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Non-Contacting Suspension and Propulsion Systems for Ground Transportation

Volume I: Low Speed Systems

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Non-Contacting Suspension and Propulsion Systems for Ground Transportation

Volume I: Low Speed Systems

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ABSTRACT

This report describes twelve urban transportation concepts using non-contacting suspension/propulsion systems. Eleven use a linear induction motor; the twelfth a linear synchronous motor. Suspension systems include both magnetic levitation and air pads.

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1. INTRODUCTION

This document presents a summary of world-wide research and development programs on non-contacting suspension and propulsion (NCS/P) systems for ground transportation vehicles. Many developers of advanced ground transportation systems have considered the use of these concepts to alleviate some of the problems associated with mechanical contact in supporting and propelling a vehicle. The practical application of electromagnetic technology to non-contacting propulsion and suspension has taken place over the past fifteen years, and has reached an advanced state in both interurban and urban applications. The purpose of this document is to show the status of development of these techniques by concentrating on systems that have reached at least the stage of testing full scale vehicles. It reviews work done in Canada, England, France, The Federal Republic of Germany, Japan, and the United States.

The first volume is devoted to low speed, mainly urban, transportation systems. Twelve urban transportation concepts using NCS/P are covered.

Section 2 covers the Intermediate Capacity Transportation System (ICTS) development in Canada. Section 3 describes magnetically levitated (Maglev) vehicles tested by the British Railways R&D Laboratories and by the University of Sussex in England. Section 4 describes the VEC and Telebus systems from France. Section 5 covers three transportation systems being developed in Germany--the C-Bahn, the H-Bahn, and the M-Bahn. Section 6 covers four developments from the United States--the Otis Transportation Development Division system, the WEDway People Mover, the Boeing Mass Transit system, and the General Motors Maglev Test Vehicle.

The development status of these concepts is summarized in Figure 1.1. All twelve use linear electric motors in which the components corresponding to the rotor and stator of a rotary motor are "unrolled", and separated with one component in the vehicle and the other on the guideway. Eleven of the systems use the linear induction motor (LIM) configuration; the M-Bahn uses a linear synchronous motor (LSM). Of the LIM propelled systems, most have the active windings (a.c. excitation) of the motor on the vehicle and a passive track; the VEC, Telebus, and WEDway systems have an "active track" with the windings in the guideway, as does the LSM-propelled M-Bahn. Three systems--those developed by British Rail, the University of Sussex, and General Motors--use controlled electromagnets to support or

		Canada	England		France		Germany			United States			
		ICTS	British Rail	Univ. of Sussex	VEC	Telebus	C-Bahn	H-Bahn	M-Bahn	Otis	WEDway	Boeing	GM
Concept	Non-Contacting Propulsion	●	●	●	●	●	●	●	●	●	●	●	●
	Non-Contacting Levitation		●	●						1		●	●
	Non-Contacting Guidance		●	●								2	●
	Integrated NCS/P								3			●	
R&D Status	Operating Vehicle	●	●	●	●	●	●	●	●	●	●	●	●
	Guideway Switching	●					●	●	●	●			
	System Network Control						●	●		●			
Instal-lations	Operating Test Facility	●	●	●	●	●	●	●	●	●	●	●	●
	Applications Studies	●	●		●		●	●	●	●	●		
	Applications Plans	●			●		●	●	●	●	●		
	Operational Application				●		4			●	●		

NOTES:
1. Non-Contacting Air Levitation
2. Contacting Guidance Used on Some Vehicle Designs
3. Propulsion Magnets Used in Suspension
4. Simple Shuttle Operating Installation

FIGURE 1.1. STATUS OF URBAN TRANSIT SYSTEMS USING NON-CONTACTING SUSPENSION AND PROPULSION (NCS/P)

levitate the vehicles, and these are consequently known as maglev vehicles. The Boeing system uses an integrated propulsion/suspension system in which magnetic attraction forces in the LIM are controlled and used to support the vehicle. The M-Bahn also uses a form of integrated propulsion and suspension in which on board permanent magnets, which form a part of the synchronous motor, also lift the vehicle. However, the suspension force is controlled by wheels.

In the urban transit applications presented in this volume the non-contacting suspension and propulsion technology has been applied in systems that operate under automatic control. This transportation mode, known as Automated Guideway Transit (AGT), has adopted automation techniques in order to eliminate the operating cost of the vehicle operator. Although AGT service may be similar to conventional transit, a wider range of performance is provided. Vehicles operating on simple shuttle or loop guideway configurations are frequently referred to as people movers; a system with small vehicles giving demand-responsive service over an extensive network is usually called personal rapid transit. Non-contacting suspension and propulsion have been used for the full spectrum of such AGT systems.

The second volume of this report describes high speed ground applications.

2. CANADA

The Canadian Urban Transportation Development Corporation (UTDC) has developed an Intermediate Capacity Transportation System (ICTS) intended to meet the transportation needs of large and intermediate size cities. Starting with system operational requirements, UTDC studies led to an AGT system that utilizes steel wheels on steel rails, LIM propulsion, and automatic train control. System development has reached the testing stage and plans are proceeding for an installation in Hamilton, Ontario.

2.1 System Background

UTDC, funded by the Ontario Provincial Government, began the ICTS program in April 1975. In emphasizing the development of a complete system, UTDC first developed the operational requirements of the system. These requirements, together with commercial viability requirements, served as the basis for selecting the subsystem technologies and the system design concept. Canadair Services Limited has served as the prime development contractor, bringing the ICTS design into an extensive hardware testing phase.

System testing with three vehicles has been performed at the UTDC Transit Development Center at Kingston, Ontario. Figure 2.1 shows one of the fifty passenger test vehicles operating there. For vehicle support and guidance, two two-axle trucks per vehicle run on conventional steel rail track. The axles are self steering, and propulsion is provided by a single-sided LIM (SLIM) mounted on each truck. The linear motor propulsion system was selected on the basis of providing the desired high level of service under the severe Canadian weather conditions. The SLIM provides adhesion independent acceleration and braking to fulfill the requirements of short trip times, small headways, good grade capability, and improved ride comfort.

The Transit Development Center is fully equipped to perform system testing. Figure 2.2 shows an overall view of the center. The facility includes a 1.8 km oval test track with both at-grade and elevated sections, three percent and six percent gradients, curves, switch points, and other standard transit track equipment. Figure 2.3 shows the track and reaction rail arrangement at one of the switch points.

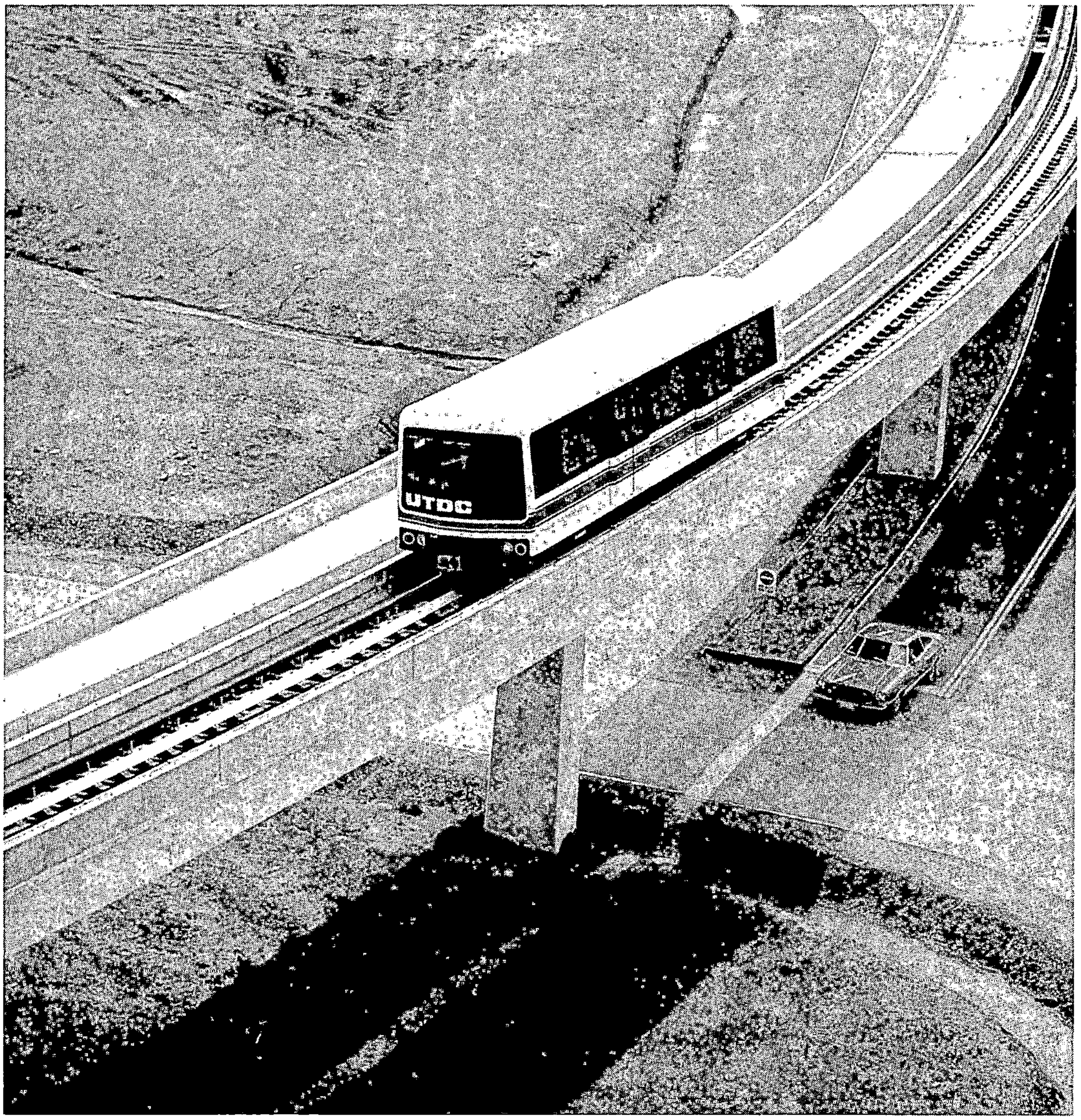

FIGURE 2.1. ICTS TEST VEHICLE AT THE UTDC TRANSIT DEVELOPMENT CENTER

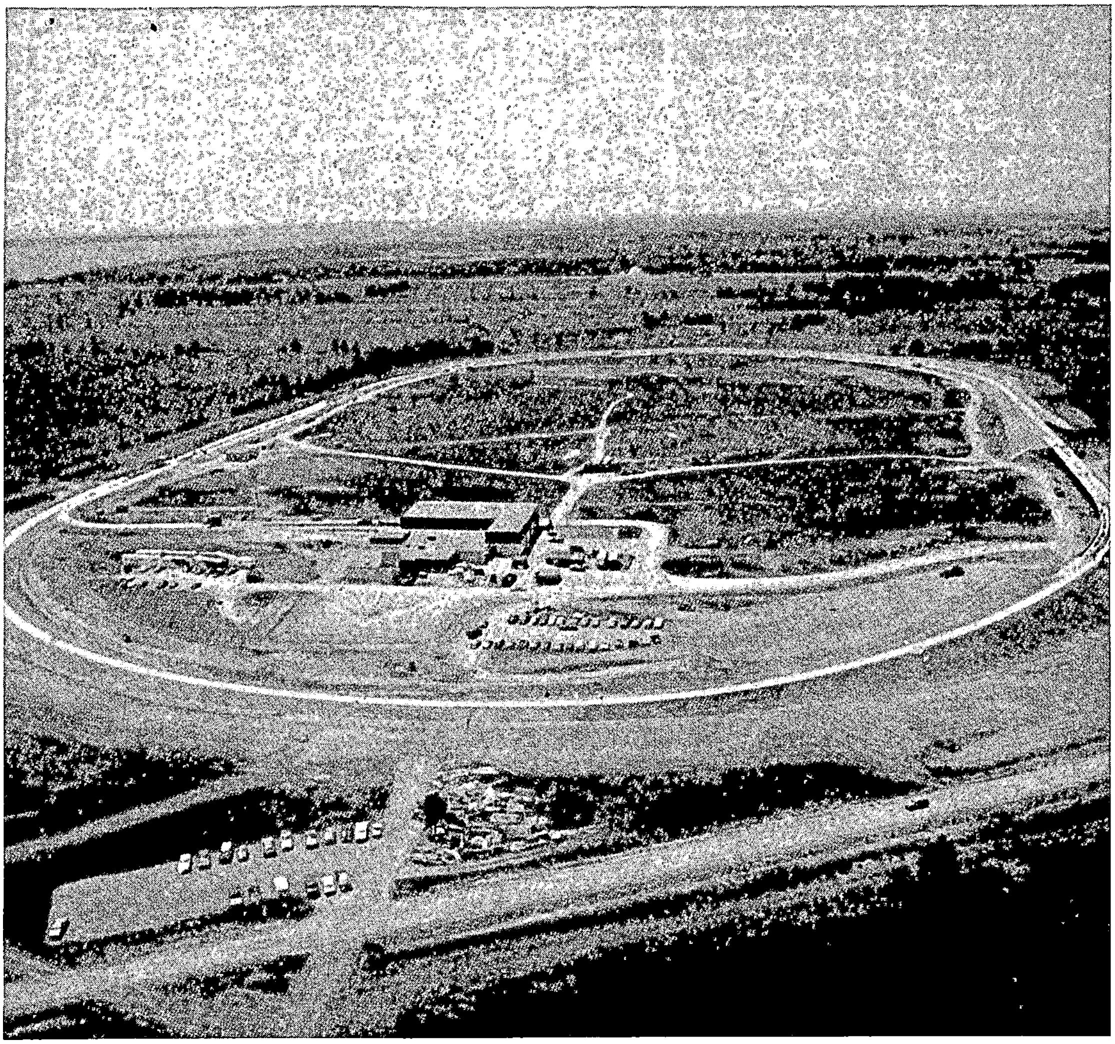

FIGURE 2.2. UTDC TRANSIT DEVELOPMENT CENTER AT KINGSTON

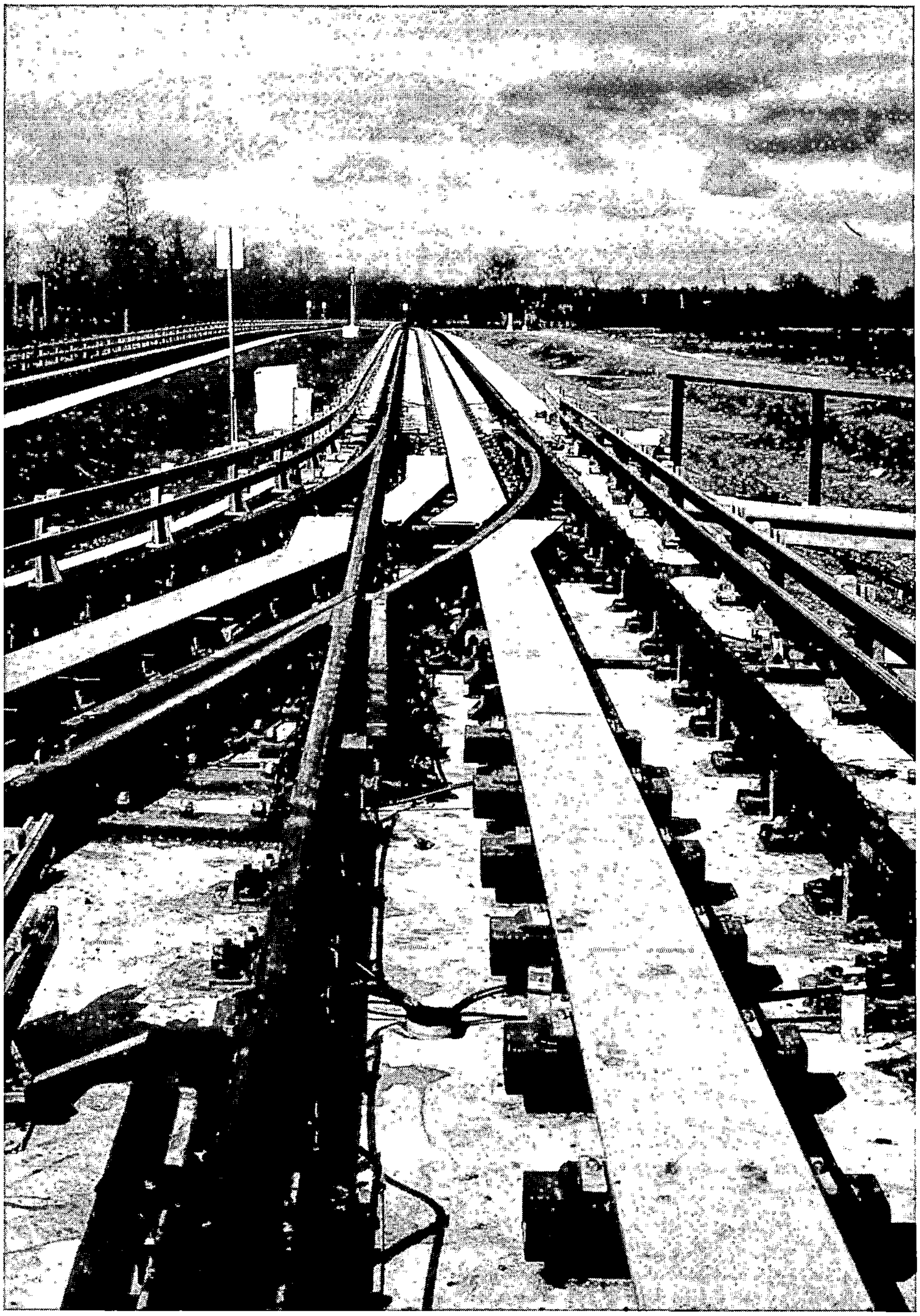

FIGURE 2.3. GUIDEWAY SWITCH POINT ON ICTS TEST TRACK

The ICTS is being considered for applications in Vancouver, British Columbia, and in Hamilton, Ontario. With initial funding now approved, the Hamilton system could be operating in four years. The projected cost of this system is $70 million (Canadian). The installation will provide a 5 km link between the city's industrial and commercial section, located on the shores of Lake Ontario, and the residential suburbs, which are built on top of an escarpment overlooking the lake. The ability of the LIM to provide traction on the steep grade (8 percent) to the escarpment was an important factor in its choice.

2.2 System Details

The ICTS program was set up to develop a commercially viable transit system with a higher level of service than surface modes such as streetcars and buses, but with lower acquisition and operating costs than subway systems. Consequently, the intermediate capacity range of 5,000 to 25,000 persons per hour per direction was identified, and system operational requirements were developed for this range. Commercial considerations included:

a. reducing system acquisition cost by minimizing underground construction;

b. increasing ridership by providing level of service with fast, frequent, comfortable all weather operations; and

c. reducing system operating and maintenance cost by using modular design concepts and innovative maintenance techniques, and by employing automatic systems where appropriate.

The fundamental system design decisions following from these requirements were to optimize the system design for elevated guideways, and to incorporate automatic train control.

2.3 System Design

With the system performance requirements established, a state-of-the-art review led to the establishment of suitable combinations of technologies, from which UTDC carried out trade-off studies to select the system design concept. A supported vehicle configuration was clearly favored, and steel wheel on steel rail support and guidance was chosen after it was demonstrated that the external noise requirements of 65 dB(A) at

15 m could be met. Rubber tires were eliminated because of operational limitations under adverse weather conditions, and combined magnetic levitation and propulsion was considered to have too high a development risk and cost. LIM propulsion was chosen because it could reliably meet the severe acceleration, service braking, cruise speed, and grade requirements. The LIM system was estimated to have life-cycle costs similar to a rotary motor system. Increased system acquisition cost, primarily due to the reaction rail, are assumed to be offset by reduced maintenance cost. In summary, the complete ICTS design concept includes:

a. light weight vehicles with a capacity of fifty passengers;

b. two two-axle trucks per vehicle, with self-steering axles to reduce noise and wear on curves;

c. steel wheel on steel rail, standard gauge with conventional track-based switching;

d. one LIM primary mounted on each truck, controlled by a variable voltage, variable frequency inverter;

e. service braking by LIM, with emergency braking by disc brakes and track brakes;

f. 600 V d.c. wayside power;

g. moving block automatic train control; and

h. elevated guideway sections of reinforced concrete with trapezoidal box-beam cross section, cantilevered flanges and short sidewalls.

The ICTS SLIM primary is 1.9 m long and has a mass of 639 kg. It is designed to produce a maximum thrust of 10.8 kN. The reaction rail, mounted on the centerline of the guideway, consists of an aluminum extrusion .32 m wide with an iron backing .22 m wide.

The LIM, mounted on the truck of a test vehicle, is shown in Figure 2.4.

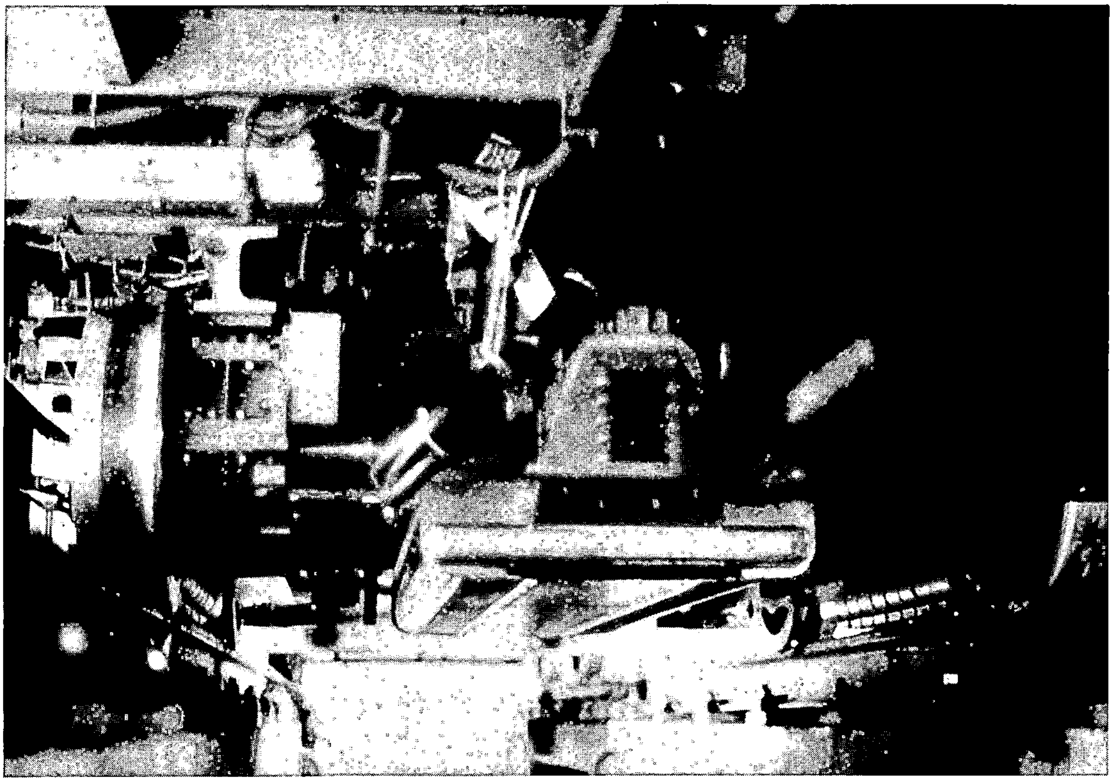

FIGURE 2.4. LIM INSTALLED ON TRUCK OF ICTS TEST VEHICLE

2.4 System Capabilities

The selected system capacity of 15,000 passengers per hour per direction formed the basis of developing the operational requirements for the ICTS. The desire for minimal visual intrusion dictated short station platforms and short train lengths with a capacity of about 200 passengers per train. Consequently, headways of about 50 to 60 seconds are required. The high level of service required an average speed of 50 km/hr with a 70 km/hr cruise. Short station lengths and short guideway by-pass sections require reliable service braking and high acceleration at speeds up to 60 percent of cruise speed. A grade capability of six percent without degraded performance was also established.

3. ENGLAND

This section describes the British Railways and the University of Sussex vehicles.

3.1 British Railways R&D Division Maglev Vehicle

The British Railways Research Division has carried out investigations with a small low speed magnetically suspended vehicle on a 100 m test track at the Railway Technical Center in Derby, England. The vehicle and test track were built in 1976 as the result of a comparative study of wheeled and magnetically suspended vehicles for urban transport applications. The study, carried out for the Transport and Road Research Laboratory of the Department of the Environment, considered a "mini-tram" scheme for the City of Sheffield.

The British Rail (BR) experimental five place vehicle is shown in Figure 3.1. It has a mass of 2.7 tonnes and uses eight controlled d.c. electromagnets* arranged in pairs that are slightly offset, as shown in Figure 3.2. These magnets form the complete suspension and guidance system of the vehicle. The vehicle is designed for a maximum speed of 15 m/s. It is propelled by two single-sided linear induction motors (SLIMs) mounted on the vehicle and acting on a horizontal aluminum reaction rail on the center of the track. Braking is provided by operating the SLIMs with reverse thrust. The SLIMs are energized directly from a 415 V three-phase 50 Hz trackside power supply.

The test track is constructed at-grade in the form of a T-shaped concrete rail, with rectangular steel rails running along the underside of the cross piece. The track contains an 8 m radius curve and a five percent gradient, as shown in Figure 3.3.

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*The magnets are longitudinal flux type, i.e., the poles alternate in the direction of vehicle motion, compared to the magnet configuration most widely used (the transverse flux type). The BR magnets require that the guideway mounted rail be laminated, as opposed to transverse flux magnets which do not.

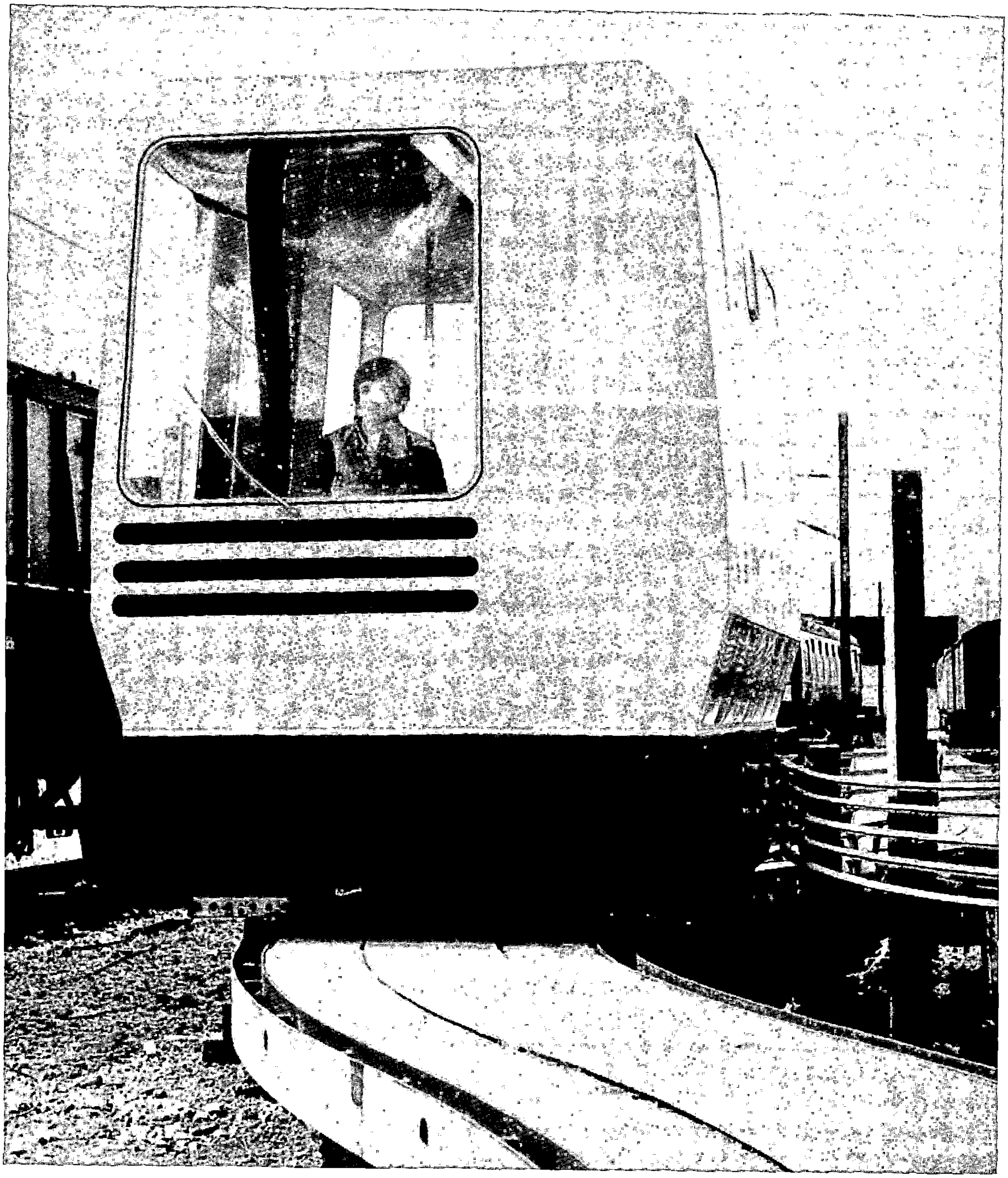


FIGURE 3.1. BRITISH RAIL MAGLEV TEST VEHICLE

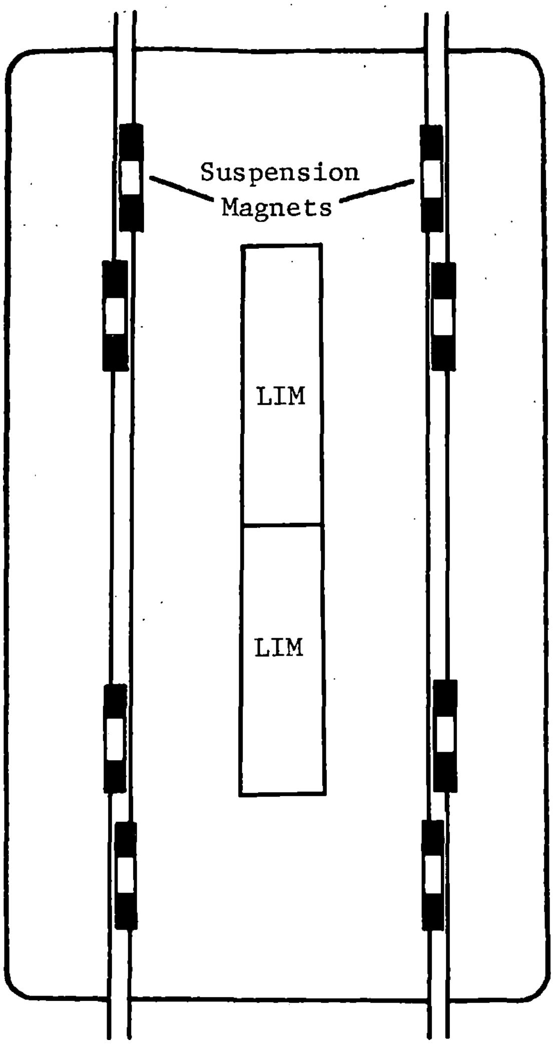


FIGURE 3.2. ARRANGEMENT OF SUSPENSION MAGNETS ON BRITISH RAIL TEST VEHICLE

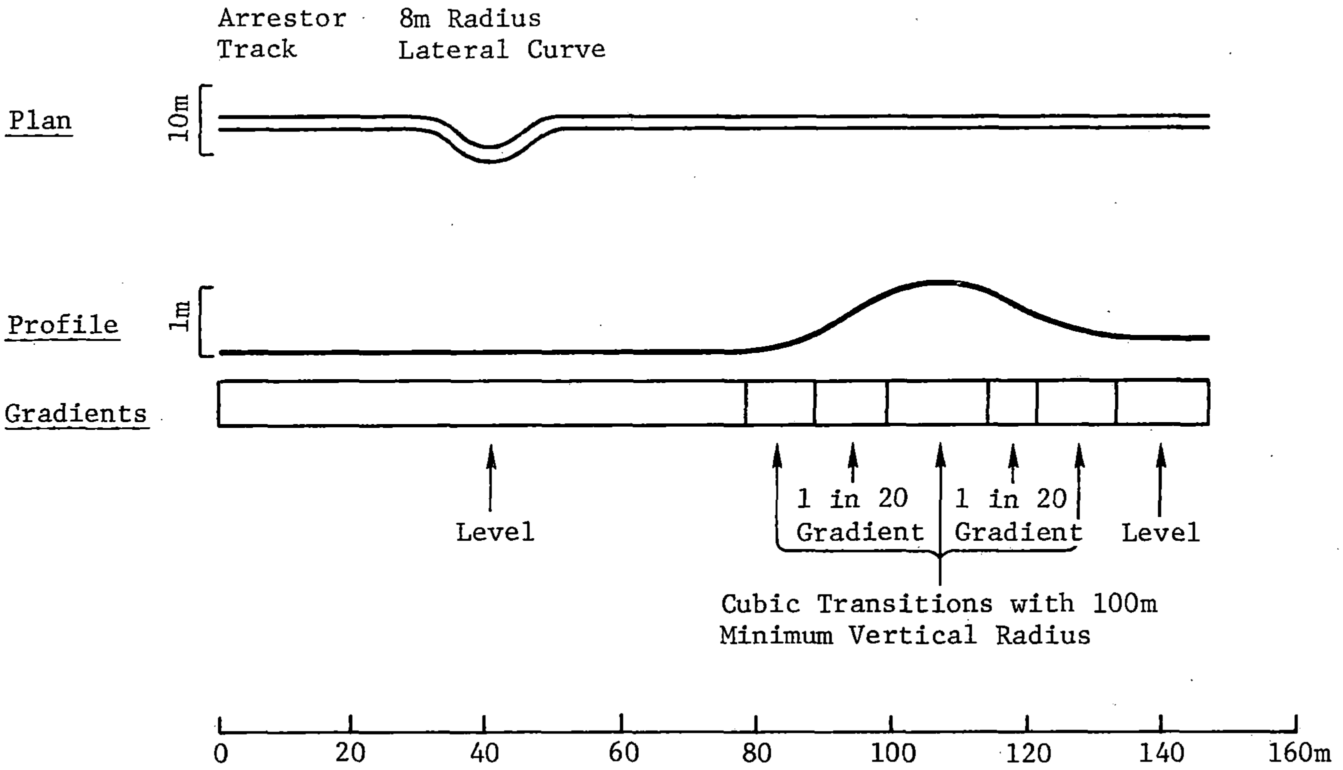


FIGURE 3.3. BRITISH RAIL MAGLEV TEST TRACK

The original Sheffield scheme was abandoned because of cost, but the test project has demonstrated the feasibility of the concept. A similar system may be utilized to provide a link between a new second terminal at Birmingham Airport and Birmingham International Railway Station, which serves the National Exhibition Center. BR estimates that the 500 m double-track link would cost about $3 million (French). The cost is estimated to be more than a conventional bus link, but, operating on a twenty-four hour basis, could be considerably cheaper to operate.

3.2 University of Sussex Magnetic Suspension

The Applied Science Laboratory at the University of Sussex in Brighton, England has studied electromagnetic suspension for several years. Their investigations have culminated in a one ton research vehicle using controlled d.c. electromagnets and capable of carrying four passengers. Powered by two single-sided LIMs, the vehicle has attained speeds of 14 m/s on a 30 m track.

The test vehicle was constructed to study the suspension characteristics and to formulate an analytical base for the design of stabilizing controllers to illustrate the feasibility of the attraction suspension system for low speed transit systems.

4. FRANCE

This section discusses the low speed urban NCS/P systems demonstrated in France by Cytec-France, and by the French General Electric Company.

4.1 VEC

The VEC system is a French AGT system developed for short-distance applications by Cytec Development, Incorporated, and its subsidiary, Cytec-France, with corporate funding. The VEC vehicles are small passive (i.e., no on board powered equipment) cabs propelled by moving belts and LIM-driven chains. Figure 4.1 shows the system operating at FNAC in Paris. Figure 4.2 shows the propulsion principle. In the station area the cabs are propelled by a slowly moving belt such that a passenger can board a moving vehicle. At the end of the station area the vehicle is accelerated by a constant speed moving belt and a friction wheel that is braked to bring the cab up to the speed of the belt. After the acceleration section, the vehicle engages a sliding conveyor driving chain which is driven by LIM primaries mounted in the guideway. To enter a station, vehicles are decelerated by using similar arrangement of belt drives.

Service is provided through a continuous flow of cabs operating with headways as short as two seconds. Headway is controlled through the conveyor belts in the station and acceleration/deceleration areas, and the conveyor chain on the main line. The maximum velocity is 32 km/hr, and grades up to 15 percent can be accomodated.

4.2 Telebus

The Telebus is a French system that has been used to test a unique LIM design. The LIM consists of a U-shaped, vehicle-mounted copper reaction rail with iron backing. Active windings are mounted at intervals in the guideway. The work has been carried out by SGEC with the French Ministry of Transportation funding. One test vehicle, capable of carrying 40 people, operates in a shuttle mode on 200 m of guideway. It uses small diameter steel wheels on steel rails for support and guidance. The design speed is 10 m/s. The test vehicle and its elevated guideway are shown in Figure 4.3. Testing of the Telebus occurred during the 1977-1979 time frame.

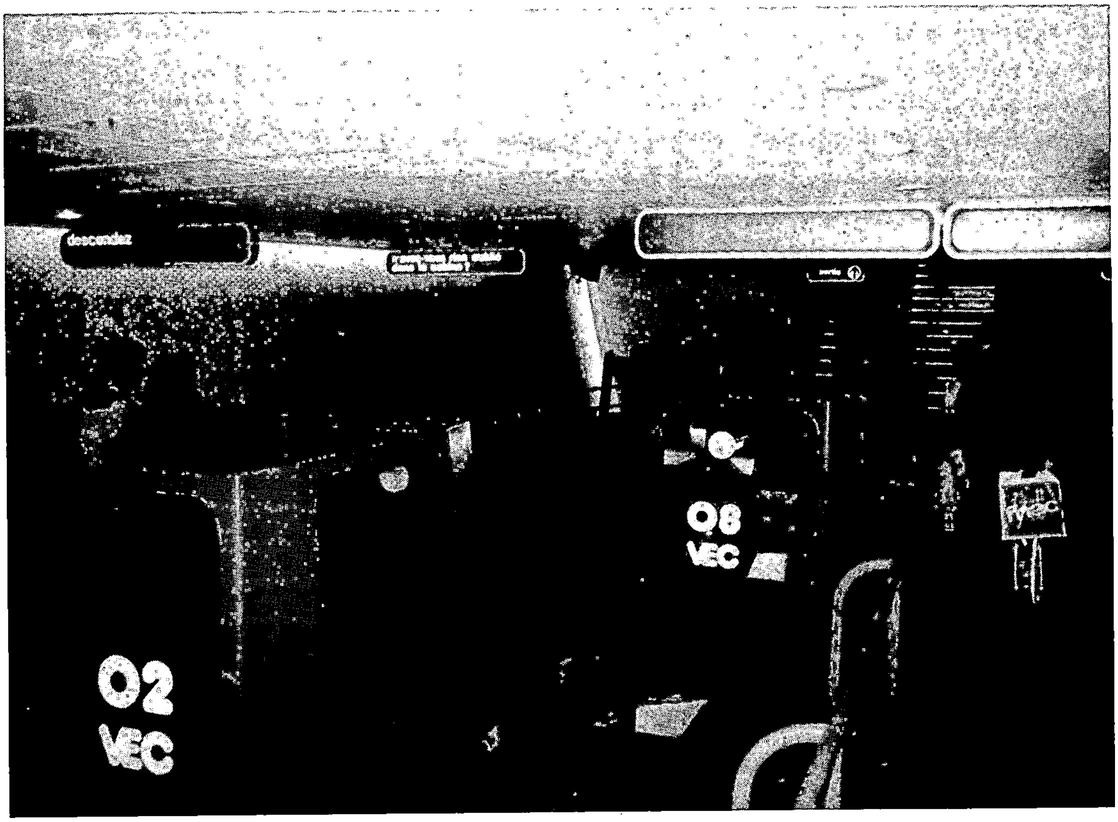
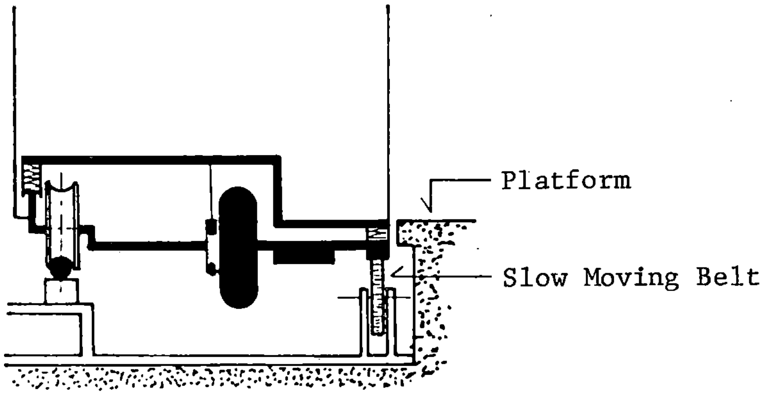
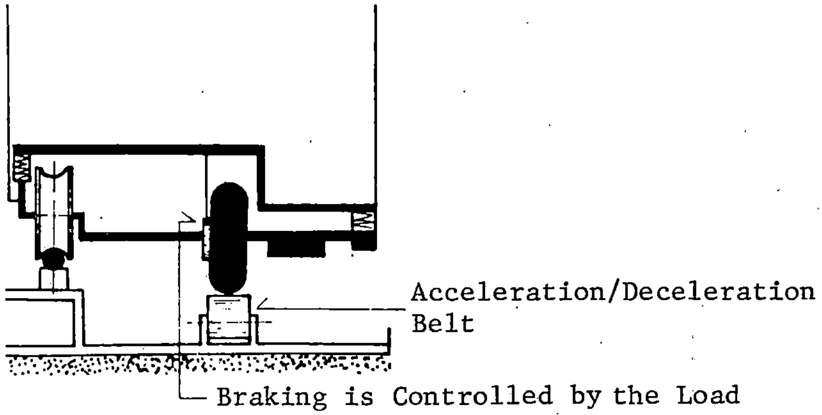


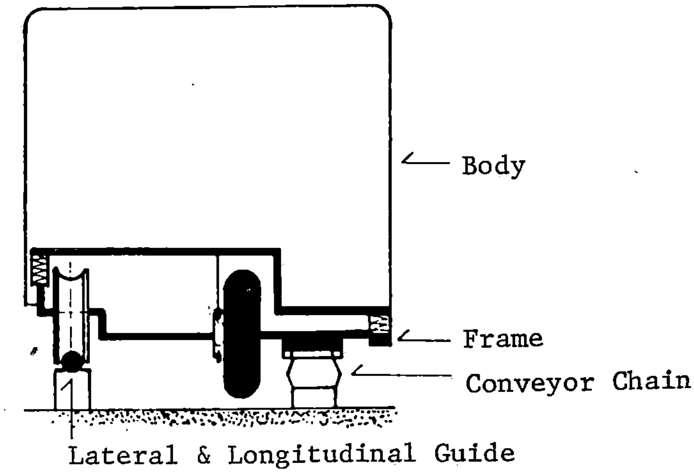
FIGURE 4.1. VEC SYSTEM AT FNAC IN PARIS



(a) Station Area



(b) Station or Deceleration Area



(c) Main Route

FIGURE 4.2. CONCEPT OF VEC PROPULSION SYSTEM

FIGURE 4.3. TELEBUS TEST VEHICLE

5. GERMANY

This section discusses the three low speed urban NCS/P systems being studied in the Federal Republic of Germany, which are the C-Bahn, H-Bahn, and M-Bahn concepts.

5.1 C-Bahn

The C-Bahn System, or Cabintaxi/Cabinlift concept, encompasses an extensive family of components sharing common technological developments. The system is capable of adaptation to a variety of configurations to meet the requirements of different AGT applications. The concept uses LIMs for vehicle propulsion and braking to obtain claimed advantages over friction drives relative to grades, noise, wear, and all-weather operations. The development of the system has been carried out in West Germany as a joint venture of two private firms, DEMAG Fordertechnik (DEMAG) and Messerschmitt-Bolkow-Blohm GmbH (MBB).

5.1.1 System Background

Independent studies of automated small cabin transport systems operating on dedicated guideways were begun in 1969 by DEMAG and MBB. These studies resulted in separate proposals to the Ministry for Research and Technology (MORT) recommending the development of such a system. Because of substantial similarities in the system concepts, MORT recommended that the two firms work together, and in 1971, they formed the "Cabintaxi Working Group" to carry out further studies, development, and testing. The MORT has carried 80 percent of the development cost since the beginning of 1972.

Many system components have reached a high level of development at an extensive test facility at Hagen. In addition, a simple, single vehicle shuttle system is operating at the Ziegenhain Hospital and plans are proceeding for the first phase of an operational system in Hamburg.

In emphasizing a modular approach in the system development, a standardized C-Bahn guideway has been designed to accomodate varied vehicle configurations. The relatively narrow elevated box-beam section is suited for both suspended and bottom-supported vehicles. Figure 5.1 shows two-way traffic on the guideway at the Hagen Test Facility.

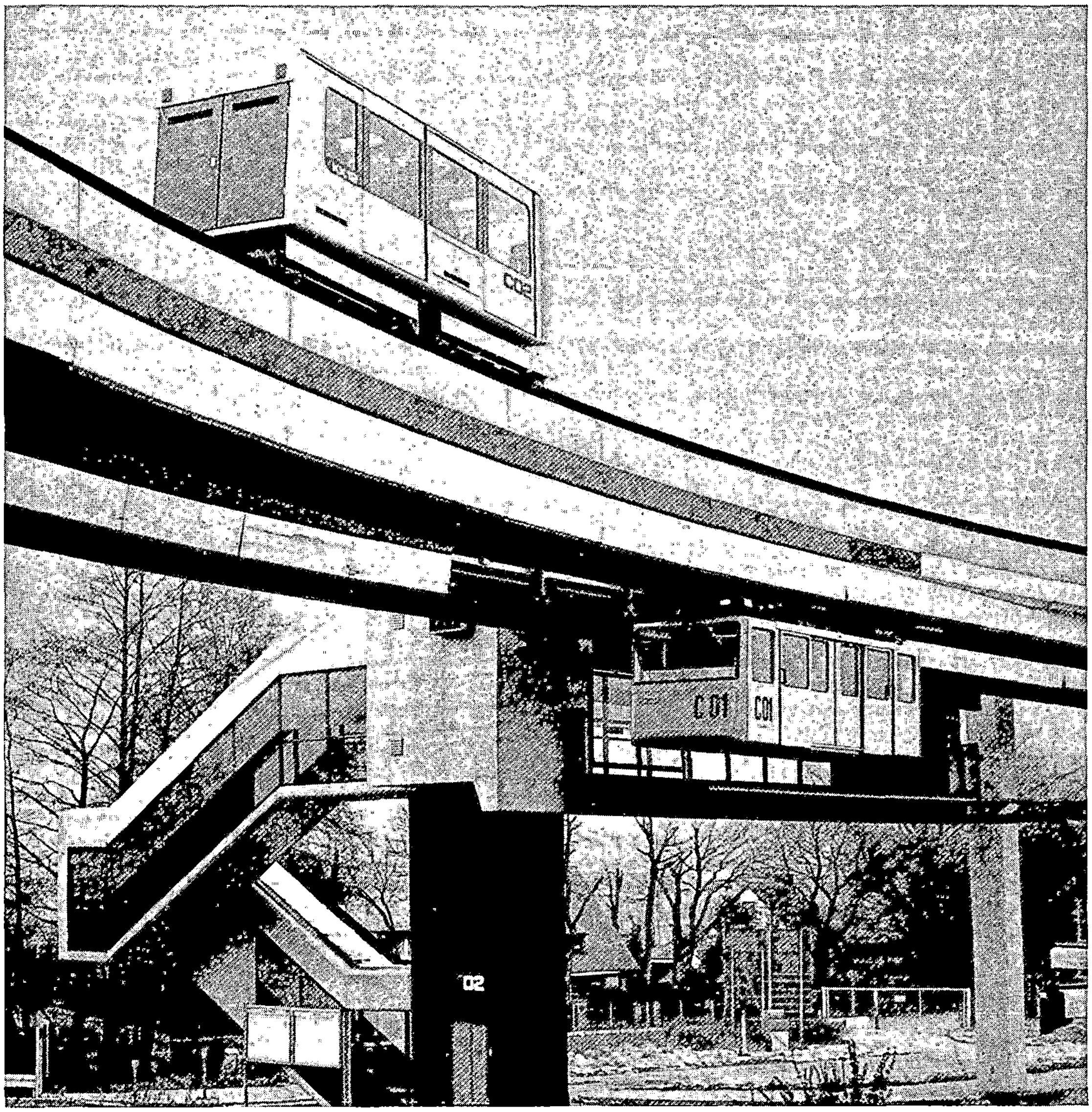


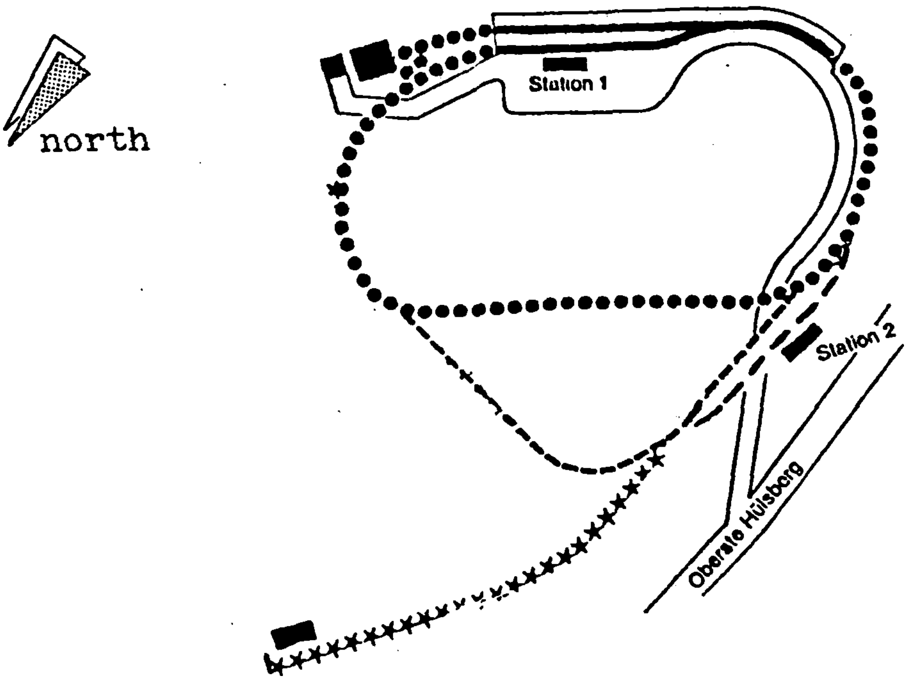
FIGURE 5.1. SUSPENDED AND BOTTOM-SUPPORTED C-BAHN TWELVE PASSENGER VEHICLES

Different C-Bahn vehicle configurations have been designed to use either of two designs for the drive unit. The drive unit or bogie contains the rubber tired support and guidance wheels and the propulsion units. In either the bottom-supported or the suspended vehicle, the drive unit spans the width of the structural box-beam. A number of different vehicle designs have been built and tested. Three primary classes of vehicles, based on different cabin configurations, represent typical cases of transit applications. The Cabintaxi KK12, which is shown in Figure 5.1, carries twelve seated passengers and is suitable for scheduled operations, with or without discretionary stops. The Cabintaxi KK3, shown in Figure 5.2, carries three seated passengers and is designed for demand-mode, non-stop to destination travel. A larger Cabinlift configuration provides standing room and is intended to carry up to 50 passengers in scheduled operations. The Cabinlift configuration is also suitable for the transportation of cargo and is used in the Ziegenhain Hospital installation.

Extensive test facilities at the DEMAG site in Hagen have provided the means for component and subsystem tests as well as vehicle operations and control system development. The test track includes 1.46 km of supported and suspended vehicle guideway sections, merging and demerging switches, various types of guideway supports, three stations, and maintenance facilities. The layout of the track, built in several phases beginning in 1973, is shown in Figure 5.3. Figure 5.4 illustrates tests with the vehicles operating at close headways.

The system at the District Hospital complex in Ziegenhain consists of a single Cabinlift type vehicle operating on a 600 m length of suspended vehicle guideway connecting the main hospital building and the out-patient clinic. The system is illustrated in Figure 5.5 and Figure 5.6. The installation provides transport services for hospital personnel, patients, equipment, and food between the two buildings. The system, built in 1976 at a cost of DM 2.2 million, uses selected portions of the overall C-Bahn technology. It represents the first example of defining certification procedures and safety standards for automated transportation systems in Germany, and has provided operational experience in a real world application.

FIGURE 5.2. CABINTAXI KK3



		Date	Vehicles	Track Length
━━━	1st Phase	8/73	2	300 m
●●●●	2nd Phase	6/74	4	700 m
— — —	3rd Phase	9/74	7	1200 m
✕✕✕✕	Extension	10/76		

FIGURE 5.3. LAYOUT OF THE C-BAHN TEST FACILITY

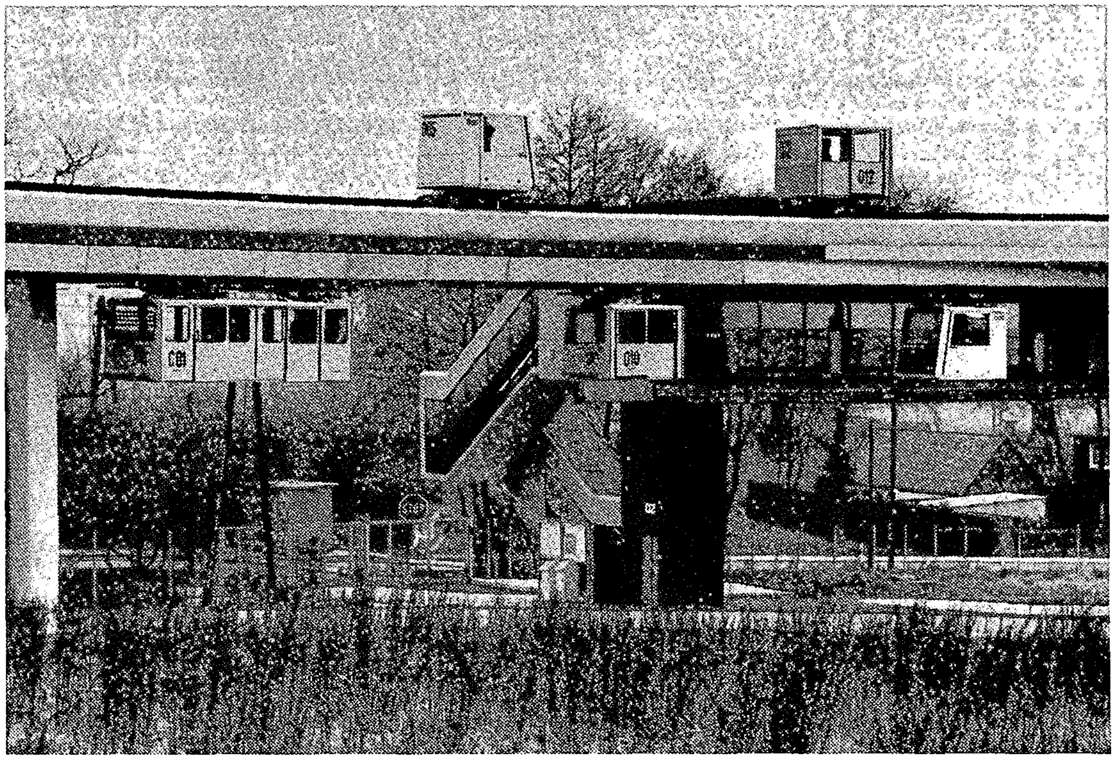


FIGURE 5.4. C-BAHN CLOSE-HEADWAY OPERATIONAL TESTING

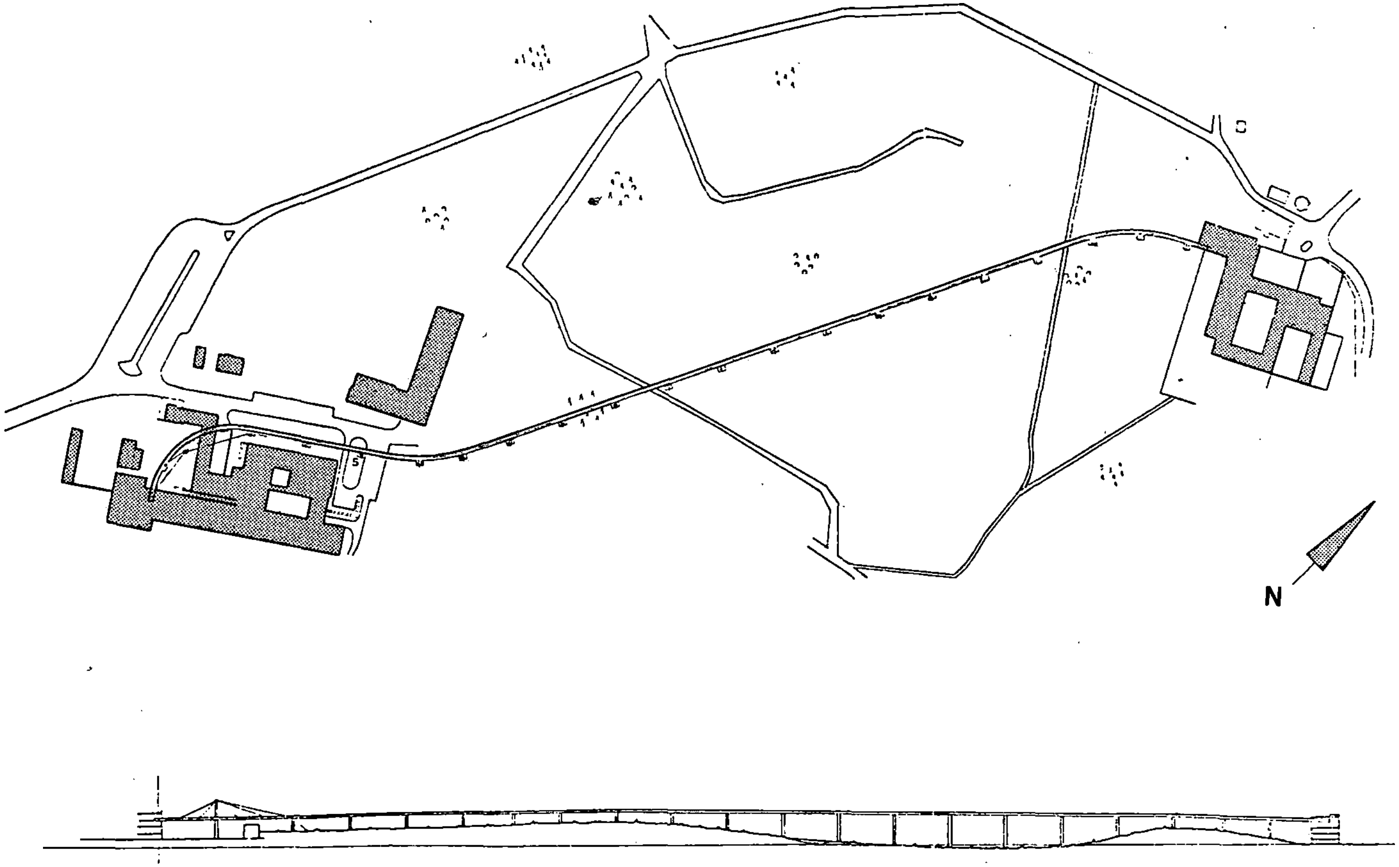


FIGURE 5.5. LAYOUT OF THE CABINLIFT SYSTEM AT ZIEGENHAIN

FIGURE 5.6. CABINLIFT INSTALLATION AT ZIEGENHAIN

5.1.2 Studies and Plans

Several applications of the C-Bahn system have been studied in detail. The City of Marl has investigated the technical, operational, and economic characteristics of a Cabintaxi system with 50 km of dual guideway, 62 stations, and 1,600 vehicles. The capital requirements for this system were calculated to be DM 573 million (at 1976 prices). In another study, a Cabinlift transit system with 2.8 km of guideway, 17 stations, and 16 vehicles for passengers, patients, and cargo was proposed for the large St. Jurgen Central Hospital in Breman. The guideway layout for this system is shown in Figure 5.7.

The Hamburg Hochbahn AG has carried out extensive studies for a suburb of the City of Hamburg. The Barmbeck/Steilshoop/-Fuhlsbuttel area, with favorable structural and traffic characteristics, would be served by a network of 32 km of dual guideway, 41 stations, and 180 twelve-seat vehicles acting as a feeder and distribution system for subways and commuter trains. The projected cost of this system, shown in Figure 5.8, is DM 370 million. The study found that this cost is far greater than that of a conventional bus system but is similar to that of a combined bus and underground railway system. The operational costs of the C-Bahn are estimated to be about 15 percent less than the bus system and 30 percent less than the combined bus and underground railway system. Based on the results of the study, the City of Hamburg has decided to proceed with an initial technical operational demonstration of the C-Bahn installation. An initial 1.7 km loop will connect the center of the City-Nord and the Ruebenkamp railway station, as shown in Figure 5.9a. If this project proves successful, the next extension will be a 8.5 km loop line as shown in Figure 5.9b.

5.1.3 System Details

Although there is a high degree of commonality between the C-Bahn system elements, there are some significant differences that depend upon the specific application.

5.1.3.1 Vehicles

The C-Bahn concept has been developed in terms of components suitable for a variety of vehicles. The Cabintaxi KK3, the Cabintaxi KK12, and the larger Cabinlift configuration, can all be designed as in either bottom-supported or suspended versions. The KK3 cabin uses a single bogie while the KK12 cabin and the Cabinlift use two bogies as shown in Figure 5.10.

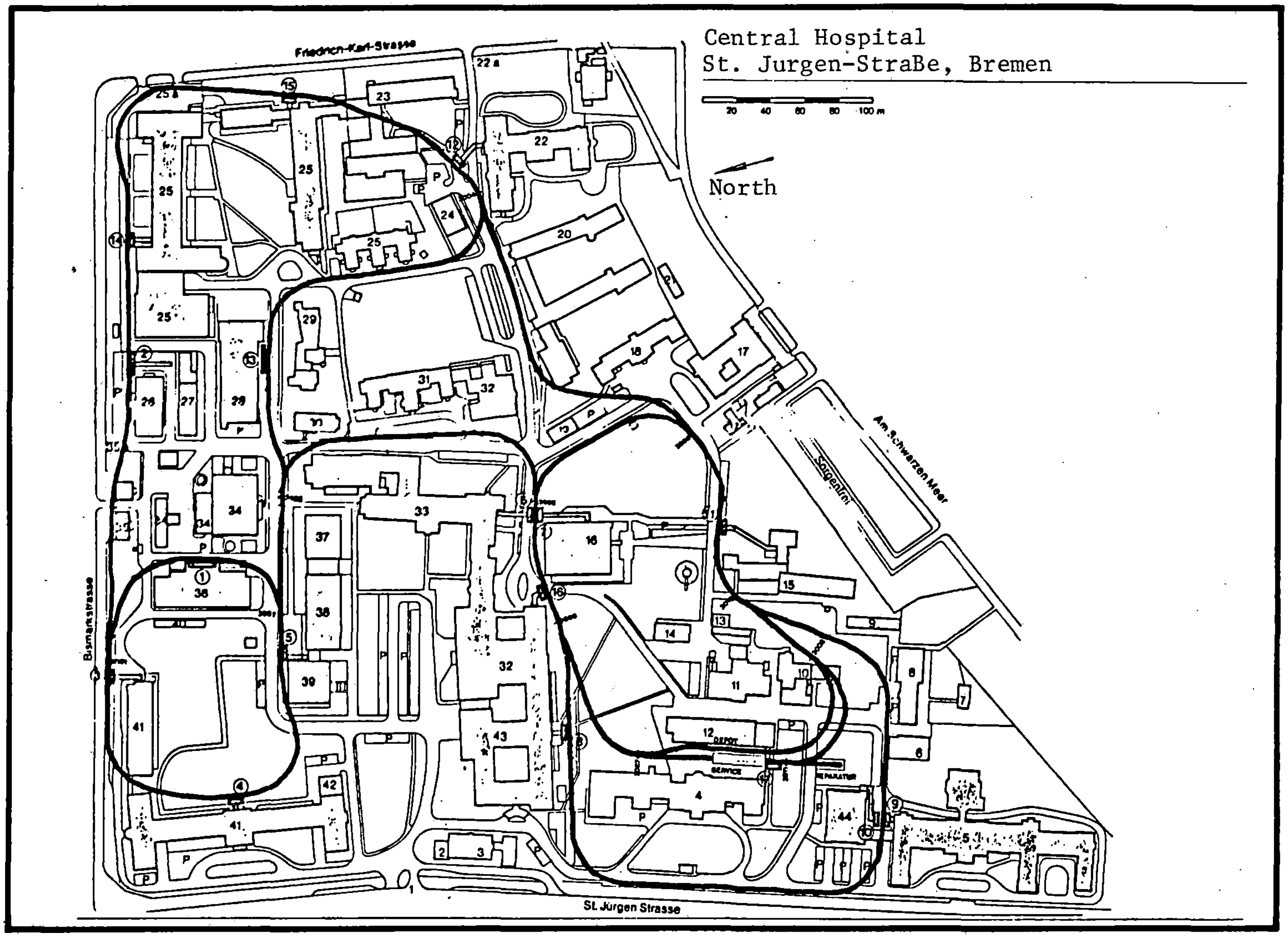


FIGURE 5.7. PROPOSED CABINLIFT SYSTEM FOR ST. JURGEN HOSPITAL

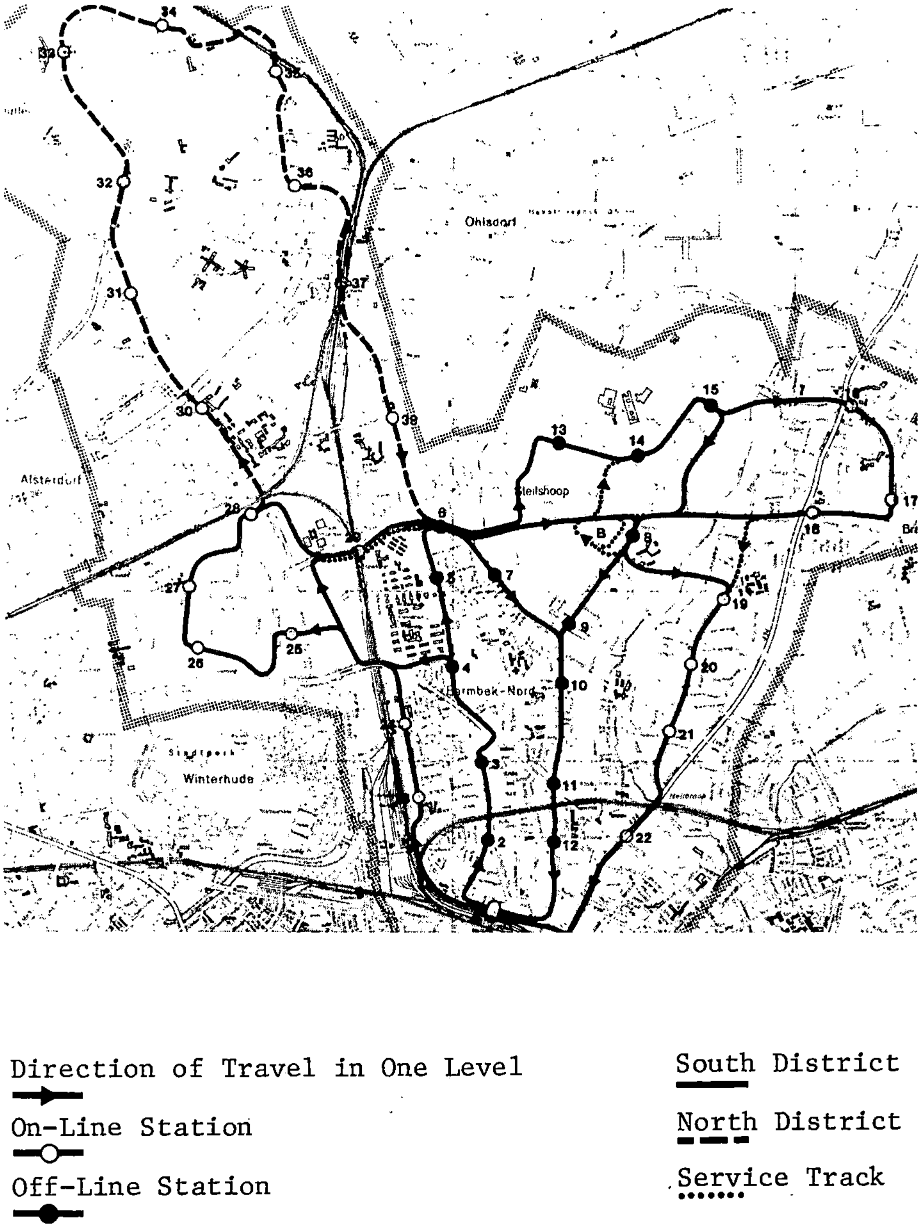
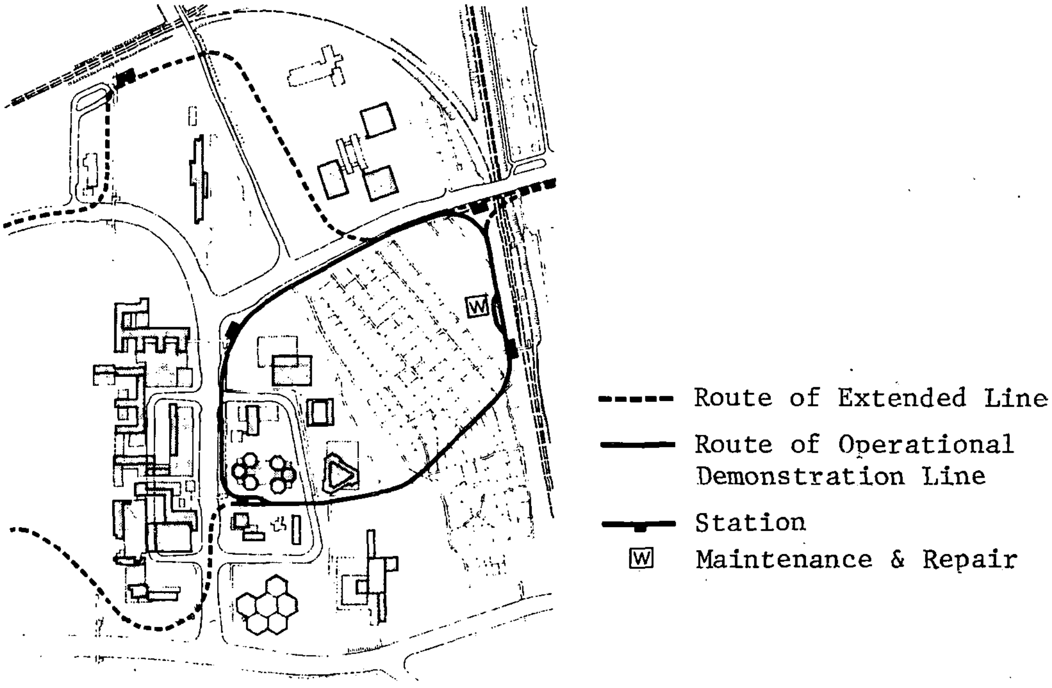
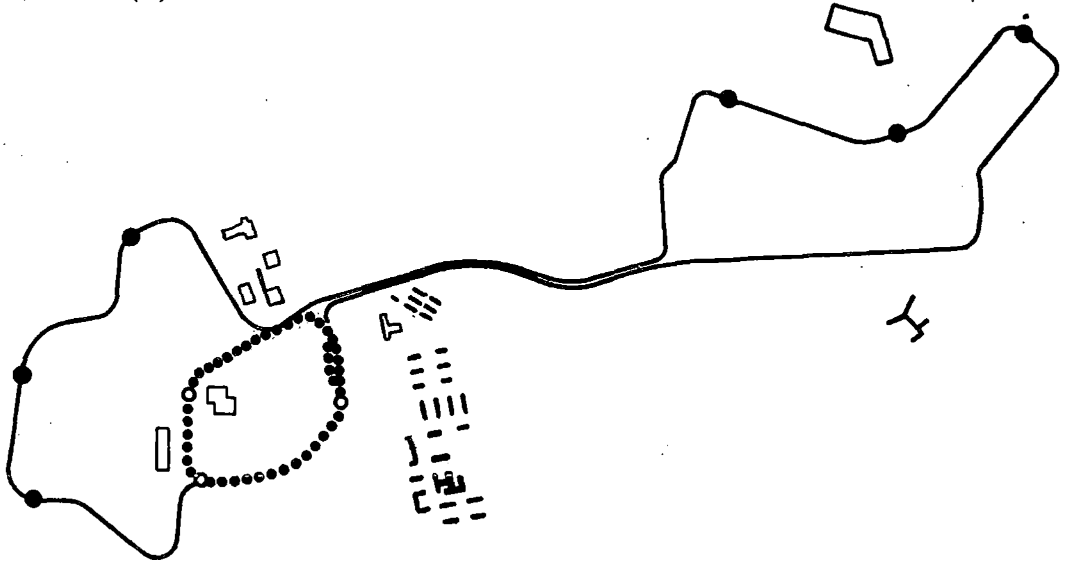


FIGURE 5.8. PROPOSED CABINTAXI SYSTEM IN HAMBURG



(a) First Phase



(b) Second Phase

FIGURE 5.9. TECHNICAL OPERATIONAL DEMONSTRATION SYSTEM FOR HAMBURG

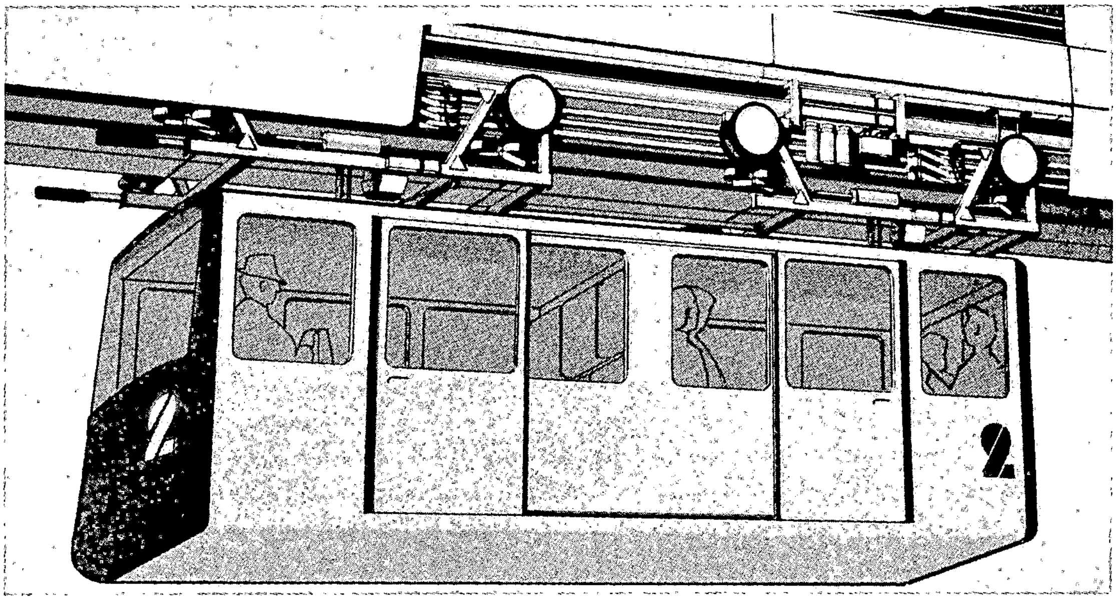


FIGURE 5.10. SUSPENDED C-BAHN KK12 VEHICLE SHOWING DRIVE UNITS

Each bogie has four support wheels and four guidance wheels. All guideway switches are passive, with the drive units containing an extra set of horizontal switching wheels to select the travel direction. The support wheels on the suspended vehicles are doubled in order to negotiate the switches.

5.1.3.2 Propulsion and Braking

The C-Bahn vehicles are equipped with linear induction motors to provide propulsion and service braking independently of contact between the wheels and support rails. This non-contacting drive reduces tire wear, eliminates detrimental effects of inclement weather and provides high acceleration and braking deceleration rates and grade negotiating capability.

The operating velocity of the Cabintaxi vehicles is 12 m/s and that of the Cabinlift system at Ziegenhain is 8 m/s. Motors producing a vehicle velocity of 15 m/s have also been tested. The normal acceleration and braking rates are 2.5 m/s^2.

A double-sided LIM is mounted horizontally on each side of the vehicle bogie. The two motors per bogie are required in order to negotiate the guideway switches. Extruded aluminum reaction rails are mounted from the central structural box-beam. For normal running, the reaction rail is mounted only on one side, but rails are used on both sides where grades exceed 5 percent. Alternating current power at either 380 V or 500 V is supplied to the motors through power rails also mounted on the box-beam. Control of the motors is provided by phase control of the a.c. supply, although frequency control is also under investigation.

Wheel drum brakes are used to provide low-speed braking and for emergency braking.

5.1.3.3 Guideways

The guideways for the C-Bahn are normally constructed as elevated units. The guideway may be configured for supported vehicles, suspended vehicles, or both in combination. The main structural member of the guideway is a welded steel box-beam. Track and directional guide beams are bolted to the box-beam through supports. Other auxiliary equipment mounted on the structure includes the power rails, reaction rail, and interval measuring cable. An exterior cover shields the running surface and auxiliary equipment. The guideway cross section is standardized for all the various vehicles, and a number of guideway support structure configurations have been developed to meet various surface and sub-surface conditions.

5.1.3.4 Operational Control System

The C-Bahn system is automated through a hierarchical control system having three independent levels. The control levels are:

1. Vehicle headway and speed regulation with merge control.

2. Station control including vehicle destination coding, switch direction setting, and traffic flow counting.

3. Network control for dispatching, monitoring, and traffic flow management.

The first level of control is critical to system safety and general operational capability, while levels two and three increase system operational capability. Failures in either level two or three will degrade, but not halt, system operation.

The longitudinal control concept is based on vehicle-to-vehicle distance measuring equipment that induces and receives a signal in an interval-measuring cable installed along the guideway. The concept permits a 1.4 second headway and vehicle platooning. In addition, a particularly innovative technique applied to the control of merging streams of vehicles minimizes the perturbation to the speed of successive vehicles in merging platoons.

5.1.4 System Capacity

Several features of the Cabintaxi KK3 and KK12 systems have been developed to assist in producing a high capacity system. The synchronous interval headway control, passive switches, off-line stations and merging control allow a minimum interval of 1.4 seconds for the KK3 vehicle and 1.6 seconds for the KK12 vehicle. These headways are based on operational speed of 10 m/s and an emergency deceleration of 5.1 m/s^2, which the developers consider suitable for seated passengers. The resulting maximum passenger capacity is 7,714 passengers per hour per direction for the twelve seat KK12. For operations with on-line stations, the headway requirements are greatly increased. For a station dwell time of 20 seconds, a vehicle interval of 28 seconds would be possible. For operations with single KK12 cars, 1,500 seats per hour per direction could be provided. Two and three car trains would double and triple this capacity.

5.2 H-Bahn

The H-Bahn is a suspended vehicle AGT system developed jointly by Siemens AG and DUWAG Waggonfabrik Uerdingen AG, with financial support from the Ministry for Research and Technology. Development began in 1973; vehicles have been operating on a test track at the Siemens Research Center since 1977. The vehicles are suspended from a drive unit that runs inside a box-type girder with a slotted lower chord. Alternative designs allow propulsion and service braking either by d.c. motors driving through the support wheels or by means of a single-sided LIM with a reaction rail mounted on the top chord of the box girder. The LIM drive removes the reliance on friction and also produces a higher starting tractive effort. H-Bahn installations have been studied for the cities of Erlangen and Dortmund.

5.2.1 System Background

The H-Bahn was conceived as a complete transportation system that can handle a variety of transportation requirements. Potential applications include the public transit needs of a medium sized city, a feeder system for intercity transportation terminals in larger cities, or localized transportation of passengers, luggage and supplies with an airport. An elevated, easily-erected guideway design and automatic vehicle operations were considered essential in developing the concept. The design was made adaptable by using varied vehicle sizes and different levels of operational controls. Feasibility studies carried out concurrently with the system development have changed the emphasis from one that stressed individual demand traffic to one of predominantly line-haul traffic.

Construction of the 1.4 km test track at Erlangen was begun in August 1976, and several vehicles are now operated there. The guideway contains several different grades and curves with various radii of curvature. Three stations are included in the facility. Figure 5.11 shows the layout of the test track. Figure 5.12 shows a 41 passenger (16 seated, 25 standing) vehicle operating there. The vehicle running gear, inside the box-type girder, includes wheels with hard rubber tires for support, guidance, and switching and the propulsion drive. Figure 5.13 shows the arrangement of the running surfaces on the other equipment installed within the guideway girder.

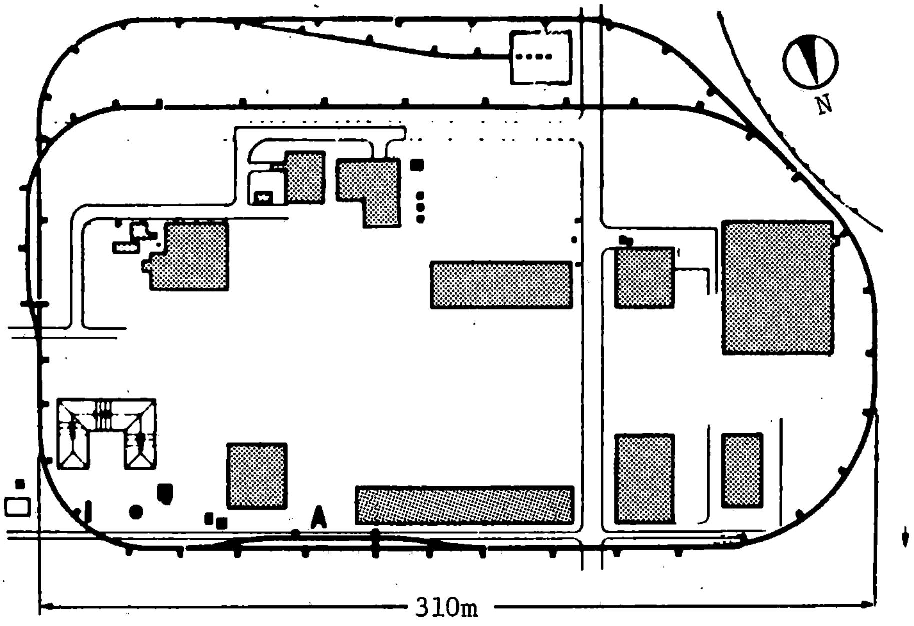


FIGURE 5.11. LAYOUT OF THE H-BAHN TEST FACILITY AT THE SIEMENS RESEARCH CENTER

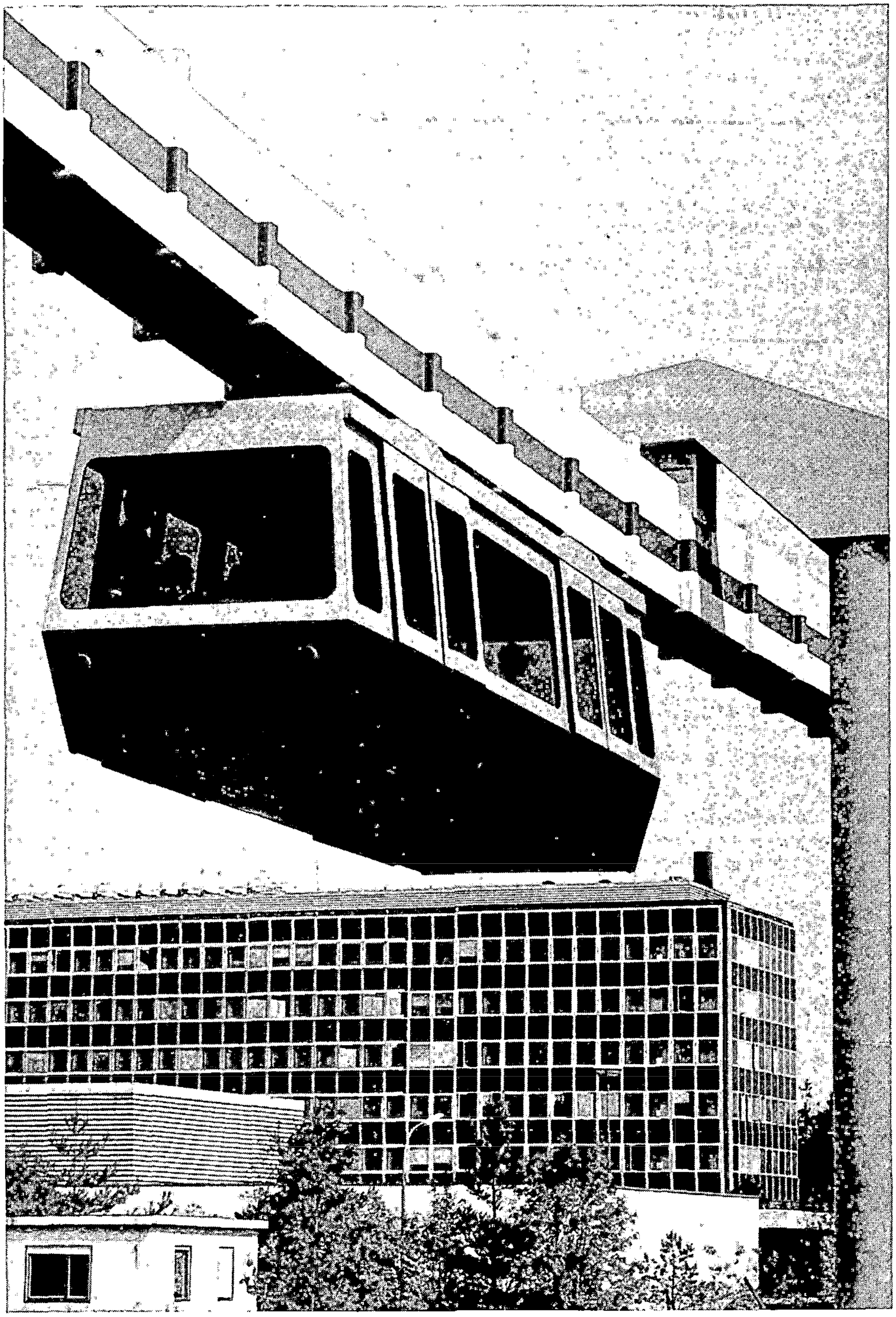
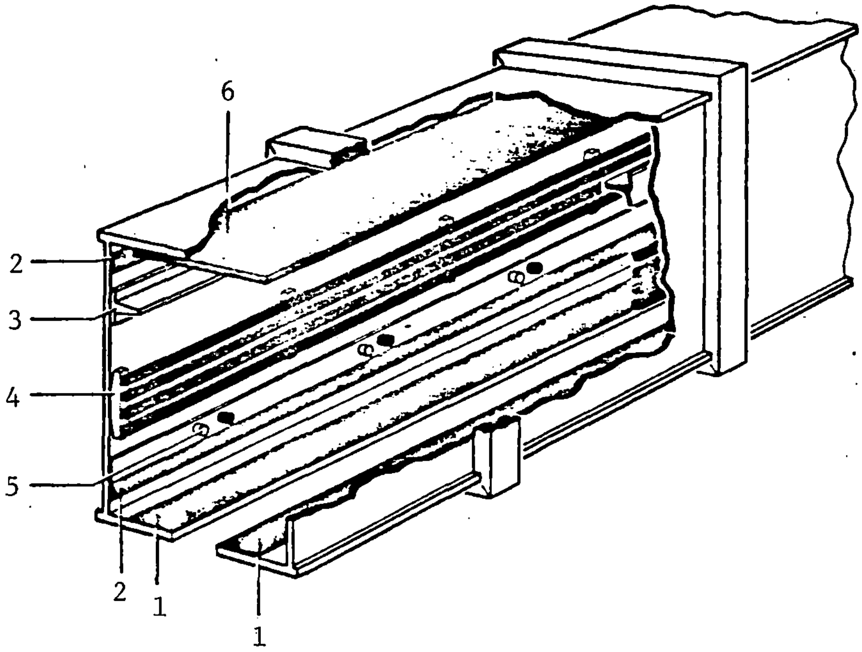


FIGURE 5.12. H-BAHN VEHICLE AND GUIDEWAY



1. Running Surfaces for Support or Drive Wheels
2. Running Surfaces for Lateral Guide Wheels
3. Antenna for Command and Voice Communication (on Both Sides)
4. Conductor Rail System (on Both Sides)
5. Magnets for Reference Speed Input
6. Brass Strip for Reaction Rail of Linear Motor

FIGURE 5.13. EQUIPMENT INSTALLATION ON GUIDEWAY GIRDER

A feasibility study for the city of Erlangen showed that the H-Bahn can handle a considerable portion of the city's public transit needs. It also showed that although the H-Bahn would initially have a higher operating cost per passenger kilometer than a comparable bus system, the fast-rising labor cost of a bus system would make the bus system more expensive than the H-Bahn beginning in the mid-eighties. An opinion poll of the Erlangen citizens, however, showed that the population did not consider the visual aspects of the H-Bahn system to be suitable for the historic city. Subsequently, the proposal to build an eight kilometer demonstration line was narrowly defeated by a small majority of the town council.

A 1.2 kilometer installation of the H-Bahn has been studied in the city of Dortmund. The system would be configured as a shuttle system with two vehicles operating between two stations. The estimated cost is DM 15 million.

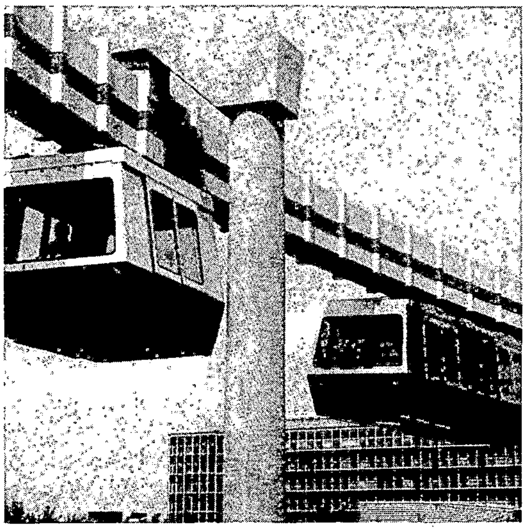
5.2.2 System Details

The H-Bahn system adopts a modular approach, and provides alternatives for propulsion.

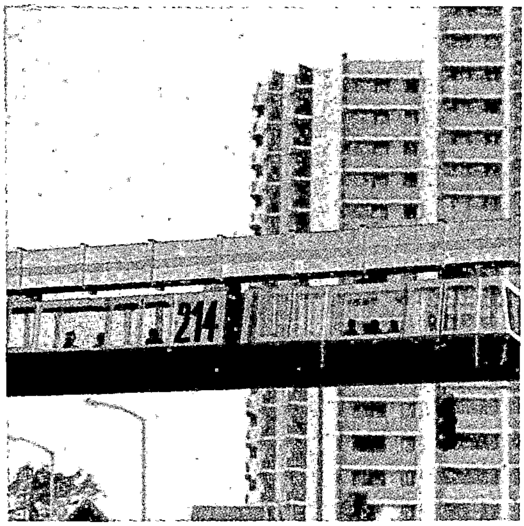
5.2.2.1 Vehicles and Drive Units

The H-Bahn vehicles are propelled by running gear units inside the guideway beams. Standard running gear units allow for cars of various sizes to be built upon modular principles. Figure 5.14 shows how the size of both the single and the articulated vehicles utilize a common running gear. In keeping with the modular principles, the door spacing of all vehicles is the same. Each running gear is fitted with two twin rubber tired support wheel sets which run on the lower chord of the guideway beam. Four pairs of lateral guide wheels, which run on the web of the beam, also have rubber tires. For negotiating switch points, the support wheels run on one side only, with guidance and stability coming from additional rocker-mounted guide wheels on the running gear. The arrangement of the wheels in the drive unit traversing the passive guideway switch point is shown in Figure 5.15.

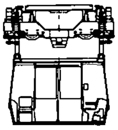
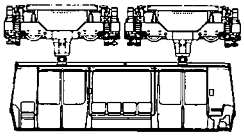
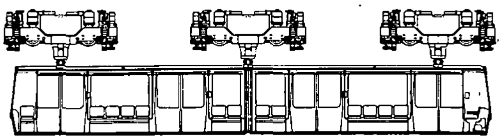
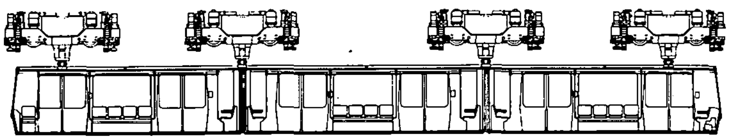
The alternative d.c. traction motor and LIM drives are shown in Figure 5.16. Both propulsion systems use 380 Volt three-phase a.c. and have a maximum speed of 50 km/hr. The d.c. motor drive has a starting tractive effort of 6.8 kN and the capability to climb a six percent gradient. The LIM, which is controlled by three-phase controllers, has a starting thrust of 10 kN and the



H-Bahn coach for 8 seated and 9 standing passengers and H-Bahn coach for 16 seated and 25 standing passengers



H-Bahn articulated coach for 28 seated and 70 standing passengers

	Seats	Standing*	Total	
Single coaches	8	9	17	
	16	25	41	
Articulated coaches	28	70	98	
	38	111	149	

*4 passengers/m^2

FIGURE 5.14. H-BAHN VEHICLE ARRANGEMENTS

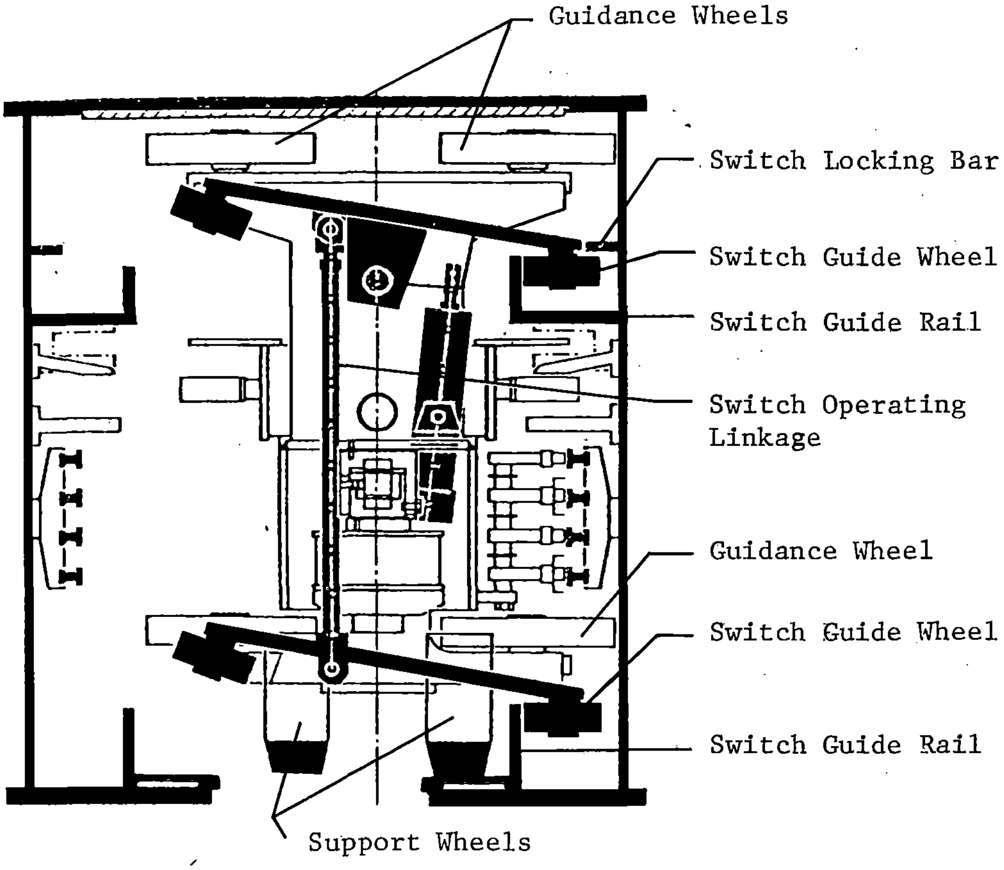
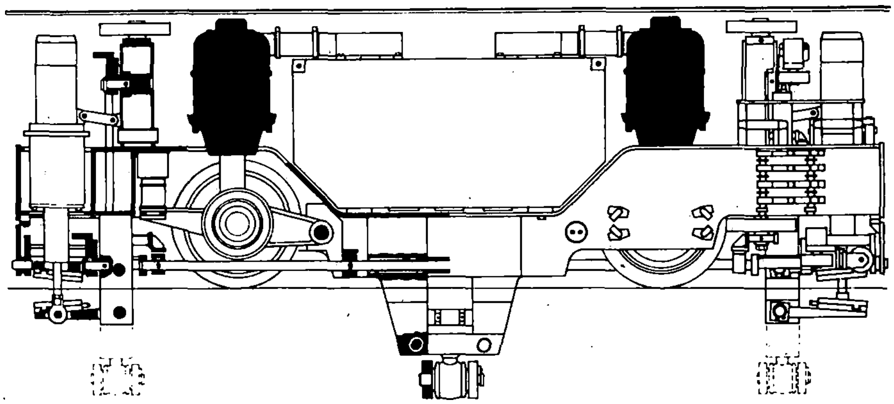
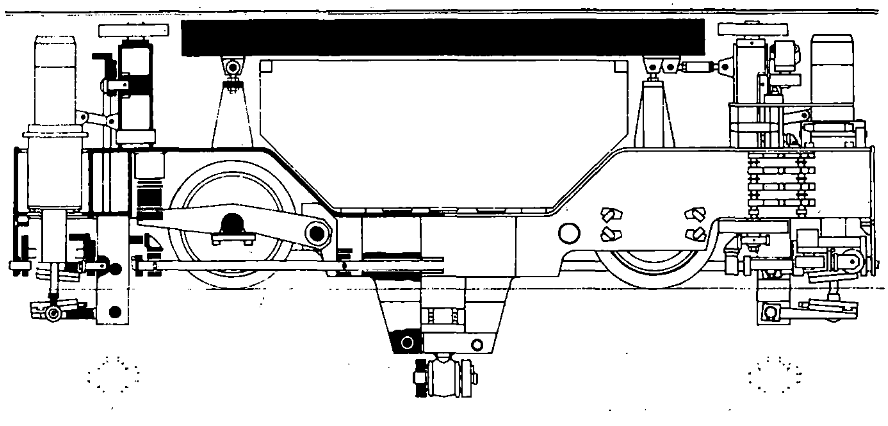


FIGURE 5.15. VEHICLE RUNNING GEAR AT A SWITCH POINT



(a) Running Gear Unit with D.C. Motor



(b) Running Gear Unit with Linear Motor

FIGURE 5.16. ALTERNATIVE PROPULSION SYSTEMS FOR THE H-BAHN

capability to climb a 15 percent gradient. Emergency braking is accomplished by motor-operated spring energy storage brakes, at each end of the drive unit, which clamp the upper and lower faces of the lower chord of the guideway girder.

5.2.2.2 Guideway

Track beams are of welded steel plate construction with external stiffening frames. The beams are suspended from steel or concrete supports to provide a nominal 4.5 m ground clearance for the vehicles. A wide variety of support structures are possible to suit the particular system configuration and foundation conditions. A number of different designs are used in the Erlangen test track. Although the girders are prefabricated and easily erected, close tolerances are required in the beams and joints to avoid vertical and lateral inputs to the vehicles.

5.2.2.3 Operational Control Systems

The operational control system of the H-Bahn is arranged in three levels to permit progress automation. The three levels are:

1. A safety level built up on railroad block principles, for monitoring the headway, the local maximum speed, and the correct switch settings.

2. A traffic control level, for vehicle handling in the stations and traffic movements on the associated track sections, handled by individual station computers.

3. An operations control level, for central traffic control through commands to the station computers as well as for monitoring the proper functioning of automatic operations.

The operational central system utilizes proven technology and components and is used on the test track where vehicles are operated under computer control.

5.2.3 System Capacity

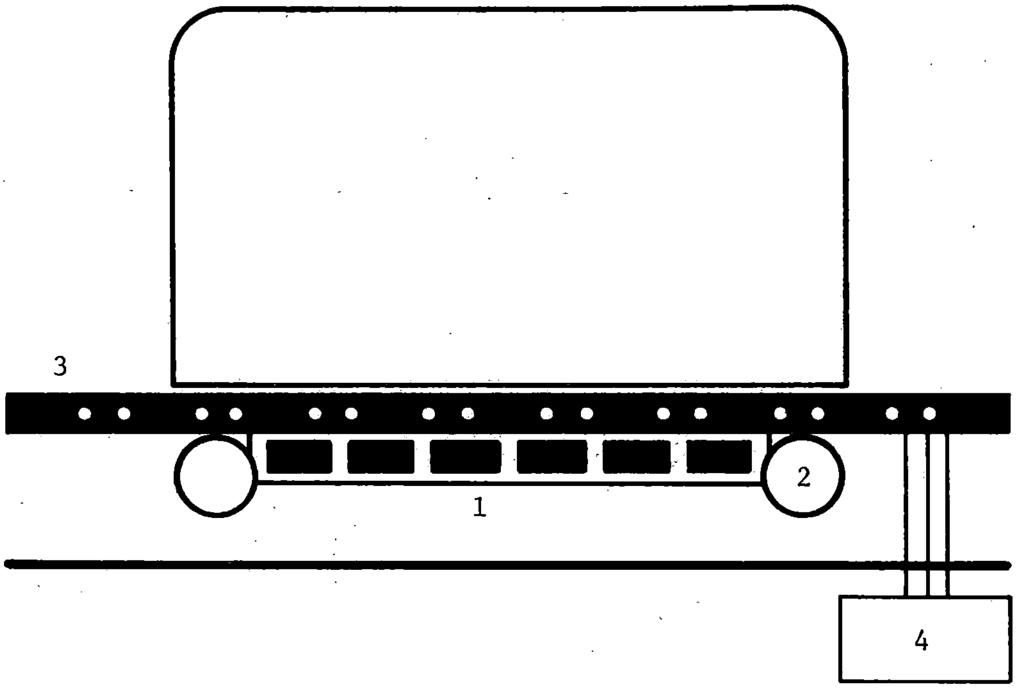
With automated operations at 60 second headways, the H-Bahn can produce a system capacity of 1,000 to 4,200 passengers per hour per direction with single cars. With trains and articulated vehicles, capacities up to 15,000 passengers per hour per direction can be obtained.

5.3 M-Bahn

The M-Bahn, an AGT system developed by Magnetbahn GmbH, is based on the principle of an active track linear synchronous motor integrated with on board permanent magnets which supplement the vehicle suspension. Since the magnetic field of the permanent magnets is not controlled, wheels are necessary for tracking forces. With the energized a.c. field windings on the guideway and the power conditioning equipment at the wayside, the on board vehicle propulsion equipment is greatly simplified. M-Bahn development activities were begun in 1973 and activities since that time have been funded by MORT. The M-Bahn system has undergone extensive testing since 1976 at a facility in Branschweig. The Hanover Industrial Fair is developing plans for installing an M-Bahn system to transport people within the fairgrounds.

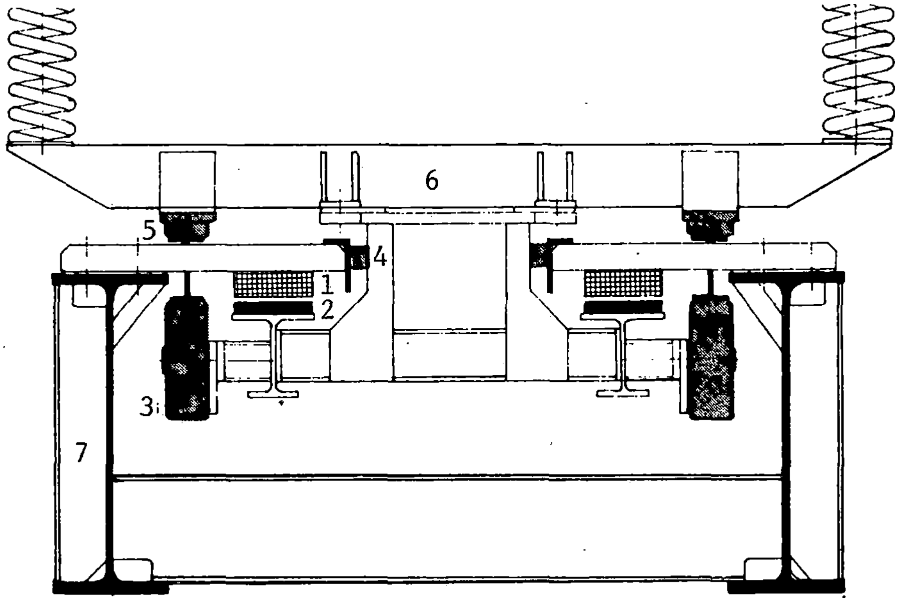
5.3.1 System Background

The development of the M-Bahn has centered around the principle of providing propulsion by a linear synchronous motor. The M-Bahn concept consists of permanent magnets on the vehicle reacting with guideway mounted energized windings. The windings provide a traveling electromagnetic field on the guideway under the control of wayside power conditioning equipment. This arrangement is shown conceptually in Figure 5.17. The permanent magnets, traveling under the guidway surface, also supplement the support of the vehicle. The permanent magnets carry the nominal load at the nominal air gap, but do not provide a stable equilibrium state. Small wheels are required to control the tracking forces. Rollers are used for vehicle lateral guidance. Figure 5.18 shows the arrangement of the vehicle running gear and the guideway cross section. The M-Bahn developers claim that the concept produces smaller, lighter weight vehicles, with ensuing reduced propulsion power requirements and lighter guideway structures.



1. Vehicle-Mounted Permanent Magnets
2. Wheels to Control Magnetic Forces
3. Guideway Field Windings
4. Wayside Power Control Equipment

FIGURE 5.17. PRINCIPLE OF THE M-BAHN



1. Field Winding (on Guideway)
2. Permanent Magnets (on Vehicle)
3. Control Wheels
4. Lateral Guidance Wheels
5. Emergency Wheels and Brakes
6. Vehicle
7. Guideway Support Beams

FIGURE 5.18. M-BAHN RUNNING GEAR

The system has undergone extensive testing since 1976 at the Magnetbahn facility at the University of Braunschweig. The test track includes two continuous loops (1,000 m and 400 m in length) connected by switches. Guideway construction consists of both elevated and at-grade sections. Two vehicles are in operation, and two stations are located on the test track. Figure 5.19 shows a vehicle with a capacity of 16 seated and 24 standing passengers on an elevated portion of the test track. Figure 5.20 illustrates the layout of the test facility.

5.3.2 Future Plans

The Hamburg Industrial Fair plans to install the M-Bahn system as a means of transporting visitors and exhibitors at the fairgrounds. The exposition annually attracts approximately 5,000 exhibitors and half a million visitors. Many of these persons must travel long distances between various exhibition sections on the grounds. The fair organizers evaluated several new passenger transportation concepts and decided that a large cabin AGT system using elevated guideways appeared to be the most suitable in terms of meeting their requirements. Reasons given for the selection of the M-Bahn were technological advancement, simplicity, and low investment and operating cost.

The plan for the Hanover installation uses an L-shaped loop approximately 3.5 km long, covering the exhibition grounds. With ten stops, any location in the grounds will be within approximately two minutes of the nearest station. The planned layout is shown in Figure 5.21. The service will utilize seven trains of three vehicles each with a capacity of 40 passengers (16 seated and 24 standing). Trains will operate at one minute headways under automatic block control, giving a capacity of 7,200 passengers per hour.

The estimated cost of the M-Bahn system at the Hanover Industrial Fair is DM 35 million; the fair organizers are working on arrangements for funding the project. The Federal Ministry for Research and Development is expected to subscribe a nominal percentage of the cost, with the balance expected from state and industry sources. The current planning schedule aims at a 1982 installation date.

5.3.3 System Details

The M-Bahn system differs from the others described in the report in a number of areas.

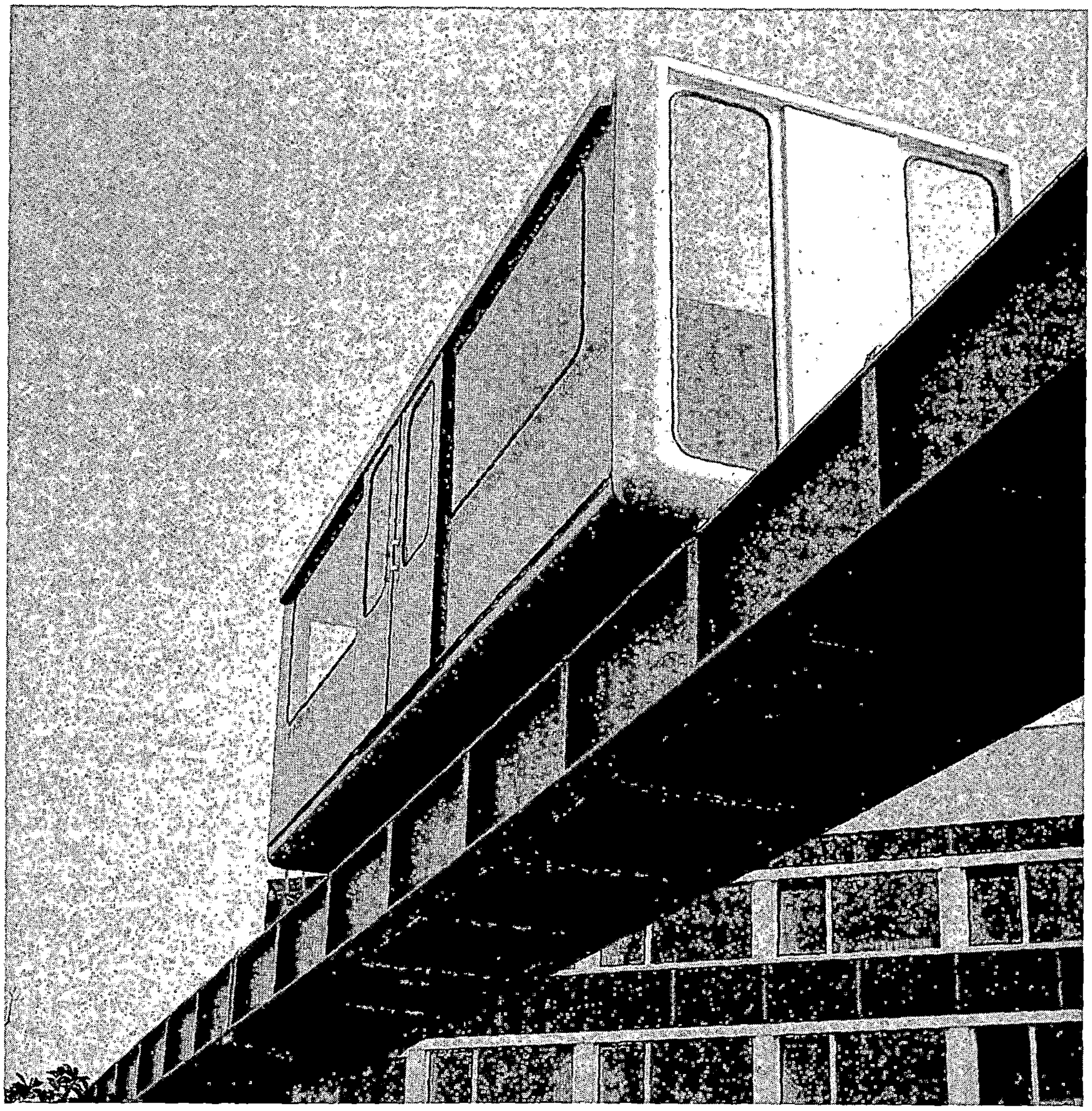


FIGURE 5.19. M-BAHN VEHICLE AT THE UNIVERSITY OF BRAUNSCHWEIG TEST TRACK

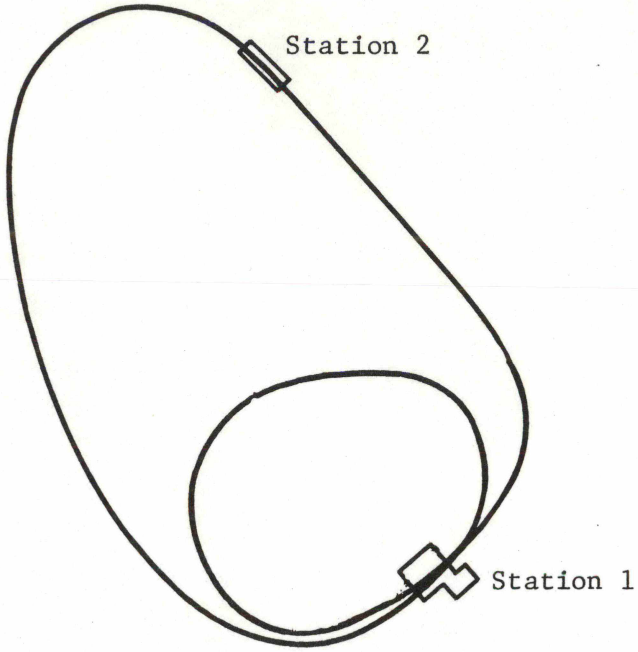


FIGURE 5.20. M-BAHN TEST FACILITY

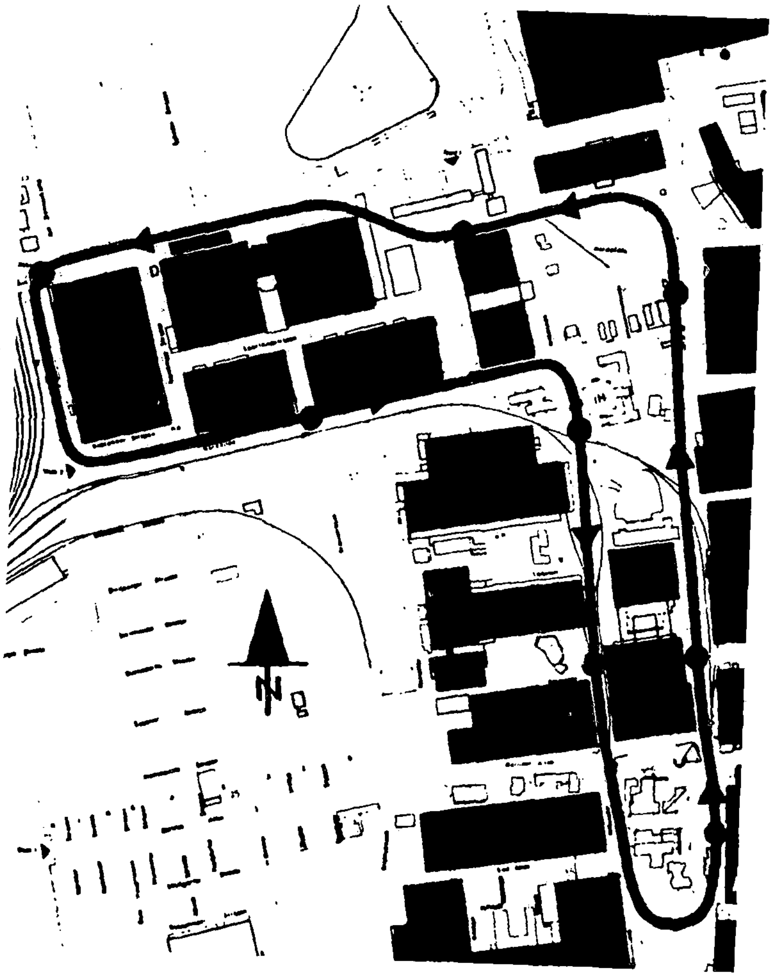


FIGURE 5.21. PROPOSED M-BAHN SYSTEM FOR THE HANOVER INDUSTRIAL FAIR

5.3.3.1 Propulsion

The M-Bahn utilizes a non-contacting electrical propulsion system of a configuration different from other transit systems. The magnetic field of permanent magnets on the vehicle reacts with a traveling electromagnetic field on the guideway to form a linear synchronous motor. A guideway-mounted primary uses a three-phase winding to produce the traveling field. The electrical current for the windings is controlled by stationary converters on the wayside, providing the variable frequency a.c. field that produces the desired speed. The M-Bahn system uses two primaries mounted parallel inside the guideway structure. Figure 5.22 shows the appearance of the primary.

Because of the elimination of the on board traction devices, the weight of the vehicle is reduced. The M-Bahn developers claim that their vehicle is nearly half the weight of a conventional vehicle, and that the weight reduction permits the installed propulsion power to also be reduced by one-half. The wayside control equipment for propulsion power also benefits from reduced power requirements compared to a LIM. In addition, it can be designed without regard to on board limitations for weight or volume. The guideway winding is divided into separately powered sections that are shorter than the vehicle operational spacing. Energy is supplied only to the guideway section occupied by the vehicle.

5.3.3.2 Vehicles

The permanent magnets used in the propulsion system are fixed to the running gear of the vehicle and carry the weight of the vehicle by attraction to the guideway structure. Small wheels control the force between the track and the magnet to maintain the gap required by the vehicle and payload. The load on the wheels is less than the weight of the vehicle. The simplified running gear leads to a compact vehicle, as shown in Figure 5.23. The cabin of the forty passenger vehicle has exterior dimensions of 2.1 m high, 2.1 m wide, and 6.3 m long. Conceptually, all requirements for power rails can be eliminated with the auxiliary power for heating, ventilation, lighting and air compressors coming from batteries that are recharged at stations stops.

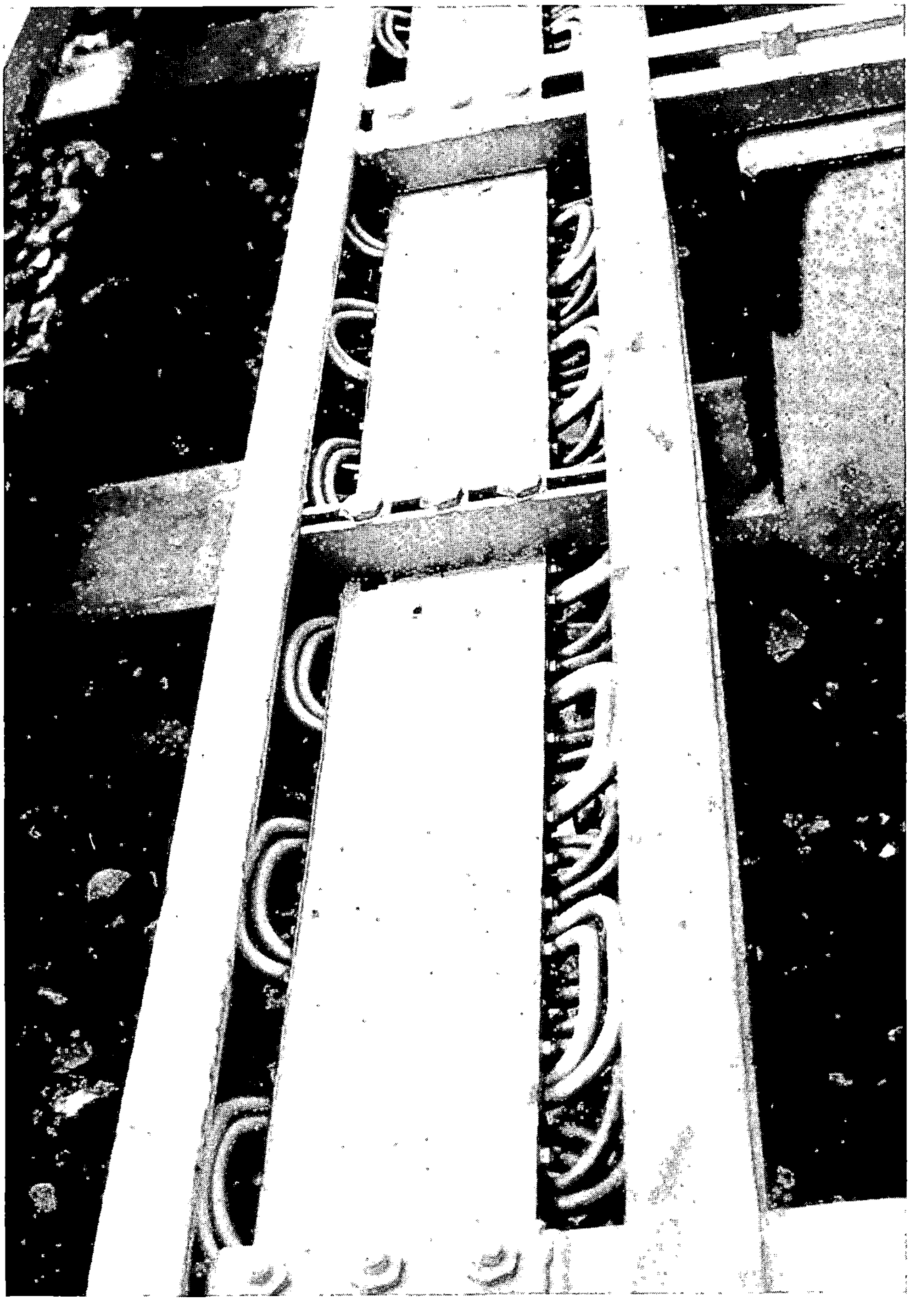


FIGURE 5.22. M-BAHN GUIDEWAY WINDING

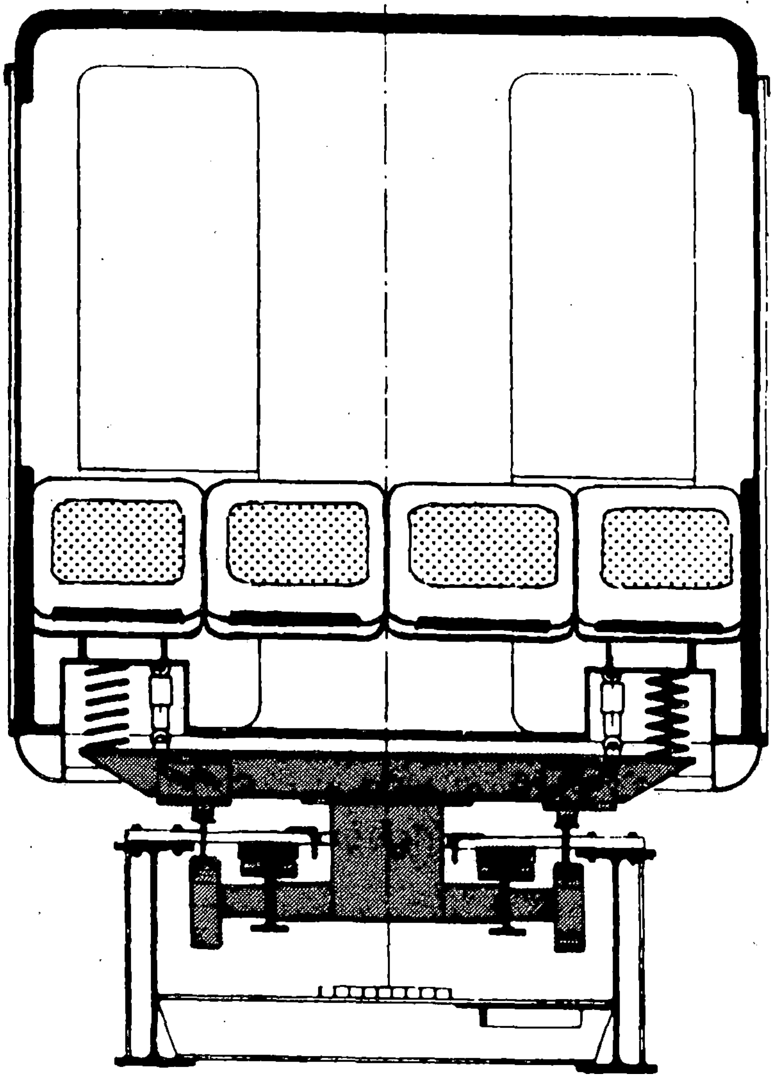


FIGURE 5.23. CROSS SECTION OF M-BAHN VEHICLE

5.3.3.3 Guideway

The M-Bahn guideway is based on simple, light weight construction techniques. The elevated sections of the test guideway use both steel girders and prestressed concrete girders. Both types were prefabricated for rapid construction. Guideway switch points are electro-mechanically activated, with the vehicle remaining completely passive.

6. UNITED STATES

This section describes the work that has been, and is being, performed in the United States by Otis/TTD, WEDway, Rohr, Boeing, and General Motors.

6.1 Otis/TTD

The Transportation Technology Division (TTD) of the Otis Elevator Company represents the current corporate structure of an organization that has carried out a sustained research effort and the development of a LIM propelled/air-levitated AGT system. The effort was initiated in 1968 with private funding and has been aided at times by UMTA contracts.

6.1.1 System Background

During TRANSPO 72 at Dulles International Airport near Washington, D.C., Otis/TTD demonstrated a system, pictured in Figure 6.1, that included two vehicles, a station building, and a limited length of guideway. The fully automated system with off-line stations carried approximately 14,000 passengers during the ten day exhibit. After TRANSPO 72, UMTA contracted for approximately six months of operations to carry out tests that established performance limits and capabilities of the system.

Otis/TTD has also developed a test facility near Denver, Colorado. The at-grade test track is a 0.8 km long loop that contains a station siding with two vehicle berths. This facility is shown in Figure 6.2.

More recently, Otis/TTD system has been installed on an automated people/cargo transportation system for the Duke University Medical Center complex in Durham, North Carolina. The installation at Duke University resulted from a 1973 plan developed by Duke for integrating the existing hospital with other facilities then under construction. Specifications for an AGT system and a request for proposals were developed in early 1975 and Otis/TTD received the design contract in July 1975. After the procurement option was exercised in August 1976, the construction proceeded, with system acceptance testing taking place in late 1979 and early 1980. The layout of the Duke University installation is shown in Figure 6.3. The vehicle, based largely on the design of the earlier developmental vehicle, is shown in Figure 6.4, with the vehicle and guideway cross section given in Figure 6.5. The integration of the guideway and the hospital buildings is illustrated by Figure 6.6.

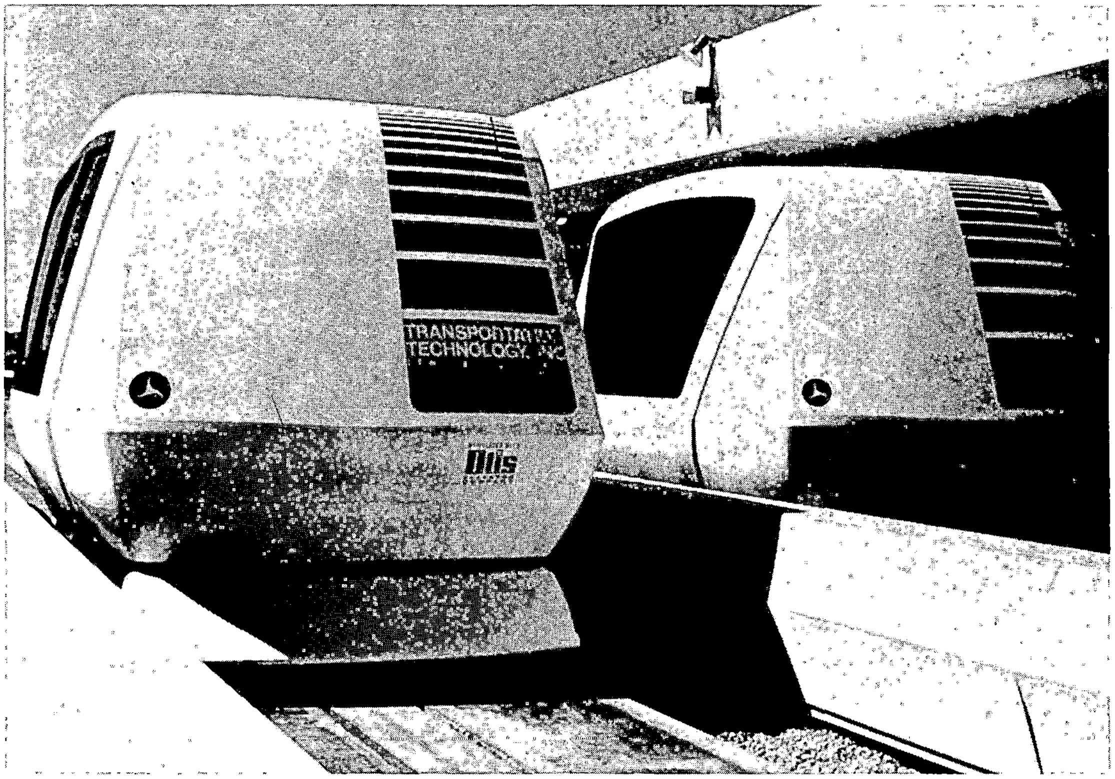


FIGURE 6.1. OTIS/TTD VEHICLES AT TRANSPO '72

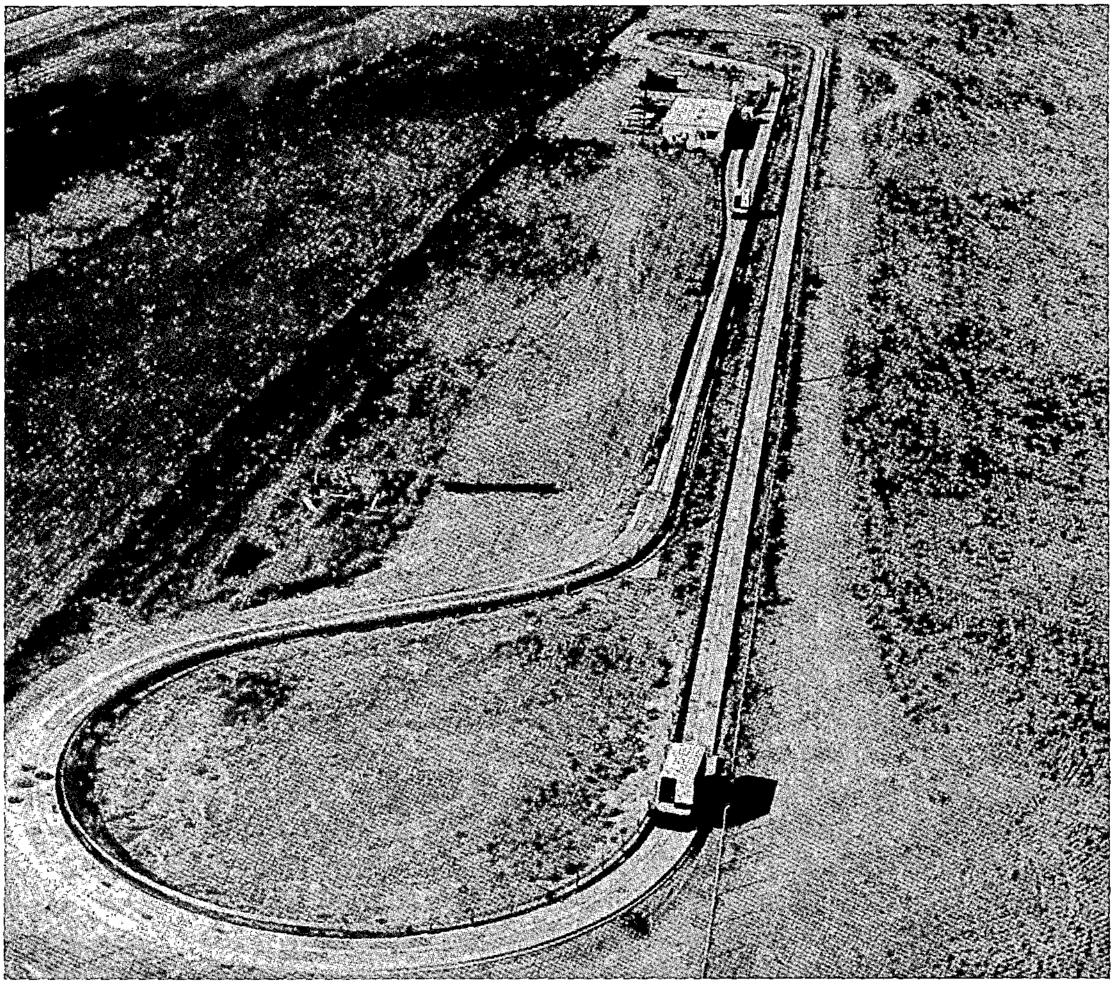


FIGURE 6.2. OTIS/TTD TEST TRACK NEAR DENVER, COLORADO

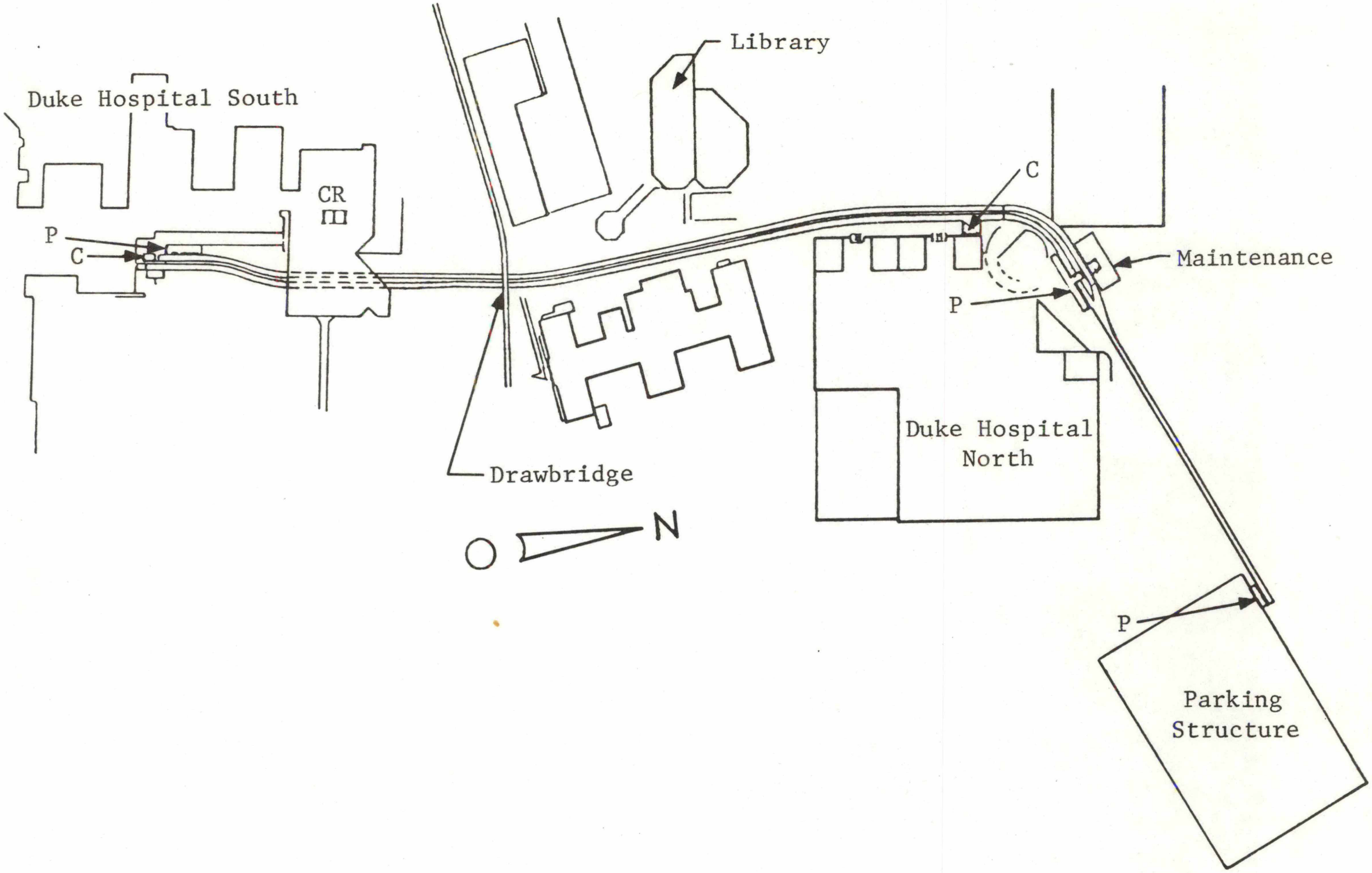


FIGURE 6.3. SYSTEM LAYOUT AT THE DUKE UNIVERSITY MEDICAL CENTER

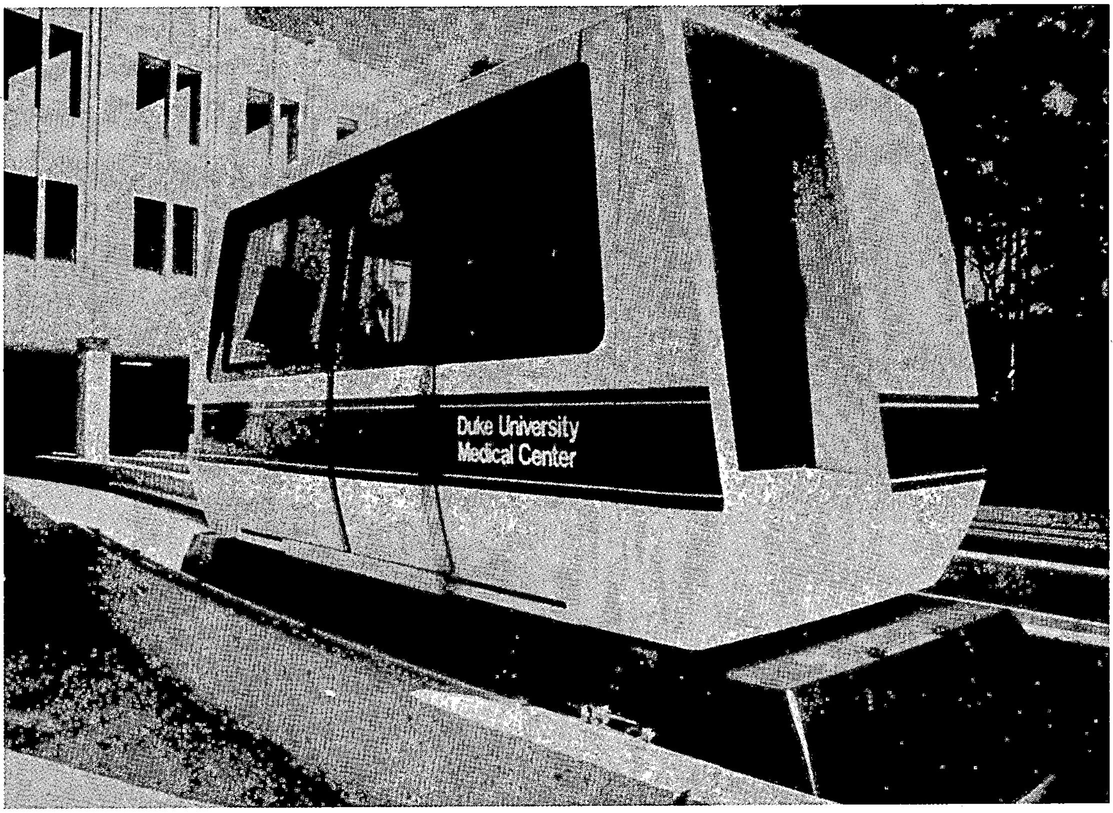


FIGURE 6.4. DUKE UNIVERSITY SYSTEM VEHICLE

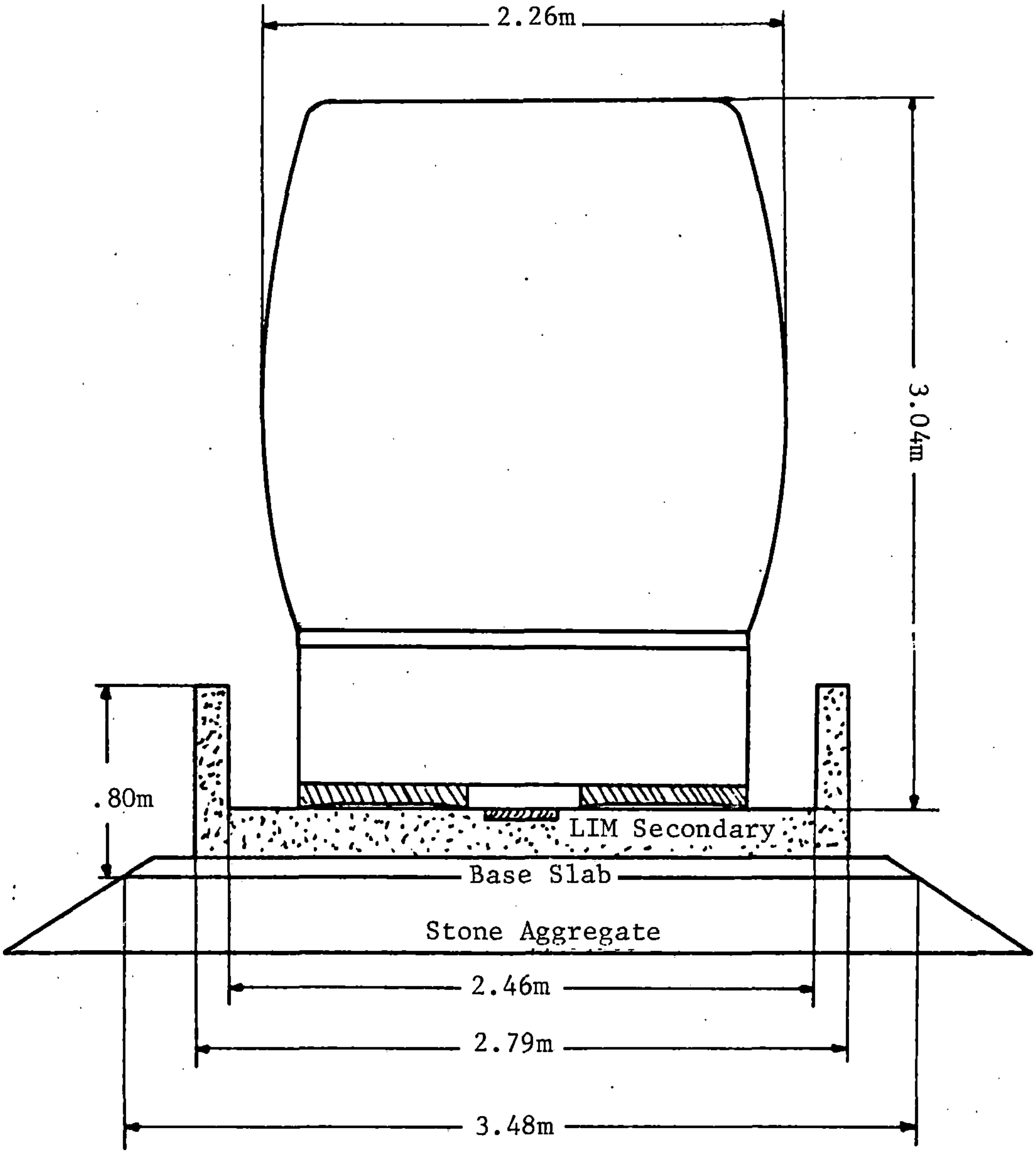


FIGURE 6.5. VEHICLE AND GUIDEWAY CROSS SECTION

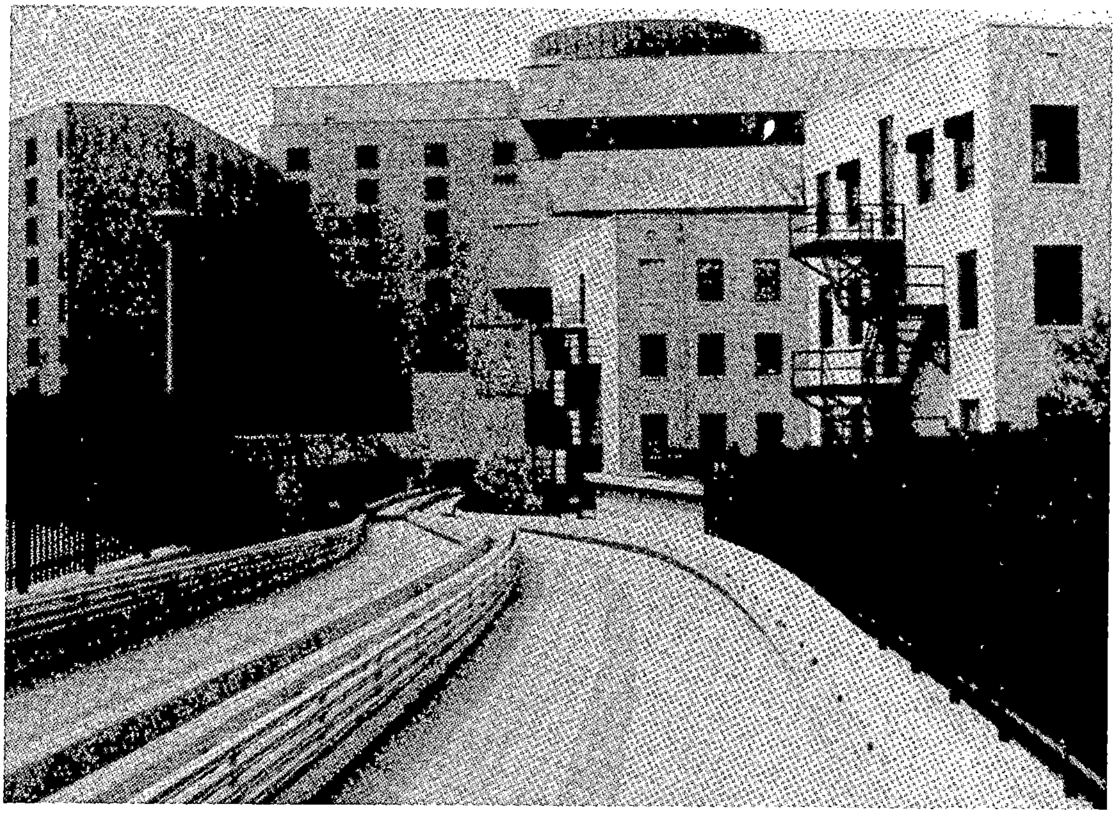


FIGURE 6.6. GUIDEWAY LEADING INTO HOSPITAL BUILDING

The installation at Duke University represents a completed operating system. The system was financed privately, and the costs have not been released. UMTA has selected this Otis/TTD as one system for further study and developmental testing to prove out critical control system technology under the Advanced Group Rapid Transit (AGRT) Program.

6.1.2 Duke University System Details

The Duke University system was designed by Otis/TTD as an automated transportation system for people and cargo, connecting an existing hospital building with a new hospital facility and a new parking structure. Two passenger vehicles and one cargo vehicle carry hospital personnel, patients, visitors, and cargo approximately 400 m between the two hospital buildings on a two lane guideway. A separate car shuttles approximately 200 m on a single lane guideway extension between the new hospital building and the parking area.

The system uses non-contacting compliant air pad suspension and LIM propulsion. The guidance and switching functions use wheeled assemblies acting on guide rails on the guideway parapet walls. When the guidance assemblies are disengaged, the flat guideway surface with its flush reaction rail allow the vehicle to be moved laterally on the air pads for off-line berthing and vehicle removal to the maintenance area. The air pad suspension system also facilitates simple loading of the cargo vehicle onto an elevator for transfer to a different level.

6.1.2.1 Vehicles

The vehicles for the system at Duke University are derived from past testing and development carried out by Otis/TTD. The passenger/cargo module, customized for the specific requirements at Duke, has a design capacity of 22 passengers. The body shells of the passenger and cargo vehicles are the same, with two removable double-seat assemblies attached to the floor of the passenger vehicle. A chassis, or underframe, contains the running gear such as propulsion and braking, suspension system, electrical power equipment, propulsion control, and lateral guidance. The vehicles are operated bi-directionally as single units or in a two-car train. They are configured for the following performance characteristics:

a. maximum speed of 43.6 km/hr,

b. service acceleration/deceleration of 0.1 g,

c. longitudinal acceleration from zero to 0.1 g with longitudinal jerk limited to 0.1 g/s, and

d. maximum allowable limits for emergency braking and deceleration of 0.25 g and jerk of 0.25 g/s.

6.1.2.2 Propulsion and Braking

The vehicle is propelled by two linear induction motors mounted on the vehicle. Two identical primaries are wound side-by-side on an iron core and mounted along the bottom centerline of the chassis. Cooling is accomplished by forcing air through a shroud enclosing the LIM. The passive LIM secondary consists of an aluminum and steel sandwich embedded in the center of the guideway.

Power for the motor and other on board systems comes from a 480 V a.c., three-phase 60 Hz power supply with power collector assemblies mounted on opposite sides of the chassis.

A variable voltage, variable frequency (VVVF) power conditioning unit (PCU) controls the propulsion system. This PCU is a two stage unit which first rectifies the a.c. voltage to d.c. and then inverts the d.c. to a.c. at a variable frequency by means of pulse-width modulation. For braking, the LIM is reversed into a generating mode. If the d.c. link voltage exceeds 600 V, a thyristor feeds power to an on board load resistor to dissipate the excess energy. Final braking to a standstill is accomplished by "plugging" (i.e., thrust reversal at minimum inverter frequency).

6.1.2.3 Guideway

The guideway for the Otis/TTD system uses concrete as the primary structural material. The flat surface of the guideway includes a sealed "flying" surface for the air pads, the LIM reaction rail, and emergency braking skid surfaces. The parapet walls provide support for lateral guidance rails, power rails, signal rails, and the voice/data communications antenna.

The guideway at Duke University includes sections at-grade, elevated, and below grade. For the specific conditions at Duke, the double-lane section of guideway between the two hospital buildings includes a draw bridge to cross a railroad spur track.

6.1.2.4 Operations Control System

The Duke University system operation is completely automated with supervision by one dispatcher. Control and communications functions are executed by a combination of wayside and on board equipment. The computer control system can operate the passenger vehicle in a scheduled mode or a demand mode on either guideway section, while the cargo vehicle operates in a demand mode only. A fixed block headway central system protects the vehicles against collision and overspeed. Station control programs enable synchronized operation of vehicle and station doors.

6.1.3 System Capabilities

The Otis/TTD system technology lends itself to AGT installations in various activity centers. In an expanded form it can be applied to a larger area utilization, as in a central business district. With two-way operation, such as at Duke University, the capacity is dictated by travel time. The Duke system has a maximum line capacity of 800 passengers per hour per direction. With one-way operation on the guideway, an operational headway of 54 seconds is possible, giving a single lane capacity of 2,933 passengers per hour.

6.2 WEDway People Mover

The WEDway People Mover is an active track LIM-powered system in operation at the Walt Disney World recreation complex in Lake Buena Vista, Florida. The system, developed by Walt Disney Productions with corporate funding, began revenue operation in 1975. In the first application outside Disney properties, the system will be used to upgrade the people mover at Houston Intercontinental Airport.

6.2.1 System Background

The Disney World installation in the Magic Kingdom Theme Park consists of a single 1,400 m closed loop with one station. It moves as many as 3,600 passengers per hour on a tour through the Tomorrow Land and Theme Area as shown in Figures 6.7 and 6.8. The vehicles, being powered by single-sided LIMs in the guideway, are completely passive (i.e., they have no powered equipment on board). The concept evolved from earlier Disney installations at the New York's World's Fair and at Disneyland in Southern California, in which passive vehicles were propelled by electric motor driven rubber wheels mounted within the

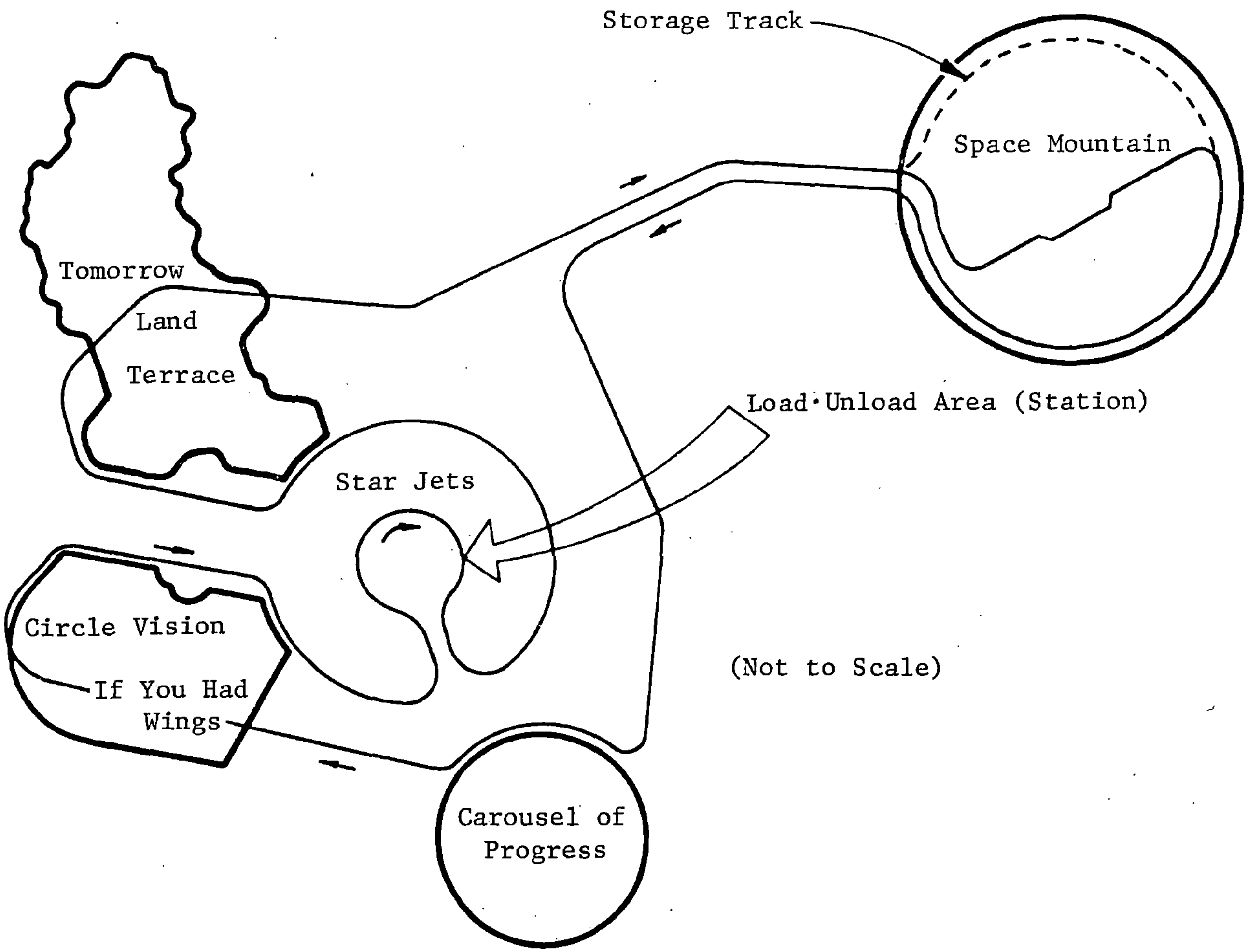


FIGURE 6.7. LAYOUT OF THE WEDWAY PEOPLE MOVER SYSTEM AT WALT DISNEY WORLD

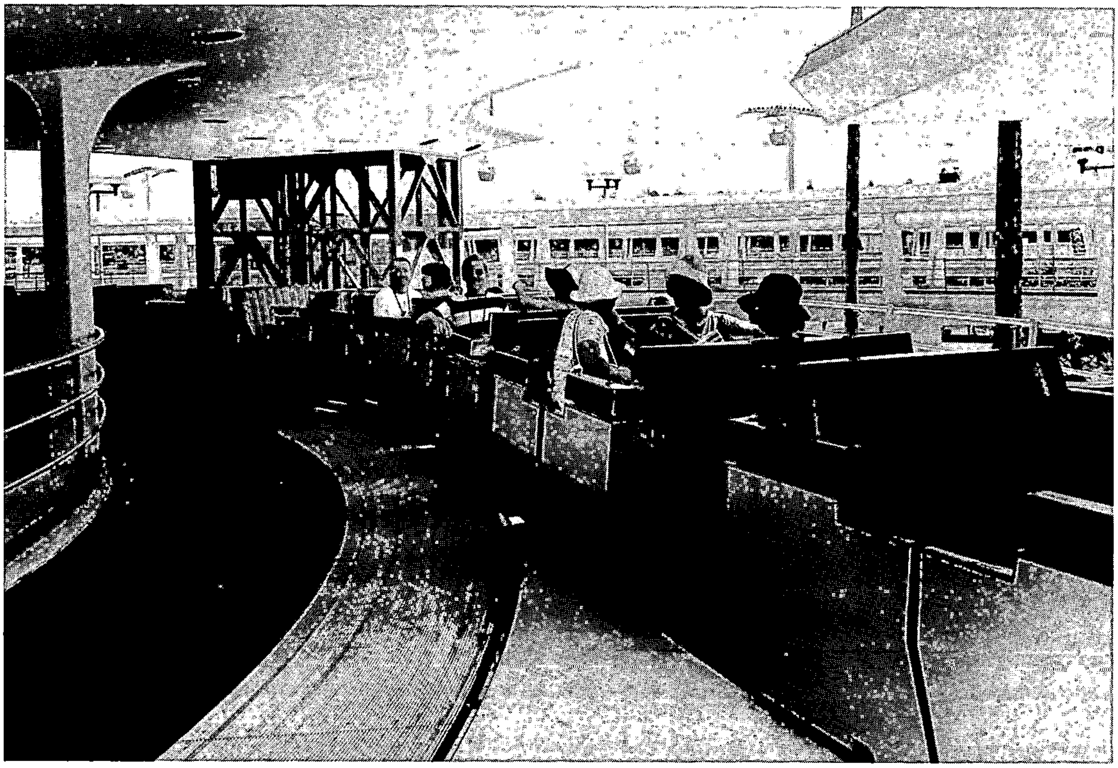


FIGURE 6.8. WEDWAY VEHICLES AT THE MOVING PLATFORM STATION

guideway. The advantage of LIM propulsion is that the thrust is independent of environmental conditions that would affect a frictional drive. LIM propulsion also eliminates the wear of mechanical drive elements. With passive vehicles the potential hazard of electrified power rails is eliminated.

6.2.2 Future Plans

Although the WEDway People Mover was originally developed for Disney properties, the organization is now marketing the system elsewhere. The concept has been certified by UMTA for federal aid projects. The Houston Intercontinental Airport has selected the WEDway concept to upgrade and extend its underground people mover system. When completed in 1981, the new 2.3 km loop will link three terminals and the airport hotel and parking area.

6.2.3 System Details

In the Disney World WEDway People Mover, small four-passenger vehicles operate in five-car trains that are open to the air. Support and guidance of the vehicles comes from urethane load-bearing and guidance wheels operating on tubular steel guideway beams of rectangular cross section. The guideway-mounted LIM primaries react with iron-backed aluminum reaction plates mounted on the bottom of the vehicles. Details of the vehicle and guideway are shown in Figures 6.9. and 6.10. The track is divided into zones of various speeds which vary from a maximum of approximately 11 km/hr to less than 3 km/hr in the revolving platform station area. The average speed over the loop is 8 km/hr. The spacing and configuration of the LIM active elements vary to meet speed and acceleration/deceleration requirements. In the constant speed areas the spacing is 10 feet (3.05 m), placing four motors under a five-car train. In the station area the spacing is five feet (1.52 m) and in the acceleration and deceleration zones it is 2.5 feet (.76 m). The motors are .38 m long, 64 mm thick and .25 m wide in the constant speed zones. The vehicle-mounted reaction plate is .36m wide with aluminum 3.2 mm thick backed by iron 6.4 mm thick. Each LIM element produces a nominal thrust of 400 N. The motors are driven with 240 V three-phase a.c., which is controlled by SCR circuitry to produce the actual desired thrust. The predetermined speed profile for the entire length of the system is stored in hardwired motor logic cards at a motor logic center for each zone. At each motor location a proximity sensor detects a vehicle reaction plate as it approaches and produces a signal to turn on the motor. A lead/lag sensor determines the actual vehicle speed. If a speed

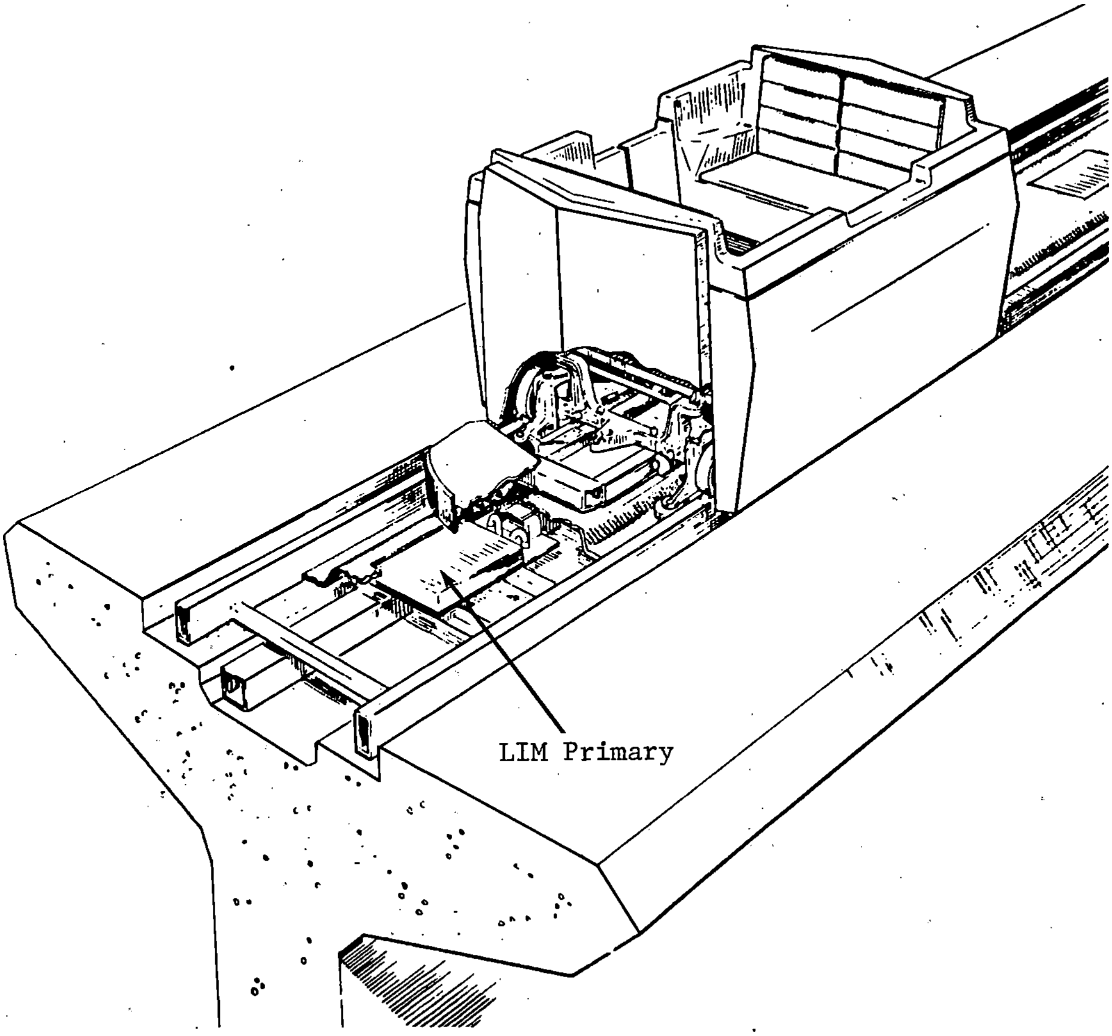


FIGURE 6.9. VEHICLE AND GUIDEWAY DETAILS FOR THE WEDWAY PEOPLE MOVER

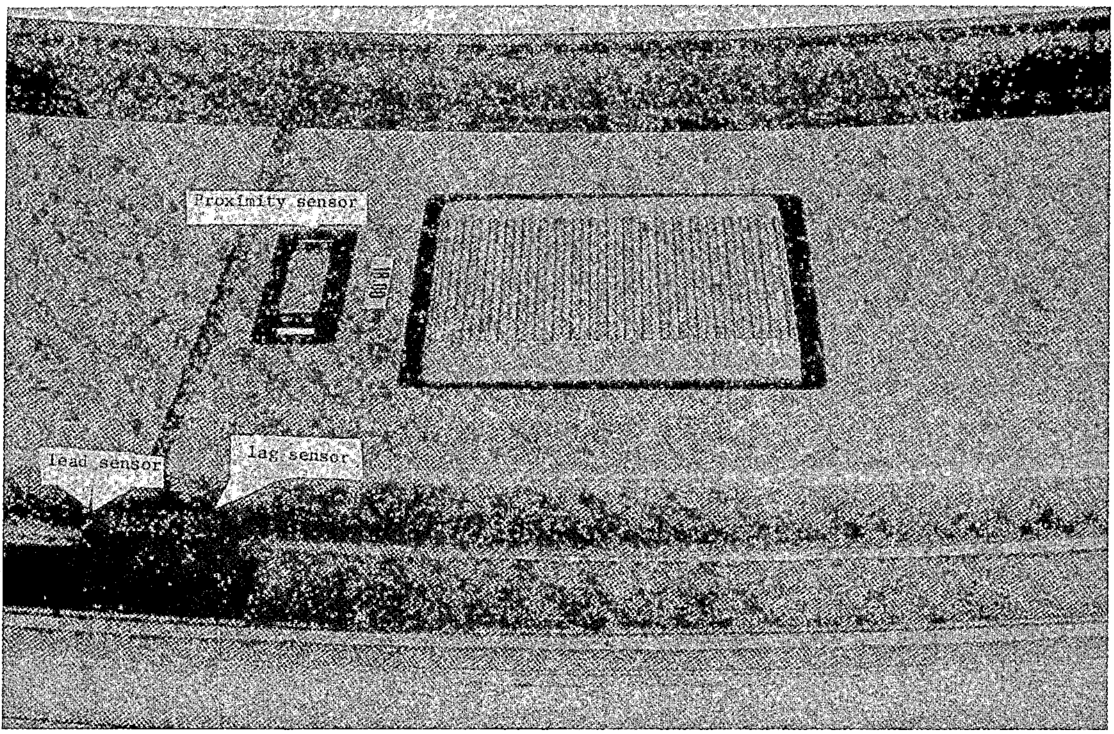


FIGURE 6.10. LIM PRIMARY AND SENSORS ON THE WEDWAY GUIDEWAY

correction is necessary, the control logic alters the thrust as required. Normal braking is accomplished by reversing the polarity of the motors to produce reverse thrust. In braking to a halt, the speed sensors shut off the motors as the speed reaches zero.

The Houston airport installation will be similar to that at Disney World, but with the vehicles configured to carry passengers and their baggage. Six three-car trains will be provided and each will carry 72 passengers. The top speed will be 22.5 km/hr and the normal waiting time will be 2.8 minutes.

6.3 Boeing Mag Transit

The Boeing Mag Transit concept integrates magnetic levitation and LIM propulsion into a single machine for a people mover or automated guideway transit system. The conception and initial development of the magnetic levitation system used in Mag Transit was accomplished by Rohr Industries under the ROMAG name. In the ROMAG system, single-sided linear electric motors are used for levitation, propulsion, braking, guidance, and suspension.

Rohr first exhibited a bottom-supported vehicle at TRANSPO 72. They then continued the development with the construction of two test tracks and a top-suspended vehicle as shown in Figure 6.11, at their Chula Vista, California plant. Figure 6.12 shows the application of the ROMAG motors in these vehicles. Rohr subsequently decided to withdraw from the automated transportation business. The Boeing Aerospace Company entered into a license agreement with Rohr in February 1978, to continue the development of the technology and to market the system. The Boeing Mag Transit concept reached the point of operation of passenger-carrying test vehicles under Rohr's development, but the demonstration of the combined non-contacting propulsion/suspension/guidance technology is the fundamental outcome of the program to date. Boeing plans to continue the development of the technology and to define a family of vehicles and guideway configurations for a variety of AGT applications. Figure 6.13 illustrates one possible vehicle suspension design in which the concept of using the LIM for guidance has been dropped. The development plans include the verification of system design and performance with an AGT shuttle prototype.

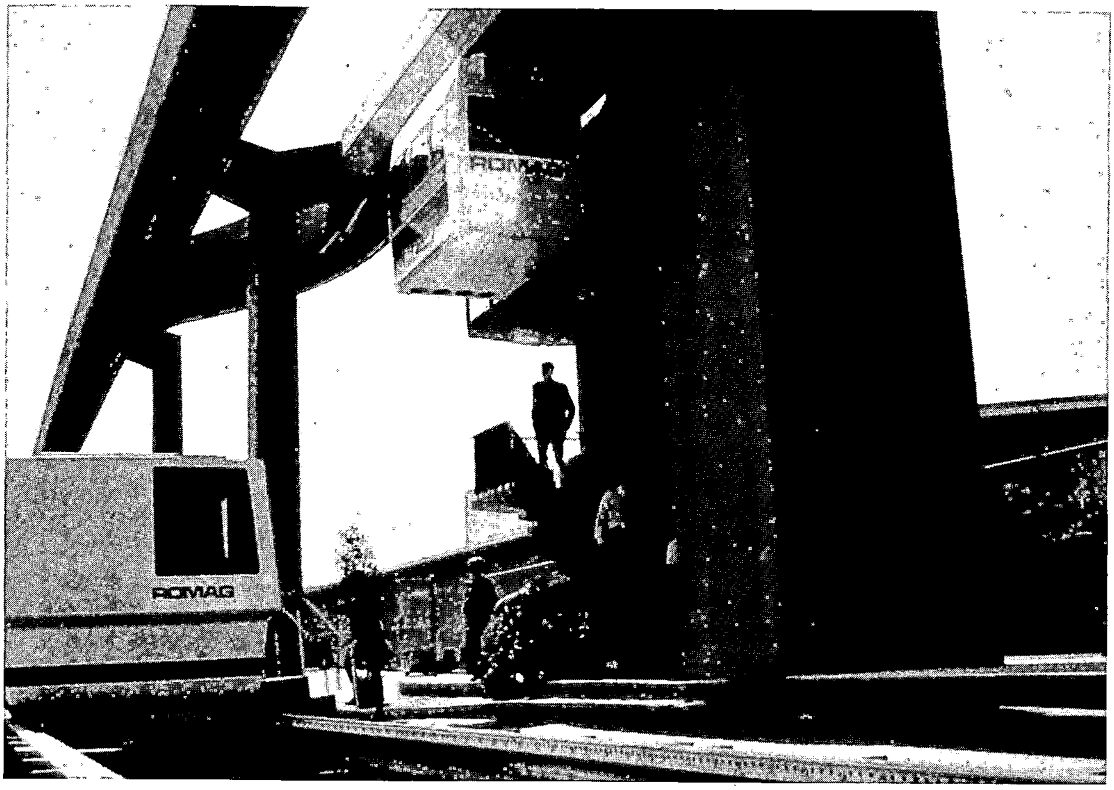
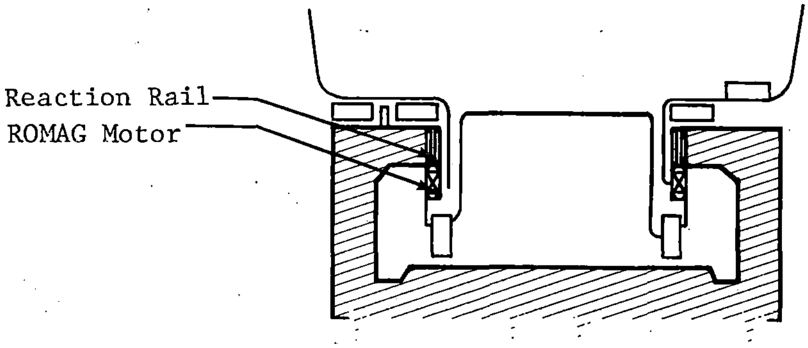
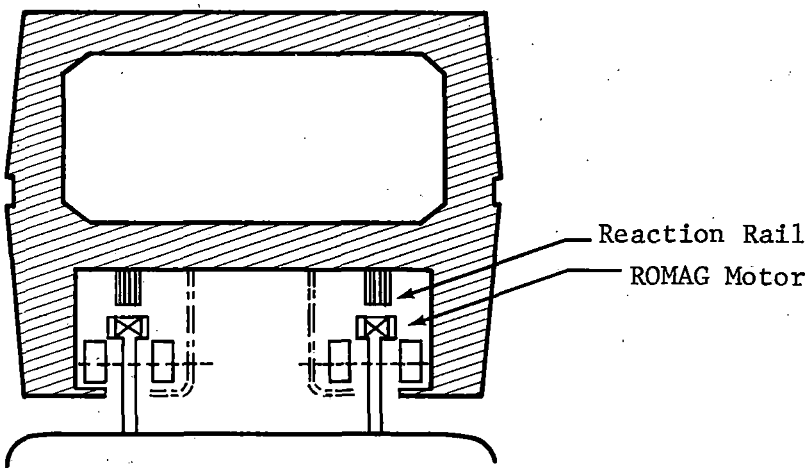


FIGURE 6.11. TOP SUSPENDED AND BOTTOM-SUPPORTED VEHICLES AT THE ROHR FACILITY IN CHULA VISTA, CALIFORNIA



Bottom-Supported Vehicle



Top-Suspended Vehicle

FIGURE 6.12. ROMAG SUSPENSION DESIGNS

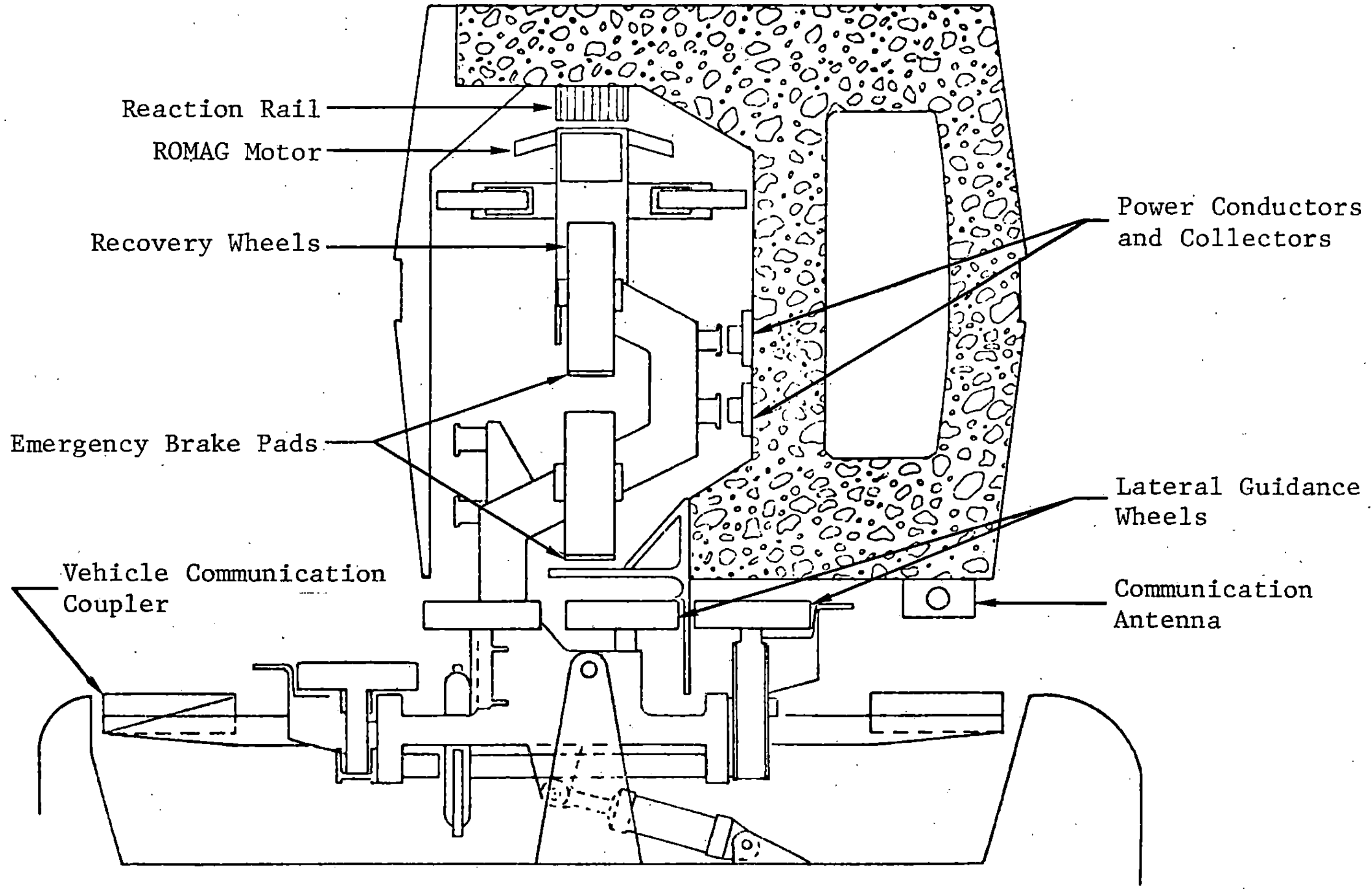


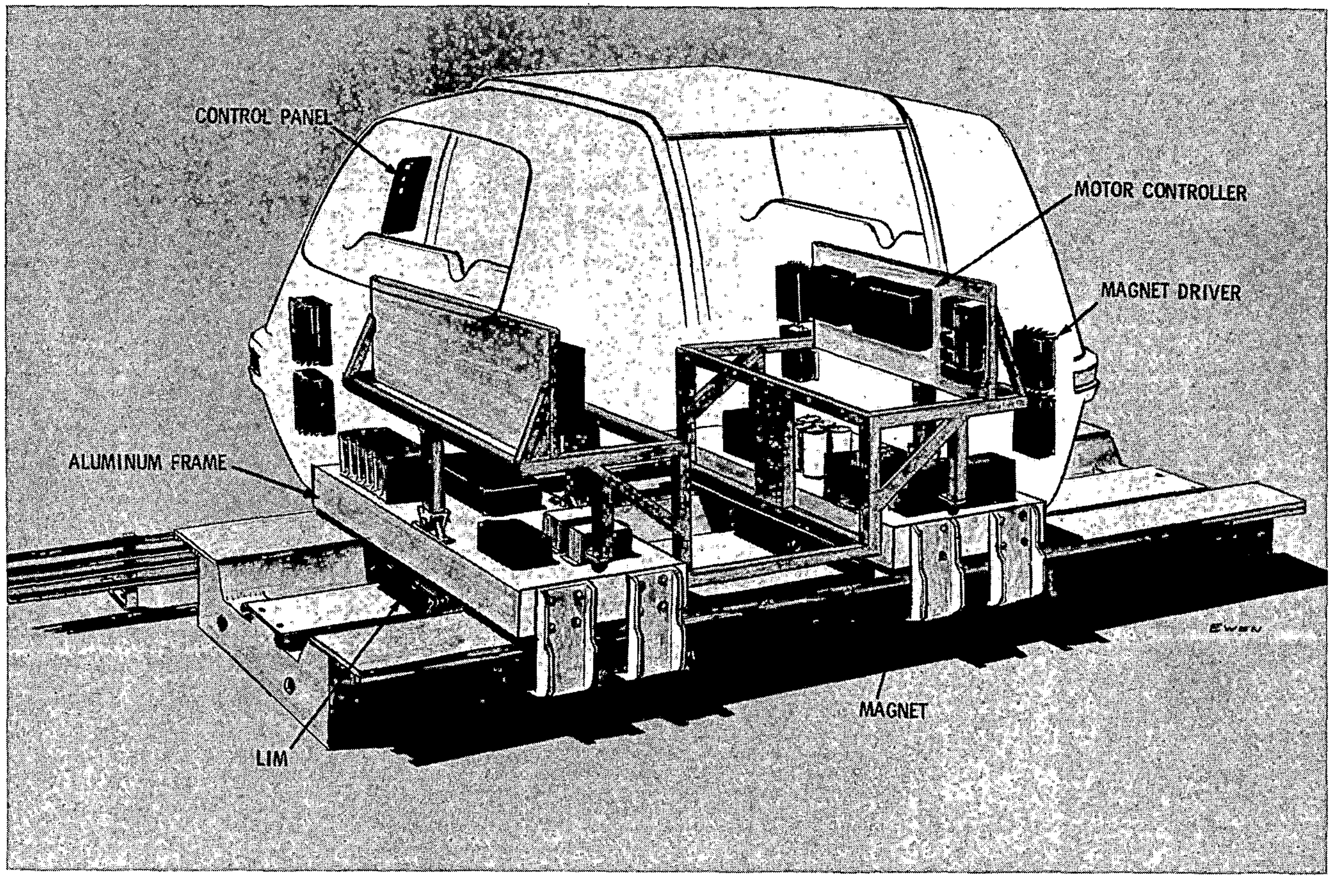
FIGURE 6.13. ONE OF SEVERAL PROPOSED SUSPENSION DESIGNS FOR BOEING MAG TRANSIT

6.4 General Motors Maglev Test Vehicle

The General Motors Research Laboratories has built and tested a magnetically levitated, LIM-propelled vehicle at the GM Technical Center in Warren, Michigan. The purpose of this program was to identify the practical problems of magnet control and longitudinal position control as they might appear in an operating personal rapid transit system.

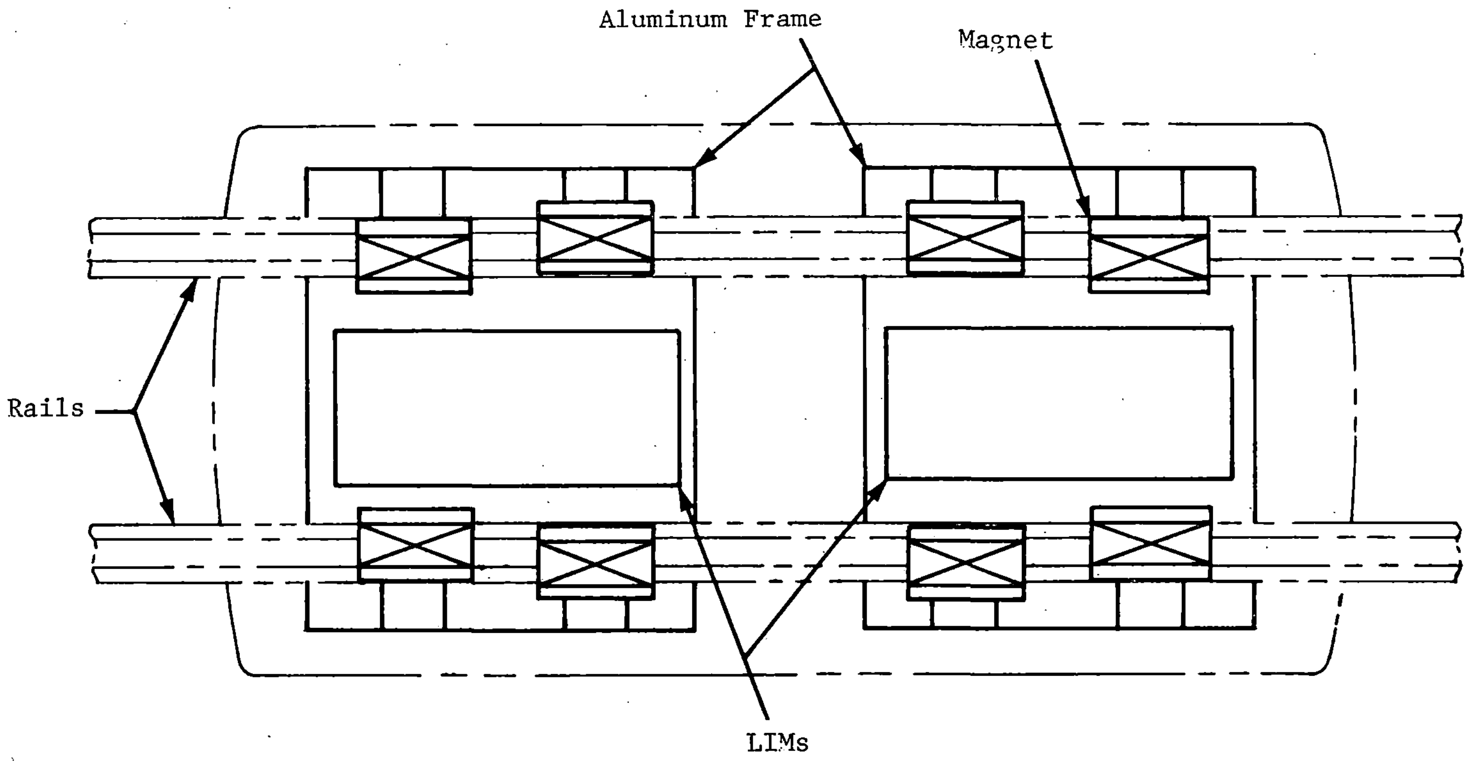
The vehicle, shown in Figure 6.14, has a loaded weight of 1,800 kg. Levitation and guidance are provided by eight U-shaped, controlled d.c. electromagnets that attract toward a U-shaped steel rail. Two magnets at each corner are slightly offset from the rail centerline so that each magnet produces both a vertical and a horizontal force component. The propulsion is provided by two parallel-connected single-sided linear induction motors. The arrangement of the magnets and LIMs is shown in Figure 6.15. Motor thrust is controlled by varying the magnitude and phase sequence of the applied voltage with two 60 Hz variable voltage power controllers. The reaction rail is of aluminum, 4.8 mm thick and 30.5 cm wide, backed with unlaminated iron 6.3 mm thick.

The longitudinal control system was designed to study the start/stop problems of an operating system. The test vehicle uses 15 m of guideway. On a demonstration ride the vehicle is programmed to automatically levitate, accelerate to 2.6 m/s, brake to a stop and then return. The acceleration and jerk levels are programmed to give a comfortable ride, and the vehicle stops with ± 20 mm of the desired stopping point. To date, the vehicle has made approximately 2,500 round trips.



Source: R. Fruechte, "Power Conditioning Systems for Magnetically Levitated Test Vehicle," IEEE Transactions on Vehicular Technology, Volume VT 29, Number 1, February 1980.

FIGURE 6.14. GENERAL MOTORS MAGLEV TEST VEHICLE



Source: R. Fruechte, "Power Conditioning Systems for Magnetically Levitated Test Vehicle," IEEE Transactions on Vehicular Technology, Volume VT 29, Number 1, February 1980.

FIGURE 6.15. UNDERSIDE OF GENERAL MOTORS MAGLEV TEST VEHICLE

MITRE Department
and Project Approval: P. Wood
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