); and the safety valve is set at 10.5 bar (152 psig).

HSM Driver's Brake Control Valve. The driver's brake control valve Type HSM-PEP, located in the power unit cab, controls the automatic air brake system (with additional electro-pneumatic EP-assist units) by indirect (or direct) regulation of the brake pipe pressure. The valve is used to set the desired train braking level, either manually by the operator or by the automatic train control (ATC) system. Manual operation has priority over the ATC operation. Set values are monitored by microprocessor brake control units in power and trailer cars, which control the dynamic and/or friction brake systems. In addition to the electronic control, the driver's brake valve contains an independent pneumatic control. Changeover can be effected manually by the operator or automatically through fault diagnosis by the computer. The major components of the driver's brake control system are:

- Driver's brake valve FS1
- Electrical assimilation button (for releasing overcharged brakes)
- Electronic/pneumatic operation switch (switches off microprocessor)
- Emergency vent valve NB4 (direct venting of brake pipe)
- Emergency brake unit
- Changeover unit (electronic to pneumatic operation)
- Relay valve unit
- Equalization reservoir
- Assimilator function reservoir
- Electrical relay for emergency cut-off solenoid valve
- Electronic microprocessor control HSM

The driver's brake valve FS1 has two (redundant) potentiometers generating the brake force electrical analog signal. In addition, there is a pressure regulator setting the equalization reservoir pressure, a rapid vent valve for direct or pre-controlled venting of the brake pipe, a key-operated cut-off valve, and cam-controlled switches for a) suppressing passenger emergency brake commands (inactive in U.S. demonstrations), b) emergency brake applications, and c) traction. The valve has notched positions for the following:

- Filling (suppression of passenger emergency command -- not active for U.S. operations)
- Running position
- Service brake (and release) position
    - Minimum application [1]
    - Service brake [2-5]
    - Suppression [6]
    - Service brake [7]
    - Full service [8]
- Emergency

Driver's Brake Control Unit (Brake Electronics). The brake electronics unit, located in a 19-inch rack installed in the power car, connects with the control desk, the fiber optic train data bus, the central vehicle diagnostic computer ("DAVID"), and with the drive control/regenerative brake through the train control unit (ZSG), as shown in Figure 3-6. The unit also communicates through a second RS 323 bus with microprocessor-based anti-skid units (MGS), sharing speed and diagnostic information.

The driver's brake control unit (HSM-MGS) combines brake control electronics, comprehensive diagnostics of the automatic air brake system, and anti-skid (wheel slip) protection for the power car, both in braking and traction modes. The unit controls brake pipe pressure (through EP assist) to set or release brakes, distributes brake forces to available brakes, controls the automatic brake test and continuity check, generates diagnostic data for the power car, and initiates emergency braking electrically. Each power car has one HSM-MGS unit which exchanges data with the second power car, the coaches, and other electronic devices on board via a serial interface. Data distribution is organized by the train control unit (ZSG).

Brake Control/Anti-Skid Device. The brake control and anti-skid device (MGS-SVB) is located in the center trailer car in a single 19-inch rack. This unit controls the trailer car anti-skid functions, processes signals commanding the electro-pneumatic (EP) solenoid valves for the main reservoir pipe pressure control, processes brake diagnostic information, and controls the magnetic track brakes. As shown in Figure 3-7, the unit communicates with the diagnostic computer ("ZEUS") and with the fiber optic train data bus through an RS 485 bus. Brake control signals are passed directly to the unit, bypassing the ZEUS computer, to assure fast response.

The SVB portion of the device detects the condition of each brake on the cars (pneumatic and hand brakes), monitors the operational ability of brakes, and processes this information to generate detailed status and fault messages. These data and reports are transmitted via the train data bus during both tests and in service. In addition, the unit monitors (and blocks, in the event of failure) commands to the EPZ solenoid valves.

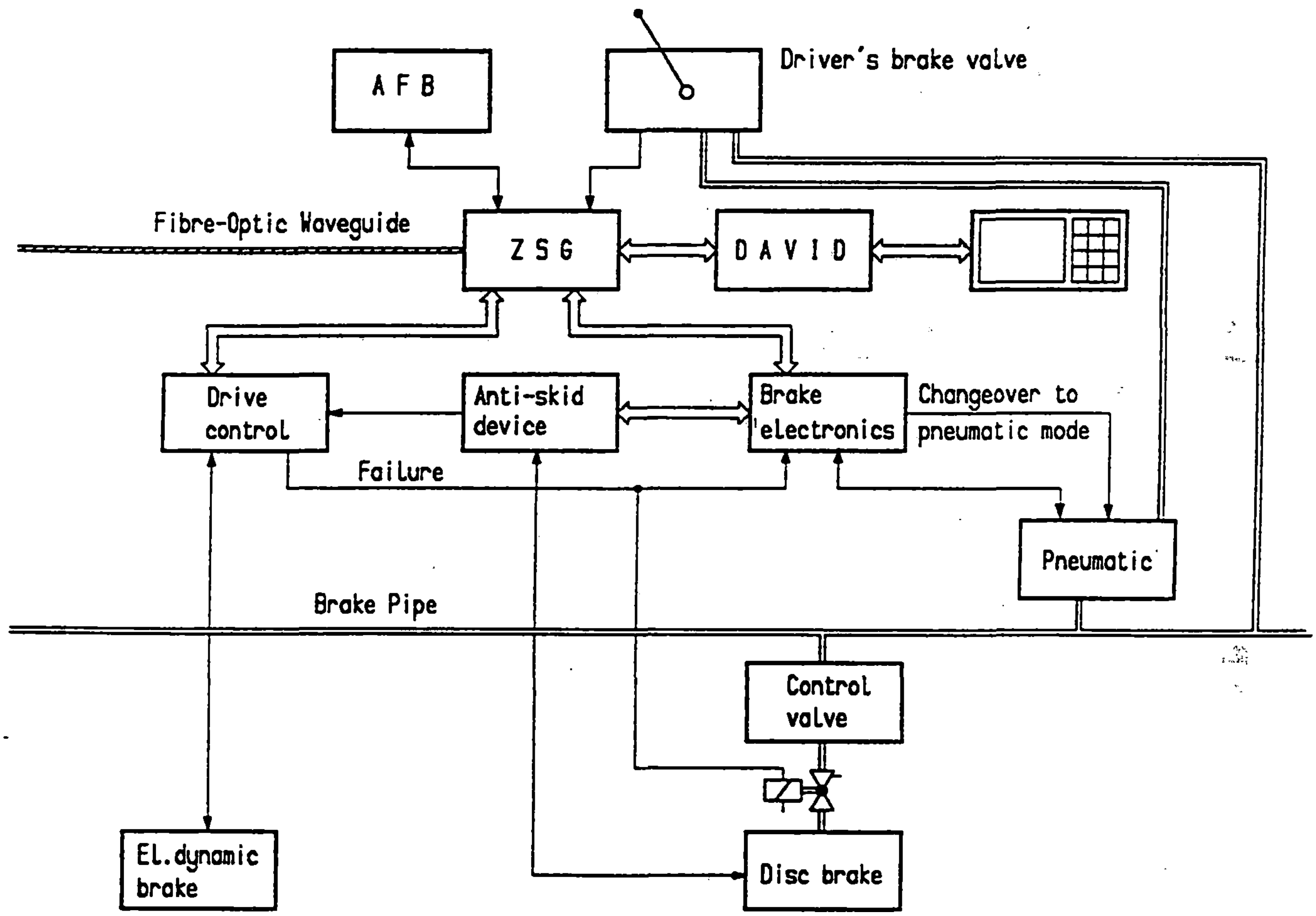

Figure 3-6. Brake Control Schematic for ICE Power Car (Ref. 12)

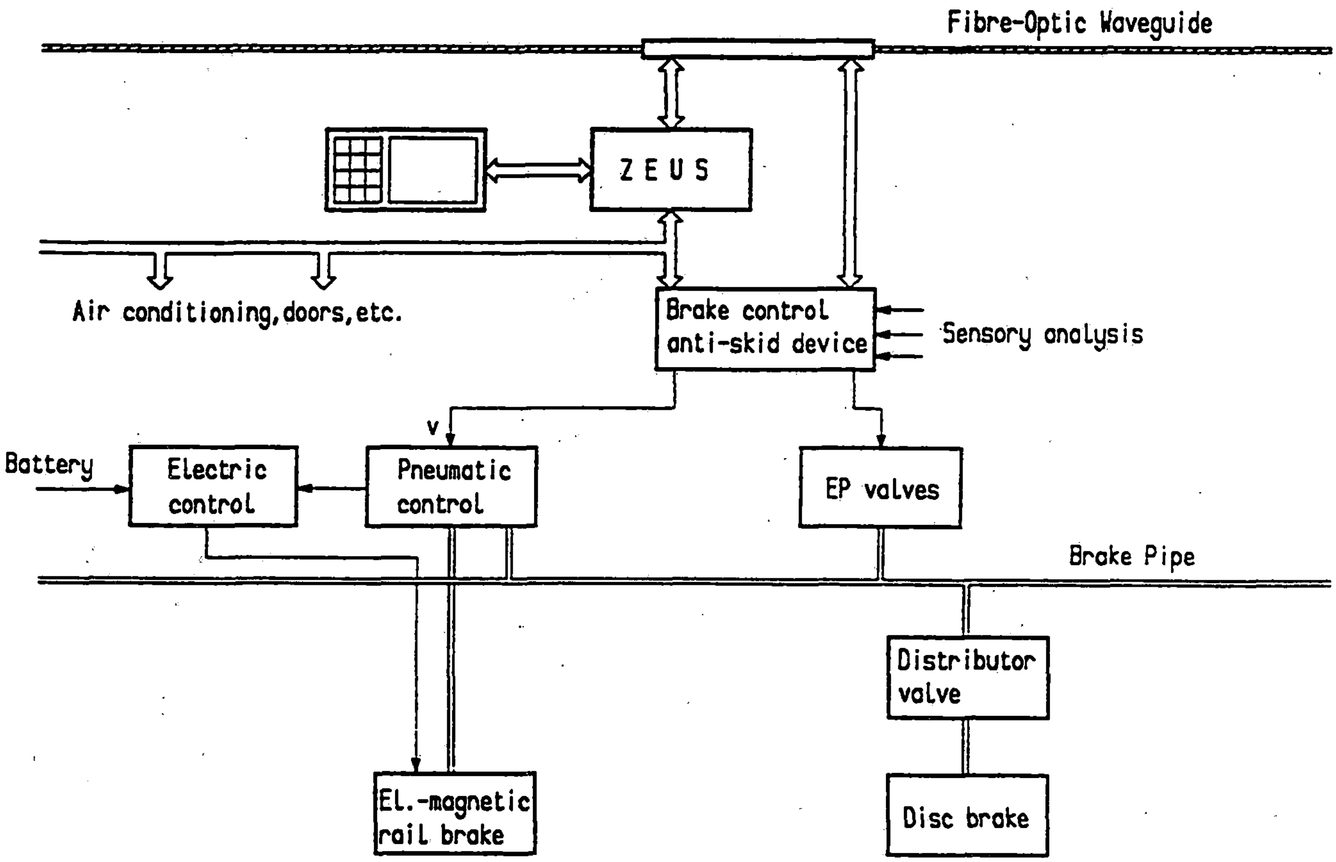

Figure 3-7. Brake Control Schematic for ICE Trailer Car (Ref. 12)

The MGS portion of the device provides microprocessor control of wheel slip through modulation of brake cylinder pressure. Control logic is based on individual axle acceleration and speed criteria to maintain braking force at optimum levels without loss of adhesion.

Anti-Skid Device (MGS). The anti-skid (wheel slip control) device reads the signal from a speed sensor, which is an 80-tooth ferromagnetic gear wheel on each axle scanned by a stationary magnetic pickup. These pulses are used to determine wheel rotational speed and change in speed, and these data are then processed to detect wheel slip through approximately 30 combined speed and retardation criteria. The microprocessor controls the anti-skid valve, which is in turn connected pneumatically to the distribution valve, allowing brake cylinder pressure to be momentarily reduced to restore the wheelset torque balance. The unit has non-volatile memory and an additional microprocessor-independent safety circuit to assure reliability.

The anti-skid device on the power car interfaces with the traction control as well as the dynamic and friction braking systems to assure optimum use of adhesion during both power and braking modes. To improve wheel/rail adhesion in adverse conditions, power cars are also equipped with sanders to sand the rail ahead of the leading wheelsets of the two bogies of the leading power car. Sand is metered according to train speed, above or below 140 km/h (87 mph), to distribute roughly the same amount of sand per distance traveled.

Passenger Emergency Brake. In revenue service on the DB, there is no emergency brake valve available for passenger access, only crew notification of an emergency. For demonstration in the U.S., however, passenger emergency brake applications could be initiated electrically by opening the emergency loop circuit with pull boxes in the coaches, venting the pre-control pressure holding the vent valve (NB11) with the magnet valve (SBV).

Deadman Control. The ICE power cars are equipped with "deadman" control which interface with one of the two magnets (FGN) which, when deenergized, cause a full service pneumatic brake application. The deadman control, however, can be pneumatically cut out by a cock [Ref. 16].

Brake System Operation

The ICE braking system is designed primarily for computer-controlled automatic speed control operations in which the on-board system is integrated with track circuits controlled from a central dispatching computer. Manual operation can override the automatic train control, but operation is still enhanced by the on-board computers and microprocessors through controlled deceleration, priority distribution of braking, and fault monitoring and diagnostics.

Automatic (Normal) Operation. Train speed is set by the automatic speed control unit (AFB) based on track circuit signals. Distribution of braking forces is executed by the AFB electronics, which will transmit a set value of dynamic braking to the traction control and any set value for additional friction braking to the HSM electronics, which in turn controls the brake pipe pressure.

Manual Operation. This mode of operation can be selected, and then the distribution of braking forces is executed by the HSM electronics. Manual operation has priority over the AFB unit. Priority braking first uses the regenerative brakes, then brings in trailer car brakes as required by speed level and deceleration needs. The power car disc brakes are not used as long as regenerative brakes are active. The dynamic brakes can be suppressed and only disc friction brakes used if, for example, disc de-icing is necessary.

The traction control receives a set value from the train control. This set value can be reduced by the HSM to achieve an optimum distribution of braking power. Control of the dynamic brakes has hysteresis to prevent unnecessary cycling of set and release.

Pneumatic Operation. In the event of an electronic failure, the brake system can switch to pneumatic operation, either manually by the operator or automatically by computer diagnostics. This mode of operation can be maintained in normal service, but wear increases on brake pads and discs.

Emergency Brake Application. In an emergency situation, all available brake systems (including the magnetic track brakes) are actuated at full levels. In the powered bogies, brake cylinder pressure remains locked except at speeds higher than 160 km/h (100 mph). In this higher speed range, a two-bar (29 psig) pressure is applied to supplement the dynamic braking, which drops off in braking power with higher speeds.

3.3.3 Braking System Performance

Technical Specifications

There is a maximum deceleration rate of 1.4 m/s^2 (0.143 g, 3.12 mph/s) with all braking systems operating, but a limit of 1.3 m/s^2 (0.133 g, 2.90 mph/s) is imposed. Braking with only friction gives a deceleration rate of 0.9 m/s^2 (0.092 g, 2.01 mph/s), where a rate of 0.85 m/s^2 is required by the UIC. A rate of 0.7 m/s^2 (0.071 g, 1.56 mph/s) is used to compute stopping distances. The dynamic brakes provide alone a deceleration rate of about 0.25 m/s^2 below 140 km/h, but drop off to about 0.1 m/s^2 by 280 km/h. Calculated braking distances for different combinations of ICE brake systems are shown in Table 3-8.

Diagnostics and Monitoring

The various brake components and subsystems are continuously monitored to determine current status and to warn of failures. The objectives of brake system monitoring and diagnosis are to maintain as many functions as possible with component or subsystem failures, and to define conditions and capabilities of the brakes at the time of failure. Error messages are reported to the appropriate computer by error codes which allocate the fault to specific components or subsystems. Faults are displayed to the operator and stored in nonvolatile memory.

Diagnostics and monitoring functions include the **automatic brake test**, which is initiated by the central computer (DAVID) as part of the automatic procedure to put the ICE train into service. This is controlled by the HSM of the occupied power car. The HSM of the

Table 3-8. Calculated Braking Distances for the ICE/USA Demonstration Train (Ref. 16)

Initial Speed, km/h (mph)	Friction Brakes meters (ft)	Friction plus Dynamic Brakes meters (ft)	Friction plus EM Track Brakes meters (ft)	Friction plus Dynamic plus EM Track Brakes meters (ft)
145 (90)	1010 (3314)	830 (2723)	790 (2592)	680 (2231)
177 (110)	1480 (4856)	1245 (4085)	1160 (3806)	1015 (3330)
210 (130)	2020 (6627)	1750 (5741)	1610 (5282)	1440 (4724)
242 (150)	2650 (8694)	2340 (7677)	2140 (7021)	1950 (6398)

unoccupied power car and the SVB units of the trailer cars have execution ("slave") functions only.

The HSM electronic unit initiates braking actions step-by-step in the automatic brake test. Brake test signals are transmitted to the subsystems via the fiber optic train data bus, and each subsystem carries out the commanded special test. A positive acknowledgement of each test criterion must be received within a set time interval, otherwise the inverted status (error) remains active. Each brake subsystem determines the correct function or a fault by self-diagnosis, comparing the set value with the actual value from a sensor. Resulting brake test diagnosis data are transmitted to the vehicle diagnostic system (computers DAVID and ZEUS) and to the HSM electronic unit. Partial brake subsystem failures are stored in the HSM electronics unit and are used in calculating distribution of braking forces.

The diagnostic system is sketched in Figure 3-8.

3.3.4 Braking System Effects on Vehicle, Guideway, and Infrastructure

Electro-magnetic rail brakes exhibit excessive wear when used and are therefore restricted to emergency stops. Similar wear of the rail running surface is probable. An eddy-current braking system is totally non-contact. It will not eliminate the use of either friction or dynamic braking, especially at high speeds. As previously stated, Amtrak is not considering the use of an eddy-current brake. However, if eddy-current braking were under consideration, substantial gains could be realized at all friction braking contact surfaces because the contribution of friction braking would decline significantly. Test results of the ICE on DB were furnished in a report provided to Mr. Al Shaw, Track Design, Amtrak. The German ICE tests revealed rail heating could be a problem with eddy-current brakes when trains are run frequently over a given track segment. Amtrak train frequency is not likely to approach those headways currently operated on DB. Some electro-magnetic interference (EMI) problems have been noted by DB in tests of eddy current brakes, particularly with axle counters and older-type track circuits.

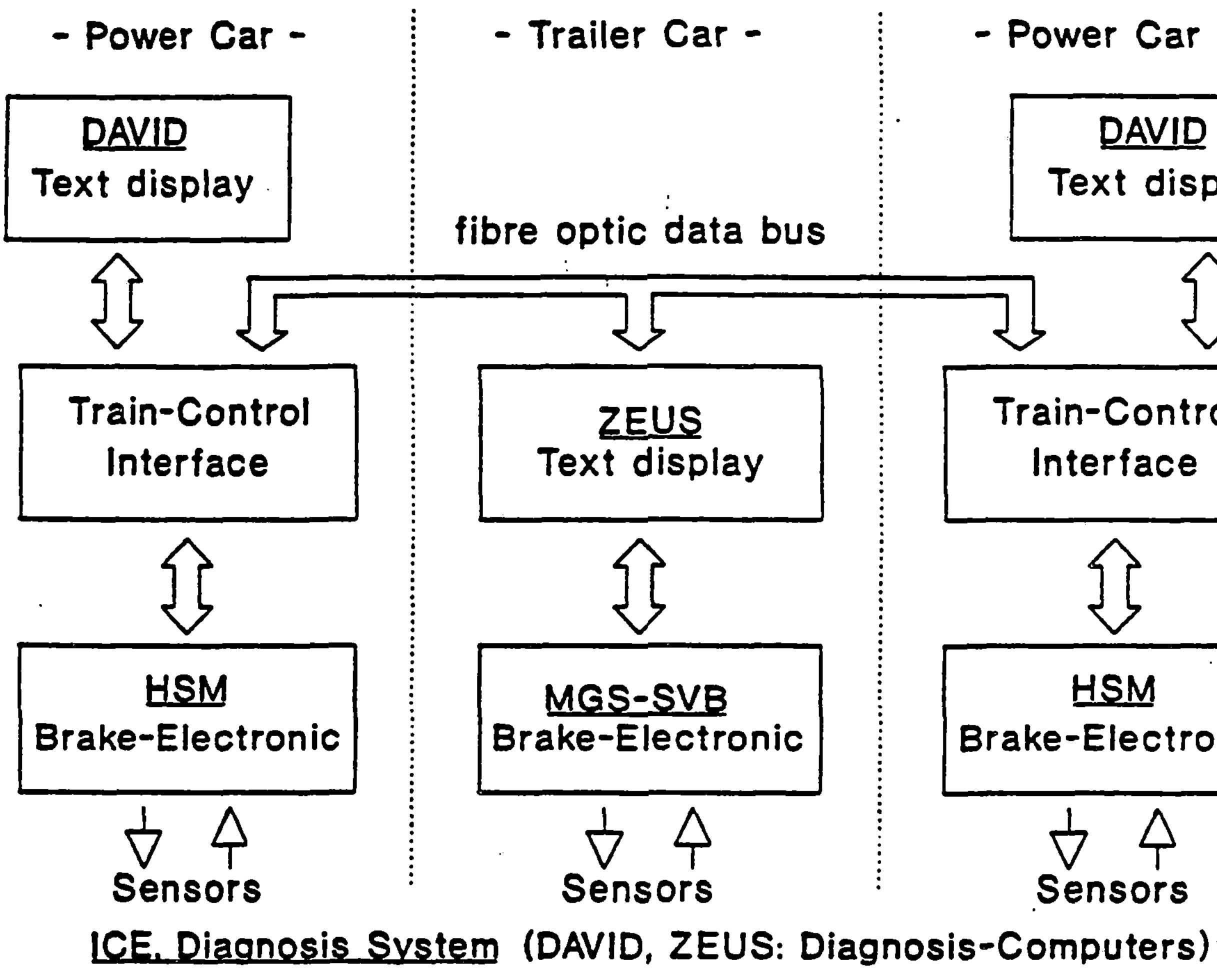

Figure 3-8. Diagnostic System of ICE Trainset (Ref. 13)

Table 3-9. ICE FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

ICE—InterCity Express (Germany) — Page 1 of 6

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Braking Control							
Pneumatic Braking Control Unit (Electronic-Pneumatic Changeover)	Fails Off	Disc brakes not automatically applied.	Operator must manually apply disc brakes. Eddy current braking ineffective below 40 km/hr; Electrodynamic braking much less effective below 20 km/hr. In emergency, operator must manually apply disc brakes. Other systems are not sufficient to stop train at low speed.	Detected by warning signal in cab and loss of braking power.	N	N	A2
	Improper Calibration	Disc brakes disproportionately applied.	None. Feedback from wheel-speed sensor should increase/decrease non-friction braking systems to compensate. Stopping distances should be maintained.	Detected by inspection and routine calibration.	Y	Y	D
Driver's Brake Valve	Fails On	Overrides ATC and applies brakes.	Assuming all other systems are functioning correctly, brake blending will occur as normal.	Indicator light and brake application	N	Y	C
	Fails Off	Loss of manual brake control.	ATC will apply brakes as needed as long as EBCU and diagnostic equipment are functioning properly.	Indicator light	Y	N	B2
"DAVID" (Power Car Diagnostic Computer)	Fails Off	Loss of primary brake status indicators. Backup unit in other power car continues to relay diagnostics.	Train switches to manual operation. DAVID unit in second power car continues to monitor train. Note, however, that train may not begin travel without undergoing an automatic brake diagnostic.	Loss of status indicators in cab. Error message sent via radio link to wayside to alert maintenance personnel.	Y[1]	Y[2]	D
	Sends Incorrect Signal	The DAVID computers in each power car and ZEUS computer in the middle trailer car are constantly monitoring the train and each other. Automatic braking will not respond to conflicting diagnostic information.	Control reverts to operator. Braking systems otherwise unaffected.	Indicator in cab. Error message sent via radio link to wayside to alert maintenance personnel.	Y	N	B2

Table 3-9. ICE FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

ICE—InterCity Express (Germany)							Page 2 of 6
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
"ZEUS" (Diagnostic computer in middle trailer car)(MGS)	Fails Off	No reduction in brake power.	Control reverts to operator. Braking systems otherwise unaffected.	Indicator in cab. Error message sent via radio link to wayside to alert maintenance personnel.	Y	N	B2
	Sends Incorrect Signal	The ZEUS computer in the middle trailer car and the DAVID computers in each power car are constantly monitoring the train and each other. Automatic braking will not respond to conflicting diagnostic information.	Control reverts to operator. Braking systems otherwise unaffected.	Indicator in cab. Error message sent via radio link to wayside to alert maintenance personnel.	Y	N	B2
Electronic Braking Control Unit (HSM-MGS)	Fails to send signal	1) Fails to activate electrodynamic brakes. 2) Fails to activate Friction brakes. 3) Fails to activate Eddy-Current brakes.	Substantial loss of braking.	Requires emergency braking/manual application of brakes	N	N	A2
	Sends incorrect signal to Electrodynamic brakes	1) Brakes over-applied. 2) Brakes under-applied.	Feedback from accelerometers should counter this effect with little change in brake operation.	1) Driver may sense extreme deceleration. 2) Unusual amount of wear to friction brakes may suggest Electrodynamic brakes are not being applied at optimum levels.	1)Y 2)Y	1)Y 2)Y	D
	Sends incorrect signal to Pneumatics	1) Brakes over-applied. Unusual wear to brake pads and discs. 2) Brakes under-applied.	1) Feedback system reduces Friction braking to compensate for over-braking. 2) Feedback system increases Friction braking. Regenerative and Eddy Current braking should already be maximized.	1) Unusual wear to brake pads and discs. 2) Undetectable, except by inspection.	1)Y 2)Y	1)Y 2)Y	D
Wheel-slip (Anti-skid) Device	Fails to detect slip	Brakes lock. Wheel skids, possibly causing wheel damage and increasing chance for future locking.	Electronic Braking Control Unit must sense that train is not decelerating properly and decrease braking.	Indicator in cab	N	N	A3

Table 3-9. ICE FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

ICE—InterCity Express (Germany)							Page 3 of 6
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Wheel-slip (Anti-skid) Device	Detects slip when none exists.	Releases brake prematurely, reducing braking power.	In either case, loss of brake power requires increasing braking. Braking distance may not be maintained at speeds under 45km/hr. Emergency braking may require use of Magnetic Track Brakes.	Indicator in cab or by inspection.	Y	N	B3
Fibre-optic Train Data Bus	Fails to carry signal (break in line)	Pneumatic braking off-line requiring manual mechanical operation. Electrodynamic brakes operational only in lead car. Loss of Eddy Current brakes "downstream" of break. Possible loss of entire Eddy Current brake subsystem.	Friction brakes must provide most of the braking force. Neither Regenerative braking nor Eddy Current braking is sufficient to stop the train within required distances.	Indicator in cab (or lack thereof)	Y	N	B2
Pneumatic (Air) Brake Pipe	Fails Closed (pipe blocked)	None. Air can still be vented to apply brakes. Brakes cannot be released, however, if blockage cuts off pressure from main line to individual axle or calipers.	None. Same levels of braking are available. Clog may need to be removed to release disc brakes.	Slight difference in pressure on either side of blockage. May require shutting off one compressor. Blocked lines feeding individual trucks will result in some brakes remaining engaged as pressure is returned to system.	N	Y	C
	Fail Open (leak)	All disc brakes are applied.	None. Friction brakes will be fully applied.	Brakes applied automatically. Gauges show loss of pressure.	N	Y	C
Regenerative Electrodynamic Braking							
Traction Motor/Generator	Fails to accept/produce current	Loss of electrodynamic braking	Friction brakes utilized. Friction brakes alone are sufficient to safely stop the train in minimum required distance. In emergency, apply both Disc and Eddy Current brakes. Disc brakes alone are sufficient to stop train in safe distance. Eddy Current brakes will help relieve wear on discs.	Indicator in cab.	Y	Y	D

Table 3-9. ICE FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

ICE—InterCity Express (Germany)							Page 4 of 6
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Traction Motor/Generator	Bearing failure, axle seizes.	Braking power may be maintained. Seizure of motor/generator may seize the associated axle, causing wheel slip.	Total loss of Electrodynamic braking power at that axle. Reduction in Friction braking at that axle if wheel locks. Friction braking at other axles must be increased to compensate.	Loss of power to that axle.	N	N	A2
Catenary for Dissipating Brake Energy	Fail to accept/dissipate energy	Dissipation occurs in motor/wiring. Loss of brake power.	Friction brakes must be applied with the help of Eddy Current brake system.	Indicator in cab.	Y	Y	D
Pneumatic Friction Brakes System							
Disc Brake Calipers	Fail Open (no braking)	Disc Brake inoperable. Feedback system increases braking at other axles to compensate.	Negligible effect on system as whole unless many calipers are effected. If brakes do not apply, feedback should signal emergency brakes to apply.	By inspection.	Y[3]	N	B3
	Fail Closed (brakes applied)	1) Wheel held fixed. Damage to wheel possible. 2) Brake pads fail. 3) Excessive wear on disc.	Brakes applied in order to quickly stop train and minimize damage.	By inspection. Damage may be obvious.	N	N	A3
Brake Discs	Fractured	Damage to brake pads. Loss of brake adhesion.	Negligible unless many discs are effected.	By inspection.	Y	N	B3
Main Air Reservoir	Fails to hold pressure	None. Second reservoir in other power car can provide enough air pressure for entire train.	None.	Gauges show loss of pressure. Brakes cannot be disengaged once applied.	Y	Y	D
Pressure Monitoring (Control/ Distributor) Valve (per Car)	Fails Open	Pressure released; brakes applied.	Above 45 km/hr, the other brake subsystems assist in slowing train, minimizing wear on disc brakes. In emergency, other braking systems contribute to stopping train up to limit of allowable deceleration.	Brakes applied. Low-Pressure indicator in cab. Requires test to determine cause.	N	Y	C

Table 3-9. ICE FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

ICE—InterCity Express (Germany)							Page 5 of 6
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Pressure Monitoring (Control/ Distributor) Valve (per Car)	Fails Closed	Pressure not released at this valve. Unless bleeding occurs at other valves, brakes will not be applied.	Negligible if venting occurs at another valve. Response time suffers. In emergency, negligible above 45 km/hr unless all valves have failed. Electrodynamic brakes can slow vehicle to about 10 km/hr. Magnetic track brake may be required.	By inspection.	Y	N	B3
Rotary-Screw Air Compressor	Fails to provide pressure	Second compressor initiated. One compressor alone can supply enough pressure for train. If both compressors fail and pressure is lost - brakes are applied. Takes longer to recharge air reservoirs and release brakes. May cause premature wear to discs and brake pads. Problem is with brake release, not application.Friction brakes not disengaging.	None.	Low-pressure indicator in cab. Compressor failure indicator.	Y	Y	D
	Supplies too much pressure	Pressure regulating valve vents excess air to maintain pressure at acceptable level. Electropneumatic changeover calibration may be effected.	Brake application may be slightly delayed while venting excess air. Electrodynamic brakes should slow train. Overall effect should be negligible.	High pressure light on. Compressor status indicator in cab.	Y	Y	D
Magnetic Track Brakes							
Wear Plate (contact surface with rail)	No magnetic attraction/fails to make contact	Substantial (if not complete) loss of magnetic track braking on that car.	Braking power reduced in emergency situation. This is an emergency measure which is applied only after all other brake subsystems are fully applied.	Indicator in cab.	Y	N	B3

Table 3-9. ICE FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

ICE—InterCity Express (Germany)							Page 6 of 6
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Eddy Current Brake System[4]							
Eddy Current Brake System (Magnetic Coils, switching equip., etc.)	Fail Off	Loss of Eddy Current braking.	ATO senses train not slowing down, increases braking effort in electrodynamic and disc brakes.	Indicator in cab. Unusual wear to disc brakes, result of inspection/diagnostic.	Y	N	B3

1. If train is in motion.
2. Due to redundant unit, operator action is not required.
3. If few axles affected.
4. Eddy current brakes not yet available in revenue service. A truck would be fitted with either eddy current brakes or magnetic track brakes, not both.

3.4 TGV ATLANTIQUE

3.4.1 Description of Trainset

The French National Railway (SNCF) Train a Grande Vitesse (TGV) represents a French high-speed rail technology that has been in successful service operation since 1981. To date, SNCF has transported over 160 million people on two operating TGV lines with an impressive safety record.* The TGV Sud-Est (TGV-SE) has been in revenue operation since 1981 at a maximum speed of 270 km/h (168 mph). Planning for the TGV Atlantique (TGV-A), began in 1978 and construction was started in 1985. The TGV-A provides high-speed service between Paris and Brittany and Bordeaux. Over sections of dedicated right-of-way, the train operates at normal service speeds of 300 km/h (186 mph). On conventional lines, the speed is restricted to 220 km/h (137 mph). Maximum gradients on these lines are 2.5 percent (1 in 40), and less than the 3.5 percent (1 in 28.5) on the TGV-SE lines to Lyon.

The TGV-A consists of the following equipment:

- two power cars (two 2-axle bogies each, 8 axles total at 17 metric tons/axles),
- two transition cars connected by articulated joints (one 2-axle bogie, one shared, 2-axle bogie each, 6 axles total at 17 metric tons/axle, maximum under any operating condition), and
- eight trailing cars connected by articulated joints (2 shared bogies each, 16 axles axles total at 17 metric tons/axle, maximum under any operating condition).

The TGV-A trainset weighs 475 metric tons (523 tons) with a normal passenger load. The trainset length is 237.59 meters (779 ft-6 in). This trainset includes many technological advances including: 1) three-phase synchronous traction motors, 2) carbody mounted traction motors with a unique sliding tripod transmission, 3) articulated intercar connections forming a fixed consist arrangement, 4) very high-speed stucks with a unique pneumatic secondary suspension, and 5) a computerized communication network for distributed train control.

3.4.2 Braking System Design

The braking system of the TGV train has been described in general in several publications [Refs. 17-20]. Details of the braking system on the TGV train for NEC demonstration was provided in a proprietary "white paper" prepared by GEC Alsthom/Bombardier Inc. [Ref. 21]. The TGV train has an electro-pneumatic two-pipe brake system conforming with UIC standards. A key feature of the braking system is the control, from a brake demand, on a

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* In a recent incident, an undetected underground WW1 bunker collapsed beneath the track, causing a 7-meter-long hole. A TGV travelling at about 295 km/h passed over the hole, which derailed the last four cars of the train. In braking to an emergency stop in over 2 km, the four cars remained upright and only one of 200 passengers was slightly injured.

per-truck basis. To achieve this, each truck has its own pneumatic brake control panel. In addition, wheel slide protection is provided on a per-axle basis for the trailer trucks. Other salient features of the brake system include 1) fixed-consist operation, 2) on-board monitoring and diagnostics, 3) advanced train control systems, and 4) a failsafe, fault-tolerant design.

Major components of the TGV brake system are described below.

Major Braking Components

The TGV braking system consists of a combination of rheostatic (dynamic resistive), electro-pneumatic, and friction braking which are blended automatically. In the power car, the proportion of electric brake effort provided varies with speed and the brake demand. These are independent systems for each driving bogie on the power cars. Normally, the dynamic brake is powered from the catenary, but there are backup batteries for each driving truck. Resistor grids are located on the roof of power cars. The power is not fed back to catenary, but always dissipated into heat, avoiding loss of dynamic braking in the event of catenary power loss or rejection.

The pneumatic friction brake system powers all axles of the trainset. These brakes are controlled by commands transmitted through brakepipe pressure changes, complemented by an electro-pneumatic train line for faster response throughout the length of the train. The main features of the friction braking are:

- Two double disc brakes (eight brake cylinders per truck) and four non-ventilated discs per axle on non-driving axles, with alloy steel discs and sintered metal linings (pads) to withstand higher temperatures,
- Tread brakes on the wheels of driving bogie,
- Pneumatic power (UIC standards) via brake pipe, complemented by electro-pneumatic valves and trainline for faster response,
- Independent and redundant controls per bogie, including microprocessor-based anti-skid system which controls each axle independently,
- Spring loaded, air released parking brakes on one axle per driving bogie, with no hand or parking brakes on other car axles.

Braking is blended automatically by the computer to maximize dynamic braking. Blending will use the dynamic brake up to its maximum power level 1620 kW/truck, or about 6480 k/W trainset) and distribute the remaining braking power to the trainset friction brakes. Tread brakes on the powered bogies are used only as the train nears a stop, or as a backup to the dynamic brake in case of a failure.

Uniform distribution of a command brake pipe pressure reduction is achieved by the electro-pneumatic (EP) valves for each truck. Pressure is modulated at additional EP valves on each axle by the electronic anti-skid control units. A separate EP valve on the truck changes braking effort level as a function of train speed. Electrical speed sensors provide the axle speed signals for both slip control and braking level functions.

3.4.3 Braking System Performance

Technical Specifications

A full train weighs approximately 475 metric tons (523 tons). A maximum emergency deceleration rate of 1.2 m/s^2 (0.122 g, 2.70 mph/s) is quoted for the trainset from 320 km/h with a stopping distance of 4.38 km in 98 seconds. The operating deceleration rate is 0.33 m/s^2 (0.034 g, 0.75 mph/s) for a stopping distance of 11.91 km in 266 seconds. Typical braking distances to stop are given in Table 3-10.

Table 3-10. TGV-A Trainset Stopping Distances for Typical Conditions

Speed km/h (mph)	Distance m (ft)	Condition
180 (112)	1150 (3772)	Dry rail, level tangent track, emergency braking, dynamic brake on batteries
270 (168)	2700 (8856)	
300 (186)	3580 (11750)	
230 (143)	2300 (7544)	Wet rail, automatic sanders

For braking purposes, the following reduced adhesion levels are assumed: 8 percent at 300 km/h, 11 percent at 200+ km/h, and 15 percent from 200 down to 40 km/h. Brake cylinder pressure is modulated according to speed: 2.9 bar (42.6 psig) for speeds less than 215 km/h (134 mph), 2.3 bar (33.8 psig) for speeds of 215 km/h or higher for maximum service brake pipe reduction (1.5 bar, 22 psig) to emergency brake pipe reduction (three bar, 44 psig).

Diagnostics and Monitoring

The TGV trainset has an on-board detection, monitoring, and self-diagnostic system. Individual microprocessors on power and trailer car trucks monitor equipment, detect faults, and store fault code and circumstances for future maintenance. Fault codes are sent to the driver's cab computers for display and transmission to other central computers, such as train control and maintenance facility computers.

Braking System Operation, Control and Safety Features

Operation and Control. The train operator (driver) controls acceleration/ deceleration by means of the traction controller wheel, which sets the intensity of the function (traction power or rheostatic braking). A separate control sets friction braking through pneumatic and electro-pneumatic control, blended with the rheostatic braking automatically by the computer to maximize dynamic braking.

The driver is responsible for normal on-board operational train control, assisted by microprocessor monitoring and display. The dynamic brake function is available to the driver through the traction-braking master controller. This controller permits the driver to apply power per brake to control train speed. A separate control allows access to the air brakes for the trainset via the brake pipe. When this control is used, the control computers will normally rely on dynamic braking with no reduction in brake pipe pressure until required for additional braking effort. This reduces friction wear. Separate microprocessors control traction-braking of each motor truck, providing the following functions:

- Distributes braking (dynamic has priority),
- Monitors dynamic brake power dissipated,
- Provides wheel slip control,
- Detects, records, and displays faults such as brakes not released, truck running instability.

Separate microprocessors on each trailer car truck similarly provide wheel slip control in braking and fault detection.

Braking is also controlled through the driver's automatic brake valve (ABV) through the electrical train line and EP valves, or through pneumatic control of the brake pipe directly. Independent from the ABV are additional brake control features. These include:

- Automatic Train Control (ATC),
- Deadman control,
- Emergency "punch" valves in the cab (two),
- Emergency brake valves in cars T1 and T3 for crew use.

Passengers have no direct access to emergency brakes per se, but instead have emergency signals which alert the crew to problems.

Safety Features

Brake tests are initiated by the operator, automatically assisted by computer controls, data processing networks, and remote sensors (pressure, running stability, etc.). Automatic inspection and diagnostic systems check system status once per minute by car and bogie, and provide status read-out for the operator. Anti-skid functions on each axle are checked during each stop.

Speed reduction tables, which provide a matrix of maximum operating speeds for different combinations of brake failures, are used to define the allowed speeds as faults occur. For example:

- Failure of one trailer car bogie friction brake, plus one power car bogie dynamic brake is the limit for no speed reduction.

- Failure of four friction and four rheostatic (dynamic) bogie brake systems requires initiation of emergency stop.

The driver is required to notify Central Traffic Control of any combination of failures. An automatic train stop is initiated if operator exceeds speed limit (per signal aspect) plus 10 km/h. There is no override, and a full stop penalty is assessed.

Failsafe features of the TGV trainset, with more than 10 years of revenue service experience, may be summarized as follows:

- System complies with UIC standards,

- Vital functions are continuously and automatically monitored, including...
  - brakes
  - truck stability
  - cab signalling
  - traction drive equipment

- Monitoring functions are tested automatically at regular intervals,

- There is built-in redundancy in system components,

- There is information exchange between on-board computers and microprocessors and wayside installations,

- There is a standby computer (the auxiliary cab computer), and,

- The dynamic brakes are independent of catenary power.

Braking System Effects on Vehicle, Guideway, and Infrastructure

The TGV trainsets do not use auxiliary emergency braking systems such as electro-magnetic friction track brakes or eddy current brakes. Future use of such systems is not addressed in any of the available documents. Effects on the guideway and infrastructure are therefore limited to maximum longitudinal wheel forces generated at the wheel/rail contact patch for the expected levels of adhesion. High dissipated heat levels will be generated at the dynamic brake resistor grids and at the friction brake discs. Much research and development has been applied in the design of high-temperature brake discs and pads to withstand these high temperatures without damage or failure.

No unusual electro-magnetic effects on signalling or control due to braking functions are anticipated from TGV operations.

Table 3-11. TGV FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France)							**Page 1 of 9**
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Braking Control							
Driver's Cab Computer	Fails incorrect output, off	Auxiliary computer comes on-line instantaneously.	No effect.	Computer senses failure, notifies operator, and continues operation with auxiliary computer.	Y	Y[1]	D
ElectroPneumatic (EP) Brake Control (includes electric signal lines)	Fails on	Friction brakes applied or stays applied for all trucks.	Unintentional friction braking for all trucks.	Operator notified via the cab control computer. Train stops.	N	Y[2]	C
	Fails off	Friction brakes not applied or released if already applied for all trucks.	Friction braking not available for all trucks.	Operator notified via the cab control computer. Operator must utilize pneumatic brake control.	Y	N[3]	B2
Pneumatic Control	Fails on	All friction brakes on the train would not release or would be applied resulting in excessive wear on brakes and discs and possibly wheels.	All friction brakes on the train would not release or would be applied resulting in excessive wear on brakes and discs and possibly wheels.	Operator notified via cab control computer. Train stops.	N	Y[2]	C
	Fails off	No effect, continues to use EP control. However, now there is no backup control for the friction brakes.	No effect, continues to use EP control. However, now there is no backup control for the friction brakes.	Assume operator is notified via cab control computer. Maintenance action taken at first opportunity. Emergency valves still available as backup.	Y	Y	D
Passenger Car Control Computer (Assume it monitors the equivalent of one trailer truck's, two axles, wheel slide system)	Fails off with wheels sliding	No wheel slide protection for the truck. Wheel slide resulting in excessive wear on wheels and rails.	Two (2) axles may experience wheel slide.	Operator notified via cab control computer. Must stop and manually isolate failed brakes and continue within speed limits defined for operating with failed brakes.	N	N	A3
Control for Wheel Slide Protection (controls each axle independently, includes speed sensor and EP valve per axle)	Fails with output failing to modulate the brake cylinder pressure.	Results in maintaining current brake level, not alleviating wheel slip. Braking applied to axle is above desired braking level resulting in wheel slip. This causes excessive wear on wheels and rails.	Over application of brakes on one axle causing wheel slide for the axle.	Wheelslide indicated to driver. Assume driver can isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France) — Page 2 of 9

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Control for Wheel Slide Protection (controls each axle independently, includes speed sensor and EP valve per axle)	Fails with output requesting brake cylinder pressure to be vented, thus keeping the valve open.	Braking applied to axle is below desired braking level resulting in reduced or no braking for the axle associated with the failed control.	Reduces available braking by the effect of one axle.	Assume operator receives indication of lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3
AE1 (Trailer Truck)	Incorrect input signal	AE2 from adjacent truck is used. (AE2 obtained via electronics independent of AE1)	No effect.	Wheel Slide Protection Control senses failure and switches to AE2 and stores failure for future diagnostics.	Y	Y	D
AE2 (Trailer Truck)	Incorrect input signal	No effect, AE1 is still used, but only EB will be available as a backup to AE1.	No effect, AE1 is still used, but only EB will be available as a backup to AE1.	AE1 still available so nothing is effected. Wheel Slide Protection Control senses failure and stores failure for future diagnostics.	Y	Y	D
EB (Trailer Truck)	Incorrect input signal.	No effect, uses AE1 or AE2. No backup for AE2 will be available if AE1 fails.	No effect, uses AE1 or AE2. No backup for AE2 will be available if AE1 fails.	Wheel Slide Protection Control senses failure and stores failure for future diagnostics.	Y	Y	D
AE (Motor Truck)	Incorrect input signal	EB from adjacent truck is used. (EB obtained via electronics independent of AE)	No effect.	Wheel Slide Protection Control senses failure and switches to EB and stores failure for future diagnostics.	Y	Y	D
EB (Motor Truck)	Incorrect input signal.	No effect, uses AE signal, but no backup is available for AE.	No effect, uses AE signal, but no backup is available for AE.	Wheel Slide Protection Control senses failure and stores for future diagnostics.	Y	Y	D
Control and EP Valve Changing Brake Effort Level (includes speed sensor)	Fails with output requesting braking above level required.	Braking applied to truck is above desired braking level, but Wheel Slide Protection Control prevents wheel slide.	One truck may brake too much. Overheating of brakes and wear on components possible.	Speed reduction beyond level desired. Wheel Slide Protection control may be overworked. If excessive, operator may stop train, isolate failed brake(s) manually, continue within speed limits for operation with failed brake.	N	Y	C

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France)							Page 3 of 9
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Control and EP Valve Changing Brake Effort Level (includes speed sensor)	Fails with output requesting braking below level required.	Braking applied to truck is below desired braking level resulting in reduced or no friction braking for the truck associated with the failed control.	Reduces available friction braking by the effort of one truck.	Assume computer signals operator. Continue without braking of one axle, or stop and isolate failed axle and continue within speed limits for operation with failed brake.	Y^4	N	B3
Traction Motor Control Computer	Fails, braking is above level requested.	Braking power for the truck with the failed computer will be too high and distribution between braking systems may be incorrect. Excessive wear on wheels as they potentially slide.	Too much rheostatic braking for the one truck with the failed computer. Distribution of braking power between systems may not be correct.	Computer signals operator. Operator can manually decrease braking via traction control wheel and/or pneumatic brake controller.	N	Y	C
	Fails, braking is below level requested including no braking.	Braking power requested will not be supplied. Braking power for the truck with the failed computer will be too low and distribution between braking systems may be incorrect.	Too little rheostatic braking for the one truck with the failed computer. Distribution of braking power between systems may not be correct resulting in excessive wear on friction brakes.	Computer signals operator. Operator can manually increase braking via traction control wheel and/or pneumatic brake controller.	Y^4	N	B3
Rheostatic Braking							
Motor Truck							
Resistor Grids (2)	Inability to dissipate energy/heat	Decrease or loss of rheostatic braking for the truck.	Braking force distribution must be weighted more or all with friction braking. Increased wear on friction brakes.	Computer monitors power dissipation and informs operator of this level. Increase friction braking as required via computer blending.	Y^5	Y	D
Catenary Power	No power	Switch to battery power.	Increase in friction braking to offset lower rheostatic braking so that total braking effort is only marginally decreased.	Computer automatically switches power when senses failure, then automatically changes power source and braking power distribution.	Y	Y	D
Battery and Battery Charging System	No battery power	No effect except that there will be no backup for rheostatic braking for the truck with a failed battery system.	No effect except that there will be no backup for rheostatic braking for the truck with a failed battery system.	Assume computer notifies operator of battery loss for the truck. Repair at first maintenance opportunity.	Y	Y	D

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France)							Page 4 of 9
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Traction Motor (2)	Does not produce current to dissipate in resistor grids.	No rheostatic braking for the truck associated with the failed traction motor.	No rheostatic braking for this truck. Increased braking necessary from other trucks, possibly rheostatic or friction or both via blending of the brakes.	Computer signals operator of braking loss for the truck. Continue operation within speed limits defined for operation with failed brakes.	Y[6]	N	B3
	Bearing failure, axle seizes.	Unintentional wheel slide. Wheel slide protection control attempts to alleviate wheel slide.	Unintentional wheel slide for one motor truck.	Computer signal operator of wheel slide. Stop train, manually isolate failure if possible, continue operation within speed limits for operation with failed brake.	N	N	A2
Blowers for Resistors (powered by current to resistor grids) (3 blowers)	Fail on/high	Increased wear on blower.	Eventual early replacement of blower.	Computer monitors power dissipation. Maintenance and inspection.	Y	Y	D
	Fail off/low	Increased heating of resistors and potential for resistor failure.	Over time loss of rheostatic braking potential for the truck associated with the overheating resistors.	Computer monitors power dissipation. Maintenance and inspection.	Y	N	B3
Blowers for Motors (powered by current to resistor grids) (1 blower)	Fail on/high	Increased wear on blower.	Eventual early replacement of blower.	Computer monitors power dissipation. Maintenance and inspection.	Y	Y	D
	Fail off/low	More wear on motors (2) and heat dissipation in motor. Could result in failed motor.	Over time decreased capability for rheostatic braking for the truck as well as reduced ability for traction power. Potential loss of motor.	Computer monitors power dissipation. Maintenance and inspection.	Y	N	B3
Friction Brake System							
Trailer Truck							
Electropneumatic Valve Apply	Fails open	Brake applied or stays applied for all friction brakes. If valve fails partially open, brakes will gradually be applied as the pressure drop becomes larger in the brake pipe.	Unintentional braking for all friction brakes. Effects entire trainset.	Operator notified via the cab control computer.	N	Y[2]	C

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France)							Page 5 of 9
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Electropneumatic Valve Apply	Fails closed	Brake not applied or released if already applied for the trailer truck associated with the failed valve.	Friction braking not available for the trailer truck associated with the failed valve.	Operator notified via the cab control computer. Continue within speed limits for failed brakes.	Y[4]	N	B3
Electropneumatic Valve Release	Fails open	Brake not applied, or released if already applied, for the trailer truck associated with the failed valve. If valve fails partially open, brake will gradually be released or unable to be applied as the pressure increases in the brake pipe.	Friction braking not available for trailer truck associated with failed valve.	Operator notified via the cab control computer. Continue within speed limits for failed brakes.	Y[4]	N	B3
	Fails closed	Once brakes applied for the trailer truck associated with the failed valve, they cannot be released.	Once brakes applied for the trailer truck associated with the failed valve, they cannot be released.	Operator notified via the cab control computer. Manually isolate failed brakes and continue within speed limits defined for operating with failed brakes.	N	Y[7]	C
Main Reservoir Line	Low Pressure	Potentially unable to recharge auxiliary reservoir pressure after brake application.	Potentially unable to apply friction brake for all friction brakes if all reservoirs and main line have insufficient pressure.	Pressure sensor signal transmits to cab control computer which sends information to operator. Main reservoir opens to increase pressure in main reservoir line. Compressor turns on.	N[8]	Y	C
Brake Pipe Line	Low Pressure	Applies friction brake.	Friction brake is applied for all trailer and driving trucks.	Computer signals operator of low pressure. If braking not desired, operator acts to restore pressure via compressor and reservoirs.	N	Y[2]	C
Brake Cylinder (8 per truck)	Fails no pressure on disc brake	Loss of friction braking for disc associated with failed brake cylinder.	Loss of friction braking for disc associated with failed brake cylinder.	Computer monitoring notifies operator. The number of failures is considered when braking is applied to ensure sufficient braking is available. If sufficient number fail, speed limits for failed brake operation must be followed.	Y[4]	N	B3

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France) Page 6 of 9

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Brake Cylinder (8 per truck)	Fails full pressure on brakes	Friction brake applied for disc associated with failed brake cylinder. Excessive wear on brakes and/or overheating possible.	Friction brake applied for disc associated with failed brake cylinder.	Computer monitoring notifies operator. Operator stops train to isolate failed brakes, speed limits for failed brake operation must be followed.	N	N	A3
Disc (4 discs per axle)	Missing disc	Reduces friction braking power on one trailer truck axle by 25%	Reduces friction braking power on one trailer truck axle by 25%	Detected via maintenance and inspection. Increase other friction braking and/or increase rheostatic to offset lost braking power.	Y[4]	N	B3
	Worn disc	Reduces friction braking power on one trailer truck axle by <25%	Reduces friction braking power on one trailer truck axle by < 25%	Detected via maintenance and inspection. Increase other friction braking and/or increase rheostatic to offset lost braking power.	Y[4]	N	B3
Caliper	Fail open or slightly open	Reduces friction braking power on one trailer truck axle by 25% or some amount less than 25% if partially fails open.	Reduces friction braking power on one trailer truck axle by 25% or some amount less than 25% if partially fails open.	Detected via maintenance and inspection, computer signals to operator. Increase other friction braking and/or increase rheostatic to offset lost braking power.	Y[4]	N	B3
	Fails closed	Brake constantly applied to disc associated with failed caliper. Excessive wear on brakes and/or overheating possible.	Brake associated with failed caliper is constantly applied. Results in braking when braking not requested.	Detected via maintenance and inspection, computer signals operator. Stop train, isolate failed brake(s) manually, continue within speed limits for operation with failed brake.	N	N	A3
Auxiliary Reservoir	Fails with low pressure	Potentially unable to apply friction brake or, if already applied, will release friction brakes for the trailer truck associated with the auxiliary reservoir with low pressure.	Potentially unable to apply friction brake or, if already applied, will release friction brakes for the trailer truck associated with the auxiliary reservoir with low pressure.	Computer signals operator. Main reservoir and line open to feed auxiliary reservoir to normal pressure. Compressor turns on to fill main reservoir.	Y[4]	N	B3

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France)							Page 7 of 9
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Compressor (2)	Fails to provide enough pressure	Potentially unable to apply or release friction brakes for all trailer and motor trucks. May be offset by second compressor in other locomotive.	Potentially unable to apply or release friction brakes for all trailer and motor trucks.	Computer signals operator of compressor operation. Assume emergency brakes applied until pressure can be reestablished, if possible.	N	Y	C
	Fails by providing too much pressure	High pressure builds in main reservoir.	Assume pressure relief valve is available on main reservoir.	Assume operator is notified and relief valve operates automatically. Compressor(s) can be shut off to prevent further pressure build up.	Y	Y	D
Main Reservoir (2)	Fails with low pressure	Potentially unable to apply or release friction brakes for all trailer and motor trucks. May be offset by second reservoir in other locomotive.	Potentially unable to apply or release friction brakes for all trailer and motor trucks.	Computer signals operator. Compressor turns on to recharge reservoir.	N	Y	C
	Fails with high pressure	High pressure builds in main reservoir.	Assume pressure relief valve is available on main reservoir.	Assume operator is notified and relief valve operates automatically. Compressor (s) can be shut off to prevent further pressure build up.	Y	Y	D
Main Reservoir Safety Pressure Valve	Fails open	Air is vented from main reservoir resulting in low pressure in main reservoir resulting in application of friction brakes or excessive running of compressors or both will result.	Air is vented from main reservoir resulting in low pressure in main reservoir resulting in application of friction brakes or excessive running of compressors or both will result.	Gauges in cab indicate low pressure of reservoir. Assume driver has indicator of compressor operation in cab also.	N	Y	C
	Fails closed	No effect. If a combination of MRS overpressurization and safety valve failing closed occurs, there would be no relief for overpressurization.	No effect. This requires a second failure for this failure to have any impact.	Inspection and maintenance should detect valve failure. Repair at first maintenance opportunity.	Y	Y	D
Air Dryer (2)	Fails with air too wet	Wear on components. Component corrosion over time.	Wear on components. System contamination and possible corrosion.	Maintenance and inspection checks.	N	Y	C

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France)							**Page 8 of 9**
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Motor Truck[9]							
Tread Brakes (in place of disc brakes of trailer truck) only used at low speed, < 30km/hr or emergency	Fail open or slightly open	Reduces friction braking power on one motor truck axle by 25% or some amount less than 25% if partially fails open.	Reduces friction braking power on one motor truck axle by 25% or some amount less than 25% if partially fails open.	Detected via maintenance and inspection, computer signals to operator. Increase other friction braking and/or increase rheostatic to offset lost braking power.	Y[4]	N	B3
	Fails closed	Brake constantly applied to wheel associated with failed tread brake. Wear on treads and wheels may result as well as brakes overheating.	Brake associated with failed tread brake is constantly applied. Results in braking when braking not requested. Potential of wheel slide and excessive wear on tread brakes.	Detected via maintenance and inspection, computer signals operator. Stop train, isolate failed brake(s) manually, continue within speed limits for operation with failed brake.	N	N	A3
Emergency Braking[10]							
Emergency Punch Valves (2) Operator Access	Fails open	Brake applied or stays applied for the train.	Unintentional emergency braking for all cars.	Operator notified via the control computer. Must recharge system and restore valve to closed position.	N	Y	C
	Fails closed	Unable to apply emergency brakes via the valve. They are independent so that assume only one fails at a time.	Need to apply remaining emergency punch valve. Emergency brakes can still be applied.	Braking not begun by application of first valve. Apply second valve.	Y[11]	N	B2
Electropneumatic Valve Deadman (activated by speed control, if 10 km/hr over limit, suppression control, or deadman control)	Fails open	Brake applied or stays applied for the train.	Unintentional emergency braking for all cars.	Operator notified via the control computer. Must recharge system and restore valve to closed position.	N	Y	C
	Fails closed	Unable to apply emergency brakes via the valve.	Emergency braking not automatically applied. Slight delay as operator is informed to apply emergency brake.	Computer signals operator of need to apply emergency brake. Operator applies emergency brake via punch valve.	Y[11]	N	B2

Table 3-11. TGV FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

TGV Atlantique—Train a Grande Vitesse (France)							Page 9 of 9
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Traction Motor Control Computer	Fails to provide rheostatic braking.	No rheostatic braking for the truck with the failed Traction Motor Control Computer.	No rheostatic braking. Friction braking increased to maximum and other trucks braking increased as necessary, if available.	Detected via electromechanical relays, independent of electric, that sense rheostatic brake failure in which case the relays proceed with emergency braking that is all friction braking.	Y	Y	D
Emergency Valves (2) Crew Access	Fails open	Brake applied or stays applied for the train.	Unintentional emergency braking for all cars.	Operator notified via the control computer. Must recharge system and restore valve to closed position.	Y	Y	D
	Fails closed	Unable to apply emergency brakes via the valve.	Delay in application of emergency brakes.	Crew unable to apply emergency brake. Crew must contact driver to apply emergency brakes. Assume condition warranting emergency braking is signalled to operator via computer.	Y[11]	N	B2
Sanders (automatically initiated by Wheel Slip Protection Control of motor truck for speeds >30 km/hr)	Do not sand sufficiently	Increased stopping distance	Increased stopping distance	Not detected except by increased stopping distance unless computer monitors to what degree the sanders are operating.	Y[12]	Y[12]	D

Table 3-11. TGV FMEA Worksheet (cont.)

1. Backup computer.
2. Even though this failure results in the friction brakes being applied, this failure may not be failsafe if it occurs at high speeds.
3. Redundant pneumatic control can be applied by operator.
4. If few failures.
5. Computer increases friction brake.
6. Computer increases other braking.
7. Brake applied only for this truck. Even though this failure results in the friction brakes being applied, this failure may not be failsafe if it occurs at high speeds.
8. Unless ABP can recharge Auxiliary reservoir.
9. Same as trailer truck except as noted here.
10. Includes means to apply the friction and rheostatic brakes that are both utilized, if possible, in emergency situations. Capable of stopping with only friction brakes.
11. Operator must apply another valve.
12. May result in unexpected increase in stopping distance.

3.5 BRITISH RAIL INTERCITY 125

3.5.1 Description of Trainset

The InterCity 125 is also known as the High Speed Train (HST). The IC125's were procured between 1976 and 1980 to operate at speeds up to 201 km/h (125 mph) over routes where conventional locomotive-hauled services were limited to 161 km/h (100 mph).

The IC125 operates in fixed formations of either 7 or 8 MkIII trailer coaches with a Class 43 diesel-electric locomotives (power cars) at each end. These locomotives are each powered by a 12-cylinder, 1680 kW (2250 hp) diesel engine. In tests, the prototype trainset achieved a top speed of 230 km/h (143 mph). There are a total of 90 IC125 formations in service, which operate over the following non-electrified routes:

London-Bristol-South Wales
London-Bristol-Penzance
London-Derby-Leeds
Edinburgh-Derby-Bristol-Penzance

The IC125 is also used to operate a limited number of services over partially electrified routes between:

London-Crewe-Holyhead
London-Edinburgh-Inverness
London-Hull
Manchester-Bournemouth

Standard British Rail air brakes are used on the trainset, with the system designed to stop the train from 200 km/h in distances slightly less than existing locomotive-hauled trains at 160 km/h within the existing signalling blocks.

3.5.2 Braking System Design

The InterCity 125 vehicles are fitted with a two-pipe Automatic Air Brake system. The braking equipment is supplied by Davies and Metcalfe and Westinghouse Brakes.

Class 43 Power Car

The power car has two graduated apply and release distributors connected to the Automatic Air Brake Pipe (ABP). Each distributor has a dedicated reservoir charged via a check valve from the vehicle's Main Reservoir Supply (MRS).

The output from each distributor supplies one of the bogies on the power car. The bogies are fitted with wheel mounted brake discs using air operated actuators fitted to calipers acting on non-asbestos brake pads. In parallel with the disc brakes, the bogies are fitted with air operated tread brakes using cast iron brake blocks. The tread brakes incorporate an air release spring apply parking brake.

The power car is also fitted with the BR Mark 2 WSP system, which operates on an individual wheelset releasing both the disc brake and its associated tread brake.

The power car is fitted with a single continuously driven compressor charging the local MRS to a nominal 10 bar (145 psig). The train's MRP is charged via a pressure control valve to a nominal seven bar (102 psig). In the event of a compressor not running (power car shut down), the MRS can be charged to seven bar from the other compressor (in the second power car) via the MRP.

The power car controls the ABP by either a Davies and Metcalfe E70 brake control unit or a Westinghouse DW2 brake control unit. The brake control unit is connected electrically to the driver brake controller via the train brake control wires.

Class 43 Power Car Major Components

Air Compressor and Delivery Systems. A single two-stage compressor is fitted supplying air via a check valve to the Main Reservoir supply. The pressure in the MRS causes an unloader to operate upstream of the check valve when the MRS reaches 10 Bar. The system is protected by a safety valve set at 10.7 bar (155 psig).

The air is cooled and fed to two externally mounted main reservoirs. Condensate is removed by automatic drain valves. The power cars are not fitted with air dryers. For winter operation antifreeze is introduced into the air system.

Distributors. The distributor has the characteristic of a graduated apply-and-release unit with a similar operation to a "UIC" unit.

Brake Actuator/Caliper System. The brake actuators have integral slack adjusters to maintain the required pad-to-disc clearances. A non-latching resetting mechanism is included to allow the renewal of brake pads. The caliper pad holders are fitted with 500 cm^2 pads utilizing the UIC style dovetail attachment. Retention of the pads is by means of a sliding gate which is latched when inserted in the pad holder.

Tread Brake Unit. This is a twin unit mounted on the bogie acting independently on each wheelset. Each unit contains the service brake cylinder, which is air applied. The output force is taken through an integral slack adjuster to maintain the required block wheel clearance. Resetting the adjuster allows the changing of the single brake block, which is retained by a key through the holder and block.

Brake Control Unit. The Air Brake Pipe Control signal, which is derived from the train brake control wires, is fed to a relay valve to charge/vent the ABP. The ABP can only be charged if the feed cut off valve is energized.

The method by which the control signal is generated depends on which manufacturer's equipment is fitted. The Davies and Metcalfe E70 uses electronically controlled Electro-Pneumatic (EP) valves monitored by pressure transducers to produce the appropriate pneumatic control signal corresponding to the brake demand train wire signal. The Westinghouse DW2 uses the train wire signals to switch pressure signals into a multi-diaphragm unit, which uses the different diameters of the enclosed chambers to produce the appropriate pneumatic control signal.

The output pressure from the E70 and DW2 units are the same for all the braking steps and can operate together on the same trainset.

MkIII Trailer Coach

The MkIII vehicle has a single "UIC" style graduated apply-and-release distributor which is connected to the automatic air brake which is continuous throughout the train. The distributor has a dedicated auxiliary reservoir, which can be charged via the distributor from the ABP. Normally the main reservoir pipe (MRP) will charge the auxiliary reservoir at seven barvia a check valve thus forming the two-pipe system.

The distributor supplies air pressure to the brake actuators. These are fitted to bogie-mounted brake calipers and apply the non-asbestos brake pads to the wheel-mounted brake discs. The air pressure in the actuator can be varied depending on braking demand and the load in the vehicles. The MkIII vehicles are fitted with BT10 air suspension bogies. An air suspension pressure output signal is fed into a variable load relay valve in the brake system.

The MkIII vehicles are fitted with BR Mark 2 Wheel Slide Protection (WSP) equipment which operates on a local vehicle basis acting on individual wheelsets.

MkIII Trailer Coach Major Components

Brake Module. All the equipment associated with the braking system and the air suspension is fitted within a detachable brake module. Modules with Westinghouse equipment can be exchanged for those with Davies and Metcalfe equipment on a module-by-module basis.

Distributor. The distributor has the characteristics of a "UIC" style graduated apply-and-release unit.

Variable Load Relay Valve. Depending on the supplier, this is either a separate unit or is combined with the distributor. The output pressure from the distributor is fed into the relay valve, which has a variable position fulcrum. The output signal from the averaging valve sets the fulcrum position, thus the pressure to the brake actuator is proportional to the vehicle's load. A "no load" signal causes the variable load relay valve to operate in the tare condition.

Averaging Valve. The averaging valve supplies a control signal to the variable load relay valve. This is derived by averaging the pressure in the two independent air bags of a single bogie.

Brake Actuators/Caliper System. The brake actuators have an integral slack adjuster to maintain the required pad-to-disc clearance. A non-latching resetting mechanism is included to allow the renewal of brake pads. The caliper pad holders are fitted with 500 cm^2 pads utilizing the "UIC" style dovetail attachment. Retention of the pads is by means of a latch which itself is captive to the pad holder.

3.5.3 System Operation and Control

The principal operation of the air brake system is such that, after an initial reduction of pressure in the ABP sufficient to trigger the distributor, the amount of brake application is proportional to the reduction in the ABP pressure. The brake is released by recharging the ABP pressure. A reduction of 1.5 bar (22 psig) in the ABP pressure is required to produce a full service brake application. In an emergency brake application, the ABP falls to zero.

The reduction or increase in ABP pressure is achieved by means of the brake control units at both ends of the trainset responding to the electrical signals derived from the driver's brake controller in the operational cab. A reduction in the ABP pressure can also be achieved by the safety systems fitted to the trainsets.

The driver's brake controller has eight positions: Running, 1 through 6, and Emergency. The air brakes are fully released, provided none of the safety systems have operated, when the driver's brake controller in the operational cab is in the running position. This energizes the three train brake control wires throughout the trainset allowing the ABP to be charged to the running pressure of 5.1 bar (74 psig).

Moving the driver's brake controller through the other positions causes the control wires to be switched in a binary code sequence such that when in the Emergency position all the control wires are de-energized.

The two brake control units, one at each end of the trainset, respond to the status of the control wires resulting in even braking steps being achieved between Initial (Step 1) and Full Service (Step 6). While both control units are capable of venting the ABP to achieve the required brake step, the rear unit is prevented from recharging the ABP from its local MRS supply by a de-energized feed cut off valve.

The ABP is thus vented from both ends of the IC125 in response to the driver's brake demand, but can only be recharged from the leading power car. There is no direct connection between the train brake control wires and the vehicles' distributors. The distributors respond solely to variations in the ABP pressure. The characteristic of the distributors is such that the driver can continually vary the amount of brake demand throughout the brake application.

Braking Control System

Service and Override Capability. The braking control system uses electrically controlled brake units located in the power cars to control the pressure in the Air Brake Pipe. The brake control units respond to binary code signals generated by the driver's brake controller in the operational cab. Three train lines (three-wire bus) are used to generate seven steps of brake control. All lines need to be energized to release the brakes. The lines are progressively switched until in notch 7 (Emergency) they are all de-energized.

The distributors on the vehicles respond directly to the ABP pressure controlled by the brake units. Application/increase in the brake force is initiated from both brake control units when reducing the ABP pressure. Reduction/release of the brake force is only achieved by the brake unit in the operational power car during recharging of the ABP pressure.

The control system design is such that once any of the safety systems fitted to the train are triggered, the driver cannot override its application.

Diagnostic Systems

The IC125 is fitted with no diagnostics and only limited monitoring systems. The driver is presented with system pressure gauges from tappings on the leading power car and an indication of WSP activity on either power car. The coaches have a latched relay to indicate if WSP lockout has occurred. This is primarily to advise the maintenance staff of its operation.

Under fault conditions the driver can isolate individual systems on the IC125 with the train proceeding forward at reduced speed or at line speed with additional footplate staff depending on which system/component has been isolated.

3.5.4 Safety Features

The Power Car

The power car's braking system is fitted with the following safety features:

(i) *Driver's Safety Devices (DSD), Vigilance System and Speed Switch*

While the master controller is in either Forward or Reverse, the driver must retain pressure on a foot pedal. Once every 60 seconds, however, the driver must release and then reapply pressure to the foot pedal to prevent the ABP being vented.

To prevent uncontrolled coasting with the master switch at Off or Neutral, a speed switch will apply the brakes if the train is travelling at over 5 km/h (3 mph).

(ii) Automatic Warning System (AWS)

The Automatic Warning System monitors the condition of the lineside signals. If green, the driver will hear a bell. However, on passing a signal not showing green, the driver will hear a horn. Failure to cancel the horn within three seconds will result in the ABP being vented.

(iii) *Low Main Reservoir Pipe Pressure*

The pressure in the MRP is continually monitored to ensure that there is sufficient energy available to stop the train. Reduction in MRP pressure through compressor shutdown or failure of intervehicle hose connections will result in the ABP being vented, thus applying the train brakes.

(iv) *Brake Control Unit Charging*

The rate at which the Brake Control unit can recharge the ABP is restricted such that it is insufficient to overcome the loss of air from the ABP when one of the safety systems is activated.

(v) *Driver's Brake Controller Emergency Position*

In addition to the train brake control wires being de-energized, the Emergency position causes the ABP to be vented directly. This feature is also available from the non-operational cab.

(vi) *Driver's Emergency Plunger*

The cab is fitted with a plunger that also causes the ABP to be vented directly. Once operated it remains in a latched position until reset by a twisting action.

(vii) *Parking Brake Interlock*

Applying the parking brake system will also result in the ABP being vented.

Trailer Coach

The trailer coach's braking system is fitted with the following safety features:

(i) *Passenger Communication System*

Operation of any of the passenger alarm handles vents a pilot line which in turn causes the ABP to be vented by a pilot-operated exhaust valve. No override features are fitted to the MkIII vehicles.

(ii) *Air Suspension Charging Valve*

The air suspension system derives its air from the MRP, which is primarily for the brake system. The charging valve prevents the air suspension system being charged before the vehicles auxiliary reservoir has been charged to in excess of five bar.

(iii) *Emergency Brake Valve*

The Guard/Senior Conductor's compartment is fitted with an isolating cock capable of venting the ABP.

Train continuity is continually monitored by the brake system. Should the train divide, the ABP intervehicle couplings will part, venting the ABP in both parts of the train and thus applying the brake.

The condition of the brake train control wires is monitored by the rear control unit, which will apply the brake in the event of a loss of the "Running" signal. In this case, it is permissible to isolate the rear control unit and continue at a maximum speed of 160 km/h.

3.5.5 Technical Specifications of the Braking System

Speed Range

The technical specification for the IC125 to stop from 200 km/h was set in the signaling distance originally established for the 160 km/h locomotive-hauled trains. The minimum signaling distance to allow 200 km/h running is thus 2,040 meters between the first caution signal (double yellow) and the red signal. The signaling distance can be greater than the minimum and was usually set when the signaling system was introduced. The minimum performance of the IC125 is such that it should not exceed 1,770 meters from 200 km/h. The safety margin is to allow for speedometer error and adverse rail conditions.

Currently, 200 km/h operation is only being achieved on the London-to-Bristol route. Operational restrictions mean that the maximum speed elsewhere is 177 km/h (110 mph). The IC125 has to comply with all other speed restrictions applied to the routes.

Wheel Slide Protection

The BR Mark 2 WSP uses analog electronics to determine if the wheelset is sliding or rapidly slowing. Each wheelset sends a speed signal into the control unit, which compares the individual speeds and their rates of deceleration against the unit's internal performance characteristics. A dump valve venting the brakes on the appropriate wheelset will be activated whenever the WSP unit identifies that the wheelset is rapidly decelerating or sliding. The dump valve will reapply the brakes when the wheelset speed again matches the WSP unit's predicted vehicle speed or if the valve has been operating continuously for four seconds. In the latter case, the WSP unit assumes a fault on that WSP and locks out the dump valve for the rest of the stop or until all four wheelsets are operating within 10 km/h (6 mph) of each other.

Retarding Force

Each vehicle in the IC125 was designed to brake its own proportion of the train's mass. The braking of the power car's 63.5 metric tons (70 tons) mass is split 80 percent by the disc brakes and 20 percent by the tread brakes. The trailer coaches have a tare mass of 30.8

metric tons (34 tons) and nominal 5.4 metric tons (6 tons) passenger payload. The catering vehicle in the formation has a 38 tons tare mass but has corresponding lower passenger payload.

Deceleration Rate

The characteristics of the non-asbestos brake pads is such that they generate a uniform retardation force throughout the speed range. The cast iron tread brakes have a low high-speed frictional characteristic rising to a higher value as the speed slows. The low proportion of the tread braking is such that it can be assumed that the IC125 has a uniform deceleration rate across the speed range.

To obtain the Full Service stopping distance of 1,770 m from 200 km/h requires an established deceleration rate of 3.4 km/h/s (0.946 m/s^2), having taken into account the brake propagation and actuator fill times. The Emergency braking also results in a deceleration rate of 3.4 km/h/s; however, the stopping distance is slightly reduced due to a faster brake propagation.

The IC125 requires 10 percent adhesion levels to sustain the Full Service retardation rates. Normally, drivers are able to control the vehicle's speed with lower braking demands. Typically, stops from 200 km/h will be done in Notch 4, which is approximately 65 percent of Full Service. This is because the signaling distances are in excess of the minimum value.

Each vehicle in the IC125 is designed to brake its own mass/payload irrespective of vehicle speed and braking duty. Thus theoretically there is no minimum formation. However, to be consistent with other standard rules, a minimum formation of seven coaches has been adopted to allow 200 km/h operation.

Shorter formations or ones operating with a distributor isolated are limited to 10 mph below line speed. A 160 km/h speed restriction is also imposed in the event of loss of a vehicle's air suspension.

3.5.6 Environmental Considerations

During the winter months the air in the brake system is treated with antifreeze. Also, in periods of falling snow the maximum speed is limited to 160 km/h. The driver is required to apply sufficient brake every 10 minutes to register a slowing of the train to ensure that the calipers are not allowed to freeze and to prevent a water film from the melted snow from developing on the discs.

Braking Effects on Other Systems

The use of wheel-mounted discs throughout the IC125 means that the brake system has a minimal effect on the drag experienced by the trainset. The use of wheel mounted discs, however, requires the wheel web to be designed to accommodate the discs through the use of a straight web and the inclusion of attachment holes. The use of split ring discs on the coach wheelsets necessitates the use of 24 bolt attachments to attach the discs to each wheel. On the other hand, the annulus discs on the power car only use eight attachments per wheel.

The bolting attachments have to be such that they allow relative expansion of the disc relative to the wheel while having sufficient load paths to transmit the braking torque. The actual techniques used depend on the individual designs of the disc manufacturers.

The most serious mechanical effect on the wheelsets is the possibility of martensite generation in the wheel tread following wheel slide activity. This can lead to mechanical tread damage which requires remedial action. Modifications to the WSP system are being investigated to reduce the effect. The tread brake on the power car will have a conditioning effect on the tread not available on the coaches.

The IC125 originally operated with brake pads with resin that emitted a strong pungent smell under hard braking. The air conditioning system was fitted with air shutters which closed when braking to reduce intake into the vehicle. The vehicles have now been converted to operate with pads having reduced smell. The disc brake design is such that there is little noise generated during braking.

The braking of the IC125 has no known effects on the track and, as it is fully mechanically braked, there are no effects on electrical systems.

3.5.7 Inspection and Test Requirements

Pre-Departure

During the initial preparation of the IC125, the traincrew carry out a continuity test of the brake system. With the driver's brake controller in the leading operational cab in Running, thereby charging the ABP to 5.1 bar, the guard will move the brake controller in the trailing cab into the emergency position, thus venting the ABP. The driver should register an emergency brake application on his cab gauges.

The guard/senior conductor will advise the driver of any isolations of the brake system on the coaches that will affect the train's operation.

In Service

With the exception of operating during falling snow, there are no other in-service inspections or testing requirements. During falling snow, the driver is required to apply sufficient brake force every 10 minutes to register a slowing of the train.

Maintenance Testing

Maintenance testing falls into two categories. First, functional tests are carried out every 50 days to check the basic operation of the brake system together with a detailed annual leakage and functional test. Second, tests for fault diagnosis or checks following equipment replacement are conducted.

The basic functional test checks the output from the brake control units and the corresponding operation of the distributors. Operation of the DSD and AWS systems are also checked. Checks on the operation of the WSP system are carried out using test equipment which can also be used to diagnose faults.

Following overhaul, a detailed performance check is carried out on the brake equipment including functional and leakage testing.

Maintenance Requirements

Routine. The minimum interval between examination is four days. During this examination, the pad thickness is checked and any pads below the minimum acceptable size renewed. The acceptability is determined using slide-in gauges. The minimum thickness has an allowance to ensure that a pad just passing the acceptable thickness does not wear into its backing plate during the next four days. Pad lives are typically 40 days on the power car and 80 days on the coaches. When changing the pads, the freedom of the caliper equipment is checked.

The 50-day maintenance examination also checks the correct operation of the bogie brake equipment. All reservoirs fitted with manual drain cocks are checked for the presence of condensate which is drained. Automatic drain cocks are checked for correct operation. The brakes are subjected to the functional test outlined earlier.

Overhaul. The overhaul of the brake system can be divided between that carried out on the bogies and that on the bodies. The power car and the MkIII coach are subject to differing overhaul regimes.

The bogies of the power car are overhauled every two years. The brake discs currently last two overhaul periods before renewal. The caliper actuator and tread brake units are overhauled at each bogie overhaul. With the exception of the reservoirs, the body mounted brake equipment on the power car is overhauled every six years. Reservoirs are overhauled every 12 years.

The MkIII bogies are overhauled every 2-1/2 years. As with the power bogies, the brake discs last two overhaul periods. The actuator calipers and bogie-mounted WSP dump valves are overhauled at every bogie overhaul. The body-mounted equipment is overhauled every five years except the reservoirs, which are overhauled every 15 years.

Rubber air hoses are generally renewed when the bodies are overhauled with the notable exception of the intervehicle hoses which are date stamped on fitting and renewed after five years.

The overhaul of the components is either carried out at the main works or by specialists (including original manufacturers) contracted to undertake the work.

Special Staff or Skill Needs

The traincrew are trained on the operation of the train systems and are given a rudimentary fault finding course. All IC125 sets are fitted with cab radios so assistance can be obtained from central maintenance controllers in the event of difficulties.

The maintenance staff also receive training on the specific systems on the trainsets. The maintenance staff have received sufficient training to enable them to tackle both mechanical or electrical maintenance on the trainsets. In the case of fault finding, depot-based technical staff or specially trained maintenance staff will be employed. The depot-based fault finding will be such that faulty components or sub-assemblies can be identified. These will be exchanged for overhauled units and the defective item sent for repair/overhaul.

3.6 BRITISH RAIL INTERCITY 225

3.6.1 Description of Trainset

The InterCity 225 trainsets were procured between 1988 and 1990 to operate at speeds of up to 225 km/h (140 mph) over the recently electrified East Coast Main Line. The principle routes are:

London-Doncaster-Leeds
London-York-Edinburgh-Glasgow

The routes had previously used InterCity 125 trainsets operating at speeds up to 201 km/h (125 mph). The IC225's operate in fixed formations of a Class 91 electric locomotive, 9 MkIV trailer coaches, and a MkIV Driving Van Trailer. There are 31 trainsets operating 26 daily diagrams. The trainsets are currently operating at a maximum speed of 201 km/h, due to signalling and operational constraints.

The IC225 is required to stop from 201 km/h (125 mph) in the same signalling distance required for the IC125 trains. The IC225 has a maximum working speed of 225 km/h (140 mph). Stopping from this speed requires an extra signal spacing. This allows the braking rate above 201 km/h to be reduced to 60 percent of that below 201 km/h for the corresponding braking demand. The vehicles are thus fitted with a speed controlled two-stage brake.

3.6.2 Braking System Design

The InterCity 225 vehicles are fitted with a two-pipe Automatic Air Brake System. The Class 91 locomotive equipment was supplied by Davies and Metcalfe (D&M). The MkIV coach equipment was supplied by Westinghouse Brakes.

Class 91 Electric Locomotive

The Class 91 locomotive regulates the air brake pipe (ABP) by a version of the D&M E70 brake control unit. This is connected electrically to the driver's brake controllers on the locomotive and via a Time Division Multiplex (TDM) system to a remote driving trailer, which is also fitted with an electrically controlled brake unit.

The two bogies of the locomotive have independent brake control systems. Each bogie has its own graduated apply and release "UIC" style distributor connected to the ABP. Each distributor has a dedicated brake supply reservoir charged via a check valve from the locomotive's nominal 10 bar (145 psig) Main Reservoir Supply (MRS). When working as a dead locomotive, the air supply can be obtained from the Main Reservoir Pipe (MRP) charging the MRS to 7 bar (102 psig). In the event of no MRP supply, the brake supply reservoirs can be charged via the distributor from the ABP.

The brake control system provides the control of the two rheostatic brake units, one per bogie. The output signal from the distributor is fed into a rheostatic brake control unit. Additionally, it feeds a brake demand signal into a two-stage relay valve with hold off chambers. The level of rheostatic brake initiated by the rheostatic brake unit is monitored and converted into an air signal which is fed into the hold off chamber of the relay valve. This ensures that the rheostatic brake is fully blended with the friction brake.

The locomotive has two friction brake systems. First, disc brake units are fitted on each of the four body-mounted traction motors, the calipers of which are fitted with non-asbestos brake pads. Second, the bogies are fitted with air operated tread brake units using composition block materials. The tread brake units also incorporate a separate hydraulic apply-and-release parking brake actuator. The disc and tread brake systems operate in parallel.

In addition to the automatic air brake system, the locomotive has a direct acting independent brake for use when buffering up to the train and for light locomotive movements.

The locomotive is fitted with two start/stop compressors charging the local MRS to a nominal 10 bar. The train's MRP is charged via a pressure control valve to a nominal 7 bar.

The locomotive is fitted with a GEC wheel slide protection (WSP) system which operates on individual wheelsets. The WSP was originally linked to a doppler speed sensing system; however, this feature has been isolated, relying solely on wheelset-generated speed signals.

Class 91 Electric Locomotive Major Components

Air Compressor and Delivery Systems. The D&M two-stage compressors are fitted to supply air via a check valve to the main reservoir supply. The compressors operate under the control of a main reservoir supply governor starting and stopping the compressors to maintain a nominal 10 bar (145 psig) pressure. The system is protected by a safety valve set at 10.7 bar (155 psig).

The air is cooled externally and fed to the four main reservoirs which are mounted one externally and three within the body. Condensate is removed by automatic drain valves. The locomotive is not fitted with an air dryer. For winter operation, antifreeze is introduced into the air system.

Brake Control Unit. The D&M E70 brake unit controls the ABP pressure in seven steps using a three-wire binary coded signal between the driver's brake controller and the brake unit. The Air Brake Pipe Control signal is fed to a relay valve to charge/vent the ABP. The ABP can only be charged if the feed cut off valve is energized. The E70 unit generates the control signal using electronically controlled Electro-Pneumatic (EP) valves monitored by pressure transducers to produce the appropriate control signal corresponding to the brake demanded by the train wire signal. The control unit obtains its air supply from the locomotive main reservoir supply.

Distributors. The distributors are D&M "UIC" style graduated apply-and-release units. The distributors incorporate the ability to charge their brake supply reservoirs from the ABP in the event of no main reservoir supply.

Brake Relay Valve. The Relay Valve has two main functions. First, to switch the output pressure between the two brake duty conditions above and below 201 km/h (125 mph). Second, to hold off the friction brake proportional to the achieved rheostatic braking. A fully-rated rheostatic brake is fitted to the Class 91. In general, the friction brake will only be blended in below 48 km/h (30 mph), where the rheostatic brake performance drops sharply with lower speed. Final stopping is performed by the friction brake.

Rheostatic Brake Control Unit. The amount of rheostatic brake required is derived from the distributor output pressure. The control unit also reduces rheostatic duty above 201 km/h (125 mph) to match the friction brake duty. The control unit monitors the performance of the rheostatic brake and converts this into a pneumatic signal that is fed to the brake relay valve to hold off the equivalent friction brake.

Disc Brake Actuators/Caliper System. The brake actuators have integral slack adjusters to maintain the required pad to disc clearance. A non-latching resetting mechanism is included to allow the renewal of brake pads. The calipers, which are mounted on the traction motors, have pad holders fitted with 500 cm^2 pads utilizing the UIC style dovetail attachment. Retention of the pads is by means of a latch which is captive to the pad holder.

Tread Brake Unit. The tread brake unit is mounted on the bogie acting independently on each wheelset. Each unit contains the service brake cylinder which is air applied and a hydraulic apply-and-release parking brake actuator. The output force is taken through an integral slack adjuster to maintain the required block/wheel clearance. The block holder is fitted with a pair of composite material brake blocks.

MkIV Trailer Coach

The MkIV vehicle has a single "UIC" style graduated apply and release distributor which is connected to the ABP. The distributor has a dedicated auxiliary reservoir which can be charged via the distributor from the ABP. Normally, the MRP will charge the auxiliary reservoir at 7 bar via a check valve thus forming the two pipe system.

The distributor supplies an air pressure signal to a two-stage variable load relay valve. The air pressure in the brake actuator can be varied depending on braking demand, load in the vehicles, and whether the speed is above or below 201 km/h. The MkIV vehicles are fitted with BT41 air suspension bogies. An output of the air suspension pressure is fed into the variable load relay valve.

The output pressure from the relay valve is fed to the brake actuators which are fitted to the bogie-mounted brake calipers. These apply non-asbestos brake pads to three axle-mounted brake discs which are fitted to each wheelset.

The MkIV vehicles are fitted with a Faiveley Wheel Slide Protection (WSP) system which operates on a local vehicle basis acting on individual wheelsets.

MkIV Trailer Coach Major Components

Brake Module. All the equipment associated with the braking system and the air suspension is fitted within a detachable brake module.

Distributor. The distributor has the characteristics of a "UIC" style graduated apply and release unit.

Variable Load Relay Valve. The output pressure from the distributor is fed into the two-stage relay valve which has a variable position fulcrum. The output pressure from the air suspension averaging valve sets the fulcrum position; thus, the pressure to the brake actuator is proportional to the vehicle's load. A "no load" signal causes the variable load relay valve to operate in the tare condition. The changeover between the two-stage braking duties is carried out independently on each coach. The control signal is generated from the WSP system.

Brake Actuators/Caliper System. The brake actuators have an integral slack adjuster to maintain the required pad-to-disc clearance. A non-latching resetting mechanism is included to allow the renewal of brake pads. The caliper pad holders are fitted with $500cm^2$ pads utilizing the "UIC" style dovetail attachment. Retention of the pads is by means of a latch which itself is captive to the pad holder.

Disc Brakes. Three low-drag cast iron discs are fitted to each wheelset. The grade of cast iron used depends on the disc manufacturer. The discs and caliper systems have been obtained from SAB WABCO and Knorr Bremse.

MkIV Driving Van Trailer

The MkIV Driving Van Trailer (DVT) regulates the ABP by a Westinghouse DW3 brake control unit. This is connected electrically to the driver's brake controllers and via a TDM system to the locomotive at the other end of the train formation.

The friction brake system is basically the same as that fitted to the MkIV coach, with the principal exception being that each bogie has its own two-stage relay valve due to differing bogie loads.

One brake actuator of each wheelset also incorporates a hydraulic apply-and-release parking brake actuator.

MkIV Driving Van Trailer Major Components

The MkIV trailer coach components described above are also fitted to the driving van trailer.

Variable Load Relay Valves. The difference in pivot loads between the two bogies necessitates the fitting of two variable load relay valves, one per bogie. A single distributor feeds the brake demand signal to both units.

Brake Actuators. One actuator per wheelset is fitted with a hydraulic apply-and-release parking brake actuator.

Brake Control Unit. The DVT is fitted with the Westinghouse DW3 brake control unit. The role of the unit is the same as the E70 unit fitted to the Class 91 locomotive. The DW3 unit generates the brake pipe control signal by using the brake control wire to switch pressure signals into a multi-diaphragm unit which uses the different diameters of the enclosed chambers to produce the appropriate pneumatic control signal. The DW3 unit obtains its air supply from the Main Reservoir Pipe.

3.6.3 System Operation and Control

The principal operation of the air brake system is such that, after an initial reduction of pressure in the ABP sufficient to trigger the distributor, the amount of brake application is proportional to the reduction in the ABP pressure. The brake is released by recharging the ABP pressure. A reduction of 1.5 (17.4 psig) bar in the ABP pressure is required to produce a Full Service brake application. In an emergency brake application, the ABP falls to zero.

The reduction or increase in ABP pressure is achieved by means of the brake control units at both ends of the trainset responding to the electrical signals derived from the driver's brake controller in the operational cab. A reduction in the ABP pressure can also be achieved by the safety systems fitted to the trainsets.

The driver's brake controller has eight positions, which are Running, 1 through 6, and Emergency. The brakes are fully released, provided none of the safety systems have operated, when the driver's brake controller in the operational cab is in the Running position. This energizes the three brake control wires at each end of the train via the TDM system allowing the ABP to be charged to the Running pressure of 5.0 bar (72.5 psig).

Moving the driver's brake controller through the other positions causes the control wires to be switched in a binary code sequence such that when in the Emergency position all the control wires are de-energized.

The two brake control units, one at each end of the trainset, respond to the status of the control wires resulting in even braking steps being achieved between Initial (Step 1) and Full Service (Step 6). While both brake control units are capable of venting the ABP to achieve the required brake step, the rear unit is prevented from recharging the ABP by a de-energized feed cut-off valve.

The ABP is thus vented from both ends of the IC225 in response to the driver's brake demand, but can only be recharged from the leading vehicle. There is no direct connection between the brake control signals and the vehicles' distributors. The distributors respond solely to variations in the ABP pressure. The characteristic of the distributors is such that the driver can continually vary the amount of brake demand throughout the brake application.

The two-stage brake relay valves fitted to all the IC225 vehicles change over between the two brake duties at approximately 201 km/h. Each vehicle changes over independently. When operating above 201 km/h, a speed signal derived from the WSP system energizes an EP valve causing the relay valves to adopt the lower braking rate. Since the IC225's are currently limited operationally to 201 km/h, the relay valves remain in the higher braking rate condition.

The Class 91 locomotives rheostatic brake responds to distributor output pressure via the rheostatic brake unit, which also converts the achieved braking rate into a signal to back off the friction brake by feeding it into the hold off chambers of the relay valve. This arrangement means that the rheostatic brake is used in preference to the friction brake. The use of the locomotive's batteries to establish the field currents in the motors during rheostatic braking means that the rheostatic brake can remain operational in the absence of an overhead line supply. Rheostatic braking is available in all braking steps including Emergency.

Service and Override Capability

The braking control system uses electrically controlled brake units located in the Class 91 and MkIV DVT at each end of the IC225 to control the pressure in the Air Brake Pipe. The brake control units respond to a binary code signal on three brake control lines generated by the driver's brake controller in the leading operational cab. All lines need to be energized to release the brakes. The lines are progressively switched. When they reach Notch 7 (Emergency), they are all de-energized.

The brake control lines at the rear of the IC225 are energized via a TDM communication system copying the status of the control lines in the leading vehicle. Loss of TDM configuration will cause the rear brake control lines to be de-energized, thus applying the brake.

The distributors and hence the relay valves respond directly to the ABP pressure controlled by the brake units. Application/increase in brake force is initiated from both brake control units reducing the ABP pressure. Reduction/release of the brake force is only achieved by the brake unit in the leading vehicle recharging ABP pressure.

The control system design is such that once any of the safety systems fitted to the train are triggered, the driver cannot override its application. The only exception is that the driver can hold off a passenger-initiated brake application when the passenger communication system is operated.

Diagnostic Systems

The IC225 is fitted with no diagnostics and only limited monitoring systems. The driver is presented with system pressure gauges derived from tappings on the vehicle. The driver gets an indication of WSP activity on the leading vehicle.

The coaches have a latched relay to indicate if WSP lockout has occurred. This is primarily to advise the maintenance staff of its operation.

Under fault conditions, the driver can isolate individual systems on the IC225 with the train proceeding forward at reduced speed or at line speed depending on which system/component has been isolated.

3.6.4 Safety Features

Class 91 Locomotive and MkIV DVT

The Class 91 locomotive and the MkIV DVT are fitted with the following safety features:

(i) *Driver's Safety Devices (DSD), Vigilance System and Speed Switch*

While the master controller is in either Forward or Reverse, the driver must retain pressure on a foot pedal. Once every 60 seconds, however, the driver has to release and then reapply pressure to the foot pedal to prevent the ABP from being vented.

To prevent uncontrolled coasting with the master switch at Off or Neutral, a speed switch will apply the brakes if travelling over 5 km/h (3 mph).

(ii) *Automatic Warning System (AWS)*

The AWS monitors the condition of the lineside signals. If green, the driver will hear a bell. However, on passing a signal not showing green, the driver will hear a horn. Failure to cancel the horn within three seconds will result in the ABP being vented, thus applying the train brakes.

To enable the 225 km/h capability of the IC225 to be used, British Rail is currently evaluating Automatic Train Protection Systems. These will monitor not only the lineside signals, but also the driver's control of the train and will automatically apply the brake if the train speed is outside set limits. Until fitted, the IC225 will be limited to 201 km/h.

(iii) *Low Main Reservoir Pipe Pressure*

The pressure in the MRP is continually monitored to ensure that there is sufficient energy available to stop the train.

(iv) *Brake Control Unit Charging Capacity*

The rate at which the brake control units can recharge the ABP is restricted such that it is insufficient to overcome the loss of air from the ABP when one of the safety systems is activated.

(v) *Driver's Brake Controller Emergency Position*

In addition to the train brake control wires being de-energized, the Emergency position causes the ABP to be vented directly. This feature is also available from all non-operational cabs.

(vi) *Driver's Emergency Plunger*

The cab is fitted with a plunger that also causes the ABP to be vented directly. Once operated, it remains in a latched position until reset.

(vii) *Hydraulic Parking Brake Interlock*

The interlock ensures that should the indicators, built within the parking brake control units, not be in the "Off" position, the ABP will be vented.

MkIV Trailer Coaches

The MkIV trailer coach's braking system is fitted with the following safety features:

(i) *Passenger Communication System*

Operation of any of the passenger alarm handles, including releasing the emergency window hammers, vents a pilot line. This in turn causes the ABP to be vented by a pilot-controlled exhaust valve. The driver is advised electrically that the passenger communication system has been activated. The driver can override the venting of the ABP caused by the Passenger Communication System.

(ii) *Emergency Door Release Interlock*

The MkIV vehicles are fitted with power-operated external doors. If a passenger operates the door release, this will vent a pilot-controlled exhaust valve venting the ABP. The driver is unable to override this brake application.

(iii) *Air Suspension Charging Valve*

The air suspension system derives air from the MRP which is primarily for the brake system. The charging valve prevents the air suspension being charged before the vehicle's auxiliary reservoir has been charged in excess of five bar.

Additional Safety Features

The IC225 formation incorporates the following additional safety features:

(i) *Train Continuity*

Train continuity is continually monitored by the brake system. Should the train divide, the ABP inter-vehicle couplings will part, venting the ABP in both parts of the train, thus applying the brake.

(ii) *TDM System*

The condition of the TDM system is monitored by the rear control unit which will apply the brake in the event of a loss of the "Running" signal.

(iii) *Parking Brakes*

Electric operation of the parking brakes on either the Class 91 or the MkIV DVT will cause the parking brake to be applied or released on both units. Local manual application and release facilities are fitted to both vehicles.

3.6.5 Technical Specifications of the Braking System

Speed Range

The technical specification for the braking system was set by the requirement for the IC225 to stop from 201 km/h in the same signalling distance required for the IC125 trains. This signalling distance was originally set for 161 km/h (100 mph) operation with locomotive-hauled tread brake trains.

The minimum signalling distance to allow 201 km/h running is thus 2,040 meters between the first caution signal (double yellow) and the red signal. The signalling distance generally is greater than the minimum and was usually set when the signalling system was introduced. The minimum performance requirement is that the IC225 shall be capable of stopping from 201 km/h in 1,770 meters. The safety margin is to allow for speedometer error and adverse rail conditions.

The IC225 has a maximum working speed of 225 km/h. Stopping from this speed requires an extra signal spacing to be added to that for 201 km/h. Thus for 225 km/h running, the signalling distance has been increased to 3,060 meters. Sections of the East Coast Main Line have had the signalling system modified to give an extra signalling aspect (flashing green) to permit 225 km/h running. However, running at 225 km/h is suspended, pending the introduction of an Automatic Train Protection (ATP) system onto this route.

Wheel Slide Protection

The GEC WSP and Faiveley WSP fitted to the Class 91 and MkIVs, respectively, utilize digital electronics to determine if the wheelset is sliding or rapidly slowing. Each wheelset sends a speed signal into the control unit which compares the individual speeds and their rates of deceleration against the unit's internal performance characteristics. A dump valve releases the brakes on the appropriate wheelset whenever the WSP unit identifies the wheelset rapidly slowing or sliding. The dump valve has a blending action capable of progressively exhausting and filling the brake actuators as the WSP system attempts to match the available adhesion.

If the dump valve has been venting the air continuously for 10 seconds, the WSP unit assumes a fault and progressively re-establishes full braking and locks out the dump valve for the rest of the stop or until all four wheelsets are operating within 6 mph (10 km/h) of each other.

Retarding Force

Each vehicle in the IC225 was originally required to brake its own proportion of the train's mass. The Class 91 locomotive achieves this requirement when operating with its blended rheostatic brake. In the event of rheostatic brake failure/isolation, the friction brake only establishes 80 percent of the retarding force required to brake the 84 ton locomotive independently.

The MkIV trailer coaches have a tare mass of 40 tons and a nominal six ton passenger payload. The catering vehicle in the formation has a 46 ton tare mass but has a lower passenger payload. The DVT also has a 46 ton tare load split asymmetrically between the bogies. Current British Rail policy states that passengers are not allowed in the leading vehicle when the train is operating above 161 km/h. The van area is used for parcels and mail traffic.

The performance of the MkIV vehicles exceeds the minimum requirement such that if IC225 were to operate with the Class 91 locomotive's rheostatic brake isolated, there is sufficient retarding force in the train to stop within the 1,770 meters minimum performance requirement.

Deceleration Rate

The characteristics of the non-asbestos brake pads and the composite brake blocks used on the IC225 vehicles are such that they generate a uniform retarding force throughout the speed range.

To obtain the Full Service stopping distance of 1,770 meters from 201 km/h requires an established deceleration rate of 3.4 km/h/sec (0.946 m/s^2), having taken into account the brake propagation and actuator fill times. The Emergency brake rate requirement is also 0.946 m/s^2.

The characteristics of the brake pads and the use of three discs per wheelset originally designed to dissipate the energy for a 225 km/h stop has meant that the MkIV coaches can achieve a deceleration rate of better than 3.9 km/h/s (1.1 m/s^2) from 201 km/h.

The fully rated rheostatic brake means that the Class 91 will normally achieve the required 0.946 m/s^2 deceleration rate. The overall performance of the IC225 is in excess of this value due to the effect of the MkIV vehicles. The normal IC225 formation is capable of compensating for a Class 91 locomotive operating with both its rheostatic brake units isolated.

The IC225 requires 12 percent adhesion levels to sustain the Full Service retardation rates of the MkIV vehicles. Normally, drivers are able to control the vehicle's speed with lower braking demands. Typically, stops from 201 km/h will be done in Notch 4, which is approximately 65 percent of Full Service. This is because the signalling distances are generally in excess of the minimum value.

3.6.6 Environmental Considerations

Environmental Considerations

During the winter months the air in the brake system is treated with antifreeze. Also, in periods of falling snow, the maximum speed is limited to 161 km/h (100 mph). The driver is required to apply sufficient brake every 10 minutes to register a slowing of the train to ensure that the calipers are not allowed to freeze and to prevent a water film from the melted snow from developing on the discs.

Vehicle Configuration

The normal formation of an IC225 is a Class 91, 9 MkIV coaches and a MkIV DVT. The minimum formation that still allows 201 km/h running, even with a class 91 working without an operational rheostatic brake, is Class 91, 6 MkIV and a MkIV DVT.

Shorter formations or ones operating with a distributor isolated are limited to 16 km/h (10 mph) below line speed. A 161 km/h speed restriction is also imposed in the event of loss of vehicle air suspension.

Braking Effects on Other Systems

The Class 91 locomotive was originally designed to be capable of braking its own weight with or without rheostatic brake assistance. Thermal modelling of the wheel showed that under mechanical braking alone the wheel/hub interference could be compromised. Consequently, half the tread brake duty has been removed leaving the Class 91 locomotives 80 percent braked when operating with both the rheostatic brakes isolated.

The maximum braking duty of the rheostatic brake on the Class 91 is within the continuous rated duty of the traction motors. The field currents for the motors are derived from the vehicle batteries so the use of rheostatic brake is independent of an overhead train supply.

The MkIV coaches are fitted with low drag discs to minimize the effects on train resistance when not braking. The internal connections between the braking faces are arranged in pillars. This pattern ensures good thermal conductivity with minimal pumping losses. The drag of the discs is typically half that of radially cooled discs.

The vehicles operate with non-asbestos pads and blocks that have a low smell and noise emission during braking. There are no known effects of the brakes on the track.

3.6.7 Inspection and Test Requirements

Pre-Departure

During the initial preparation of the IC225, the driver will carry out a continuity test of the brake system. With the driver's brake controller in the operational cab in Running, thereby charging the ABP to 5.0 bar (72.5 psig), the driver will operate the brake test switch. This has the effect of temporarily stopping the leading brake control unit from charging the ABP and initiating an emergency brake application on the rear brake control unit. The driver should register an emergency brake application on his cab gauges.

The guard/senior conductor will advise the driver of any isolations of the brake system on the coaches that will affect the train's operation.

In Service

With the exception of operating during falling snow, there are no other in-service inspections or testing requirements. During falling snow, the driver is required to apply sufficient brake force every 10 minutes to register a slowing of the train.

Maintenance Testing

Maintenance testing falls into two categories. First, functional tests are carried out every 12 weeks to check the basic operation of the brake system.

The basic functional test checks the output from the brake control units and the corresponding operation of the distributors. Operation of the DSD and AWS systems are also checked. Checks on the operation of the WSP and rheostatic brake systems are carried out using automated test equipment, which can also be used to diagnose faults.

Following overhaul, a detailed performance check is carried out on the brake equipment including functional and leakage testing.

Maintenance Requirements

Routine. The minimum interval between examination is seven days. During this examination the pad thickness is checked and any pads below the minimum acceptable size renewed. The minimum thickness has an allowance to ensure that a pad just passing the acceptable thickness does not wear into its backing plate during the next seven days. Pad lives are typically in excess of 750 days. The Class 91 pad and block life is dependent on the number of days operating with the rheostatic brake isolated.

When changing the pads, the freedom of the caliper equipment is checked. The operation of the caliper equipment is checked during a six-week examination, and also forms part of the 12-week functional checks. All reservoirs with manual drain cocks are checked as part of the six-week examination.

Overhaul. The IC225 was procured with a six-year overhaul interval. Currently, the Class 91 locomotives receive an extensive examination/light overhaul at three years.

The actuators and tread brake units receive a performance check and light repair at three years and are fully overhauled at six years. The other brake equipment is overhauled at six years with the exception of the stainless steel reservoirs which will be overhauled at 12-year intervals.

The overhaul of the components is either carried out at the main works or by specialists (including original manufacturers) contracted to undertake the work.

Special Staff or Skill Needs

The traincrew are trained on the operation of the train systems and are given a rudimentary fault finding course. All IC225 sets are fitted with cab radios so assistance can be obtained from central maintenance controllers in the event of difficulties.

The maintenance staff also receive training on the specific systems on the trainsets. The maintenance staff have received sufficient training to enable them to tackle both mechanical or electrical maintenance on the trainsets. In the case of fault finding, depot-based technical staff or specially trained maintenance staff will be employed. The depot-based fault finding will be such that faulty components or sub-assemblies can be identified. These will be exchanged for overhauled units and the defective item sent for repair/overhaul.

Table 3-12. InterCity 225 FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)							Page 1 of 11
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Braking Control							
Driver's Brake Controller (electrically signals the Brake Control Unit BCU)	Signal for too much braking	Braking occurs above desired level for the trainset.	Rapid decrease in speed beyond level desired.	Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested.	N	Y[1]	C
	Signal for too little braking.	Braking is under desired level for the trainset.	Braking effort is too low, increasing stopping distance.	Train does not slow quickly enough. Must increase level of braking requested, possibly even emergency braking.	N	N	A2
	No signal for braking when braking requested.	Braking does not occur at all.	Braking does not occur at all.	Train does not slow down. Must utilize emergency brake.	N	N	A2
Brake Control Unit[2] (Includes electropneumatic valves, pressure transducers, relay valve) One BCU per locomotive or DVT.	Signal for too much braking	Braking occurs above desired level for trainset.	Rapid decrease in speed beyond level desired.	Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested.	N	Y[1]	C
	Signal for too little braking.	Braking is under desired level.	Braking effort is too low, increasing stopping distance for trainset.	Train does not slow quickly enough. Must increase level of braking requested.	N	N	A2
	No signal for braking when braking requested.	Braking does not occur at all.	Braking does not occur at all.	Train does not slow down. Must utilize emergency brake.	N	N	A2
Rheostatic Brake Control Unit	Fails indicating higher than actual rheostatic braking effort.	Two stage relay valve holds off more friction braking than it should given the actual rheostatic braking level.	Friction braking is too low resulting in increased stopping distances.	Train does not slow quickly enough. Must increase level of braking requested, possibly via emergency brakes.	Y	N	B2

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain) Page 2 of 11

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Rheostatic Brake Control Unit	Fails indicating lower than actual rheostatic braking effort.	Two stage relay valve does not hold off enough friction braking given the actual rheostatic braking level. This results in too much friction braking being applied for the actual rheostatic braking level. Excessive wear and/or overheating for friction brake components.	Friction braking is higher than required. Wheelset Slip Protection may be overworked as a result.	Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested.	Y	Y	D
Wheelset Slip Protection[3], WSP, Control (includes speed sensor) Operates on individual wheelsets	Fails with output failing to modulate the brake cylinder pressure.	Results in maintaining current brake level, not alleviating wheel slip. Braking applied to wheelset is above desired braking level resulting in wheel slip. This causes excessive wear on wheels and rails.	Over application of brakes on one wheelset causing wheel slide for the wheelset.	Wheelslide indicated to driver. Assume driver can isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3
	Fails with output requesting brake cylinder pressure to be vented, thus keeping the valve open.	Braking applied to wheelset is below desired braking level resulting in reduced or no braking for the wheelset associated with the failed control. Continuous venting beyond 10 seconds results in WSP lockout, then gradual brake application until all wheelsets are within 10 km/hr of each other.	Braking applied to wheelset is below desired braking level resulting in reduced or no braking for the wheelset associated with the failed control. Continuous venting beyond 10 seconds results in WSP lockout, then gradual brake application until all wheelsets are within 10 km/hr of each other.	Assume operator receives indication of lower braking effort than requested. WSP is locked out and brakes applied so that all wheelsets are within 10 km/hr of each other.	Y	N	B3
Two Stage Relay Valve (high or low speed braking level)	Fails to high speed level.	Braking duty is O.K. for the truck if V>201 km/hr, but once V< 201 km/hr, braking duty will be too low for the truck.	Braking duty is O.K. for the truck if V>201 km/hr, but once V< 201 km/hr, braking duty will be too low for the truck.	Once V < 201 km/hr braking effort will be too low. Driver can try to increase braking level, possibly via emergency brakes.	Y	N	B3
	Fails to low speed level.	Braking duty is O.K. for the truck if V< 201 km/hr, but if V > 201 km/hr, braking duty will be too high for the truck.	Braking duty is O.K. for the truck if V< 201 km/hr, but if V > 201 km/hr, braking duty will be too high for the truck.	When V > 201 km/hr, braking rate is too high resulting in excessive wear on friction brakes. Inspection and maintenance indicates wear.	Y	N	B3

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)				Page 3 of 11			
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Rheostatic Braking[4]							
Motor Truck							
Catenary Power	Loss of power or decrease in power.	Battery back up power initiates.	Battery supplies power and rheostatic braking is still available.	Assume driver has indicators on catenary and battery status. Battery power allows brake to operate if needed.	Y	Y	D
Battery (Assume a battery system is available for each truck)	Loss of battery power or decrease in battery power.	No effect, except no backup is available for the rheostatic brake for the truck with the failed battery system.	No effect, except no backup is available for the rheostatic brake for the truck with the failed battery system.	Assume driver has indicators on battery status. Repair at first maintenance opportunity.	Y	Y	D
Traction Motor (2 per truck)	Does not produce current to dissipate current in resistor grids.	Loss of or decrease in rheostatic braking for the motor truck.	Relay valve will allow more or all of requested braking effort to be friction braking.	Relay valve reacts to lower rheostatic braking by allowing more friction braking.	Y	Y	D
	Bearing failure, axle seizes.	Unintentional wheel slide for the motor truck. WSP attempts to alleviate wheel slide.	Unintentional wheel slide for the motor truck. WSP attempts to alleviate wheel slide.	WSP monitored by driver. Failure of motor, driver can isolate the wheelset and continue and lower speed or line speed.	N	N	A2
Resistor Grids	Inability to dissipate energy/heat	Loss of or decrease in rheostatic braking for the motor truck.	Relay valve will allow more or all of requested braking effort to be friction braking.	Relay valve reacts to lower rheostatic braking by allowing more friction braking.	Y	Y	D
Friction Braking							
Motor Truck[5]							
Air Brake Pipe (ABP)	Fails with Low Pressure (Effects entire brake system)	Friction brakes applied.	All brakes applied to degree of low pressure failure.	Speed reduction. Pressure gauges in cab indicate low pressure.	N	Y[1]	C

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)							Page 4 of 11
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Distributor	Signal for braking above desired level, fails open.	Braking occurs above desired level for the truck. Wheelslide protection (WSP) prevents wheelslide. Excessive wear and/or overheating on brake components possible.	Truck with failed distributor brakes too much, overworks WSP for the truck. WSP lockout may occur possibly isolating the distributor.	Braking effort is too high resulting in rapid speed decrease. If possible, reduce level of braking requested. If WSP is locked out and distributor isolated, operator can continue at reduced line speed.	N	N	A3
	Signal for too little or no braking, fails closed.	Braking is under desired level for the truck affected including no braking.	Braking effort is too low for the truck.	Truck does not brake sufficiently. Continue at reduced speed.	Y	N	B3
Two Stage Relay Valve (Blending of friction and rheostatic brakes)	Indicates higher than actual rheostatic braking	If current level of rheostatic braking is sufficient, there is no problem. If it is not and friction braking is needed, not enough friction braking will be applied for the locomotive.	Potentially lower braking level than desired for the locomotive. Friction braking is only blended at speeds below 30 mph so only in this low, small speed regime is this failure a problem.	Braking effort must be increased because the train does not slow quickly enough. Possibility of utilizing emergency brakes if failure is extreme.	Y	N	B2
	Signals lower than actual rheostatic braking.	Friction braking may be applied for the locomotive when it is not required. The wheel slip control should compensate to avoid wheel slip.	Unneeded friction braking may be applied for the locomotive.	Locomotive slows too quickly. Must decrease level of braking requested for the truck, possibly via isolation of this truck's brake and continuing at a reduced speed.	N	Y	C
Disc Brake Actuators (Assume one per axle)	Fail discs brakes on	Brake effort constantly applied is equivalent to effort from 3 discs or 1 axle, these are equivalent in braking effort. Excessive wear on brakes or overheating of brakes.	Brake effort constantly applied is equivalent to effort from 3 discs or 1 axle, these are equivalent in braking effort. Excessive wear on discs, calipers, and even wheels possible.	Potentially, speed reduction when not requested. Driver could isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3
	Fail disc brakes off	Brake effort not applied, lost braking capability equivalent to effort from 3 discs or 1 axle, these are equivalent in braking effort.	Brake effort not applied, lost braking capability equivalent to effort from 3 discs or 1 axle, these are equivalent in braking effort.	Lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)							Page 5 of 11
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Disc Brakes (Disc or caliper, 3 discs per axle)	Fail brakes on	Brake effort constantly applied is equivalent to effort from one disc. Excessive wear on brakes or overheating of brakes.	Brake effort constantly applied is equivalent to effort from one disc.	Potentially, speed reduction when not requested. Driver could isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3
	Fail brakes off	Brake effort not applied, lost braking capability equivalent to effort from one disc.	Brake effort not applied, lost braking capability equivalent to effort from one disc.	Lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3
Tread Brakes (Acts independently on each wheelset) Air applied brake cylinder for each unit	Fail on	Brake effort constantly applied to one wheelset. Excessive wear on brakes or overheating of brakes.	Brake effort constantly applied to one wheelset.	Potentially, speed reduction when not requested. Driver could isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3
	Fail off	Brake effort not applied, lost brake capability equivalent to effort on one wheelset.	Brake effort not applied, lost brake capability equivalent to effort on one wheelset.	Lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3
Compressor (2) and MRS governor	Fails on	Pressure builds in the main reservoir and continues beyond normal levels. Safety valve on main reservoir vents excess pressure.	None. Safety valve on main reservoir acts to vent the reservoir to the correct pressure.	Safety valve senses overpressure. Gauges in cab indicate high pressure. Assume driver has indicator of compressor operation in cab also.	Y	Y	D
	Fails off	May not be able to energize brake system. The result is that the friction brakes are unavailable. However, the second compressor may be able to provide enough air at the required pressure to keep the system operating.	Either no friction brakes or, if second compressor has enough capacity, no effect as the second compressor takes over the duty of the failed compressor.	Gauges in cab indicate low pressure of reservoir. Assume driver has indicator of compressor operation in cab and can operate one of the compressors. If necessary, assume operator must apply emergency brakes.	N	Y	C

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain) — Page 6 of 11

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Main Reservoir Supply (MRS)	Fails high pressure	Safety valve on main reservoir vents excess pressure once pressure reaches 10.7 bar to maintain desired pressure of 10 bar in reservoir.	None. Safety valve on main reservoir acts to vent the reservoir to the correct pressure.	Safety valve senses overpressure and vents to 10 bar pressure in reservoir. Gauges in cab indicate high pressure. Assume driver has indicator of compressor operation in cab also.	Y	Y	D
	Fails low pressure	May not be able to re-energize brake system. The result is that the friction brakes cannot be released. Compressors may try to compensate by running hard trying to reach the desired 10 bar.	Friction brakes may not be released or excessive running of compressors or both will result.	Gauges in cab indicate low pressure of reservoir. Assume driver has indicator of compressor operation in cab and can charge pressure via compressors.	N	Y	C
MRS Safety Valve	Fails open	Air is vented from main reservoir resulting in low pressure in main reservoir. Friction brakes unavailable or excessive running of compressors or both will result.	Air is vented from main reservoir resulting in low pressure in main reservoir. Friction brakes unavailable or excessive running of compressors or both will result.	Gauges in cab indicate low pressure of reservoir. Assume driver has indicator of compressor operation in cab also.	N	Y	C
	Fails closed	No effect. If a combination of MRS overpressurization and safety valve failing closed occurs, there would be no relief for overpressurization.	No effect. This requires a second failure for this failure to have any impact.	Inspection and maintenance should detect valve failure. Repair at first maintenance opportunity.	Y	Y	D
Pressure Control Valve	Fails open	Pressure could build up in MRS to excessive levels.	The MRS safety valve should vent the air to maintain safe pressures in the MRS.	Gauges in cab indicate pressure of MRS to ensure sufficient energy is available to stop the train. Driver can vent MRS/MRP to relieve pressure build up or safety valve relieves pressure.	Y	Y	D

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)							Page 7 of 11
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Pressure Control Valve	Fails closed	Pressure is not available to MRS so that once the friction brakes are applied, they may not be able to be reapplied because of the pressure deficiency in the MRP.	The friction brakes cannot be released once applied.	Gauges in cab indicate pressure of MRS to ensure sufficient energy is available to stop the train.	N	Y	C
Automatic Drain Valves	Fails open	Potential air leak and pressure loss if no condensate is present.	Potential air leak and pressure loss if no condensate is present. Assume compressor makeup can compensate for open drain valve and maintain pressure.	Maintenance and inspection checks.	Y	Y	D
	Fails closed	Condensate mixes with air supply adding moisture to air system. This may result in wear on components and changing brake responses based on the amount of moisture in the air supply. System may become contaminated, leading to corrosion.	Condensate mixes with air supply adding moisture to air system. This may result in wear on components and changing brake responses based on the amount of moisture in the air supply.	Maintenance and inspection checks.	Y	Y	D
Main Reservoir Pipe[6]	Fails with low pressure	Pressure is not available in MRP so the distributor recharges the brake supply reservoir via the ABP.	Pressure is not available in MRP so the distributor recharges the brake supply reservoir via the ABP.	Gauges in cab indicate pressure of MRP to ensure sufficient energy is available to stop the train. ABP can charge brake supply reservoir.	Y	Y[7]	D
Brake Supply Reservoir	Fails with low pressure	If MRP cannot recharge the brake supply reservoir, the distributor recharges the reservoir via the ABP. If low pressure remains, distributor will be unable to release the friction brakes for the truck.	If MRP cannot recharge the brake supply reservoir, the distributor recharges the reservoir via the ABP. If low pressure remains, distributor will be unable to release the friction brakes for the truck.	Gauges in cab indicate pressure levels to driver. Initial response is charge reservoir via ABP.	Y	Y	D

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)							**Page 8 of 11**
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Addition of Antifreeze into the Air System (Winter only)	Too much antifreeze	May potentially contaminate the system if the drain valves cannot dispose of the excess antifreeze.	May potentially contaminate the system if the drain valves cannot dispose of the excess antifreeze.	Inspection and maintenance are the means of detection. If the braking level is incorrect, the operator will have to compensate.	Y	N	B3
	Insufficient amount of antifreeze	In colder weather there is a potential of moisture in the air freezing in a valve or air line.	May potentially freeze up a valve or control line so that the brakes are not applied to the desired level.	Operator will only be aware of the situation if the braking response is obviously different from what was desired. Inspection and maintenance are the means of detection. If the braking level is incorrect, the operator will have to compensate.	N	N	A3
Trailer Coach							
Distributor	Signal for braking above desired level, fails open.	Braking occurs above desired level for the coach. Wheelslide protection (WSP) prevents wheelslide. Excessive wear and/or overheating on brake components possible.	Coach with failed distributor brakes too much, overworks WSP for the truck. WSP lockout may occur possibly isolating the distributor.	Braking effort is too high resulting in rapid speed decrease. If possible, reduce level of braking requested. If WSP is locked out and distributor isolated, operator can continue at reduced line speed.	N	N	A3
	Signal for too little or no braking, fails closed.	Braking is under desired level for the coach effected including no braking.	Braking effort is too low for the coach.	Coach does not brake sufficiently. Continue at reduced speed.	Y	N	B3
Auxiliary Reservoir[8]	Fails with low pressure	If MRP cannot recharge the auxiliary reservoir, the distributor recharges the reservoir via the ABP. If low pressure remains, distributor will be unable to apply the friction brakes for the coach.	Friction brakes not available for the coach.	Gauges in cab indicate pressure levels to driver. Initial response is charge reservoir via ABP.	Y	Y	D
Two Stage Variable Load Relay Valve (1 for each coach)	Signal for too much braking, indicates higher load than exists for the coach.	Braking occurs above desired level for the coach. WSP should compensate to avoid wheel slip.	Decrease in speed beyond level desired.	Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested. WSP may lockout, may need to isolate brakes on this coach.	N	N	A3

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain) —

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Two Stage Variable Load Relay Valve (1 for each coach)	Signal for too little braking, indicates lighter or no load for the coach than really exists.	Braking is under desired level for the coach effected.	Braking effort is too low, increasing stopping distance.	Train does not slow quickly enough. Must increase level of braking requested. For no indication of load, speed limit of 161 km/hr is imposed.	Y	N	B3
Disc Brake Actuators (One per disc)	Fail discs brakes on	Brake effort constantly applied is equivalent to effort from 1 disc. Excessive wear on brakes and/or possibly overheating of brakes.	Brake effort constantly applied is equivalent to effort from 1 disc. Excessive wear on discs, calipers, and even wheels possible.	Potentially, speed reduction when not requested. Driver could isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3
	Fail disc brakes off	Brake effort not applied, lost braking capability equivalent to effort from one disc.	Brake effort not applied, lost braking capability equivalent to effort from one disc.	Lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3
Disc Brakes (Disc or caliper, 3 discs per axle)	Fail brakes on	Brake effort constantly applied is equivalent to effort from one disc. Excessive wear on brakes and/or possibly overheating of brakes.	Brake effort constantly applied is equivalent to effort from one disc.	Potentially, speed reduction when not requested. Driver could isolate system and continue at reduced speed or line speed depending on degree of failure.	N	N	A3
	Fail brakes off	Brake effort not applied, lost braking capability equivalent to effort from one disc.	Brake effort not applied, lost braking capability equivalent to effort from one disc.	Lower braking effort than requested. May have to operate at reduced speed or line speed depending on degree of failure.	Y	N	B3
Driving Van Trailer[9]							
TDM Communication to Driving Van Trailer (normal operation transmits same signal as sent from Driver's Brake Controller)	Loss of braking signal transmitted to DVT.	Full brakes applied by system from the Driving Van Trailer (DVT).	Full brakes applied by system from the Driving Van Trailer (DVT).	If system loses signal, automatically applies brakes.	N	Y	C

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)							Page 10 of 11
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Two Stage Variable Load Relay Valve (1 for each truck)	Signal for too much braking	Braking occurs above desired level. May result in some wheel sliding for the truck.	Rapid decrease in speed beyond level desired	Braking effort is too high resulting in rapid speed decrease. Reduce level of braking requested.	N	N	A3
	Signal for too little braking.	Braking is under desired level for the truck effected.	Braking effort is too low, increasing stopping distance.	Train does not slow quickly enough. Must increase level of braking requested.	Y	N	B3
	No signal for braking when braking requested.	Braking does not occur at all for the affected truck.	Braking does not occur at all.	Train does not slow down. Must utilize emergency brake.	N	N	A3
Emergency Braking[15]							
Driver's Brake Controller	Signal for too little braking.	In addition to electric signal, controller directly vents the ABP when in the emergency position. Therefore, emergency braking is still applied.	Emergency braking is applied.	Emergency braking is applied.	Y	Y	D
	No signal for braking when braking requested.	In addition to electric signal, controller directly vents the ABP when in the emergency position. Therefore, emergency braking is still applied.	Emergency braking is applied.	Emergency braking is applied.	Y	Y	D
	Venting does not occur with controller in emergency position.	Emergency braking is applied via the electric signal. Therefore, emergency braking is still applied.	Emergency braking is applied.	Assume some fault is noted so that on next available maintenance opportunity fault can be fixed.	Y	Y	D
Emergency Plunger	Does not vent ABP.	No effect. Emergency brakes are normally applied via brake controller. Emergency plunger is a backup.	No effect. Emergency brakes are normally applied via brake controller. Plunger is a backup.	Inspection and maintenance should correct any failure of the plunger.	Y	Y	D

Table 3-12. InterCity 225 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

InterCity 225 (Great Britain)							Page 11 of 11
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Passenger Emergency Vent Valves	ABP not vented when operated.	Emergency brake not initiated. Driver receives notification of valve operation and can select emergency braking if required.	Emergency brake not initiated. Driver receives notification of valve operation and can select emergency braking if required.	Emergency brake not initiated. Driver receives notification of valve operation and can select emergency braking if required.	N	N	A2
Automatic Warning System	Lineside signal not green, horn sounds.	Driver has 3 seconds to take action to cancel the horn or the ABP is automatically vented.	Driver has 3 seconds to take action to cancel the horn or the ABP is automatically vented.	Driver has 3 seconds to take action to cancel the horn or the ABP is automatically vented.	N	Y	C
Driver Safety Device	Driver does not activate foot pedal once every 60 seconds.	ABP is automatically vented initiating emergency braking.	ABP is automatically vented initiating emergency braking.	ABP is automatically vented initiating emergency braking.	N	Y	C

1. Even though this failure results in the friction brakes being applied, this failure may not be failsafe if it occurs at high speeds.
2. BCU recharges ABP at a rate much less than the rate of air loss from safety system activation.
3. WSP control locks out dump valve if continuously dumping for 10 secs and applies full brakes until train stopped or all wheelsets within 10 km/hr of each other.
4. Train can still be stopped safely without rheostatic braking using friction brakes.
5. Typically friction braking on a motor truck is only used for speeds below 30 mph, unless the rheostatic brake fails.
6. MRP continuously monitored to ensure sufficient pressure available to stop train.
7. Failsafe if distributor automatically recharges brake supply reservoir via ABP when MRP has low pressure.
8. Auxiliary reservoir always recharged before air supplied to air suspension.
9. Same as trailer coach except as noted.
10. This section only includes modes of triggering emergency braking because the actual application of the emergency brakes is done via the systems described above.

3.7 SHINKANSEN TRAINS

3.7.1 Description of Trainsets

Since the inauguration of service on the New Tokaido Line in 1964, the Tokaido Shinkansen has carried over 2.5 billion passengers. To this original line between Tokyo and Osaka, three other lines have been added: the Sanyo line, Osaka to Hakata (Kyushu); the Joetsu to Niigata; and the Tohoku line to Morioka and eventually to Sapporo (Hokkaido).

Three different series of trainsets are used in service. The 100 series trains consist of 12 motor cars (all axles powered by dc traction motors) and four trailer cars with a trainset weight of 925 metric tons. These are run in service at 220 km/h (137 mph) maximum speed, however, newer cars in current use on the Tokaido line are run at 240 km/h (150 mph). A 200 series in 12-car trainsets has all axles powered by slightly more powerful motors (230 kW vs. 185 kW) than the 100 series to cope with steeper gradients on other lines. Finally, the newest 300 series in the "Nozomi" service has increased the top speed from 220 to 270 km/h (168 mph). This trainset consists of 12 motored cars (all axles powered by ac cage asynchronous traction motors) and four trailer cars. By use of aluminum car structures, the trainset weight has been reduced to 710 metric tons.

3.7.2 Braking System Design

The three Shinkansen trainset series apply somewhat different braking system design philosophies. These differences are noted in Table 3-13 (Ref. 22). The newer 200 series cars may have incorporated some of the features of the 300 series brake design.

Prior to 1978, the electric cars in Shinkansen service were equipped with a straight air pipe system of air brakes. Since 1978, an all-electric command brake control system has been used, starting with the 100 series cars. Brake systems of all three series (100-300) are based mechanically on a pneumatic/hydraulic conversion disc brake, supplemented by dynamic (rheostatic or regenerative) braking on powered axles and eddy current brakes on non-powered trailer car axles. Cars carry two wheel cheek-mounted discs per axle. The electro-pneumatic changeover valve receives an electric current command, converting this to an air pressure command, which is amplified by the relay valve. In the air-hydraulic booster, air pressure is converted into pressurized oil. The mechanical friction brake calipers are then actuated by an hydraulic cylinder. This sequence is illustrated in the schematic diagram, Figure 3-9, for the 200 series cars (Ref. 23).

3.7.3 Brake System Performance

The specified train deceleration rates for the 200 and 300 series trainsets correspond to given speed-adhesion characteristics to account for decreasing wheelset adhesion above a speed of about 80 km/h. Nominal braking rates for these trainsets are compared in Table 3-14. Speed versus deceleration characteristic curves for the Series 300 trainset are shown in Figure 3-10 (Ref. 24).

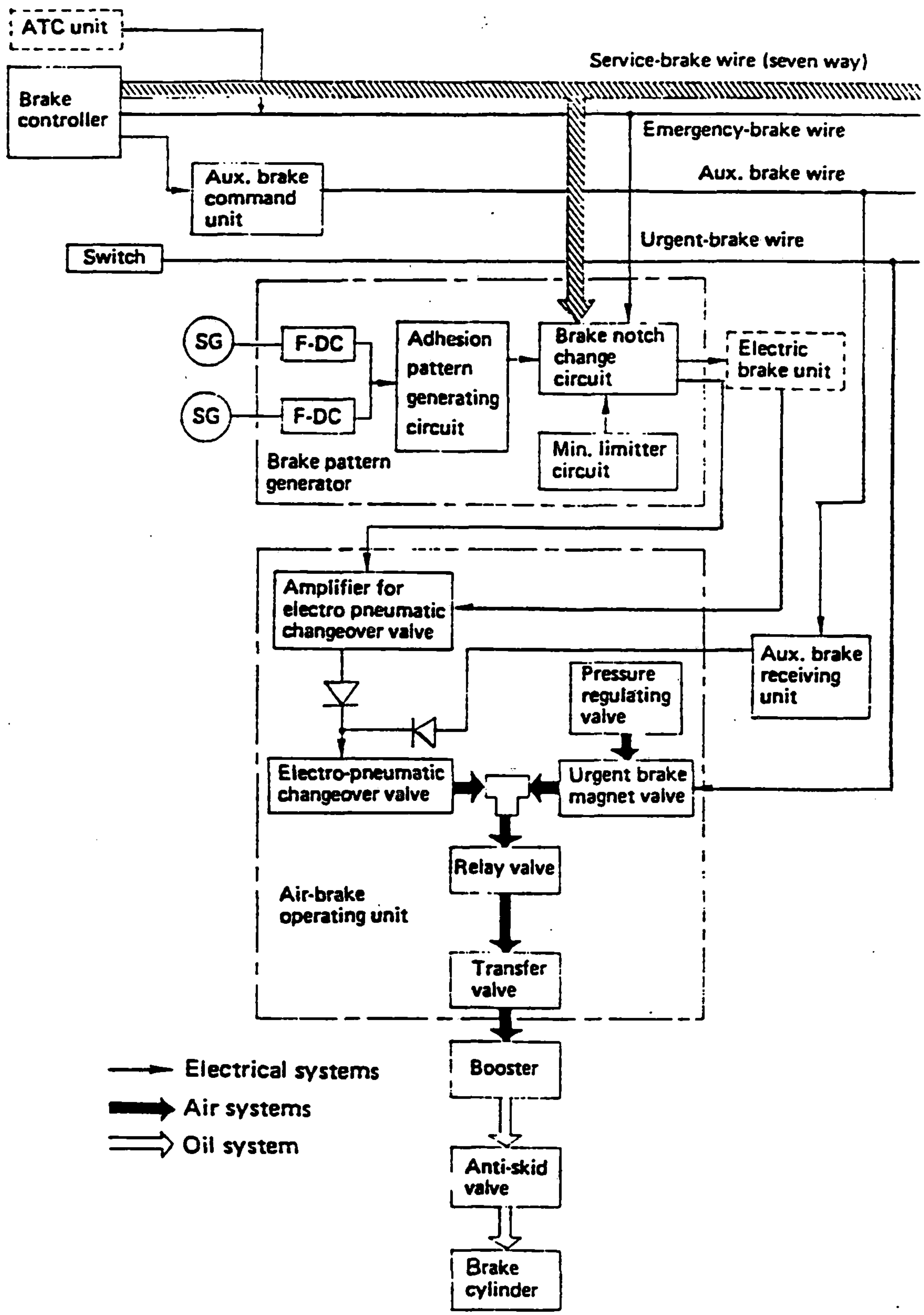

Figure 3-9. Schematic Diagram of Series 200 Trainset Brake System (Ref. 23)

Table 3-13. Braking System Design Overview for Shinkansen Trainsets

Trainset	Brake System Design Attributes
100	• Rheostatic (dynamic) braking • Electrically-controlled air brake system • Eddy current brake system on trailer cars • Continuous control along adhesion pattern
200	• Rheostatic (dynamic) braking • Electro-magnetic straight air brake system • Continuous control to ATC speed step
300	• A.C. regenerative (dynamic) braking • Electrically-controlled air brake system • Eddy current brake system on trailer cars with load response device • Continuous control along adhesion pattern

Table 3-14. Nominal Braking Rates for Shinkansen Trainsets

Condition	Series 200		Series 300 (Nozomi)	
	Below 70 km/h, km/h/s (mph/s)	At 220 km/h, km/h/s (mph/s)	Below 80 km/h, km/h/s (mph/s)	At 270 km/h, km/h/s (mph/s)
Full Service	2.6 (1.6)	1.3 (0.8)	2.6 (1.6)	1.3 (0.8)
Emergency	3.9 (2.4)	2.0 (1.2)	3.6 (2.2)	1.8 (1.1)
Urgency	2.8 (1.7)	2.8 (1.7)	2.9 (1.8)	2.2 (1.4)

3.7.4 Braking System Operation, Control and Safety Features

Operation and Control

The brake system for the Series 200 cars is controlled by electric commands over eight command levels carried over the train bus (Figure 3-9). Commands for braking effort range in seven steps (1N to 7N) up to full service braking, using a grey code (three-wire) system. A separate line commands the eighth (emergency) level. A separate "urgency" brake circuit controls the brakes of a car in abnormal conditions, such as train separation, electric power loss, or a shortage of brake force. The seven service brake levels are energized in sequence as commanded by the driver's brake controller or by the automatic train control (ATC). The emergency brake line is normally energized and is deenergized when emergency braking is commanded. Braking force in emergency is 50 percent higher than in full service (7N) braking. The urgency brake is also commanded from a normally energized line.

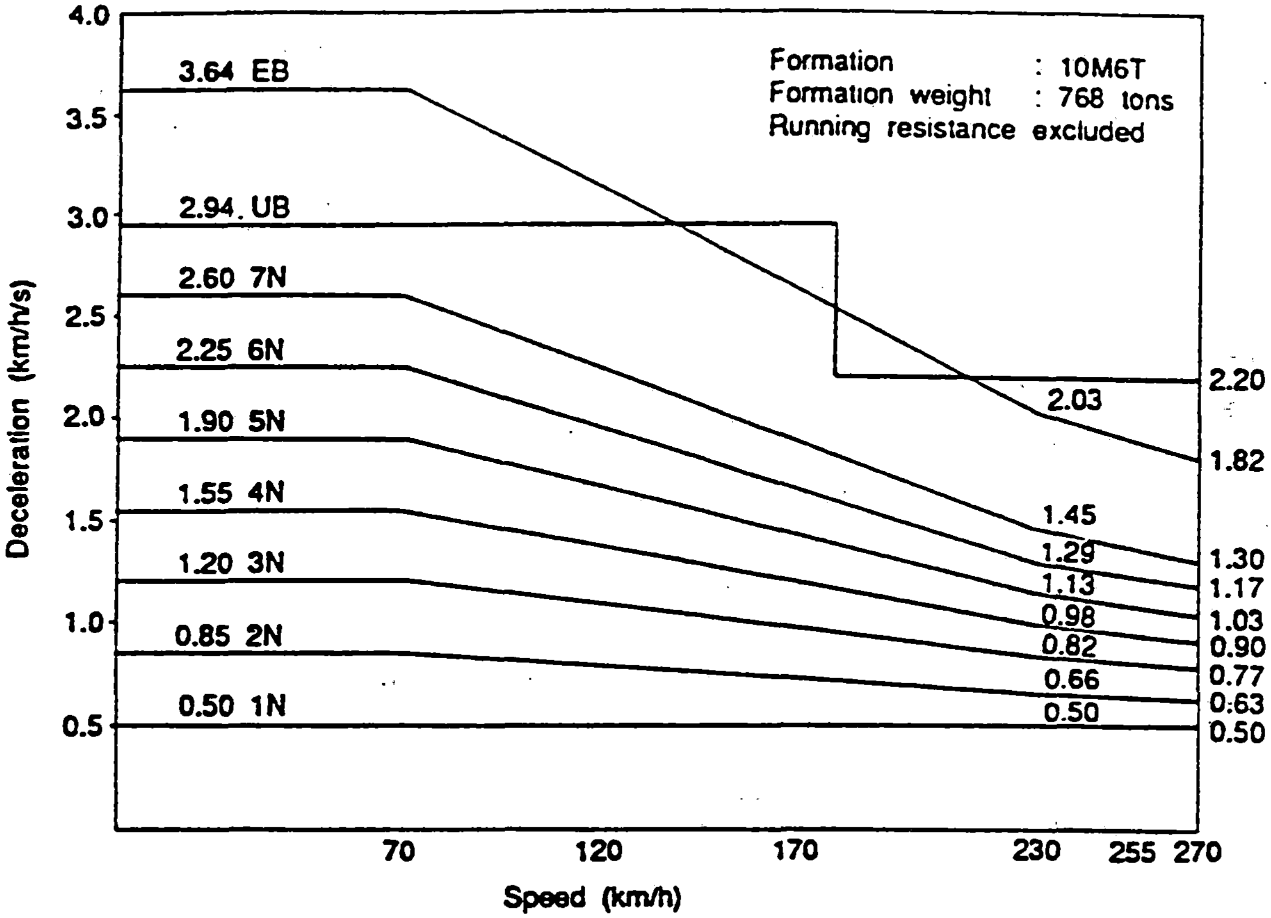

Figure 3-10. Speed vs. Deceleration Characteristics for the Series 300 (Nozomi) Trainset (Ref. 24)

The braking command line signals are interpreted by the brake pattern generator which, in conjunction with the signal from a tachometer-generator (SG in Figure 3-9) and the locally-stored speed-adhesion characteristic, sends a speed-modified signal to the chopper control equipment. This controls the electric brake unit and the electro-pneumatic changeover valve amplifier. Priority blending of brakes uses the dynamic (electric) braking to its maximum level to reduce wear on friction brake components. Speed-adhesion characteristics and anti-skid control modulate the braking force to avoid sliding the wheels.

The urgency brake is applied from its normally-energized command line by a one-step control at any speed and the speed pattern control is not applied. Urgency braking is applied only to the car in abnormal operation, while emergency braking is applied to all other cars with the corresponding speed-adhesion and antislip controls. An auxiliary brake is available to enable the train to be run at very slow speeds in the event that service and emergency brake systems are inoperable. This is a simple four-step control in the 200 series. A snow brake is used to prevent snow and ice sticking and freezing on the brake shoes in the winter season.

In the Series 300 cars, both the service and emergency brake levels are designed to control the braking force according to load condition and individual car weight condition, in addition to the speed-adhesion characteristics (Ref. 24). The urgency brake uses a two-step control to compensate for lower adhesion at higher train speeds. The service brake usually applies the electrical (regenerative dynamic) brakes with the pneumatic/hydraulic powered friction brakes taking over in the lower speed range. Emergency braking force is 40 percent higher than the full service (7N) braking level.

Command of the service and emergency braking is applied by the driver's brake controller or the ATC system as illustrated in Figure 3-11. This figure implies a seven-wire service brake train line, energized in a progressive sequence. Again, the emergency brake line is normally energized, and deenergized to command emergency braking (a fail-safe approach). These commands are directed to the brake output controller of each car. Both service and emergency brakes employ a variable load controller which detects the car suspension air spring pressures at the four locations on each car.

The auxiliary brake on the 300 series cars allows low-speed operation when service and emergency brakes are inoperable. This brake uses a three-step (two-wire) control of braking force. Leading cars of the Series 300 and older Series 0 cars have brake interface equipment so that they can operate in a "rescue" mode.

3.7.5 Braking System Effects on Vehicle, Guideway, and Infrastructure

The Shinkansen trainsets do not use track brakes such as the electro-magnetic or linear eddy current emergency brake systems used on some high-speed trains. Although the trainsets use eddy current disc brakes on trailer car axles, no detailed description of these brakes has been found in the literature. Possible problems with electro-magnetic (EMI) or radio frequency (RFI) interference have not been mentioned.

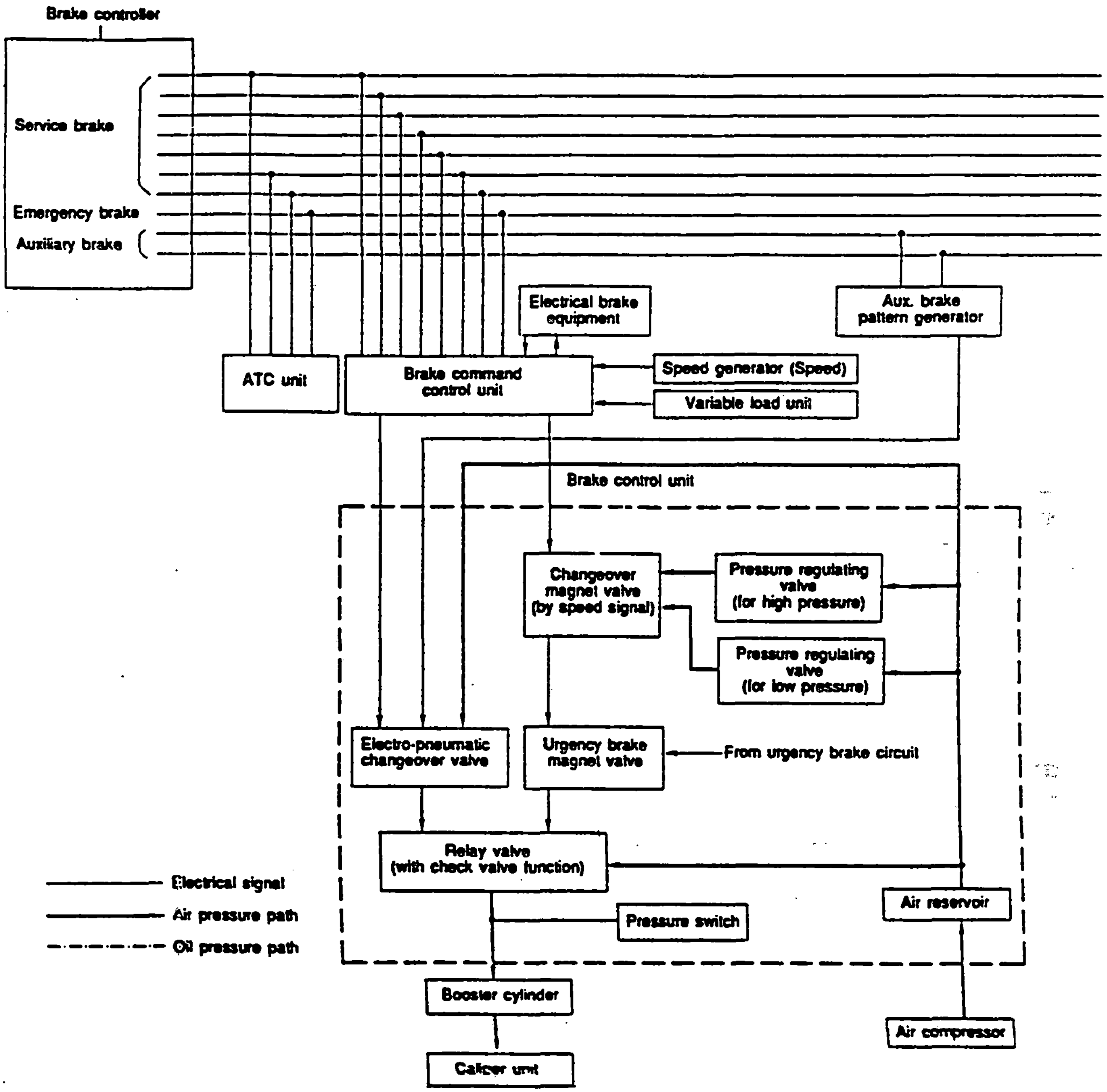

Figure 3-11. Schematic Diagram of Series 300 (Nozomi) Trainset Brake System (Ref. 24)

Table 3-15. Shinkansen 200 FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

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Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Braking Control							
Wheel-slip (Anti-skid) Device	Fails to detect slip	Wheel begins/continues to slide with loss of brake power.	Driver must increase braking effort to other wheels to compensate.	Signal in cab? Driver realizes train not slowing at proper rate.	N	Y	C
	Incorrectly detects slip	Brake power reduced to counter slip.	Driver must increase braking effort to other wheels to compensate.	Signal in cab? Driver realizes train not slowing at proper rate.	Y	N	B3
Tachometer-Generator (Speed Signal)	Fails to send signal	Braking level not adjusted for train speed. Anti-skid Valve should prevent wheel slip.	Negligible unless wheel Anti-Skid device fails. If Anti-Skid device fails, probability of locking wheels is substantially higher.	Signal in cab?	Y	N	B3
	Sends incorrect signal/Improper calibration	1) Sends incorrect "no slip" signal to Adhesion Pattern Generating Circuit possibly resulting in overbraking at higher speeds and possible wheel slip. 2) Causes Anti-Skid device to improperly detect slip (See Anti-Skid Device).	1) Possible overbraking and slip at high speed. 2) See Anti-Skid Device for other possible effects.	By inspection?	1)N 2)Y	1)N 2)N	A2 B3
Electrical Wiring/Train Data Bus (3 wires)	One line fails to carry signal	A degree of deceleration is lost in some or all cars requiring either under- or over-braking.	The effect should be negligible at high speeds where Electrodynamic braking is used; however, the train may be forced to decelerate more quickly or apply the Emergency and Urgent-brake at lower speeds.	Signal in cab?	Y	Y	D
	All three lines fail	Loss of normal service braking.	One or more cars lose normal-service braking including Electrodynamic braking. Emergency/Urgent-brakes need to be applied to slow/stop train.	Loss of braking. Signal in cab.	N	N	A2
Emergency-brake Wire	Fails to carry signal	Deenergizes wire causing emergency brakes to apply.	Emergency Service All brakes applied to comfortably stop train in minimum braking distance.	Emergency-brakes applied. Signal in cab.	N	Y	C
Brake Controller	Fails to send signal	Brakes not applied.	The ATC unit may activate the emergency brake if it senses that the train is not decelerating.	It is assumed that the Auxiliary Brake Command Unit or ATC will signal the operator.	Y	Y	D

Table 3-15. Shinkansen 200 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 200 (Japan)							Page 2 of 5
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Brake Controller	Sends incorrect signal	It is assumed that some correction will be made by the brake pattern generator to account for speed and adhesion. Brakes may be over-/under-applied.	Braking is disproportionately applied. If a failure is detected, emergency braking will be applied.	It is assumed that the Auxiliary Brake Command Unit or ATC will signal the operator.	Y	Y	D
Auxiliary Brake Command Unit	Fails to send signal	None, unless Brake Controller has failed. If both systems have failed, ATC may still activate brakes.	Emergency Service: Possible loss of braking. Operator may be required to manually apply brakes.	Signal to cab?	Y	Y	D
	Sends incorrect signal	Since this controller only operates when the Brake Controller has failed, brakes will be disproportionately applied resulting in over- or under-braking.	Emergency Service: Disproportionate braking. Auxiliary brakes only allow train to travel at low speeds at which Regenerative braking systems are ineffective.	Unusual train deceleration.	N	Y	C
Auxiliary Brake Receiving Unit (per Car)	Fails to process incoming signal	Signal not passed on to Electro-pneumatic changeover valve, and friction brakes are not applied.	Emergency Service: Loss of auxiliary braking. Regenerative brakes ineffective at low speeds. Operator may need to engage Urgent-/Emergency-brakes.	Signal in cab? Loss of brake power.	Y	N	B3
Brake Notch Change Circuit	Fails to process signal	Braking level not changed. May result in lack of brake application or lack of brake release.	May result in total loss of braking since signal to activate Electric Brakes must pass through this unit.	Signal in cab? Loss of brake power.	N	N	A2
Resistive (Dynamic) Brakes (Power Cars)							
Resistive Brake System (Traction Motor/Generator)	Fail Off	Loss of dynamic braking.	Friction brakes must be activated. Friction brakes are sufficient to stop the train.	It is assumed that warning signals will be activated in the cab.	Y	Y	D
	Bearing failure, axle seizes.	Loss of dynamic braking.	Friction brakes must be activated. Friction brakes are sufficient to stop the train.	It is assumed that warning signals will be activated in the cab.	N	N	A2

Table 3-15. Shinkansen 200 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 200 (Japan)							Page 3 of 5
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Electro-pneumatic/Friction (Power Cars)							
Amplifier for Electro-pneumatic Changeover Valve	Fails to amplify	Brakes are under-applied.	Regenerative brakes should already be optimized. If the situation requires friction braking, feedback will increase braking effort until proper deceleration is achieved. If more braking is required, emergency brakes must be applied.	Unusual braking performance. Signal in cab?	Y[1]	N	B3
	Fails as Open Circuit	Loss of braking at car.	Emergency brakes must be applied.	Signal in cab?	Y	N	B3
Electro-pneumatic Changeover Valve	Fails Off	Electric signal not converted to air pressure. Loss of braking at car.	Regenerative braking slows train from high speed, but Emergency/Urgent-brake must be used to stop train at low speed.	Signal in cab?	Y[1]	N	B3
	Improper Calibration	Brakes over- or under-applied due to improper amplification.	Regenerative braking slows train from high speed. If under-amplified, more friction-brake force must be applied. Emergency/Urgent-brake may have to be used to stop train at low speed.	Unusual braking performance. Signal in cab?	Y	Y	D
Relay Valve	Fails Open	None.	None.	Signal in cab? Inspection?	Y	Y	D
	Fails Closed	Air pressure not sent to Transfer Valve. Friction brakes not applied.	Regenerative braking will slow train from high speed. Loss of brakes at car.	Pressure sensor between Relay Valve and Transfer Valve?	Y	N	B3
Transfer Valve/Vent	Fails Open	Brakes on effected car cannot be released once applied. Relay Valve acts as check valve to prevent back-pressure to Electro-pneumatic Changeover Valve.	Friction brakes on effected car cannot be released once applied. Electrodynamic brakes unaffected.	Signal in cab? Inspection?	N	Y	C

Table 3-15. Shinkansen 200 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 200 (Japan)							Page 4 of 5
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Transfer Valve/Vent	Fails Closed	Air pressure not converted to hydraulic-oil pressure at Booster. Friction brakes not applied at effected car.	Regenerative braking will slow train from high speed. Other cars must compensate with Friction braking to stop train.	Oil pressure sensor?	Y	N	B3
Booster	Fails to amplify/produce oil pressure	No friction braking at effected car.	Regenerative braking will slow train from high speed. Other cars must compensate with Friction braking to stop train.	Lack of braking. Oil pressure sensor?	Y	N	B3
	Over-amplifies/too much oil pressure	Over-brakes. Feedback compensates by lessening air pressure?	If feedback does compensate, effect should be negligible.	Inspection? This situation is probably unnoticeable.	Y	Y	D
Disc Brake Calipers	Fail to apply (stuck open)	Loss of braking at the affected discs.	Reduction in braking power. Amount of reduction depends on number of discs effected.	Signal in cab? Inspection?	Y	N	B3
	Fail to release (stuck closed)	Disc will heat up, possibly causing damage. If axle locks-up at high speed, wheels may develop flat spots or catch fire.	May cause damage to caliper/disc resulting in reduction of brake power.	Thermocouple at discs? Warning light?	N	N	A3
Brake Discs	Fracture	Increases wear to calipers. Possible loss of braking at that disc.	Reduction in braking power. Amount of reduction depends on number of discs effected.	Inspection.	Y	N	B3
Adhesion Pattern Generating Circuit (Traction Control)	Fails to sense loss of traction	Axle locks-up, providing limited braking power.	Reduction in braking power. Amount of reduction depends on number of discs effected.	Signal in cab?	N	N	A2
	Incorrectly senses slip	Calipers modulated, reducing available braking power.	Reduction in braking power. Amount of reduction depends on number of discs effected.	Signal in cab?	Y	N	B3
Pressure Regulating Valve	Fails to regulate (limit) pressure	May cause failure in valves or pneumatic lines resulting in loss of friction braking in that car.	In severe case, friction braking could be lost on that car.	Signal in cab?	Y[2]	N	B3

Table 3-15. Shinkansen 200 FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 200 (Japan) Page 5 of 5

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Urgent Brake Magnet Valve	Fails Open	Friction brakes applied on car.	Emergency Service: Electrodynamic brakes should be applied to minimize wear.	Signal in cab	N	Y	C
	Fails Closed	Urgent-brake unusable.	Emergency Service Approximately 8% reduction in available friction braking. Other cars must compensate.	Signal in cab (or lack of signal)	Y	N	B3
Auxiliary-brake Wire	Fails to carry signal	Disables auxiliary friction braking on one or more cars.	Emergency Service Emergency/Urgent-brake must be applied to stop train.	Signal in cab?	Y	N	B3
Urgent-brake Wire	Fails to carry signal	Deenergizes wire causing emergency brakes to apply.	Emergency Service Train brakes regardless of condition of normal service braking.	Train begins to brake. Signal in cab. Inspection.	N	Y	C
Pneumatic Lines	Fail Open (leak)	Loss of friction braking in the affected car.	Braking effort in other cars increased to compensate.	Pressure gauge in cab? Inspection	Y	N	B3
	Fail Closed (clog)	Loss of friction braking in the affected car.	Braking effort in other cars increased to compensate. This may result in ruptured lines or damaged equipment in the effected car due to over-pressurization.	Pressure gauge in cab? Inspection	Y	N	B3
Hydraulic Lines	Fail Open (leak)	Loss of friction braking in the affected car.	Braking effort in other cars increased to compensate.	Pressure gauge in cab? Inspection	Y	N	B3
	Fail Closed (clog)	Loss of friction braking in the affected car.	Braking effort in other cars increased to compensate. This may result in ruptured lines or damaged equipment in the effected car due to over-pressurization.	Pressure gauge in cab? Inspection	Y	N	B3

1. If only one car fails.

2. As long as remaining brakes are functional.

Table 3-16. Shinkansen 300 FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 300 (Japan)							**Page 1 of 5**
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Braking Control							
Operator's Brake Controller	Fails to send signal	Loss of brake control. ATC unit available to activate Emergency brake.	ATC unit activates Emergency brake.	Emergency brakes applied	N	Y	C
	Sends incorrect signal	Negligible. Brake Command Control Unit and Speed Generator should compensate to provide proper deceleration. This situation probably results from operator error.	Blending or modulation of brakes adjusted to provide proper deceleration.	Inspection?	Y	Y	D
ATC Unit	Fails to send signal	Loss of automatic control of all brakes. Operator can still manually apply brakes.	Operator can still apply brakes. Brake performance is not effected.	Signal in cab?	Y	N	B2
	Sends incorrect signal	Minor. Brake Command Control Unit and Speed Generator should compensate some to provide near normal deceleration.	Slightly irregular performance. Operator can still apply brakes.	Slightly irregular performance.	Y	N	B2
Brake Command Control Unit	Fails to process data	Adhesion characteristics based on speed and load would not adjust braking level, possibly permitting wheel slip.	Loss of blending between Friction and Electrodynamic brakes	Signal in cab?	N	N	A2
	Fails to send signal	Possible loss of Electrodynamic brakes, friction brakes, or both (resulting in total loss of normal service brakes on the effected car).	Possible total loss of normal service braking.	Signal in cab?	N	N	A2
Dynamic/Regenerative Brake							
Generator (rotor)	Fails to accept/produce charge	Loss of Electrodynamic braking on axle in question.	Negligible unless many axles are effected. Friction brakes could be used for supplemental braking.	Signal in cab (Saturation)	Y	N	B3
	Bearing failure, axle seizes.	Loss of Electrodynamic braking on axle in question.	Emergency brake should be applied to stop train. Motor should be disengaged from wheel/axle to prevent further damage.	Change in train performance. Signal in cab.	N	N	A2

Table 3-16. Shinkansen 300 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 300 (Japan)							Page 2 of 5
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Catenary	Fails to accept generated power	Loss of dynamic/regenerative brake.	Friction brakes required to stop train.	Indication in cab. Loss of motive power.	Y	N	B2
Electro-pneumatic (Power Cars)							
Auxiliary Brake Pattern Generator	Fails to process data/send signal	Loss of auxiliary friction braking on car in question.	Emergency Service Auxiliary brakes on other cars must compensate.	Signal in cab?	Y	N	B3
	Sends incorrect signal	Over- or Under-braking on effected car.	Emergency Service Braking systems on remaining cars must compensate to produce smooth deceleration.	Should be unnoticeable unless error is significant.	Y	N	B3
Speed Generator	Fails to detect speed/send signal	Adhesion characteristic not modified for speed. Wheel slip possible.	Negligible. Other cars will compensate.	Signal in cab? Inspection?	Y	Y	D
	Sends incorrect signal/out of calibration	Adhesion characteristic improperly modified for speed. Wheel slip possible.	Negligible. Other cars will compensate.	Signal in cab? Inspection?	Y	Y	D
Variable Load Unit	Fails to detect load/send signal	Adhesion characteristic not modified for load. Wheel slip possible.	Negligible. Other cars will compensate.	Signal in cab? Inspection?	Y	Y	D
	Sends incorrect signal/out of calibration	Adhesion characteristic improperly modified for load. Wheel slip possible.	Negligible. Other cars will compensate.	Signal in cab? Inspection?	Y	Y	D
Electro-pneumatic Changeover Magnet Valve (by Speed Signal)	Fails Off/Fails to send signal	Urgent brake applied automatically by deenergization of system.	Emergency brakes applied to other cars.	Signal in cab. Emergency brakes applied.	N	Y	C
	Sends incorrect signal/Out of Calibration	Urgent brake over- or under- applied.	Emergency brakes applied on other cars. Level of urgent-braking should be relatively unimportant.	Signal in cab. Emergency brakes applied.	N	Y	C
Pressure Regulating Valve (High Pressure)	Fails to regulate pressure	May allow damage to Changeover Magnet Valve or pneumatic lines, resulting in Urgent-brake application.	Emergency Service: If Urgent-brake is applied, Emergency brakes are automatically applied on other cars.	Pressure sensor. Emergency brakes applied.	N	Y	C

Table 3-16. Shinkansen 300 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 300 (Japan)							Page 3 of 5
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Pressure Regulating Valve (Low Pressure)	Fails to regulate pressure	Loss of brake pressure. Friction braking power slightly reduced.	Other cars must compensate.	Pressure sensor. Emergency brakes applied.	Y	Y	D
Electro-pneumatic Changeover Valve	Fails Off/Fails to send signal	No pressure released to brakes. Friction brakes not applied.	Electrodynamic brakes and Urgent-brake still applicable.	Emergency- and Urgent-brakes applied. Signal in cab.	Y	N	B3
	Sends incorrect signal/Out of Calibration	Relay Valve and Pressure Switch may correct for under- or over-braking. Otherwise, effect will be negligible due to compensation from other cars.	Negligible.	Inspection.	Y	Y	D
Urgency Brake Magnet Valve	Fails Open	Results in application of friction brakes.	Urgent brake applied.	Signal in cab? Train braking.	N	Y[1]	C
	Fails Closed	Urgent-brake cannot be applied to the car in question.	Emergency Service: Normal Service braking unaffected. Other cars can and must compensate in emergency braking situation.	Signal in cab? Minor loss of brake performance in emergency situation.	Y	N	B3
Relay Valve (with check valve function)	Fails Open	No longer a check-valve. Air pressure from reservoir free to activate Booster Cylinder and friction brakes.	Friction brakes on single car apply. Other cars should switch to emergency braking to stop train and limit damage to malfunctioning car.	Brakes apply.	N	Y[2]	C
	Fails Closed	Loss of friction braking on effected car.	Emergency brakes should apply to significantly slow or stop train. Auxiliary brake system will allow train to continue at low speed.	Emergency brakes apply.	Y	N	B3
Pressure Switch	Fails On	"Brakes On" Indicator in cab	None	Signal in cab.	Y	Y	D
	Fails Off	"Brakes Off" Indicator in cab	None	Signal in cab.	Y	Y	D
Air Reservoir	Fails to hold pressure	Friction brakes cannot be applied. Effects only one car. It is assumed valving is such to prevent all air from escaping through reservoir.	Negligible. Braking on other cars will compensate for the difference.	Pressure sensor	Y	N	B3

Table 3-16. Shinkansen 300 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 300 (Japan)							Page 4 of 5
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Air Compressor	Fails to supply pressure	Reservoir takes longer to fill or does not fill to maximum pressure. Applied brake pressure may be lower, slightly decreasing braking power at that car.	Negligible. Braking on other cars will compensate for the difference.	Inspection?	Y	Y	D
	Supplies too much pressure	Negligible. Pressure relief valve will limit pressure.	None.	Inspection?	Y	Y	D
Electrical Wiring/Train Data Bus (7 wires)	One or more (but not all) wires fail	Braking levels are lost since each wire commands an increasing amount of braking effort.	ATC automatically applies Emergency braking.	Signal in cab.	Y	Y	D
	All lines fail	Loss of Normal Service braking.	All normal service braking lost. Train goes to Emergency braking.	Train brakes in emergency.	N	Y	C
Emergency-brake Wire	Fails to carry signal	Friction brakes applied to stop train.	Emergency Service: Electrodynamic brakes activated at high speed to help slow train and minimize wear. Friction brakes take over at slower speeds to stop train.	Emergency brakes applied. Signal in cab.	N	Y	C
Auxiliary-brake Wires (2 wires)	One wire fails to carry signal	Auxiliary friction braking limited to one level of brake force.	Emergency Service: None. Train restricted to very low speed with no Electronic braking.	Signal in cab?	Y	Y	D
	Both fail to carry signal	Loss of auxiliary friction braking.	Emergency Service: It is very improbable that normal service and auxiliary braking will both be lost. Emergency brakes will be applied.	Signal in cab?	N	Y	C
Urgent-brake Wire	Fails to carry signal	Emergency braking applied.	Emergency Service: Depending on speed regime, appropriate brake systems applied to stop train.	Emergency brakes applied.	N	Y	C
Pneumatic Lines	Fail Open (leak)	Loss of air pressure and brake power in affected car.	Other cars must compensate with increased braking.	Pressure sensor?	Y	N	B3

Table 3-16. Shinkansen 300 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Shinkansen 300 (Japan)							Page 5 of 5
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Pneumatic Lines	Fail Closed (clog)	This failure could either 1) prevent brake application or 2) lock brakes in applied position.	1) Other cars must compensate with increased braking. 2) train brakes in emergency to prevent excessive damage.	Pressure sensor?	1)Y 2)N[3]	1)N 2)Y	B3 C
Hydraulic Lines	Fail Open (leak)	Loss of pressure and brake power.	Other cars must compensate.	Pressure sensor?	Y	N	B3
	Fail Closed (clog)	Brakes 1) cannot be applied or 2) locked in applied position.	Train brakes in emergency to prevent excessive damage.	Pressure sensor?	1)Y 2)N	1)N 2)Y	B3 C
Electro-pneumatic (Power and Trailer Cars)							
Booster Cylinder	Fails to activate calipers	Loss of friction braking at the affected axle.	Negligible. Other cars will compensate unless many axles are affected.	Inspection?	Y	N	B3
Disc Brake Calipers	Fracture	Some or complete loss of friction braking force at affected caliper.	Negligible. Other cars will compensate unless many calipers are affected.	Inspection.	Y	N	B3
	Fail to apply (stuck open)	Total loss of friction braking force at affected caliper.	Other cars will compensate unless many calipers are affected.	Inspection.	Y	N	B3
	Fail to release (stuck closed)	Friction on disc may cause excessive thermal stress with damage either to disc or pads.	Train may be forced to stop and have calipers manually reset.	Inspection.	N	Y	C
Brake discs	Excessive wear.	Loss of friction braking power at effected disc. May cause damage to brake pads or calipers.	Negligible. Other cars should compensate.	Inspection.	Y	N	B3

1. Considered fail safe at lower speeds. Train may derail if brakes are suddenly applied at high speed.
2. As long as all cars brake.
3. Since fire or damage to equipment may result.

3.8 ETR450

3.8.1 Description of Trainset

The Italian ETR450 trainsets have been in revenue service on the main lines of the Italian State Railways (FS) since early in 1990. Derived from the ETR401 passive tilting "Pendolino" trains, the ETR450 trains incorporate an aluminum body and an active tilting system based on accelerometers and gyroscopic sensors that control each car's hydraulic actuators. The bogie design includes radial steering trucks, flange lubricators, and anti-skid devices. Each bogie is powered by a 312.5 kW traction motor mounted longitudinally on the car body, driving through a U-joint drive shaft, bevel gear final drive and Cardan shafts. Trainset pantographs are carried on bogie-supported frames to allow the cars to tilt up to a maximum allowed eight degrees without interfering with power pickup from the catenary.

ETR450 trainsets are currently run in formations of eight powered cars (four sets of "married pairs") and one trailer car. With each powered car of 50 metric tons and a trailer car of 30 metric tons nominal weight, the total train weighs 430 metric tons (474 tons) with an overall length of 242 meters. The design maximum speed of 250 km/h (155 mph) is realized on the Rome-Florence Direttissima line. On other lines, train speed is limited to a maximum of 200 km/h (125 mph). These other lines include service between Rome-Naples-Salerno, Bologna-Padua-Venice, and Bologna-Milan-Turin.

3.8.2 Braking System Design

The ETR450 train braking system includes both air-activated friction brakes and rheostatic (resistive dynamic) braking. Traction motors are used to generate a maximum of 1900 kW braking power at speeds above 80 km/h (50 mph), which is dissipated as heat in resistor banks. A maximum 7800 kW braking power is achieved with both friction and dynamic braking.

Disc-type air brakes are used for the friction brake system. Each axle is equipped with two ventilated cast iron brake discs with synthetic brake pads on the brake calipers. Each bogie has four brake cylinders (one per disc) with automatic slack adjustment.

The air brake system main line charge/discharge solenoid valves are triggered electrically to speed the brake command propagation along the length of the train. In electrodynamic braking, traction motor armature current is controlled by a shunt-chopper system. Generated power is dissipated in self-ventilated resistor grids on the car body roof.

Anti-skid/anti-slip devices are included on each bogie to prevent wheel slip during traction or braking and to optimize wheelset adhesion under adverse rail conditions.

3.8.3 Brake System Performance

An ETR450 trainset traveling down an 0.8 percent (8 in 1000) grade at an initial speed of 250 km/h (155 mph) can be stopped in approximately 3400 meters, according to the manufacturer's brochure (Ref. 25). No other conditions (dry rail, etc.) are cited for this example.

3.8.4 Braking System Operation, Control and Safety Features

Operation and Control

ETR450 trainset performance is controlled from an ergonomically designed driver's cab, which provides instrumentation, control and monitoring equipment in an aircraft-style display. The brake valve includes an electronic device controlling the individual charge/discharge solenoid valves along the train. In the event of an emergency, continuous pneumatic braking control is automatically actuated. Braking systems are blended in five successive stages: the first is fully electrodynamic braking, which is used preferentially to reduce wear on friction brake components and to maintain train speeds, for example, on long downgrades. Subsequent command levels act in conjunction with the friction brakes within the speed range from 250 to 80 km/h. Below 80 km/h, only the friction brakes are active.

3.8.5 Braking System Effects on Vehicle, Guideway, and Infrastructure

The ETR450 trainset does not use track brakes such as the electromagnetic or linear eddy current emergency brake systems used on some high-speed trains. No unusual effects on vehicle, guideway, or infrastructure are anticipated with this type of train design.

3.9 TRANSRAPID TR07

3.9.1 General Description

The Transrapid TR07 maglev system is an electromagnetically-levitated transportation system designed for cruising speeds of 400 to 500 km/h (250 to 312 mph). It is being developed by a consortium of German companies with funding from the German Ministry of Research & Technology (BMFT). Testing of various (Transrapid 06/07) system operational aspects has been underway at the Emsland Test Track (TVE) in Germany since 1985. To date, there are no revenue service applications of the system.

The TR07 "train" consists of individual cars or vehicle sections, each having a length of 25.5 m, a width of 3.7 m, a height of 3.95 m, and a payload capability of eight metric tons or approximately 100 passengers. Multiple car trains can be configured for bidirectional operation with an operator's control station at each end.

The primary vehicle suspension system is based upon a "wrap around" design in which each vehicle section effectively encloses and captures the T-shaped guideway. Axial flux support magnets, mounted on the vehicle's undercarriage and powered by DC storage batteries, are oriented to produce the necessary vertical attractive force (to the laminated steel stator packs) for levitating the vehicle. An air gap of approximately 8 mm to 10 mm is maintained between the vehicle and the underside of the guideway. The secondary suspension system consists of pneumatic springs mounted between the coach body and levitation frame.

Guidance is provided by separate transverse flux electromagnets (also on the vehicle's undercarriage and powered by the same on-board storage batteries) which produce a lateral attractive force to non-laminated ferromagnetic rails on the side of the guideway structure.

Propulsion is provided by a long stator iron core linear synchronous motor, with the three phase windings mounted in a laminated stator under both sides of the guideway structure. The traveling magnetic wave in the stator reacts with the axial flux levitation magnets on the vehicle (acting as the rotor portion of the motor) thereby producing an attractive force for propelling the vehicle. Long stator motor sections (portions of the guideway) are energized as the vehicle approaches a given guideway section and de-energized as the vehicle leaves the section.

3.9.2 Braking System Design

The braking strategy of the TR07 is based upon the following key aspects:

- Normal dynamic braking via the long stator motor, controlled by wayside equipment.

- Emergency braking via an on-board eddy current braking system in conjunction with skids mounted on the vehicle's undercarriage; the latter involves deactivation of the levitation function; such braking is controlled by on-board equipment; (Note: the long stator motor is the primary emergency braking system if it is operational).

- Existence of safe stopping areas (specific locations along the guideway where the vehicle is permitted to come to a stop); this requires maintaining levitation and precisely controlling eddy current braking if guideway power is lost.

- Communications via a radio link between safety critical wayside and on-board equipment to determine and/or indicate that emergency braking is needed.

Major Braking Components

The three major braking components of the TR07 are described below.

Linear Synchronous Motor. The linear synchronous motor provides propulsion as well as braking for the TR07. Substations convert 3-phase utility power into variable voltage, variable frequency (VVVF) power for the long stator sections in the guideway. Power is fed to the long stator sections via transformers, rectifiers, inverters and feeder cables. In the propulsion mode, the 3-phase AC currents in the long stator sections create an attractive force with the battery-powered levitation magnets on-board the vehicle, thereby essentially pulling the vehicle down the guideway.

Dynamic braking is accomplished via wayside/central equipment by reversing the polarity of the magnetic fields in the long stator windings. Since, in this mode, the long stator motor acts as a generator, electrical energy is fed back to the substation where it is dissipated in resistor networks.

Each long stator motor section on both sides of the guideway is fed from both ends by two pairs of power inverters. This arrangement increases the availability of the propulsion and braking functions carried out by the long stator sections.

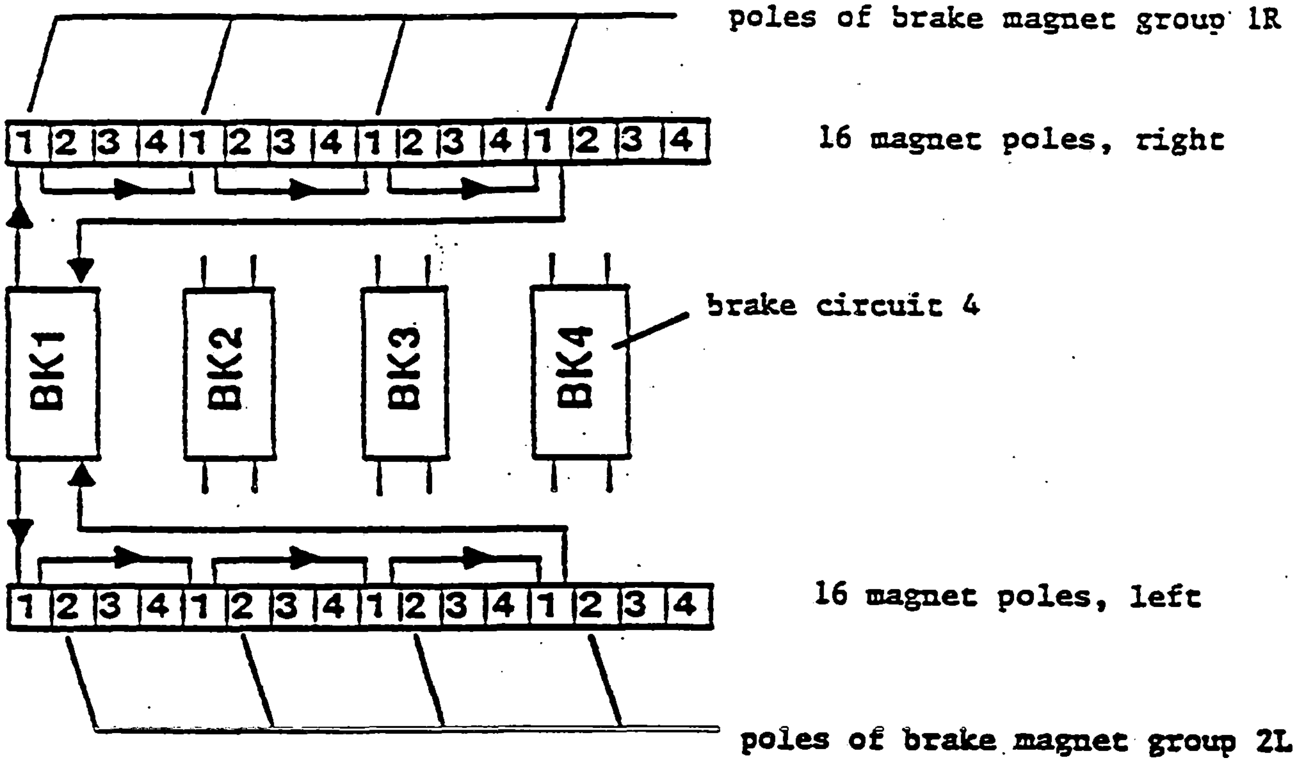
Eddy Current Brakes. Each vehicle section is equipped with a non-contact eddy current brake system which consists of four brake circuits and two 16-pole longitudinal axial flux magnets (one located on each side of the vehicle). Each longitudinal magnet is divided into four magnet groups, and each brake circuit controls two magnet groups--one on each side of the vehicle. More specifically, each of two choppers within a brake circuit controls one magnet group. The brake circuits in a given vehicle section and their relationship to the brake magnet groups are shown in Figure 3-12.

The four brake circuits are powered by separate and independent 440 volt on-board storage batteries. These batteries receive their charging power from on-board linear generators which, in turn, receive their power from the long stator motor in the guideway as long as the long stator sections are operational and the vehicle is moving. Charging starts at 60 km/hr and is at full capacity once 120 km/hr is reached.

When eddy current braking is deemed necessary (either by the on-board or wayside electronics), the choppers in the brake circuits excite the various magnet groups within the longitudinal magnets on the moving vehicle. This causes magnetic fields in the non-laminated steel guidance rails on the sides of the guideway. The magnetic fields create eddy currents in the steel guidance rail and result in a braking force on the vehicle itself in the direction of travel. A force in the vertical direction on the guidance rail is also generated in this braking process. It impacts the support of the guidance rail itself and is addressed in more detail later.

The braking force generated by the eddy currents is dependent upon the air gap, the velocity of the vehicle and the braking current fed to the magnet groups. The braking force in the direction of travel for a given air gap and brake current stays relatively constant from higher speeds down to about 100 to 120 km/h, at which point the force decreases rapidly. Thus, eddy current braking loses its effectiveness as speed decreases below 100 to 120 km/h. This is the reason for the incorporation of brake skids as described in the next section. In emergency braking operations (controlled by on-board equipment), the eddy current brake is used in conjunction with the brake skids to provide the necessary braking. A modification to make the eddy current brakes effective down to 10 km/hr is planned for future revenue service.

Brass plates are positioned on the longitudinal magnets to ensure a minimum air gap between the magnets and the guidance rail. During normal operation, no contact occurs between these brass plates and the guidance rail.



Source: Reference No. 3

Figure 3-12. Brake Circuits and Control of Brake Magnets (Ref. 26)

As discussed above, there are four brake circuits for each vehicle section, giving eight such circuits for a two-section TR07 train (the smallest consist that can be utilized). At least six of the eight brake circuits must be operational for normal travel to be permitted. This matter is discussed in more detail later.

Brake Skids. Braking (support) skids, positioned on the lower portions of the vehicle sections (just above the guideway surface), are utilized in emergency braking operations. They come in contact with slightly elevated and parallel gliding surfaces on the guideway structure when levitation is removed during the emergency braking process.

Due to irregularities in the guideway surface, the levitation frame of each vehicle section (wrapping around the guideway and providing support for the levitation and guidance magnets) is hinged at several points. There are, in fact, eight hinge points on each side of a vehicle section, making 16 hinge points per section and 32 hinge points for a minimum two-car TR07 train. Each hinge point is equipped with a brake skid (located as described above). Thus, there are 16 brake skids per vehicle section and 32 skids for a two-car train. Each skid, covered with a special material, actually consists of two parallel "bars" (one located on each side of the vehicle), running longitudinally with respect to the direction of travel.

Because of the arrangement and mounting of the skids with respect to the levitation frame, and the independent control of the levitation magnets themselves at the various hinge points of the frame, the "touchdown" of each skid is independent from one another.

Braking Control Components

The portion of the TR07 system that is responsible for the safety, control and supervision of vehicle operations (including braking) is referred to as the Operations Control System (OCS). The system is comprised of on-board, wayside and central elements, each of which performs various train control and braking functions (primarily the former two elements). A simplified functional block diagram of the OCS is provided in Figure 3-13.

As can be observed from the figure, the OCS is based on a decentralized philosophy in which each wayside (decentralized) element is assigned to one substation area and is responsible (among other things) for controlling the braking/propulsion of the vehicle in its assigned area or block via the power inverters and long stator motor sections.

The primary safety functions including those pertaining to braking are handled by the wayside and on-board elements. The central element (traffic control center) is responsible for the overall supervision and monitoring of system operations.

Wayside OCS. The wayside elements assign power inverters to the vehicles and determine the propulsion and braking values required to achieve given speed profiles and/or to comply with specific operating conditions (e.g., position of preceding vehicles, position of switches, occupancy of nearby stations, location of next station). These values are then transmitted to the appropriate guideway long stator sections to control propulsion/braking accordingly. In order to perform these functions, the wayside equipment receives safety critical vehicle

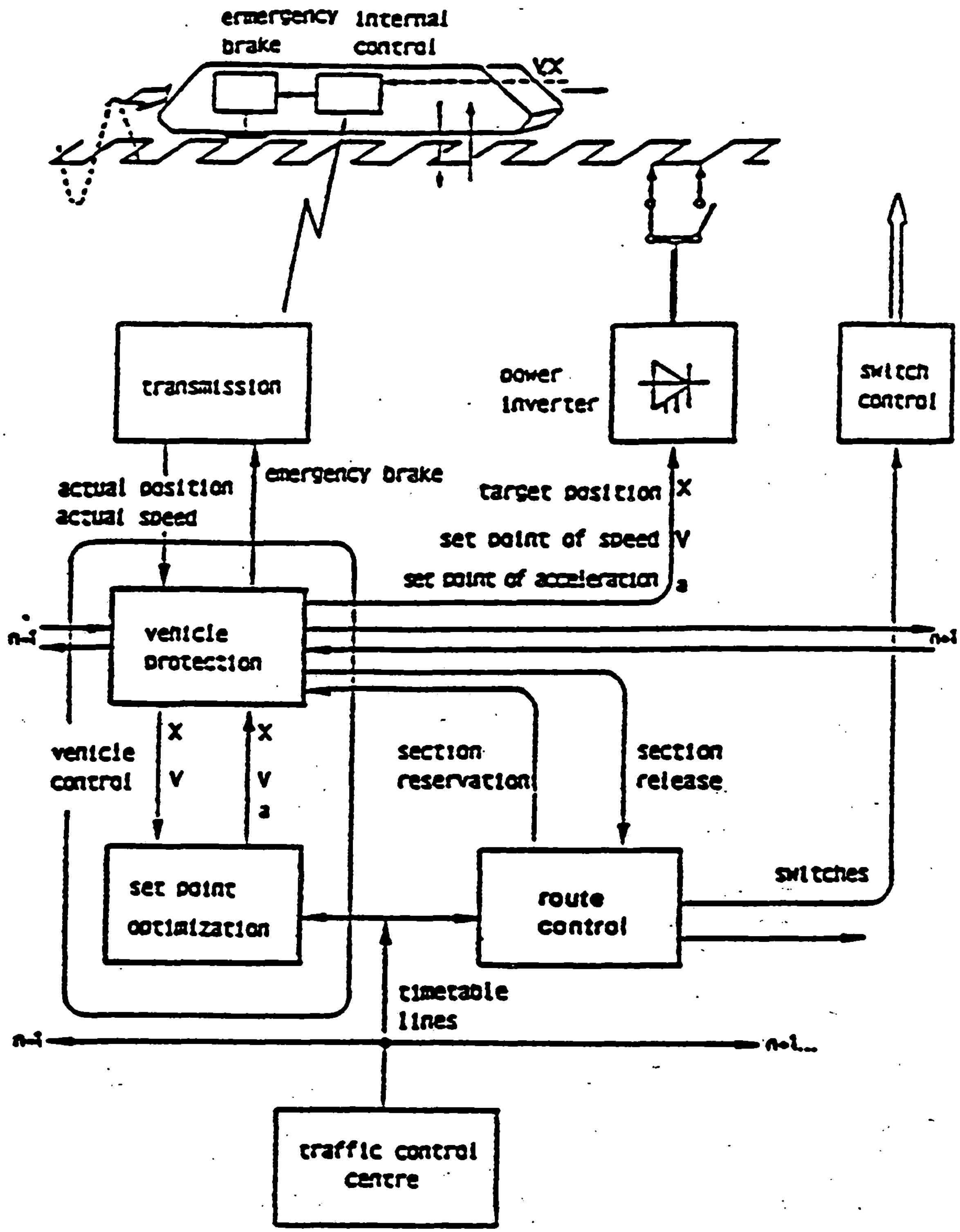


Figure 3-13. Simplified Block Diagram of TR07 OCS (Ref. 27)

location, speed and direction information from the vehicles in its governing area via radio links. It also receives safety critical route integrity information (e.g., location of other vehicles, position of switches) and information regarding status of vehicles in stations from other nearby wayside elements. A given wayside element can initiate dynamic braking via the long stator motor sections or can indicate to a given vehicle that emergency braking must be initiated on-board. The latter requires removal of propulsion power from the guideway.

The computer based wayside elements performing these propulsion/braking control functions are often referred to as BLDs. They are implemented with two sets of computers (for availability) arranged in a triple channel computer configuration (for safety).

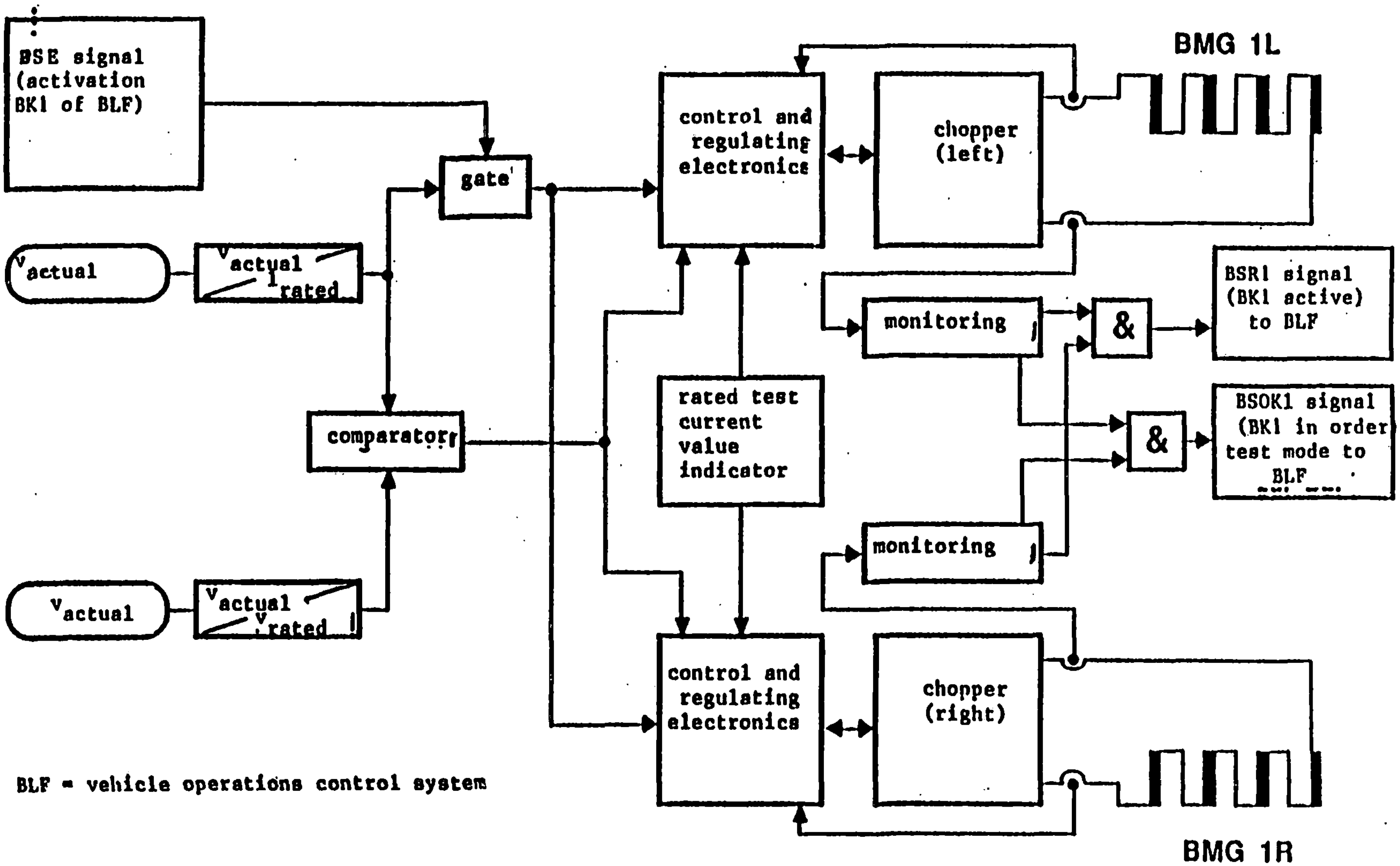
Vehicle OCS. The vehicle portion of the OCS with primary responsibility for controlling the on-board eddy current brakes and levitation magnets (for set-down when landing on the brake skids) is referred to as the vehicle operation control system or BLF. It continuously monitors vehicle location, speed, direction, location of the next safe stopping area and status of certain vehicle equipment, and receives other information from the wayside elements (e.g., status of linear synchronous motor) so as to permit stopping the vehicle at the next safe stopping location independent of the wayside propulsion/braking equipment. This is especially necessary in case of loss of communications with the wayside elements.

Information regarding the status of certain vehicle equipment (e.g., status of on-board storage batteries or location determination equipment) is transferred to the wayside elements as appropriate via the radio links. This is necessary because certain abnormal conditions of on-board equipment require removal of propulsion power and/or braking via the wayside long stator motor.

The on-board BLF equipment is configured in a similar manner as the wayside computer equipment—two sets of computers (for availability), each arranged in a triple channel configuration (for safety).

Brake Circuit. The four brake circuits on each vehicle section control the current supplied to the eddy current brakes. As indicated earlier, there are two choppers in each brake circuit, one for each of two 4-pole brake magnet groups. Thus, the four brake circuits on a vehicle section control brake current to the two 16-pole longitudinal eddy current magnets (one on each side of the vehicle). A block diagram of a single brake circuit is shown in Figure 3-14.

The normal activation of each brake circuit is controlled by the BLF, and in particular, via the BSE signal shown in Figure 3-14. This signal essentially turns on the brake circuit. Actual braking current for the magnet groups is provided by the choppers, and is a function of vehicle velocity. Vehicles with high velocity require a higher braking current. Current is supplied to the eddy current brakes as appropriate until the set-down speed is reached, at which time the braking current is removed and levitation is deactivated (causing set down on the skids).



BLF = vehicle operations control system

Figure 3-14. Block Diagram of Brake Circuit for Eddy Current Brake System (Ref. 26)

The BLF can interfere with the braking current by intermittently activating and deactivating the BSE signal. This allows the BLF to bring the vehicle to a more precise stopping location. The brake circuits also have output signals that are used for monitoring the status of the brake circuits. This monitoring takes place via the signals BSR and BSOK (shown in Figure 3-14) which are fed back to the BLF. Two types of monitoring takes place: self monitoring by the brake circuits themselves and monitoring via the BLF. In the first case, the duration of the on-time for each magnet group is monitored. Should excessive time be measured, indicating possible overheating, the BSR signal changes state. In the second case, the BLF sends a command to the brake circuit and looks for a given response in brake current. The proper response is indicated to the BLF via the BSOK signal. The combination of states of the BSR and BSOK signals indicate the status of the brake circuits.

This monitoring is important in order to ensure the integrity of the eddy current magnets and brake circuits which allow for the emergency braking of the vehicle should the long stator motor braking be lost. The breakdown of a single brake circuit before a vehicle begins travel or during travel is tolerated. However, should a second brake circuit suffer a breakdown/failure during operation, emergency braking is performed (either via the long stator motor if it is operational or via the remaining eddy current brake circuits). If more than one brake circuit failure is detected before vehicle operation is initiated, travel is prohibited.

Signal Safety Device. During the start-up phase of the BLF (vehicle operations control system) and other times in which the BLF is not active, a safety device referred to as the SSW ABI can be utilized under manual control. This device essentially takes the place of the BLF and can enable the eddy current brake circuits and rescind the levitation command at the proper set down speed. It is used only when the BLF is not available for automatic control. When the SSW ABI device is utilized for emergency braking, it can only initiate what is referred to as immediate emergency braking. In this case, maximum emergency braking occurs via the eddy current brakes and skids, and the vehicle comes to a stop (usually not at a safe stopping location). On the other hand, when the BLF is in control, a programmed emergency braking mode is available in which the BLF intermittently controls the eddy current brakes and then the set-down on the skids so as to position the vehicle at the next safe stopping point.

Magnetic Regulation Electronics. As discussed earlier, there are a total of 16 hinge points per vehicle section, eight on each side of the vehicle. There are two magnetic regulation electronic (MRE) circuits for each hinge point which control the levitation magnets connected to those hinge points. When levitation is commanded, all MRE circuits are activated. When levitation is to be rescinded, such as during the final stages of emergency braking (when the vehicle lands on the skids), commands must be given to each MRE to rescind levitation at that point.

The control to rescind levitation during the emergency braking process is provided primarily by the BLF, but can also be supplied by the SSW ABI safety device. In either case, each MRE only follows the set-down command when vehicle speed is judged to be less than the allowable set-down speed. Thus, each MRE circuit makes its own decision as to whether or not to remove levitation for a given portion of the vehicle. This arrangement makes the levitation function extremely reliable which is important given the need to maintain levitation at all times (except during the final stages of emergency braking).

Emergency Stop Key Switch. There is an emergency stop key switch on the vehicle console which, when activated, permits the operator to bring the vehicle to an emergency stop. Activating the switch activates the eddy current braking system via the brake circuits, which leads to a rescinding of the levitation command (when the proper set-down speed is reached), and signals the wayside equipment (via the radio link) to remove propulsion from the long stator sections in the guideway.

The resulting braking is of the immediate type--the vehicle is stopped at a random location on the guideway. It should be emphasized, however, that levitation is maintained until the proper set-down speed of approximately 120 km/h is reached. For revenue service in Germany, such a stop switch may be modified to only allow stopping at the next "safe stopping area."

3.9.3 Brake System Operation

Braking of the TR07 can be categorized into two major types: normal and emergency. These are discussed separately below.

Normal Braking

Normal (dynamic) Braking of the TR07 takes place via the long stator motor sections, which are under control of the wayside elements. Each wayside control element has propulsion and braking responsibility for a given number of guideway sections or blocks. These blocks may have different lengths, and may have different assigned maximum speeds. There is always a target point (i.e., station or other safe stopping location) associated with the end of each block.

The wayside control elements receive information (e.g. speed, location, direction, equipment status) from a vehicle in a given block, and based upon this and other information from adjacent wayside elements (e.g., other vehicle locations/speeds, switch positions, etc.), can automatically reverse the magnetic field in the long stator motor sections and bring the vehicle to a stop. Braking in this manner follows a programmed deceleration curve, and occurs automatically when stopping at designated stations upon requests from the central control element of the OCS and/or when vehicle speed exceeds the maximum safe speed.

Emergency Braking

Emergency braking occurs under different circumstances (e.g., failure conditions) and is initiated/controlled by either the on-board or wayside elements, depending upon the nature of the condition. This is made possible by the exchange of safety critical information via the radio link between the vehicles and wayside elements.

Emergency Braking By the Wayside Elements. A wayside OCS element initiates emergency braking under certain circumstances and, when doing so, brings the vehicle to a stop at a safe stopping location through a programmed deceleration curve. In this mode, the on-board element monitors vehicle movement and can supplement the braking process by activating the eddy current brakes and/or skids as appropriate. Examples of conditions that can cause emergency braking via the long stator motor sections are as follows:

- Failure of one on-board power supply network (i.e., DC storage battery that acts as a power source for a given eddy current brake circuit)

- Failure of two or more of the on-board vehicle location systems

- Failure of a "doors closed" signal.

Emergency Braking By the On-board Element. The most common emergency braking operation is initiated/controlled by vehicle equipment. Braking of this nature occurs under certain conditions such as the following:

- Failure of the radio communication link between the vehicle and a wayside element

- Failure of the linear synchronous motor

- Violation of the maximum design (safe) speed profile.

As indicated earlier, certain information such as the status of the linear motor and location of the next safe stopping point is "continually" transmitted to the vehicle so that decisions can be made by the vehicle OCS (BLF) as to whether to initiate an emergency stop. This information is especially critical, given that in the case of a loss of the communication link and/or guideway power, on-board equipment must be able to keep the vehicle levitated and bring the vehicle to a stop at a precise location.

The emergency braking initiated/controlled by the vehicle equipment is conducted in two phases. Initially, the eddy current brakes are utilized to reduce the vehicle's velocity to about 120 km/h. Then, the levitation command is rescinded from all magnetic reduction electronic (MRE) units, thereby causing the vehicle to lower on the skids (but only if each MRE unit determines that speed has been sufficiently reduced). The eddy current brakes are switched off after set-down has been accomplished. There is only a brief period of time during which the two braking actions overlap.

There are actually two types of emergency braking that can be initiated by the on-board equipment: immediate and programmed. In the immediate mode, the eddy current brakes are activated, followed by the landing on the skids. However, the stop occurs at a random location on the guideway (and not necessarily at a safe stopping point). This is obviously not the most desirable mode of braking, but it does lead to the most rapid stop of the vehicle. It can be controlled automatically by the on-board BLF or manually via the SSW ABI unit as discussed earlier. In either case, the vehicle does not land on the skids until the set-down speed of approximately 120 km/h is reached (as determined by the MRE units). Manual triggering of emergency braking via the Emergency Stop Key Switch on the operator's console also leads to an immediate (as opposed to programmed) braking action.

In the programmed emergency braking mode, the most common and desirable emergency braking mode, the vehicle is brought to a stop at the next safe stopping location according to a programmed deceleration curve. Again, the eddy current brakes are utilized to reduce speed to about 120 km/h, at which time the levitation command is rescinded from the MRE units, and the vehicle lands on the skids. The on-board BLF intermittently switches the various brake circuits (of the eddy current brakes) on and off to comply with the programmed braking curve and reach the desired location.

3.9.4 Brake System Performance

Technical Specifications

Practically all detailed information available for this program regarding the characteristics of braking of the TR07 pertains to emergency braking via the eddy current system and skids. In this braking mode, and more specifically, in the programmed emergency braking mode, the braking characteristics follow a deceleration curve stored in the on-board BLF computers. Brake force generated in this mode is dependent upon the current supplied to the brake magnets, the vehicle velocity, and the air gap between the magnets and the guidance rail. The (horizontal) braking force per magnet (for different air gaps) as a function of vehicle speed for a constant brake current of 120 A is shown in Figure 3-15.

As can be observed, brake force is relatively constant from higher speeds down to 100-120 km/h, and decreases rapidly below this speed.

The actual current supplied to the magnets is provided by the choppers in the brake circuits, under higher control by the BLF computers. This current varies (decreases) as the speed decreases as can be observed in Figure 3-16.

The actual deceleration of the vehicle varies with the number of available (operational) brake circuits. As indicated earlier, there are eight brake circuits per two-car train. With all eight operational, tests have shown that deceleration in the 200-400 km/h range is on the order of 1.0 to 1.4 m/s^2. Deceleration (under the same conditions) below approximately 200 km/h decreases at a relatively constant rate down to about 0.5 m/s^2 at 120 km/h (the set-down speed). Figure 3-17 shows measured deceleration of a two-car TR07 vehicle as a function of velocity for a different number of operational brake circuits. It also shows the planned deceleration curve.

After the vehicle lands on the skids and the eddy current brakes are turned off, deceleration ranges from about 0.55 to 0.65 m/s^2 until the vehicle is brought to a stop.

Figure 3-18 shows a deceleration curve for the TR07 when landing on the braking skids, and with a partial overlap of eddy current braking (with six out of eight brake circuits operational).

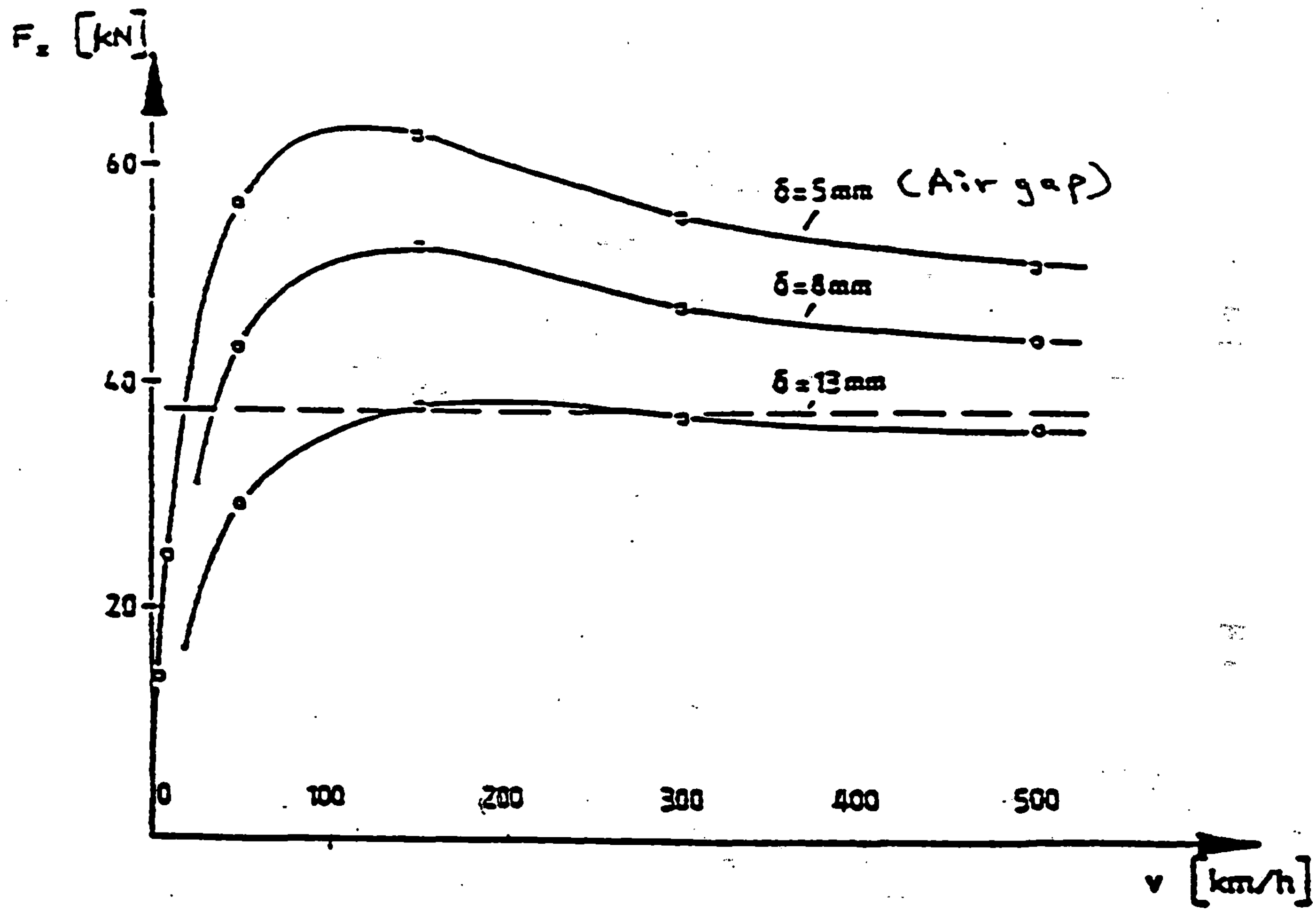


Figure 3-15. Horizontal Brake Force as a Function of Vehicle Speed (Ref. 28)

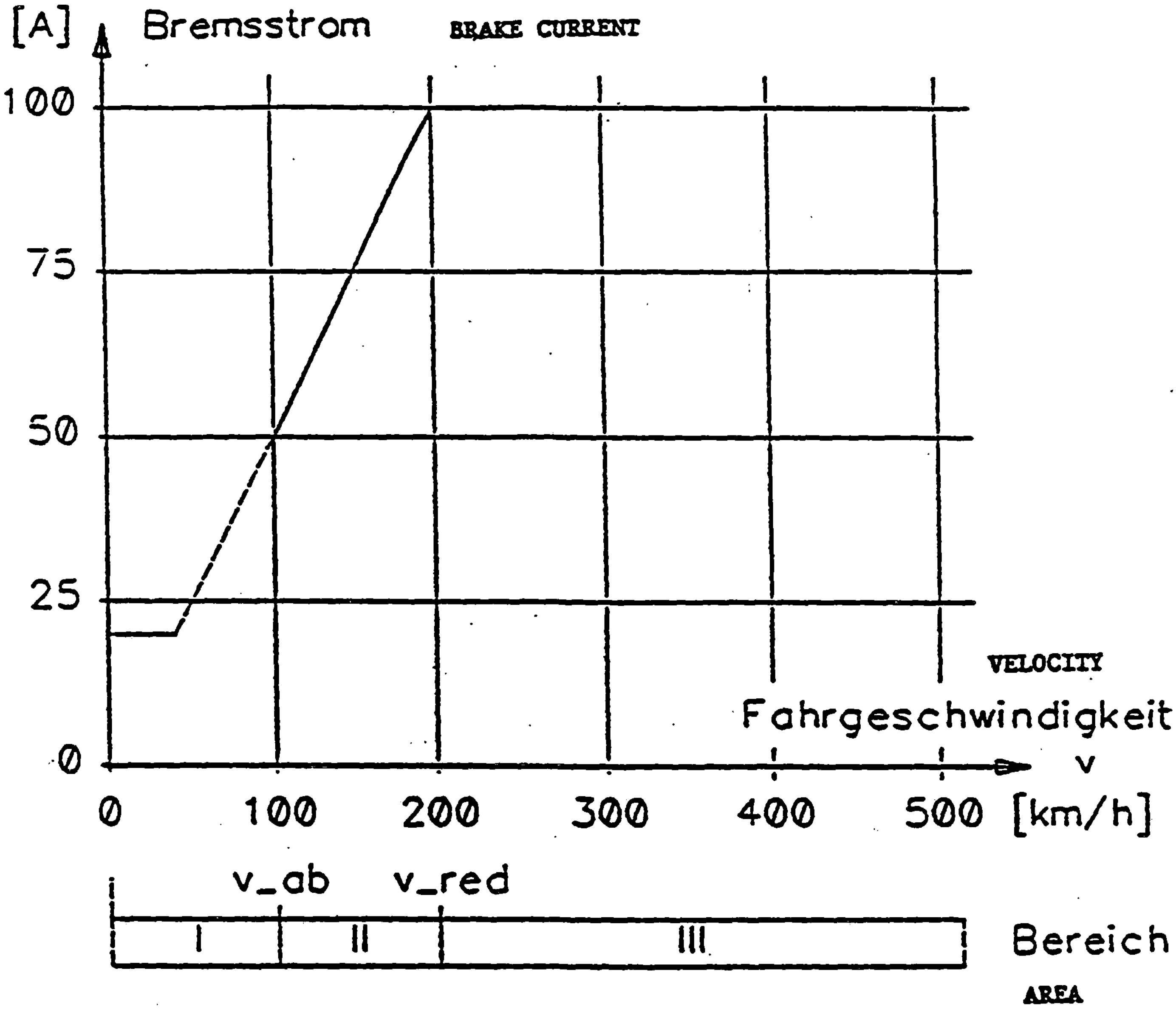
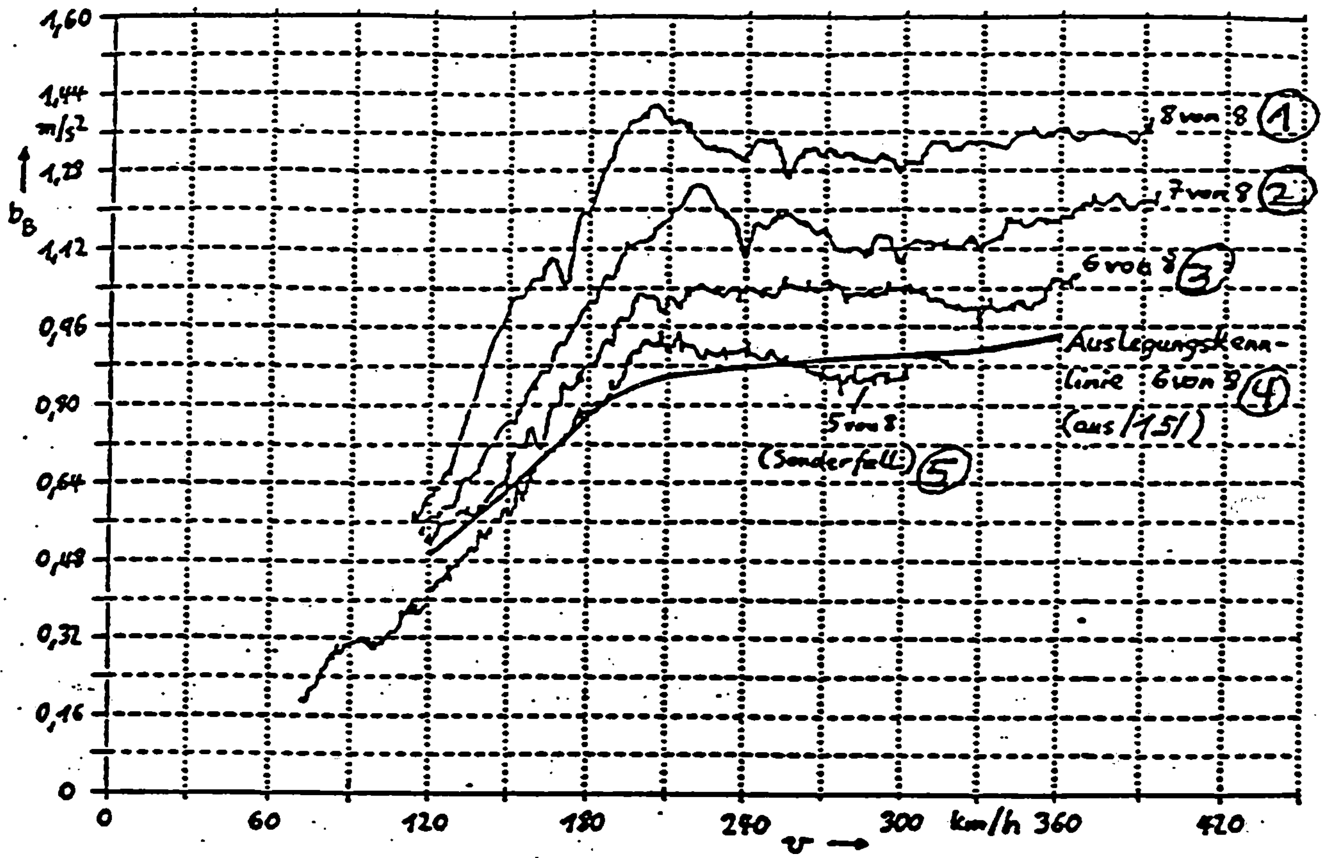
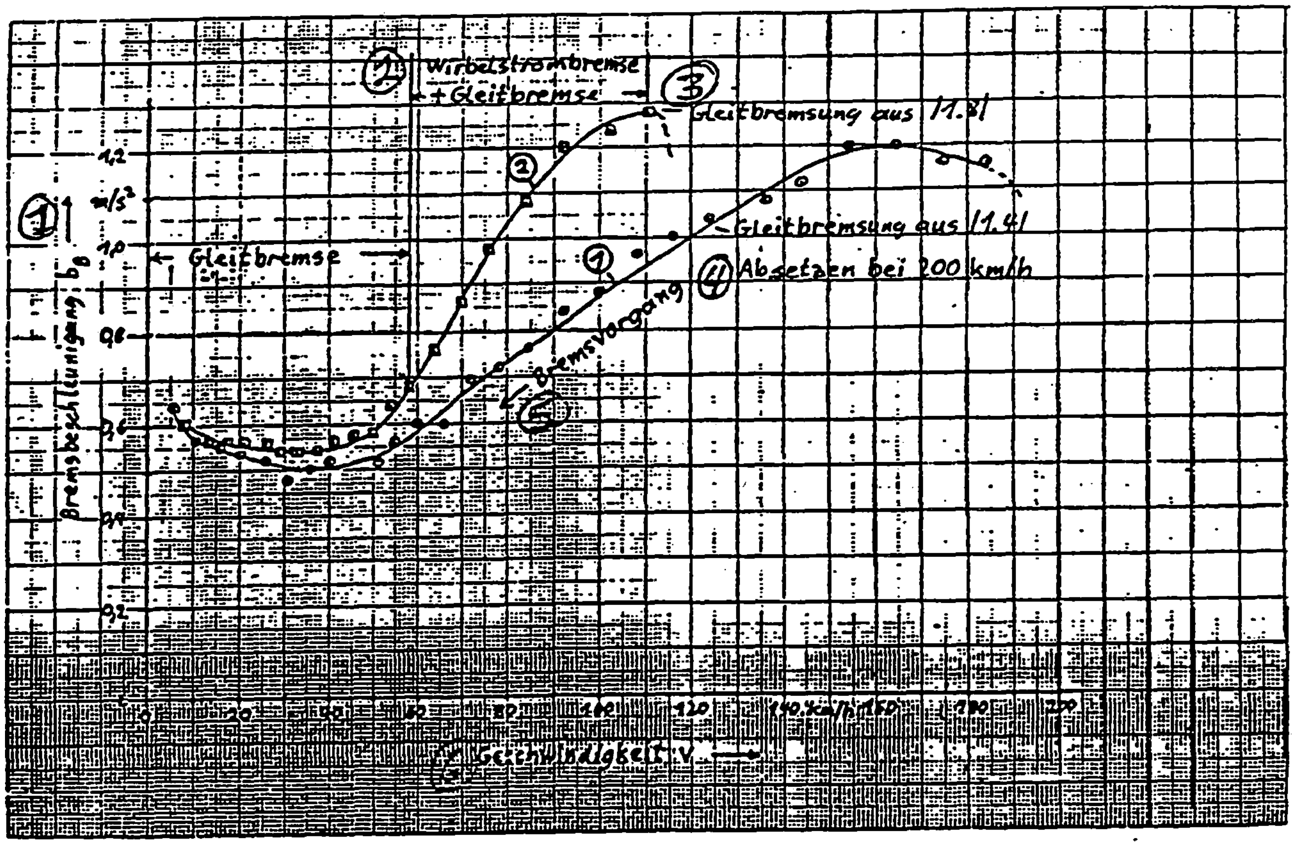


Figure 3-16. Brake Current as a Function of Vehicle Speed



Key - 1. 8 out of 8
2. 7 out of 8
3. 6 out of 8
4. Planned characteristic curve 6 out of 8 (from /1.5/).
5. Special case.

Figure 3-17. Deceleration Curves for the TR07 in Eddy Current Braking Mode



Key - 1 - Braking acceleration
2 - Eddy current brake + sliding brake
3 - Sliging braking from /1.8/.
4 - Set-down at 200 km/h.
5 - Braking process
6 - Velocity.

Figure 3-18. Deceleration Curve for TR07 on Braking Skids (Ref. 28)

Diagnostics and Monitoring

Brake Circuits. As discussed earlier, the minimum number of brake circuits needed for proper and safe functioning of the eddy current brake system for a two-car train is six (i.e., 6 out of 8). Failure of one of the circuits is tolerated either before operation begins or during actual operation. However, failure of a second brake circuit during operation results in programmed emergency braking. The brake circuits are monitored in two ways. First, the current in each of the two (4-pole) magnet groups controlled by a single brake circuit is self-monitored by the brake circuit itself. The resulting status of each magnet group is fed to the on-board control system (BLF) via the BSOK signal (i.e., one BSOK signal for each of two 4-pole magnet groups). The anticipated current of each magnet group is a known function of vehicle speed, an admissible force of attraction between the magnets and guidance rails, and the status of the BSE control input signal itself (from the BLF).

Each brake circuit is also put through a periodic functional test in which each brake circuit is separately activated by the BLF and the response monitored (via the BSR signals) by the BLF.

The BLF automatically determines the need for emergency braking based upon the status of these signals (i.e., BSOK and BSR) from the various brake circuits. If operation is under control of the SSW ABI, brake circuit status is checked manually.

Brake Magnet Switch-On Time. Brake magnets for the eddy current system are not designed to be operated continuously. Thus, the switch-on times of the brake magnets are monitored and limited by the BLF. Should a maximum switch-on time be exceeded, the vehicle is brought to a stop so that maintenance can be performed.

Braking Skids. The covers on the braking skids are monitored at regular intervals and/or after utilization to ensure the existence of adequate material on the skids for a future emergency brake application.

Inspection and Test Requirements

Available information suggests that all "appropriate means" must be used to ensure the integrity of the eddy current braking system and skids. This includes the performance of certain maintenance procedures at regular intervals (to be determined by the manufacturer and operator based on operational experiences), the inspection of the general condition of the equipment, test of the functional state of parts subject to wear (e.g., skid covers, brass sliding plates), and functional tests of the safety and monitoring devices.

A maintenance handbook (Reference No. 29), prepared by Thyssen Henschel, suggests various maintenance measures and intervals for the TR07 including components related to the braking system. These measures and intervals are associated with helping to ensure safety, availability and comfort. Various measures are given for inspection/maintenance on a daily, weekly, 14-day, quarterly, semi-annual, annual and "long term" basis. Specific maintenance-related regulations and/or documentation are also cited for the various components.

Various braking-related components addressed by the handbook include the following:

- Levitation magnets, gap monitoring equipment and magnet control unit
- Braking electronics and wiring
- Brake magnets
- On-board storage batteries and other on-board energy supply components
- Brake skids
- Guide skids
- Brake structure
- Levitation bogie and secondary suspension.

A functional test is recommended (by the literature) following the conduct of repairs on the braking components. The handbook also recommends that all maintenance related checks and intervals be adjusted in accordance with operational experience.

Braking System Effects on Vehicle, Guideway and Infrastructure

There are a number of possible effects on the vehicle and/or guideway associated with braking of the TR07; a few of them are discussed below.

Braking Skids/Planes. One of the most significant effects of (emergency) braking involves the wear on the brake skid covers due to an emergency brake application. A certain minimum thickness of the various skid covers must be ensured to permit the proper friction should an emergency brake application be required. It is also possible for the gliding surface on the guideway on which the skids contact during braking to be adversely affected over a period of time.

Force on the Guidance Rail. Eddy current braking results in a braking force on the vehicle in the direction of travel (x direction). However, there is also a force exerted on the guidance rail in the vertical (y direction) when eddy current braking is utilized. This force occurs in the air gap between the brake magnet and the guidance rail. The important aspect here is that this force increases with a decrease in vehicle speed (during braking) if brake current remains constant. For this reason, brake current must be limited as speed decreases so as to not exceed the maximum permitted vertical force of approximately 52 kN on the guidance rail and brake magnet support structures.

Heating of Brake Magnets. Brake magnets on the vehicle generate heat during eddy current braking. However, as discussed earlier, the switch-on time of the magnets is controlled to limit the amount of heat generated. Further, it appears from literature that the eddy current brake magnets can withstand full current (without switch-off from the BLF on-board computers) during an immediate mode of emergency braking.

Table 3-17. Transrapid TR07 FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Transrapid TR07 (Germany) — Page 1 of 3

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Dynamic (Normal) Brake							
Wayside control element	Fails to reverse polarity in long stator sections	Long stator sections controlled by the wayside element continue in a propulsive or non-braking mode.[1]	Only one or a few long stator sections are effected. Normal braking can occur when train enters control of the subsequent wayside element.	Central control should recognize that no braking occurs in the effected sections.	Y	N	B3
	Prematurely reverses polarity (braking applied)	Braking unexpectedly applied, or no propulsion occurs (at minimum), in the failed sections.	Only one or a few long stator sections are effected. Normal braking can occur when train enters control of the subsequent wayside element.	Central control should recognize that premature braking occurs in the effected sections.	N	Y	C
	Loss of AC power	Long stator sections controlled by the wayside element provide no propulsion or braking force.	Only one or a few long stator sections are effected. Emergency braking initiated by on-board equipment, train stops at next safe point.	Central control, wayside, and on-board equipment detect power loss.	Y	Y	D
Long stator section	Open circuit	Long stator section provides no propulsion or braking force.	Emergency braking initiated by on-board equipment, train stops at next safe point.	Wayside and on-board equipment detect power loss in the section.	Y	Y	D
Resistors	Overheat, burn out	Effected resistors do not dissipate energy, reducing braking force.	Multiple resistors are available in the network, minimal impact on overall braking.	Unknown.	N	Y	C
Radio Link between Vehicle and Wayside Control Elements	Fails Off/Loses Contact	On-board OCS (BLF) applies emergency brakes. Eddy Current brakes activated and levitation command rescinded once train slows to 120 km/hr.	It is unclear whether the on-board computers use the last location signal from the wayside to maneuver train to the next station/safety zone or if the train stops immediately.	BLF diagnostic.	N	Y	C
	Signal Interference	It is assumed that some static or signal breaks are tolerable and that if a strong signal is lost for a given period, the train will respond as if the link had failed off.	It is unclear whether the on-board computers use the last location signal from the wayside to maneuver train to the next station/safety zone or if the train stops immediately.	BLF diagnostic.	N	Y	C

Table 3-17. Transrapid TR07 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Transrapid TR07 (Germany)							Page 2 of 3
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Eddy Current Brakes							
Brake Circuits (8)	Fail Off	At least seven Brake Circuits must be operational to permit train to start. If a total of two or more circuits fail while enroute, emergency braking is applied using dynamic brake.	Dynamic braking applied and levitation command rescinded (applied once train slows to 120 km/hr). Train will be allowed to continue to next safe stopping point.	On-board computers/BLF	Y[2]	N	B3
Longitudinal Axial Flux Magnets	Fail Off	Loss of some or all Eddy Current braking. (Magnets are controlled by the 8 brake circuits above)	Electrodynamic braking applied and levitation command rescinded (applied once train slows to 120 km/hr). Train will be allowed to continue to next safe stopping point.	On-board computers/BLF	Y	N	B3
Vehicle OCS (BLF) Computers (2)	Fail Off	On-board vehicle control, including braking, is lost.	If both computers fail (unlikely), communication with the wayside OCS will be lost. This will trigger the wayside OCS to stop the train with dynamic braking at the next safe stopping point.	Wayside diagnostics of train.	N	Y	C
440 Volt Storage Batteries (8)	Fail Off/Loss of Power	Power lost to corresponding Brake Circuit and Eddy Current brake. Emergency braking may be required.	Emergency braking must be achieved by Electrodynamic braking until train slows to 120km/hr.	On-board computer (BLF) diagnostic.	Y[3]	N	B3
Linear Generators	Fail Off/No Power Output	No power fed to corresponding Storage Battery and possible loss of associated Eddy Current brake. Failure of this item will not immediately or directly affect braking performance.	Loss of generator may lead to eventual loss of stored energy in batteries, leading to a failed brake circuit. Emergency braking will be achieved by wayside-controlled electrodynamic braking.	On-board computer (BLF) diagnostic.	Y	N	B3
Friction Brakes							
Landing Skids (16 skids per vehicle)	Excessive Wear	Vehicle will skid on its undercarriage causing possible damage to the levitation frame.	Train will skid to a halt although damage to the levitation frame may result. Control of stopping location may be erratic.	Preventative maintenance inspections.	N	N	A3

Table 3-17. Transrapid TR07 FMEA (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

Transrapid TR07 (Germany)							Page 3 of 3
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
General							
SSW ABI Manual Control	Fail Off	Train cannot leave station until the BLF is active or the SSW ABI is on. Once in operation, train control is primarily from wayside OCS.	Wayside OCS brings train to a "programmed" emergency stop at the next safe location on the track.	Wayside diagnostics of train.	N	Y	C
Emergency-Stop Key Switch	Fail Off	If the switch fails, manual activation of emergency braking is unavailable.	Wayside OCS will stop train through electrodynamic braking and eventual neutralization of the guideway stator.	Wayside diagnostics of train.	N	Y	C
MREs (2 per module hinge)	Fail Off	If one MRE fails, there is little or no effect.	As soon as one MRE fails the BLF may signal an emergency stop at the next safe location. There is otherwise no effect on the braking system.	BLF vehicle diagnostic.	Y[4]	Y	D

1. Wayside control has two sets of computers arranged in a triple channel configuration.
2. If only one circuit fails. Otherwise, no.
3. If failure results in only one brake circuit failure.
4. If only one MRE fails.

3.10 HSST

3.10.1 General Description

The High Speed Surface Transport (HSST) maglev system has been under development and through various phases of testing since the 70's. Initial designs (i.e., HSST-01) were created by Japan Air Lines (JAL) in 1975. Since then, the system has evolved under leadership of the HSST Corporation through the HSST-02, -03, -04, and -05. The HSST-05 was the first two-car train in the series, and was designed for a maximum speed of 55 km/h. Various evaluation tests have since been conducted at a test track in Nagoya City, Japan. In 1993, the HSST Development Corporation was formed to market HSST technology worldwide, and in particular, the sixth generation system referred to as the HSST-100. This system is very similar to the HSST-05, and is designed for a cruising speed of 110 km/h (with a maximum speed of 200 km/h).

It should be noted that the braking system description provided herein focuses on the HSST-05 since most available technical information applies to this version. Key differences between the HSST-05 and -100 versions are cited where known. However, it is believed that the basic braking philosophy and key components of the two systems are very similar in nature.

The HSST-05 "train" consists of two cars, each of which has a length, width and height of approximately 18 m, 3 m, and 3.6 m, respectively. Each car can carry about 80 passengers.

The design is quite similar in some respects to the Transrapid system in that the vehicle wraps around a T-shaped guideway and uses attractive levitation based upon on-board magnets and steel rails in the guideway. One major difference, however, is that the HSST propulsion (and primary braking) system is based upon a short stator linear induction motor concept in which the motor primary is on the vehicle and a reaction plate in the guideway acts as the motor secondary or rotor. Electrical power for propulsion/braking is supplied to the vehicle from the wayside via power collectors.

Primary suspension is provided by the on-board magnets which are used to maintain an air gap of approximately 9 mm (8 mm in the HSST-100). Each vehicle has eight suspension modules (three modules for the HSST-100), which are connected to the vehicle body through a secondary suspension system comprised of air springs (4 springs per module). Each module contains four levitation magnets and one linear motor primary.

3.10.2 Braking System Design

The braking strategy of the HSST-05 is based upon the following key aspects:

- Dynamic/regenerative braking under normal circumstances via the on-board short stator linear induction motor

- A hydraulic/friction braking system to supplement and/or replace dynamic braking, and

- Skids on the vehicle for use as a parking brake and, in some instances, for emergency braking in case of loss of levitation.

Major Braking Components

Linear Induction Motor. The linear induction motor (LIM) is used for normal braking as well as propulsion. In the propulsion mode, three-phase variable voltage, variable frequency (VVVF) power is provided to the primary side of the motor on-board the vehicle (one LIM per each suspension module). Voltage (i.e. 1500 volts DC) is transferred to the vehicle via power collectors, located below the suspension modules. The magnetic flux generated by the AC current in the primary induces a current flow in the guideway-mounted reaction plates (two steel plates running in parallel with and on the guideway surface). This induced current, resulting magnetic flux and interaction with the primary-generated magnetic flux generates propulsion.

In the braking mode, the phase of the AC current in the primary winding on-board the vehicle is reversed, causing an interaction between the magnetic fluxes in the primary and secondary windings, thereby generating a retarding force on the vehicle. Power induced back into the primary winding as a result of the braking action is returned to the wayside via the power collectors.

Hydraulic Brakes. Each suspension module on a vehicle (eight modules for an HSST-05) is equipped with a hydraulic brake assembly, consisting of two friction caliper brake units (one on each side of the vehicle). Other associated equipment includes a hydraulic fluid source maintained at approximately 3,000 psi, two hydraulic brake control systems, a hydraulic pump control system, and a monitoring/warning system. When braking is commanded, hydraulic fluid is pumped to the brake units, thereby forcing the calipers and brake pads to make contact with an extended portion of the guideway structure. A drawing of one hydraulic brake caliper assembly is shown is shown in Figure 3-19.

Brake Skids. Each module on the vehicle is equipped with two brake skid pads, one on each side of the module. Each pad is located on the bottom of the module and parallel to the vehicle such that the pads make contact with the top of the guideway surface when the vehicle is delevitated. These brake pads are used as a parking brake, but also in the event that additional braking is needed in emergency situations beyond the dynamic and hydraulic friction brakes.

Brake Control Components

Braking is usually initiated by wayside equipment, but the primary control function occurs within on-board systems. Various control elements are discussed next.

Wayside ATP System. Automatic Train Protection (ATP) equipment (some of which is computer based) at various wayside locations receive information from vehicles in its controlling area regarding location and speed. Based upon this and other information such as

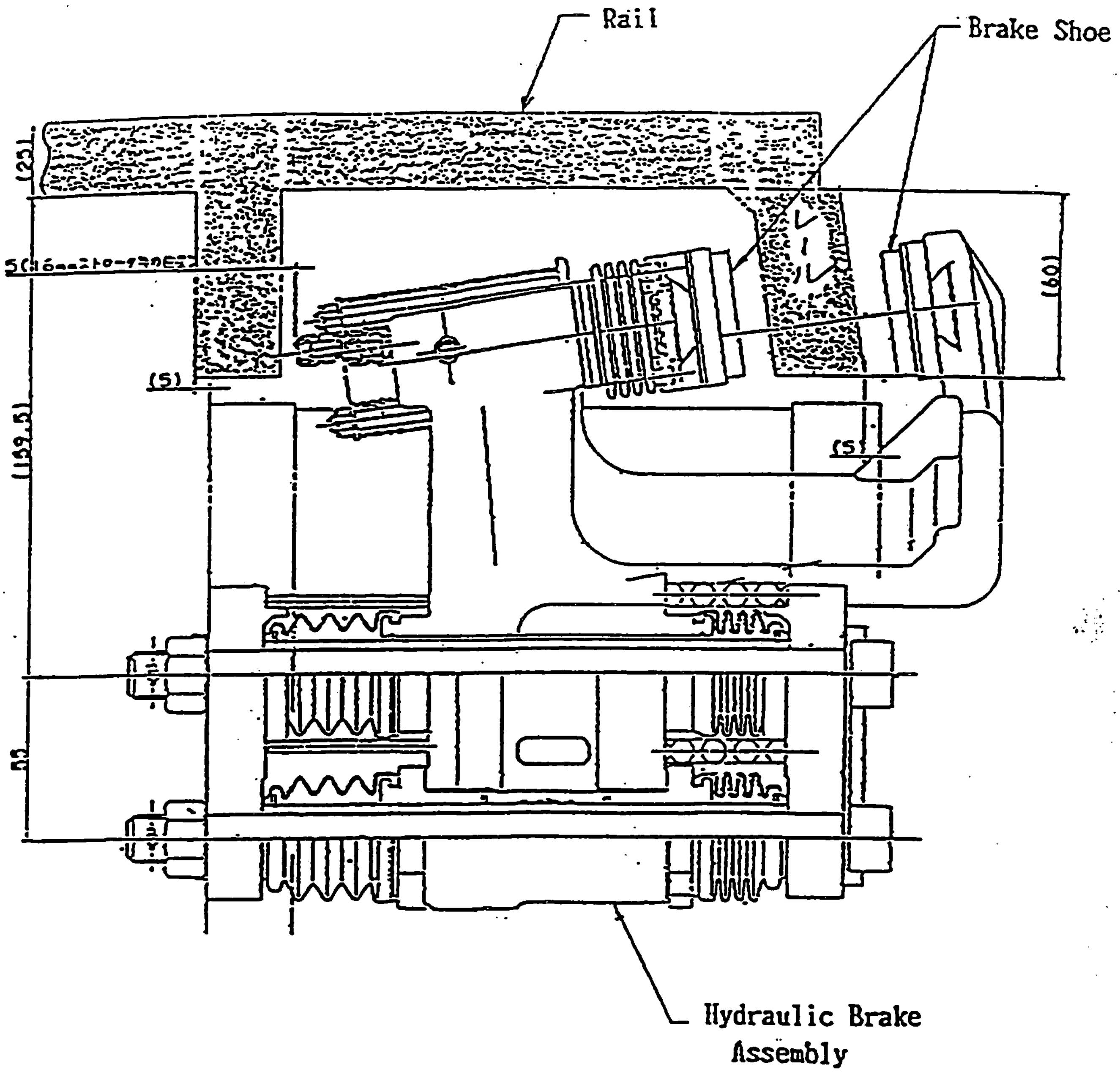


Figure 3-19. HSST Hydraulic Brake Caliper Assembly

switch status and movement requests from central control, the wayside equipment sends speed and braking commands to a vehicle in a given block. Commands are sent to the appropriate vehicle(s) via transponders and vehicle-mounted antenna.

On-Board ATP System. Under normal circumstances, on-board ATP equipment receives and interprets speed and braking commands from the wayside, determines the type of braking to be provided (i.e., dynamic, hydraulic friction and/or skids) and determines the appropriate level of braking to be achieved by each brake system. Appropriate control signals are sent from the main ATP control equipment to the various braking control subsystems for further processing. Figure 3-20 shows a general block diagram of the vehicle control system and smaller subsystems. It can be seen from the figure that the major control system in the operator's compartment interfaces with, among others, the levitation and brake control subsystems.

Brake Control Subsystem. Each module is equipped with a brake control subsystem that receives signals from the main ATP system and interfaces with the VVVF inverters and hydraulic braking system. This can be seen in Figure 3-20. In this manner, braking can be performed dynamically via the linear induction motors (LIMs) and/or mechanically via the hydraulic friction brakes. If friction braking is desired, the hydraulic pumps are commanded to provide hydraulic fluid to the caliper brake units which, in turn, force the brake shoes against the guideway. Two separate hydraulic supply systems are utilized to protect against leaks in one or the other hydraulic system.

Levitation Control Unit. As mentioned earlier, brake skids can be used as a means of braking the vehicle under certain circumstances (e.g., loss or ineffective dynamic and friction braking). The control of these skids is performed by levitation control units (two for each of the eight vehicle modules) which activate the skids by reducing or removing levitation, thereby causing the skids to make contact with the guideway surface. The amount of levitation is detected by dedicated sensors. Each levitation unit controls two of the four magnets on each vehicle module. The levitation control unit is under control of the main ATP system in the operator's compartment. A block diagram showing the configuration of the levitation control components is shown in Figure 3-21.

Master Control Lever. There is a Master Control Lever on the operator's console for the manual control of propulsion as well as braking. This control lever has a position which can be used by the operator to apply the emergency brakes (i.e., dynamic, friction and/or skids). However, even in the manual position, the ATP system monitors vehicle movement for unsafe conditions (e.g., excessive speed or insufficient braking) and commands braking as appropriate.

ATP Disable Switch. The ATP disable switch has some applicability to braking (i.e., actually relative to releasing the brakes). If a failure occurs in the ATP or other vehicle system, and is detected, braking is initiated via the main ATP and brake control systems. Although the ATP system may not permit vehicle movement under these circumstances, activation of the ATP disable switch will allow the operator to release the brakes and move the train to a safe location for passenger unloading.

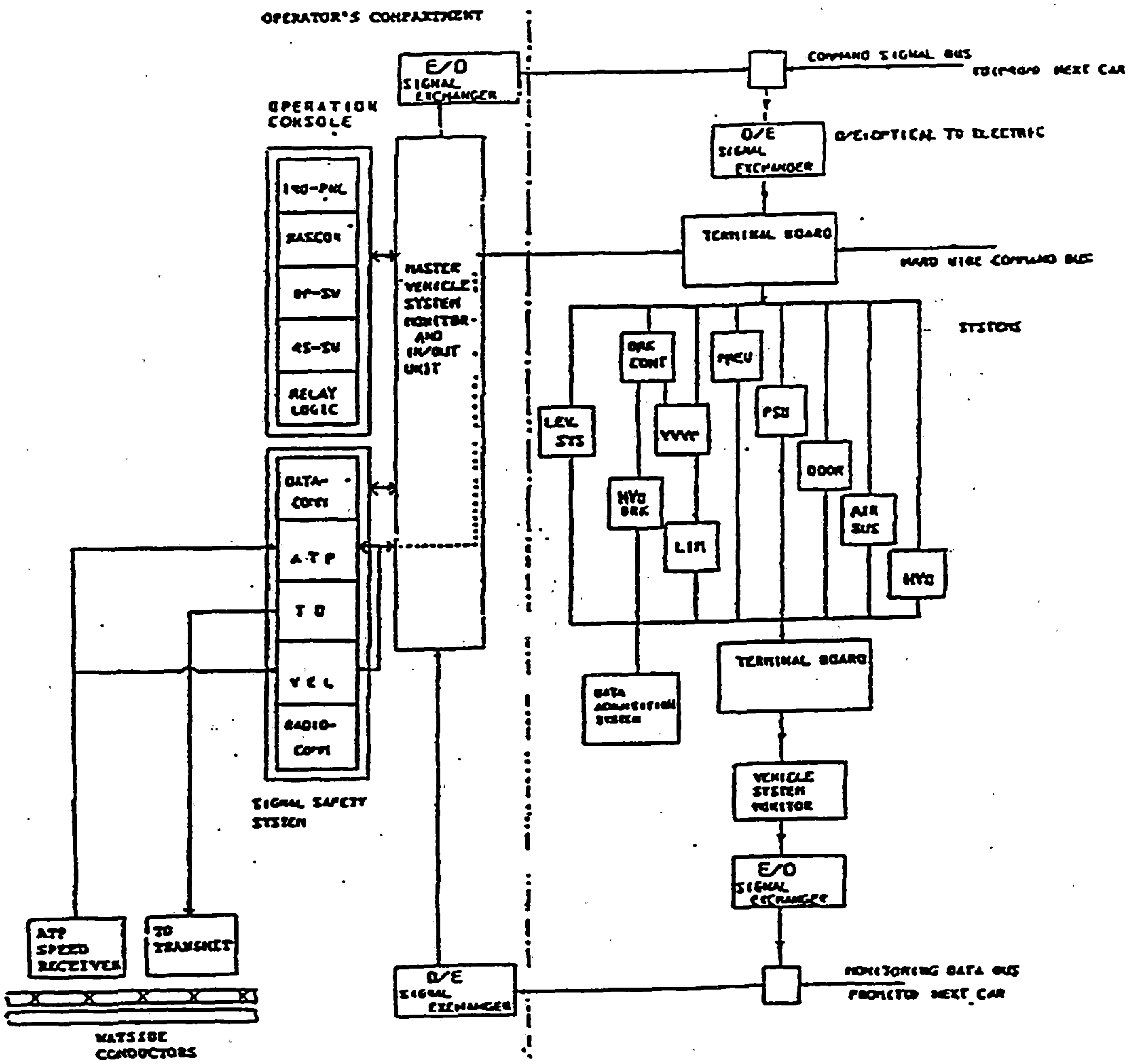


Figure 3-20. Vehicle Control System and Subsystems

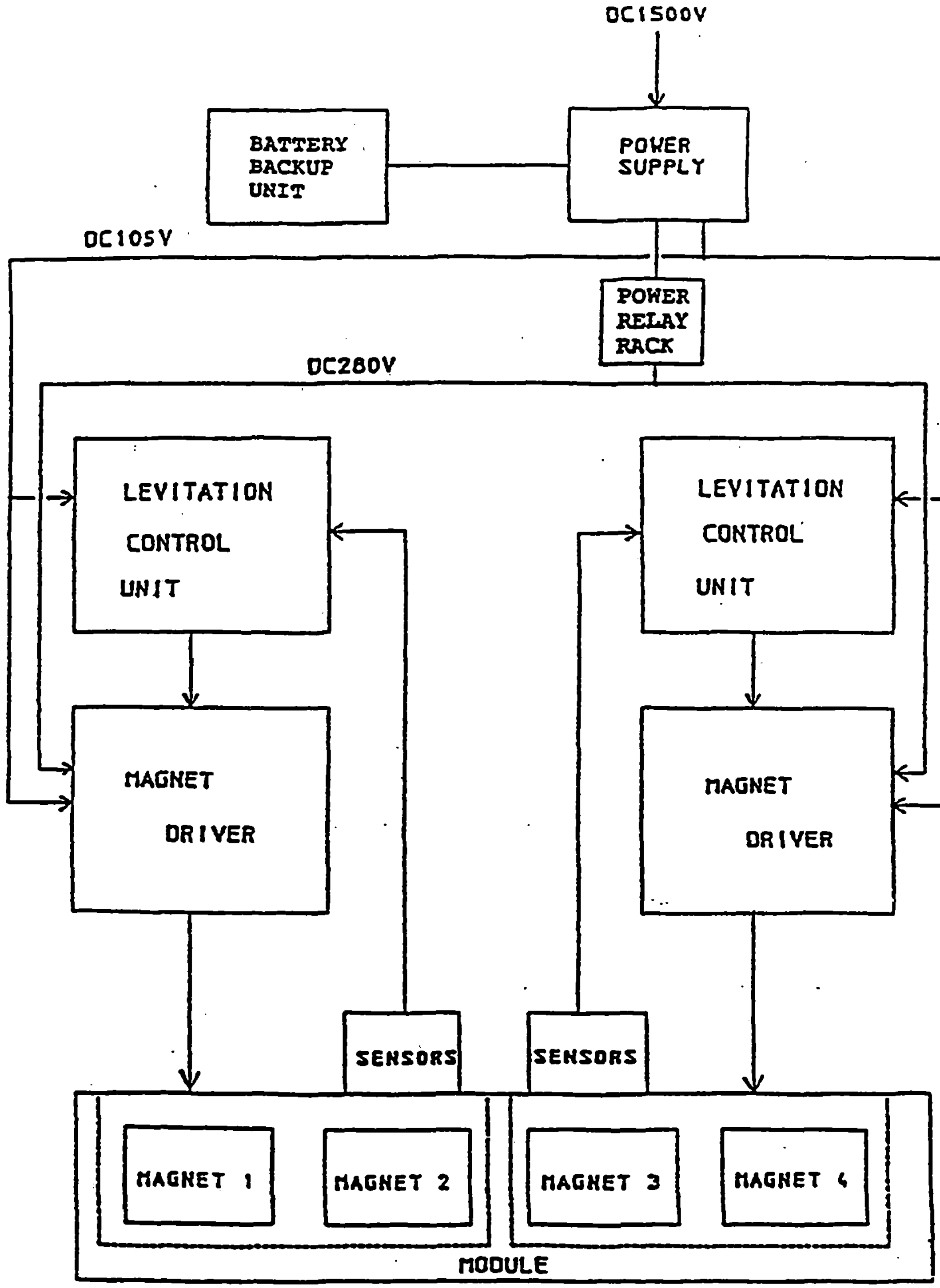


Figure 3-21. Block Diagram of Levitation Control System

3.10.3 Brake System Operation

Normal Braking

Under normal braking situations, the wayside element sends a brake command to the vehicle ATP equipment which initiates and controls braking dynamically via the LIMs. As discussed earlier, this braking is generated by reversing the phase of the AC current provided to the LIMs. The braking command is in the form of a deceleration profile. This mode of braking is used at speeds higher than eight km/h. Below this speed, dynamic braking is supplemented by the friction brakes. When friction braking is used in a normal braking mode, modulated/controlled brake pressure is provided to the hydraulic systems in only six of the eight modules on a vehicle.

Emergency Braking

Emergency braking is initiated under different circumstances, and can incorporate all three braking modes (i.e., dynamic, friction and skids). If the deceleration profile is not maintained by the dynamic brakes during a normal braking operation, additional braking at emergency rates is provided by the friction brakes. Anytime the friction brakes are used in an emergency mode, unmodulated pressure is applied to the hydraulic systems in all eight of the vehicle modules (as opposed to only six that are used in normal braking).

Should the dynamic brake system fail or the dynamic brake signal be lost, emergency braking is accomplished by the friction brakes.

Emergency braking can also be directed by the wayside or on-board ATP equipment or by the manual application of the emergency position on the Master Control Lever. In these instances, the dynamic and friction brakes are used concurrently.

In the event of insufficient emergency braking by the dynamic and friction brakes, levitation will be reduced or removed so that additional braking is provided in a controlled manner via the brake skids. This, however, is not a desired condition of operation.

3.10.4 Brake System Performance

Technical Specifications

Technical specifications for the braking system of the HSST are limited, but documentation suggests a deceleration capability of 0.07 G for the HSST-05. Normal and emergency deceleration rates for the next generation HSST-100A are listed as 2.5 and 3.5 km/h/s, respectively.

Diagnostics and Monitoring

Although specifics regarding brake system diagnostics and monitoring are not identified in documentation available for this project, it is known that some monitoring of the brake subsystems does take place.

Control System Monitoring. It can be seen from Figure 3-20 of this report that a data acquisition system and vehicle system monitor interface with the various vehicle subsystems and the master vehicle system monitor in the operator's compartment. Annunciations as to certain malfunctions are given in the operator's console. Further, some of this diagnostic information is inductively transmitted to the central control facility.

The main on-board ATP equipment in the operator's compartment is also monitored. A defect detected in this equipment causes a signal to be fed to the brake control device for the purpose of applying brakes to stop the vehicle. The ATP disable switch can be used to disable the ATP, release the brakes, and move the vehicle to a more convenient location.

Brake Performance Monitoring. As discussed earlier, braking performance is continuously monitored by the ATP system. Should a given braking mode (e.g., dynamic, friction) not be providing adequate braking (i.e., actual deceleration not staying within the deceleration profile), additional braking via the friction breaks and/or skids is commanded as necessary to maintain the required braking rate. As indicated, use of the skids requires delevitation of the vehicle.

Inspection and Test Requirements

No specific inspection and test requirements were identified in available literature other than an indication that vehicles are or will be "inspected on a daily basis prior to their release for operation." It is assumed that this will involve the braking systems to some extent.

It is also assumed that regular inspections will be needed for various braking system aspects such as the quality/thickness of pads for the hydraulic friction brakes and the brake skids. Portions of the guideway will also need inspection such as the surfaces which interact with the brake shoes and skid pads.

Braking System Effects on Vehicles, Guideway and Infrastructure

Some possible braking-related effects on the HSST vehicles and/or guideway are discussed below.

Friction Brakes. Use of the hydraulic friction brakes, which occurs at all times below 8 km/h and periodically above that speed, will result in wear of the brake shoe pads and some lesser wear on the guideway surface with which they interact.

Brake Skids. Although it is assumed that the brake skids will be used sparingly for actual braking purposes, such use will result in significant wear on the pads as well as some wear on the guideway surface itself.

Table 3-18. HSST FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

HSST—High Speed Surface Transport (Japan) — Page 1 of 3

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Dynamic/Regenerative Brake							
Short Stator Linear Induction Motors (LIM)(16 per two-car train)	Fail Off	Loss of propulsion and dynamic braking at affected motor(s).	Remaining LIMs available to reduce vehicle speed. Friction brakes applied at 8 km/hr to stop train.	On-board diagnostic and communication with wayside ATP system.	Y	N	B3
	Fails to reverse polarity (remains in Propulsion Mode)	Loss of dynamic braking at effected motors. If only some LIMs are affected, the propulsive force of the malfunctioning LIMs may negate the braking force of the remaining LIMs.	Remaining LIMs available to reduce vehicle speed. Friction brakes also available.	On-board ATP in communication with wayside ATP elements.	Y	N	B3
	Prematurely reverses polarity (braking applied)	Dynamic braking at effected motors. If only some LIMs are effected, the propulsive LIMs may negate the braking force of the malfunctioning LIMs.	Remaining LIMs available to reduce vehicle speed. Friction brakes also available.	On-board ATP in communication with wayside ATP elements.	N	Y	C
Power Collectors (16 per train)	Fail Off or fail to collect power	Negligible, if an individual collector. Collectors on other modules will compensate.	Negligible.	On-board diagnostics.	Y	Y	D
Wayside Power Source	Fails off	No dynamic braking using LIMs (assumes no battery backup for braking purposes). Also no propulsion.	Levitation maintained via battery backup. Vehicle slows due to lack of propulsion. Hydraulic brakes available for emergency application.	Wayside and on-board diagnostics.	N	Y	C
	Fails to accept regenerative power.	Assume loss of dynamic braking using LIMs.	Levitation maintained via battery backup. Hydraulic brakes available for emergency application.	Wayside and on-board diagnostics.	N	N	A2
Hydraulic/Friction Brakes							
Calipers	Fail On	Train brakes during propulsion at the failed caliper, possibly causing damage to brake pads or rail.	Train brakes in emergency with dynamic braking.	Brake subsystem control in conjunction with ATP system.	N	Y	C

Table 3-18. HSST FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

HSST—High Speed Surface Transport (Japan) — Page 2 of 3

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Calipers	Fail Off	Train underbrakes. Other calipers must compensate.	Trinset is traveling at or below 8 km/hr when friction brakes used in normal service. If the ATP senses that the train is not decelerating enough, the ATP can either increase pressure to remaining calipers or set-down train.	On-board ATP in communication with wayside ATP elements.	Y	N	B3
Hydraulic Supply System (2)	Fails to Hold Pressure/Fluid	Possible loss of friction braking. Two supply systems available to prevent complete loss.	Dynamic brakes will slow train to safe speed. ATP will then set train down for skid-braking.	Pressure sensors/Braking subsystem diagnostic.	Y[1]	N	B3
Hydraulic Brake Control System (2)	Fails Off	None.	None. A second controller exists for backup.	Braking subsystem diagnostic.	Y	N	B3
Skid Brakes							
Brake Skids (2 per module)	Excessive wear	Less stopping power, possible damage to undercarriage.	Skids normally are only used at very low train speeds. Effects may not be noticeable. Hydraulic brakes can bring train to complete stop.	Inspection.	N	N	A3
Levitation Magnets (4 per module)	Fail Off (assumed circuit fault that effects 1 or 2 magnets)[2]	Other skids may make contact. ATP will command train to set-down in emergency.	Full dynamic and friction braking available to stop train and reduce wear to skids.	Levitation sensors. On-board ATP in communication with wayside ATP elements.	N	Y	C
Levitation Control Units (2 per module, each controlling 2 levitation magnets)	Fail Off	None. On-board ATP signals remaining units to lower train. Wayside ATP may also neutralize track for same purpose.	Full dynamic and friction braking available to stop train and reduce wear to skids. Train sets down or makes partial contact with track in order to stop.	Levitation sensors. On-board ATP in communication with wayside ATP elements.	N	Y	C
	Incorrectly Signals Magnets to Delevitate	Effected portion of train tries to set down early (overbrakes).	Full dynamic and friction braking available to stop train and reduce wear to skids.	Levitation sensors. On-board ATP in communication with wayside ATP elements.	N	Y	C

Table 3-18. HSST FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

HSST—High Speed Surface Transport (Japan)							Page 3 of 3
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Levitation Control Units (2 per module, each controlling 2 levitation magnets)	Incorrectly Signals Magnets to Maintain Levitation	Effected portion of train fails to set down when expected (underbrakes).	Train is expected to be traveling at very low speeds. Hydraulic brake available to stop train.	Levitation sensors. On-board ATP in communication with wayside ATP elements.	Y	Y	D
Levitation Sensors (2 per module)	Incorrectly Measures Air Gap	On-board computers will determine that train is slowing down too slow/too fast and adjust accordingly. Skids will wear excessively if the train continues to make contact.	Train may compensate by increasing/decreasing dynamic and/or friction braking effort.	Wayside elements? On-board diagnostics?	N	N	A3
	Fail Off	ATP switches to emergency braking.	Train goes into emergency braking with dynamic and friction braking. Once train has stopped, wayside ATP can turn off levitation power to lower train.	ATP and On-board diagnostic	N	Y	C
General							
On-board Automatic Train Protection (ATP)	Fails Off	Wayside ATP commands emergency braking of the train.	Available braking systems used to stop train based on wayside instructions.	On-board and wayside Diagnostic	N	Y	C
Wayside Automatic Train Protection (ATP)	Fails Off	On-board ATP commands emergency braking of the train.	Available braking systems used to stop train.	On-board and wayside Diagnostic	N	Y	C
ATP Disable Switch	Fails Off	Will not release brakes.	Train will be immobile.		N	Y	C
Master Control Lever	Fails Off	Operator cannot put train in manual mode. If at rest, train will remain immobile. Manual control of brakes lost.	Wayside or on-board ATP will control brakes in some emergencies. Brakes will otherwise be unaffected.	Not known.	N	Y	C

1. System will tolerate loss of one supply system.
2. Assumed that a simultaneous failure of all levitation magnets is very unlikely due to back-up systems.

3.11 MLU-002N

3.11.1 General Description

The MLU002N is a Japanese maglev system that is under development and is based upon electrodynamic levitation using superconducting magnets. It is the latest in a series of maglev systems being developed by the Railway Technical Research Institute (RTRI) and funded by the Japanese Ministry of Transport. Original development work for the system was initiated by the Japanese National Railways, but was taken over by the RTRI in 1987. The predecessor to the MLU002N was the MLU002, which was destroyed by fire in 1991.

Speeds of up to 394 km/h were achieved with the MLU002 vehicle at the Miyazaki Test Track before the fire. Testing has been underway since January 1993 at Miyazaki test track using the MLU002N vehicle in order to assess the economical and technical feasibility of a 500 km/h commercial maglev system. Revenue service operation of the train is not expected to occur until about the year 2005.

The MLU002N is a single-bodied vehicle that is designed to travel in both directions. Its total weight is about 20 tons and has a total length, width and height of 22 m, 3 m, and 3.7 m, respectively. It is expected that future trainsets will consist of 3-car or 5-car units with a car containing the operator's control station on each end and passenger cars in the middle. Up to four different lightweight bodies have been developed for these applications using different materials and construction techniques.

The MLU002N vehicle, which rides in a u-shaped guideway, incorporates repelling superconducting magnets (on the lower sides of the vehicle) which interact with electromagnets on the guideway walls to provide levitation, guidance, propulsion and electric braking. Propulsion as well as braking is provided through the use of a long stator linear synchronous motor.

One unique characteristic of this electrodynamic system is that it incorporates wheels beneath the vehicle on which the vehicle rides until adequate levitation is achieved--since proper levitation does not occur via the superconducting magnets until an adequate vehicle speed is attained (which induces the proper magnetic forces). Thus, primary suspension of the vehicle is maintained by the wheels (at lower speeds) and the levitation system at higher speeds. A secondary suspension system based upon the use of air springs is also incorporated.

3.11.2 Braking System Design

The braking system design of the MLU002N is based upon the use of electrical and mechanical brakes as well as an aerodynamic brake. These brakes are used under different conditions and in different speed ranges. The specific braking strategy as anticipated for the vehicle is shown in Table 3-19. It should be noted that the braking systems, and especially the disc brake system, are under development and have not been finalized. Additional details of these developments are discussed in later sections.

Table 3-19. Braking Strategy of the MLU002N

Brake System	Usage	Speed Range
Regenerative Brake (Electric)	Normal Braking Emergency Braking	0-500 km/h
Dynamic Brake (Electric)	Failure of Regenerative Brake Failure of Substation	0-500 km/h
Landing Skid Brake (Mechanical)	Failure of Electric Brakes	0-350 km/h
Disk Brake (Mechanical)	Failure of Electric Brakes	0-500 km/h
Aerodynamic Brake	Failure of Electric Brakes	200-500 km/h

Major Braking Components

Linear Synchronous Motor (Electric Brake). The primary mode of braking for the MLU002N is electric in nature and is provided by the long stator linear synchronous motor (LSM). In a propulsion mode, three-phase current is fed to the guideway-mounted electromagnets which react with the on-board superconducting magnets to produce a propulsive force. A traveling wave in the guideway propels the vehicle via both attractive and repulsive magnetic forces. The guideway-mounted electromagnets act as the armature of the motor, while the superconducting magnets act as the rotor.

Electric braking is actually of two types: regenerative and dynamic. In regenerative braking, which is the type most often used, the phase of the current in the guideway coils is reversed, thereby inducing a brake force on the vehicle. Electrical power generated by this form of braking is returned to the substation for other usage.

Dynamic braking is provided in essentially the same manner, but the generated power is dissipated in a resistor network on the wayside. This mode is used if, for some reason, electrical power cannot be returned to the substation.

Disk Brake. Considerable attention is being directed by the designers of the MLU002N to a disk brake system that could be used as a backup should there be a failure of the electric brake. One problem has been that the downward force on the bogie wheels decreases as vehicle speed increases and levitation force increases because the wheel assemblies are raised and lowered as levitation force increases and decreases. This has resulted in a lower available braking force by the wheel disk brakes at higher speeds. Another problem has involved the development of a disk brake system that could be effective over the entire speed range of 0 to 500 km/h (and especially the higher speeds due to increased temperature generated during braking).

At the present time, should electric braking not be available, the disk brake system is utilized at lower speeds and the aerodynamic brake at higher speeds (above 200 km/h or so).

Although details of the current disk brake system are not clearly identified in available literature, it is believed that the system is very similar (if not identical) to a newly developed disk brake system that is described in documentation. It is this system that is described below. It should be noted that documentation indicates this new disk brake system has been successfully tested up to speeds of 500 km/h (Ref. 30). The lower levitation forces at the new test track have resulted in sufficient train weight on the bogie wheels at higher speeds to permit sufficient braking force (via the wheel disks) at the higher speeds.

Each bogie of the MLU002N is equipped with four wheel assemblies, one on each corner below the bogie frame. Each assembly is comprised of the following major components:

- Support arm--Mechanical arm for raising and lowering the wheels and axle, based upon applied levitation force; the arm is gradually raised as vehicle speed increases
- Wheel/axle assembly--Axle with two wheels that is attached to the support arm
- Rubber tires--Two rubber tires which make contact with the guideway surface
- Tire pressure monitor (TPIS)--Sensor for monitoring tire pressure
- Wheel speed sensor--Sensor for measuring speed of the wheel/axle assembly; used for brake control
- Disk brake assembly--Disk brake unit mounted on each wheel
- Auxiliary wheel--Additional wheel on the wheel/axle assembly that can support a corner of the bogie should the tire(s) become deflated.

A diagram of the disk brake system for a single bogie is shown in Figure 3-22.

When braking is commanded by an electronic control unit (ECU), the hydraulic system furnishes fluid at the proper pressure to all disk brakes on the vehicle bogie (two disk brakes for each of the four wheel assemblies) to generate the required braking force.

Aerodynamic Brake. The MLU002N is fitted with two sets of aerodynamic brake devices (Ref. 31). Each set consists of two panels mounted on the vehicle top, about 5 m from the end of the vehicle. The panels (in this test vehicle) are oriented in the same direction so that braking via these panels is accomplished as the vehicle travels in only one direction.

The principle of the devices is based upon the proportional relationship between air resistance (for braking) and the front face area of the vehicle and its speed. Under normal operation (no braking) the panels are closed and flush with the vehicle's surface. Should emergency braking be needed (electric brake not operable), the panels are opened to create increased air resistance. The panels are opened to about 45 degrees with the aid of a spring, after which the air resistance itself pulls the panels open even further until they are essentially perpendicular with the vehicle body. The effectiveness of the panels is greatest at higher

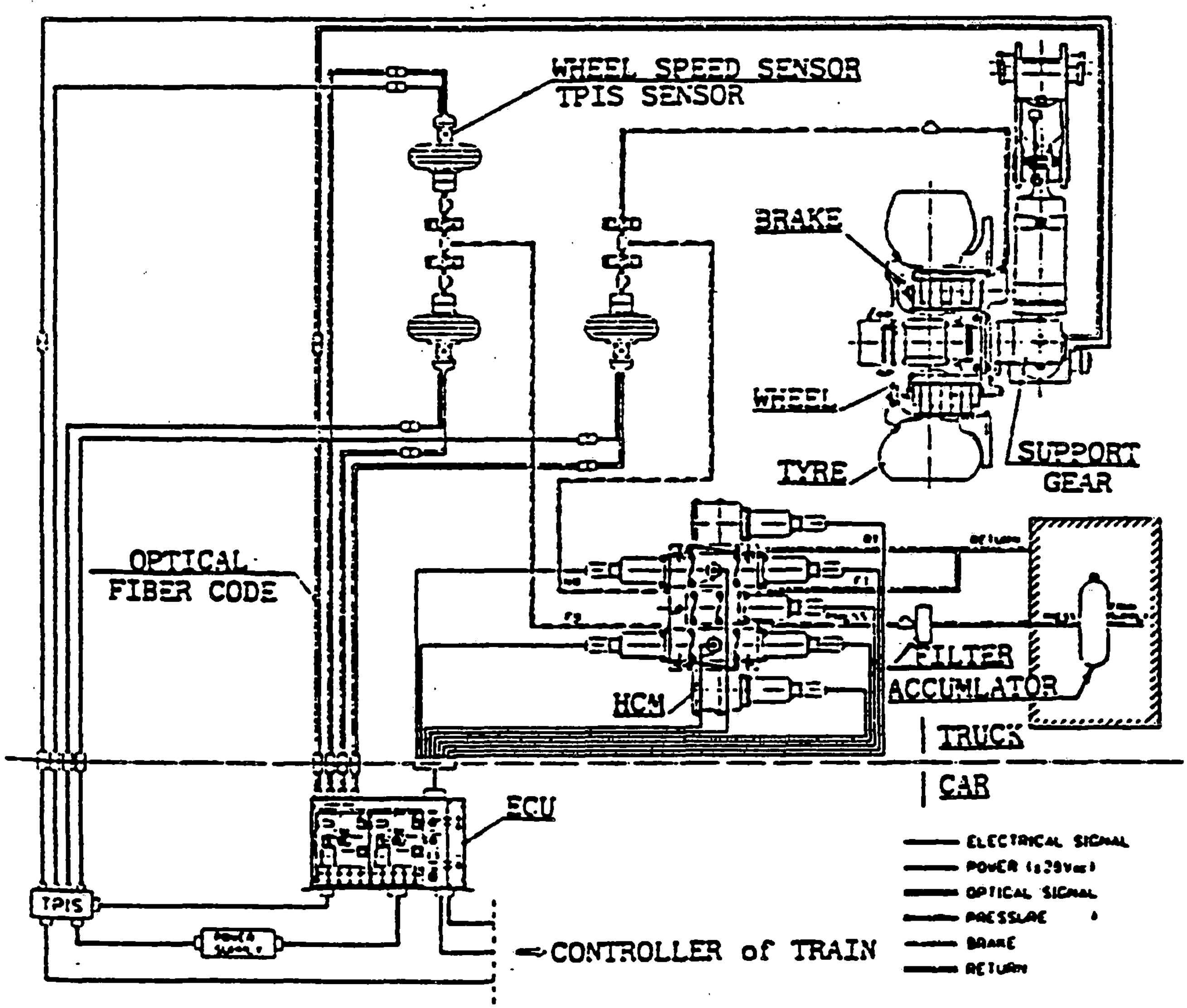


Figure 3-22. Disk Brake System for MLU002N

speeds and decreases rapidly below about 200 km/h. This is why, at the present time, a combination of aerodynamic and friction braking (via the wheel assemblies) is used for emergency braking purposes.

Major components of the aerodynamic brake system and their functions are as follows:

- Brake panels--Two sets of slightly curved panels (curved in the direction of vehicle travel) which provide air resistance when activated (opened); each has a surface area of about 1.95 m^2

- Stay dampers--Two dampers on each panel to perform four functions: 1) absorb the shock of the spring force when the panel is first opened, 2) absorb air pressure impact just before the panel is fully open, 3) provide viscous damping to control the opening speed, and 4) act as a "stopper" when the panel is fully open; (currently, panels must be closed manually after use).

- Unit box--A special compartment on the top of the vehicle in which the panels and dampers are located; it seals out water from the vehicle interior

- Locking device--A mechanical locking device (comprised of a hook, springs, magnets and other items) on each panel to keep the panel in the closed position when braking is not desired, and allow opening of the panel when braking is desired.

Figures 3-23 and 3-24 show several different views of the aerodynamic brake and opened panels on the MLU002N vehicle, respectively.

Landing Skids. Each bogie is equipped with four landing skids, two mounted underneath and on each end of the bogie. The bottom of the skids are fitted with metal shoes which can be commanded to come in contact with the guideway surface at lower speeds, when the wheel assembly is retracted, and when levitation is removed. Figure 3-25 shows the location of the skids on the new double bogie frame for the MLU002N. Indications are that the skids could be used for braking (if desired) at vehicle speeds below 350 km/h. However, should electric braking be lost, it is more desirable to use the wheel disk brakes in combination with the aerodynamic brake.

Brake Control Components

Operational Safety System. The operational safety system for the MLU002N is comprised of both wayside and on-board control elements as can be observed in Figure 3-26. One major element on the wayside that is highly involved in brake control is the safety control system which has the following responsibilities:

- Generate maximum speed, route and brake commands (including emergency brake commands) to the wayside running control system (portion of the equipment responsible for sending propulsion and brake commands to the guideway mounted

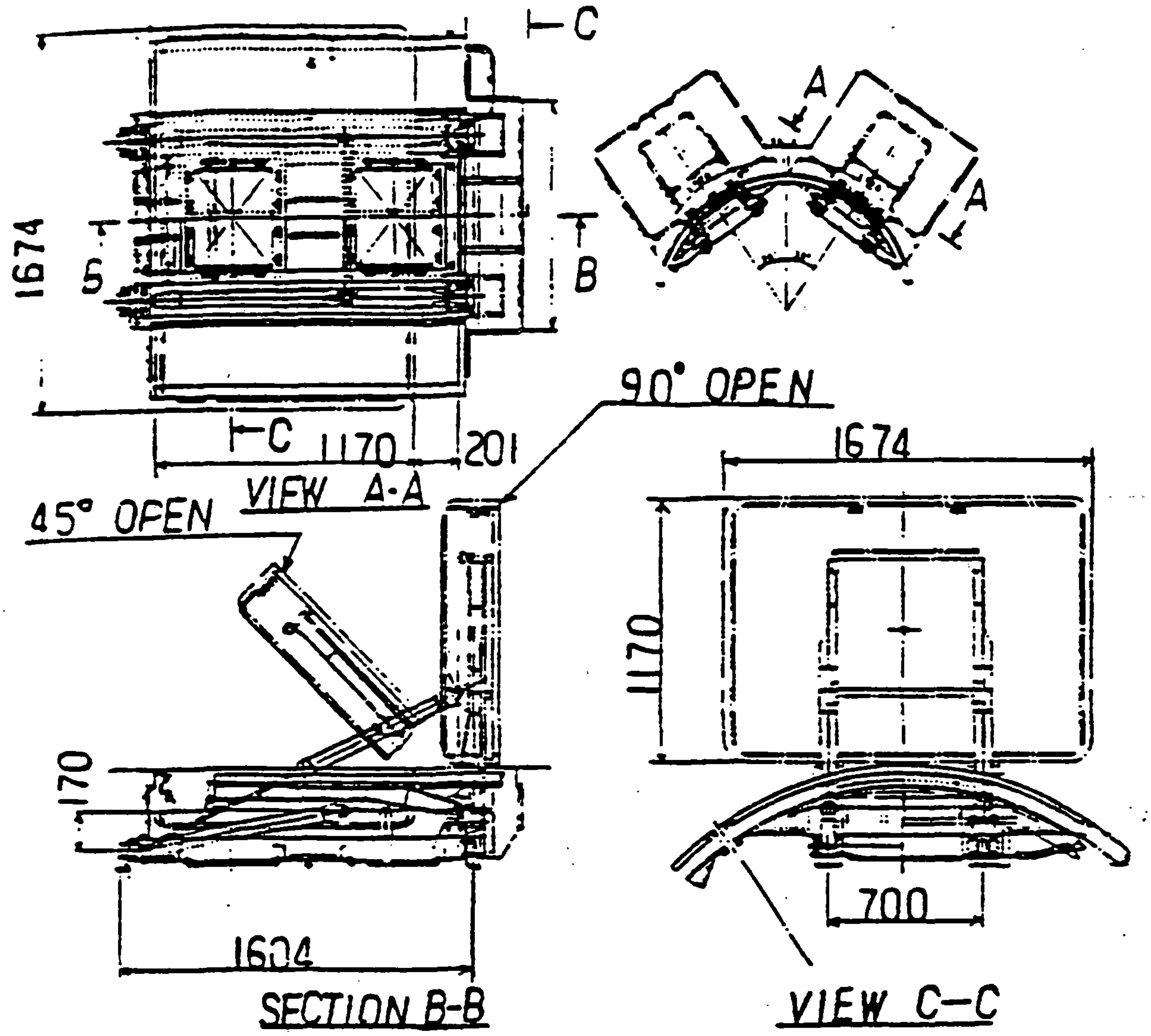


Figure 3-23. Several Views of Aerodynamic Brakes

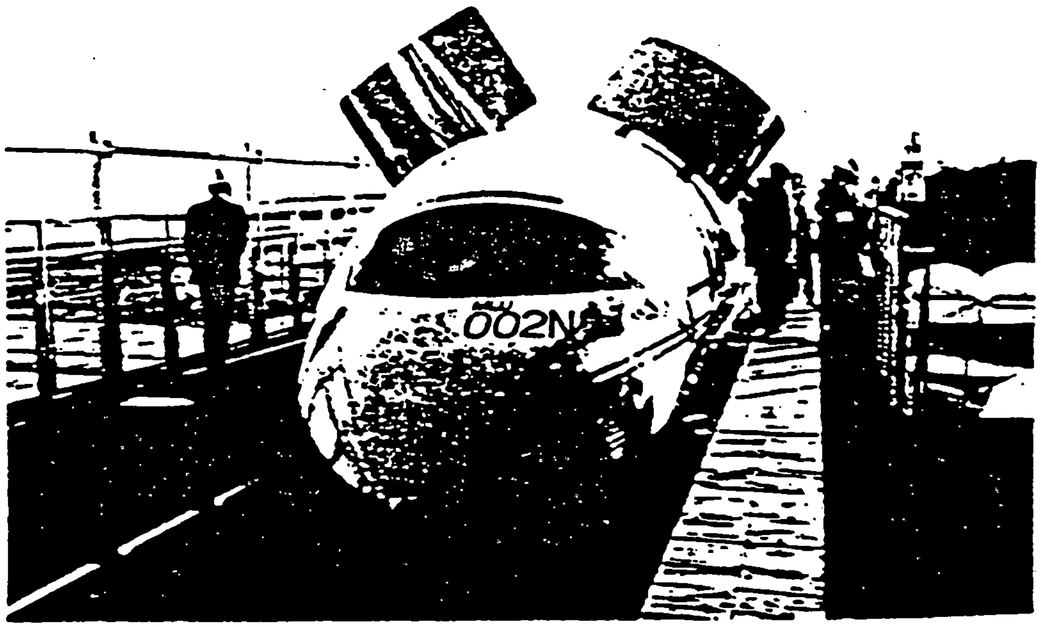


Figure 3-24. Opened Aerodynamic Brake Panels

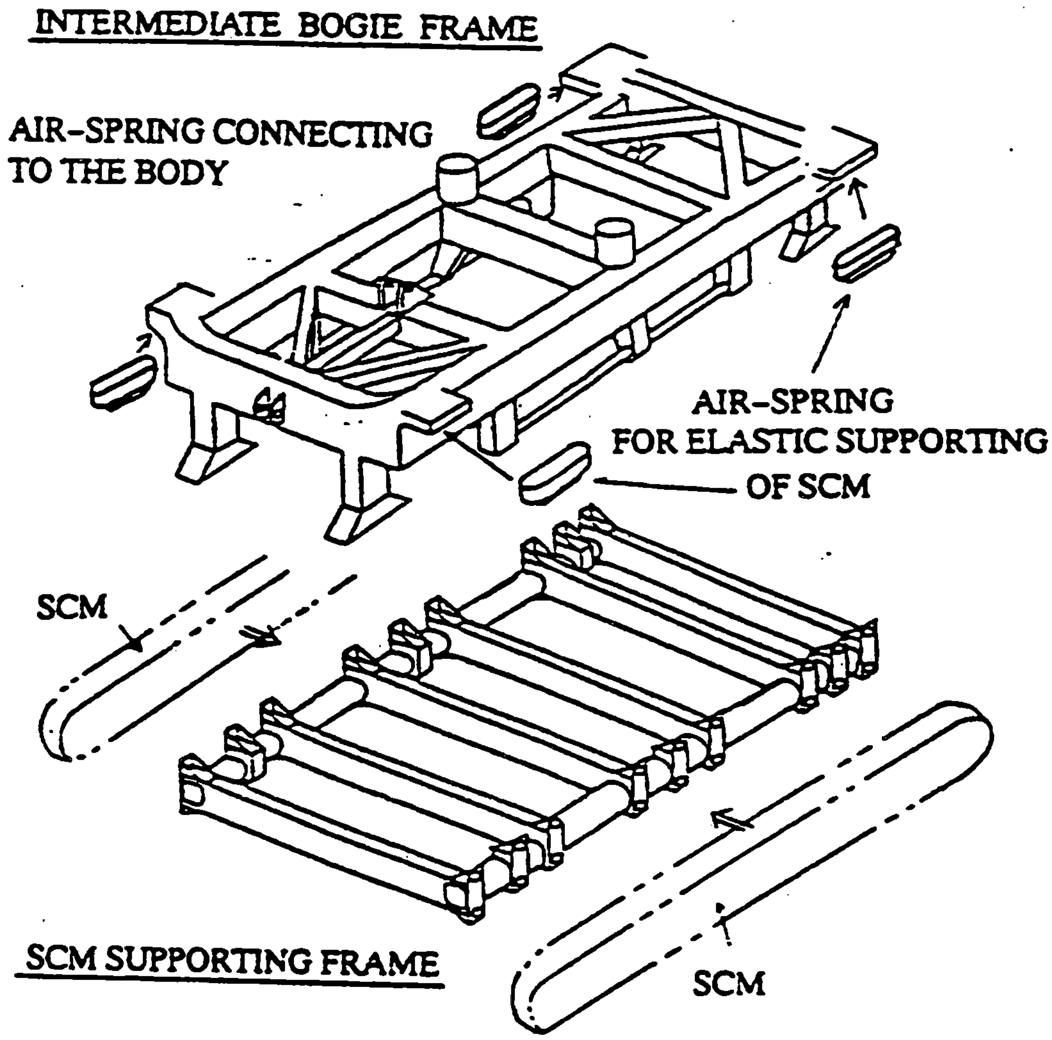


Figure 3-25. Double Bogie Frame With Landing Skids

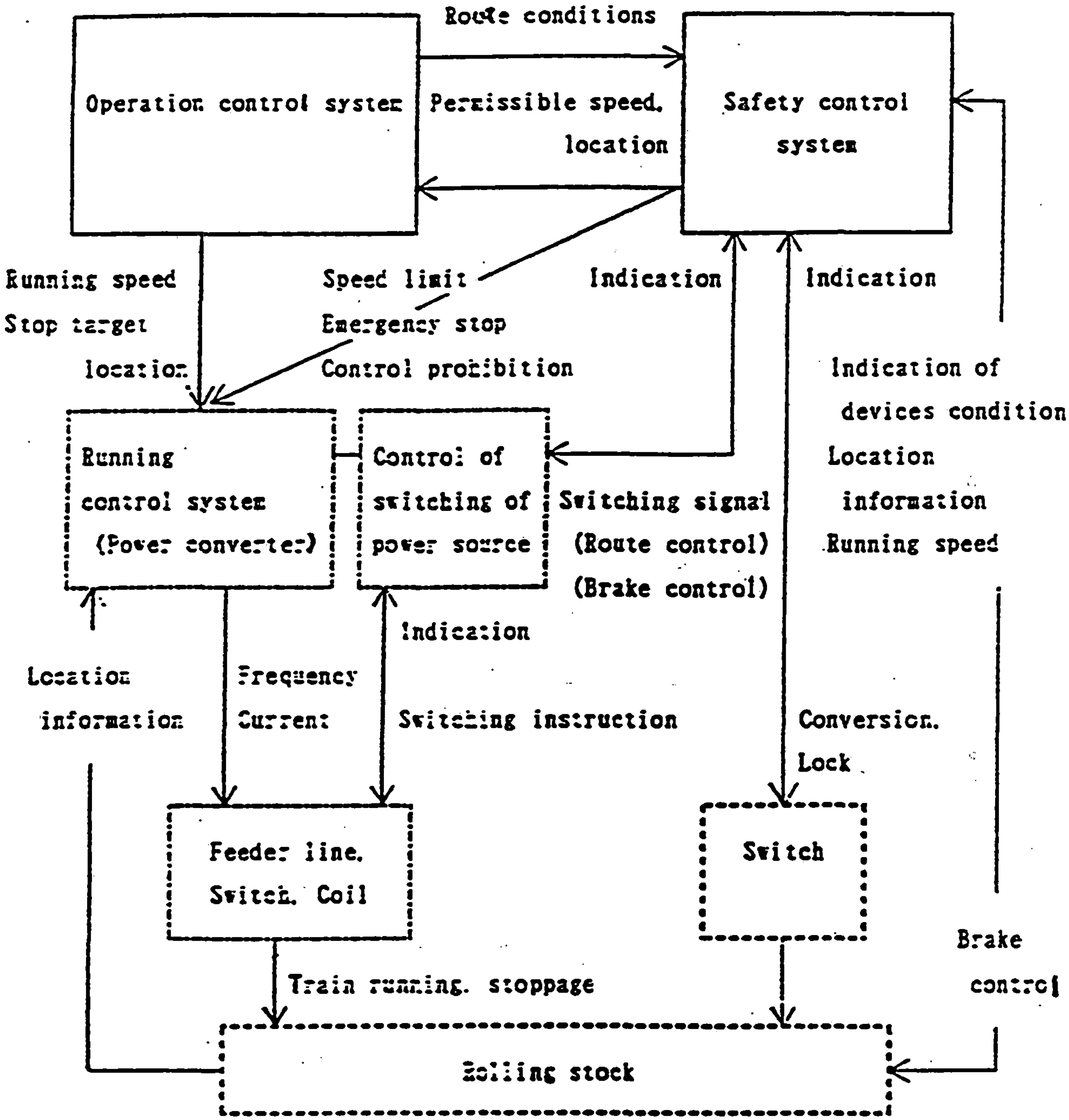


Figure 3-26. Operational Safety System

linear synchronous motor coils); electric braking of the vehicle (either regeneratively or dynamically) is controlled in this manner

- Generate and transmit brake control signal commands to the train itself; these signals form the high level control for the disk brakes, aerodynamic brakes and landing skids.

Thus, the safety control system generates safe commanded speeds, detects overspeed conditions and controls propulsion and braking systems both on and off the vehicle.

Disk Brake Control System. This on-board system, referred to as the anti-skid, auto-brake control system (ACS), controls application of the disk brakes on the wheel assemblies. It is comprised of an electronic control unit (ECU) and a hydraulic control valve module (HCM). These components and their interface with the wheel assemblies and disk brakes can be observed in Figure 3-22 (earlier in this report).

The primary purpose of the ACS is to stop the vehicle within the designated deceleration profile while preventing wheel (tire) skid. The ECU monitors wheel speed of the various wheel assemblies and commands the HCM to apply the appropriate hydraulic pressure to increase and or decrease braking force on a given wheel. Other functions of the system are to eliminate tire burst (by releasing pressure when skid is detected), to eliminate torque unbalance between the different wheel assemblies, and apply a parking brake when the vehicle is at rest.

Aerodynamic Brake Control Circuits. Four control circuits are used to control the aerodynamic brakes, one circuit for each brake panel. A diagram of the control circuit arrangement is shown in Figure 3-27.

Each control circuit involves two magnet holders and two switches. When power is applied to the magnet holders, the brake panels are closed and locked. When power is removed via a command from the control system, the lock is released and the panels begin opening via a spring-assisted stay damper that helps absorb the shock of opening the panels and serves as a stopper when the panels are fully open. With no wind, the panels open to an angle of about 45 degrees with the vehicle roof. Wind resistance will pull the panels fully open shortly after the initial release. As mentioned earlier, the stay damper controls the opening speed. Panels must be manually closed after use by pulling the stay damper to the closed position.

Landing Skid Control. Although details of the control aspects for the landing skids were not identified in available literature, it is assumed that the landing skids (and therefore the bogie) can be lowered in a controlled fashion to provide braking if so desired. However, it is also assumed that this is not a desirable braking mode, except for a parking brake.

3.11.3 Brake System Operation

Braking of the MLU002N can be categorized into two major modes: normal and emergency. These are discussed next.

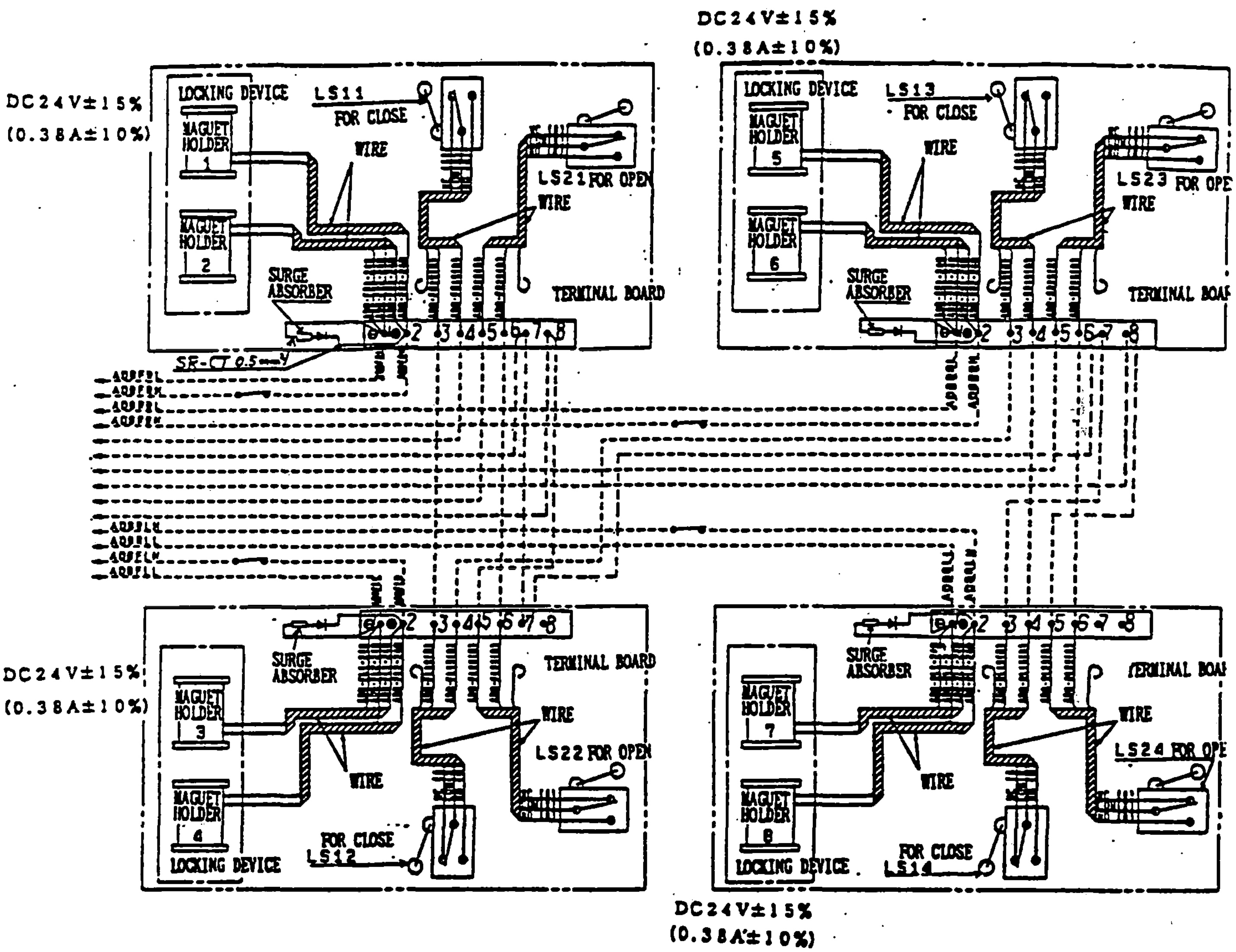


Figure 3-27. Control Circuits for Aerodynamic Brakes

Normal Braking

Normal service braking of the vehicle is provided electrically in either a regenerative or dynamic manner via the linear synchronous motor. Regenerative braking in which power is returned to the substation is used when possible, otherwise dynamic braking is utilized.

Emergency Braking

Should an emergency situation arise and electric braking be unavailable, emergency braking can be accomplished either regeneratively or dynamically via the linear synchronous motor. However, should electric braking not be available, emergency braking can be accomplished in different ways dependent upon the speed of the vehicle. If the vehicle is traveling at high speeds, aerodynamic brakes are used to reduce the speed to a point (about 200 km/h) at which the disk brakes would be more effective. The disk brakes could then be used to bring the vehicle to a stop. It should be noted that, as discussed earlier, the disk brake (and levitation) systems are being developed so that disk brakes could be used up to 500 km/h in emergency situations.

Another possibility for emergency braking involves the landing skids. These skids (and actually the bogies on which the skids are mounted) could be lowered such that the skid shoes come into contact with the guideway surface.

According to literature, considerable developments are underway in the braking system for the MLU002N, and the braking components/strategy is still in a state of change.

3.11.4 Brake System Performance

Technical Specifications

Although no quantitative data on the electric braking system were identified in available literature, some general information regarding deceleration rates was found on the aerodynamic and disk brake systems.

Aerodynamic Brakes. As described earlier, each aerodynamic brake panel (of which there are four on the MLU002N) has a projected area for braking of approximately 1.95 m^2, giving a total available braking area of 3.9 m^2 for one set of panels. The deceleration provided by one set of panels for an 18.5 ton vehicle traveling at 420 km/h is approximately 0.15 g.

Deceleration with both sets of brake panels opened is slightly higher, but the braking force provided by the second (rear) set is lower than the front set due to turbulence created by the front panels.

Tests confirmed that, although deceleration levels were lower, abnormal vehicle movement is not adversely affected with the utilization of only one of the two brake panels.

Disk Brakes. Dynamometer tests have been conducted on the new disk brake system under development. Actual deceleration was measured under different simulated conditions (e.g., emergency stopping, anti-skid), and the values ranged from approximately 0.2 g to 0.6 g. The maximum deceleration that could be achieved by the disk brakes at a (wheel) drum speed of 550 km/h was 0.6 g. Normal expected levels of deceleration are expected to be in the range of 0.2 g.

Diagnostics and Monitoring

Very limited information is available on the diagnostic and monitoring capabilities utilized in the MLU002N. However, it is known that the Central Control Unit on the wayside is the primary control and supervisory element of the system. This system does have the capability to monitor the deceleration profile, determine when electric braking is not available, and command on-board braking via the aerodynamic, disk and/or landing skid systems.

Switches are incorporated within the aerodynamic brake system to detect when each panel is closed and opened.

There are several known diagnostic/monitoring systems associated with the (disk) Brake Control System or ACS (as noted earlier) and its Electronic Control Unit (ECU). Wheel speed relative to the disk brake wheels is measured by an optical type sensor, which is replacing an inductive device. Tire pressure as well as tire skid and wheel lock are measured for each of the wheel assemblies. Low pressure or other detected problem results in removal of the brake pressure applied to a given wheel assembly. Each wheel assembly is also monitored for torque unbalance in which case brake pressure is adjusted accordingly.

Inspection and Test Requirements

Again, there is very limited information here, but it is assumed that regular tests and inspections will be necessary to assure the integrity and proper operation of both the electric and backup braking systems (i.e., aerodynamic, disk and landing skids). Periodic inspections will certainly be needed of the tires, wheels, and disk brake and landing skid pads as well as the guideway surface with which the wheel assemblies and landing skid pads interact.

A brief operating test has been developed for the aerodynamic brakes. It involves the manual control of power to permit the inspection of the opening motion of the panels. As noted earlier, the system is currently designed such that the panels must be closed manually.

An inspection port has been incorporated into the aerodynamic brake panel compartment (unit box) to allow a routine inspection of the brake panels from within the vehicle.

Braking System Effects on Vehicle, Guideway and Infrastructure

Several possible effects on the vehicle and/or guideway as a result of braking are discussed below.

Disk Brakes. The disk brake pads, wheels and tires will experience wear with usage. A minimum thickness of material must be ensured on the pads to permit the proper friction should emergency braking be necessary. It is also possible for the guideway surface with which the tires interact to experience some wear.

Landing Skids. Landing skid pads and the associated portions of the guideway surface will experience some wear if the landing skids are used for braking purposes. Again, a minimum thickness of material will be needed on the pads.

Guideway Integrity. Usage of superconducting magnets for propulsion, levitation and (electric) braking generates a strong force on the vehicle as well as on the coils mounted in the guideway walls. This requires the coils in the guideway walls to be installed accurately and with consideration of the expected forces (including vibrations) to be experienced.

Also, the superconducting magnets and high speeds of the vehicle generate eddy currents and other magnetic forces in nearby conductive materials. Therefore, the guideway must be designed to minimize interaction with such magnetic fields.

Table 3-20. MLU002N FMEA Worksheet

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

MLU002N—Linear Motor Car Maglev (Japan)							Page 1 of 4
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Dynamic Brake							
Wayside control element	Fails to reverse polarity in guideway	No dynamic braking in failed guideway sections. Propulsive force may remain.	Other braking systems available. Aerodynamic and disc brakes at high speeds, plus landing skids at lower speeds.	Assume on-board control indication.	Y	N	B3
Long stator section	Open circuit	Guideway section provides no propulsive or dynamic braking force.	Other braking systems available. Aerodynamic and disc brakes at high speeds, plus landing skids at lower speeds. Dynamic brakes usable in unaffected sections.	Assume wayside control indication.	Y	Y	D
Wayside power source	Fails off	No dynamic braking (assumes no battery backup for braking purposes). Also no propulsive power.	Other braking systems available. Aerodynamic and disc brakes at high speeds, plus landing skids at lower speeds.	Assume on-board control indication.	N	Y	C
	Fails to accept regenerative power	No effect. Dynamic braking switches to resistive mode.	None, except dynamic brake using resistive mode.	Assume on-board control indication.	Y	Y	D
Resistors	Overheat, burn out	Effected resistors are not available to dissipate energy, reducing braking power in the resistive mode.	Normally, none. Principal mode for dynamic brake is regenerative. Important only if regenerative mode fails; in that case other braking modes also available.	Assume wayside control indication.	N	Y	C
Disc Brake							
Wheel Assembly Support Arm (4 per bogie)	Fails to lower wheel assembly	One corner of bogie will have no disc brake. Will likely set down on landing skid. Other three discs should be sufficient for braking.	Dynamic and aerodynamic brakes available in addition to remaining disc brakes.	Unknown. Assume on-board control indication.	N	N	A3
Rubber tires	Burst or deflated	Ineffective disc braking at one wheel set. Auxiliary wheel supports structure.	Dynamic and aerodynamic brakes available in addition to remaining disc brakes.	Tire pressure monitor (TPIS).	Y	Y	D
Electronic Control Unit (ECU)	Fails by indicating incorrect high wheel speed	Effected wheel set is overbraked, potentially causing skidding of rubber tires.	If uncorrected, skidding tire could overheat. Dynamic and aerodynamic brakes available in addition to remaining disc brakes to stop train.	Unknown. TPIS may detect overpressure of skidding tire.	N	Y	C

Table 3-20. MLU002N FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

MLU002N—Linear Motor Car Maglev (Japan) — Page 2 of 4

Component	Failure Mode	Effect on Braking Subsystem	Effect on Overall Braking System	How Detected/Response	FT	FS	S
Electronic Control Unit (ECU)	Fails by indicating incorrect low wheel speed	Affected wheel set is underbraked.	Only one wheel set affected. Also, dynamic and aerodynamic brakes available in addition to remaining disc brakes. Change in stopping distance should be minimal.	Unknown. Assume on-board control indication.	Y	Y	D
	ECU fails off	No braking or braking command for disc brakes.	Dynamic and aerodynamic brakes available.	Unknown. Change in braking force likely to be noticeable to train operator.	N	N	A3
Wheel Speed Sensor	Fails by indicating incorrect high wheel speed	Affected wheel set is overbraked, potentially causing skidding of rubber tires.	If uncorrected, skidding tire could overheat. Dynamic and aerodynamic brakes available in addition to remaining disc brakes to stop train.	Unknown. TPIS may detect overpressure of skidding tire.	N	Y	C
	Fails by indicating incorrect low wheel speed	Affected wheel set is underbraked.	Only one wheel set effected. Also, dynamic and aerodynamic brakes available in addition to remaining disc brakes. Change in stopping distance should be minimal.	Unknown. Assume on-board control indication.	Y	Y	D
Hydraulic Control Module (HCM)	Fails by providing too much hydraulic pressure	Affected wheel set is overbraked, potentially causing skidding of rubber tires.	If uncorrected, skidding tire could overheat. Dynamic and aerodynamic brakes available in addition to remaining disc brakes to stop train.	Unknown. Assume TPIS and ECU indication, would attempt to compensate.	N	Y	C
	Fails by providing too little hydraulic pressure	Affected wheel set is underbraked.	Only one wheel set effected. Also, dynamic and aerodynamic brakes available in addition to remaining disc brakes. Change in stopping distance should be minimal.	Unknown. Assume TPIS and ECU indication, would attempt to compensate.	Y	Y	D
Hydraulic System (assume single system per bogie)	Leaks, fails to maintain pressure	Disc braking lost for the affected bogie. Would be one half of disc brakes for a two-car train.	Dynamic and aerodynamic brakes available in addition to remaining disc brakes to stop train.	HCM/ECU indication.	N	N	B3

Table 3-20. MLU002N FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

MLU002N—Linear Motor Car Maglev (Japan)							Page 3 of 4
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Aerodynamic Brake							
Brake panel (4 panels per car)	Fails to deploy	Reduced aerodynamic braking force. If front panel, significant reduction. If rear panel, less important if front panels are deployed.	Dynamic and disc brakes available to stop train.	Associated panel control circuit indicates panel position.	Y	N	B3
Brake panel locking device (each panel)	Fails to unlock	Reduced aerodynamic braking force. If front panel, significant reduction. If rear panel, less important if front panels are deployed.	Dynamic and disc brakes available to stop train.	Associated panel control circuit indicates panel position.	Y	N	B3
	Unlocks prematurely	Brake panel deployed when no braking is requested.	Train begins to brake. Panel must be stowed manually; assume train must stop to stow panel.	Associated panel control circuit indicates panel position.	N	Y	C
Brake panel control circuit	Fails to activate panel	Reduced aerodynamic braking force. If front panel, significant reduction. If rear panel, less important if front panels are deployed.	Dynamic and disc brakes available to stop train.	Associated panel control circuit indicates panel position.[1]	Y	N	B3
	Activates panel prematurely	Brake panel deployed when no braking is requested.	Train begins to brake. Panel must be stowed manually; assume train must stop to stow panel.	Associated panel control circuit indicates panel position.	N	Y	C
Brake panel stay damper (per panel)	Fails to damp opening forces	Possible brake panel damage or loss on deployment. Reduced aerodynamic braking force. If front panel, significant reduction. If rear panel, less important if front panels are deployed.	Dynamic and disc brakes available to stop train.	Unknown.	N	N	A3

Table 3-20. MLU002N FMEA Worksheet (cont.)

FT = Fault Tolerant; FS = Fail Safe; Y = Yes; N = No
S = Failure Mode Severity, described in Section 2.2

MLU002N—Linear Motor Car Maglev (Japan)							Page 4 of 4
Component	**Failure Mode**	**Effect on Braking Subsystem**	**Effect on Overall Braking System**	**How Detected/Response**	**FT**	**FS**	**S**
Landing Skids							
Skid Pads	Excessive wear	Reduced braking power and possible damage to undercarriage.	Dynamic, aerodynamic, and disc brakes available to stop train. Disc brake can stop train at low speed.	Inspection.	N	N	A3
Brake Control							
Wayside Operational Safety Control	Fails to command braking when required	Brake control reverts to on-board system.	All braking systems under control of on-board system.	On-board indication.	N	Y	C
On-board Brake Control	Fails to command braking when required	Brake control reverts to wayside system.	All braking systems under control of wayside Operational Safety System (OSS).	Indication to OSS.	N	Y	C
Communications link between Wayside and On-board Control	Fails off	Brake control reverts to on-board system.	All braking systems under control of on-board system.	On-board indication.	N	Y	C

1. Indication appears to be separate from activation.

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