UMTA-MA-06-0069-81-3
[illegible]-TSC-UMTA-81-34

Interim Assessment of the VAL Automated Guideway Transit System

U.S. Department of Transportation
Transportation Systems Center
Cambridge MA 02142

Ministere des Transports
Institut de Recherche
des Transports
B.P. 2894110 Arcueil

November 1981
Interim Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Urban Mass Transportation Administration

Office of Technology Development and Deployment
Washington DC 20590

Secretariat d' Etat
auprè du Ministere des
Transports et de
l'Amenagement du
Territoire (Transports)
75775 Paris Cedex 16

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-MA-06-0069-81-3	PB 82-163783	

4. Title and Subtitle	
Interim Assessment of the VAL Automated Guideway Transit System.	5. Report Date: November 1981
	6. Performing Organization Code: DTS-723
7. Author(s): G. Anagnostopoulos	8. Performing Organization Report No.: DOT-TSC-UMTA-81-34
9. Performing Organization Name and Address: U.S. Department of Transportation* Transportation Systems Center Kendall Square Cambridge, Massachusetts 02142	10. Work Unit No. (TRAIS): MA-06-0069(UM136/R1764)
	11. Contract or Grant No.: MA-06-0069
12. Sponsoring Agency Name and Address: U.S. Department of Transportation** Urban Mass Transportation Administration 400 Seventh Street, S.W. Washington, DC 20590	13. Type of Report and Period Covered: Interim Report August 1980
	14. Sponsoring Agency Code: UTD-10

15. Supplementary Notes

*Ministere des Transports
Institut de Recherche des Transports
B.P. 2894110 ARCUEIL

**Secretariat d'Etat auprè du Ministere des Transports et de l'Amenagement du Territoire (Transports)
75775 Paris Cedex 16

16. Abstract

Automated Guideway Transit (AGT) systems represent one new transit mode which may have the potential of meeting the current transportation needs in a cost-effective manner. The issues raised relative to these complex, unmanned AGT systems include capital and operating costs, reliability, maintainability, safety, security, and comfort. The Urban Mass Transportation Administration has initiated a program to assess and evaluate transit technologies in order to provide technical information for possible urban deployment. This report describes an interim assessment of the VAL (Véhicules Automatiques Légers or Light Automated Vehicle) AGT system which is currently under construction in Lille, France, and which is to become fully operational in December 1983. This report contains a technical description and performance data resulting from a demonstration test program performed concurrently in August 1980. This assessment was performed in accordance with the Memorandum of Understanding between the French Ministry of Transportation and the U.S. Department of Transportation concerning research and development cooperation in transportation. VAL is the first driverless AGT urban system application in France. The system operates at grade, elevated, and in tunnels on an exclusive concrete dual-lane guideway that is 12.7 kilometers long. The configuration of the system is a push-pull loop operating between 17 on-line stations. The system is designed to provide scheduled operation at 60-second headways and a normal one-way capacity of 7440 passengers per hour per direction with 55 percent of the passengers seated. Two pneumatic-tired vehicles are coupled into a single vehicle capable of carrying 124 passengers at line speeds of 60 km/hr. During the course of the demonstration test program, VAL demonstrated that it could achieve high levels of dependability and availability and could perform safely under all perceivable conditio

17. Key Words	18. Distribution Statement
AGT; Automated Guideway Transit; Driverless Transportation System; Light Automated Vehicle; Lille, France; VAL; Véhicules Automatiques Légers	Available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	200	A09

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Technical Report Documentation Page

1. Report No. UMTA-MA-06-0069-81-3	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
INTERIM ASSESSMENT OF THE VAL AUTOMATED GUIDEWAY TRANSIT SYSTEM

5. Report Date
November 1981

6. Performing Organization Code
DTS-723

7. Author(s)
G. Anagnostopoulos

8. Performing Organization Report No.
DOT-TSC-UMTA-81-34

9. Performing Organization Name and Address

U.S. Department of Transportation
Transportation Systems Center
Cambridge MA 02142

Ministere Des Transports
Institut de Recherche des Transports
B.P. 2894110 ARCUEIL

10. Work Unit No. (TRAIS)
UM136/R1764

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

U.S. Department of Transportation
Urban Mass Transportation Administration
Office of Technology Development and Deployment
Office of Socio-Economic & Special Projects
Washington DC 20590

Secretariat d' Etat
auprè du Ministere des Transports
et de l'Amenagement du Territoire
(Transports)
75775 Paris Cedex 16

13. Type of Report and Period Covered
Interim Report
August 1980

14. Sponsoring Agency Code
UTD-10

15. Supplementary Notes

16. Abstract

This is an interim assessment of the VAL (Véhicules Automatiques Légers or Light Automated Vehicle) Automated Guideway Transit (AGT) system which is currently under construction in Lille, France. It is to become fully operational in December 1983. VAL is the first driverless AGT urban system application in France. The system operates at grade, elevated, and in tunnels on an exclusive concrete dual-lane guideway that is 12.7 kilometers long. The configuration of the system is a push-pull loop operating between 17 on-line stations. The system is designed to provide scheduled operation at 60-second headways and a normal one-way capacity of 7440 passengers per hour per direction with 55 percent of the passengers seated. Two pneumatic-tired vehicles are coupled into a single vehicle capable of carrying 124 passengers at line speeds of 60 km/hr.

This interim assessment contains a technical description and performance data resulting from a demonstration test program carried out in August 1980.

17. Key Words
VAL
Automated Guideway Transit (AGT)
Driverless Transportation System

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	206	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

Automated Guideway Transit (AGT) systems represent one new transit mode which may have the potential of meeting the current transportation needs in a cost-effective manner. The issues raised relative to these complex, unmanned AGT systems include capital and operating costs, reliability, maintainability, safety, security, and comfort. The Urban Mass Transportation Administration (UMTA) of the U.S. Department of Transportation (DOT) has initiated a program to assess and evaluate transit technologies in order to provide technical information for possible urban deployment.

This report describes an interim assessment of the VAL (Véhicules Automatiques Légers or Light Automated Vehicle) AGT system which is currently under construction in Lille, France and is to become fully operational in December 1983. The report also contains a French translation of the Executive Summary. This interim assessment of the VAL system was conducted concurrently with a demonstration test program in August 1980. The assessment program was sponsored by the UMTA Office of Socio-Economic and Special Projects. This assessment was performed in accordance with the memorandum of understanding between the French Ministry of Transportation and the U.S. DOT concerning research and development cooperation in transportation. The assessment consisted of a technical review of the system, on-site inspection, measurements, technical interchange with personnel from the system operator and developers, analyses, and evaluation.

The demonstration tests were conducted at the Lille Metro Operational Test and Maintenance Facility by MATRA Corporation and its subcontractors. Technical interchange was conducted with MATRA in cooperation with the Institute de Recherche des Transports (IRT), the representative from the French Ministry of Transportation; EPALE, the public agency for the development and management of the New City of East Lille under the French Government; and CUDL, the Lille Community Development Authority. The descriptive material included in this report was primarily supplied by MATRA. This report was prepared by the Transportation Systems Center (TSC) of the U.S. DOT.

Acknowledgement and special thanks are given to the MATRA team and representatives of the IRT, EPALE and CUDL for their information and cooperation during the conduct of this interim assessment program. Without their cooperation this program would not have been possible. The overall effort was a well coordinated team effort, especially the demonstration test program, and it is of course difficult to single out individuals for their special efforts. However, an attempt will be made to acknowledge some outstanding individual efforts. Acknowledgement and special thanks are given to: Claude Soulas of the IRT for his translation of the Executive Summary and for his overall assistance and cooperation; Francois Tremong of MATRA, who was resonsible for and coordinated this assessment and demonstration test program effort; Daniel Bourasseau of MATRA for his conduct of a well run demonstration test program; J. Patrick Galopin of MATRA for overall technical assistance on the system and its operation; Samuel Mimoun, J.P. Vervaecke, A. Maire, and J.P. Derambure of the MATRA team for their technical understanding of the control system and its operation; Michel Ficheur of EPALE for his understanding of the system operator's viewpoint; and B. Guilleminot of CUDL for his overview of the civil engineering infrastructure. In addition, special thanks are given Fred Rutyna of TSC for his overall assistance.

George Anagnostopoulos,
Project Engineer

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

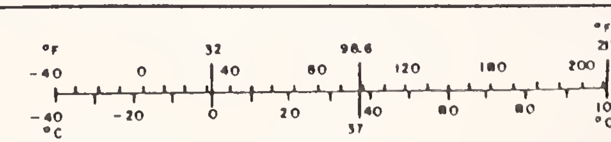


TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

LIST OF ACRONYMS

AGT	Automated Guideway Transit
ASMD	push-recovery speed limit
AVC	Automated Vehicle Control
AVO	Automated Vehicle Operation
AVP	Automated Vehicle Protection
AVS	Automated Vehicle Supervision
CC	Control Center
CCTV	closed-circuit TV
CIMT	Compagnie Industrielle de Matériel de Transport
CRT	Cathode Ray Tube
CUDL	Communauté Urbaine de Lille
DOCU	Dwell Operation Control Unit
DOT	U.S. Department of Transportation
DTT	Direction des Transports Terrestres (Ministere des Transports)
DTU	Data Transmission Unit
DVC	deceleration order
EB	emergency brake
EPALE	Establissement Public d'Aménagement de la ville nouvelle de Lille-Est
FU	emergency brake command
HR	The chopper unit of the "married pair" VAL vehicle
IRT	Institute de Recherche des Transports
MATRA	SA MATRA Transport Systems Division
MNV	normal mode
MPV	perturbed mode
ND	negative detection
PA	The control unit of the "married pair" VAL vehicle
PD	positive detection
PEPD	direct electropneumatic pilot
PP	perturbed program
PR	power rectifier
RATP	Régie Autonome des Transports Parisiens
REB	reset emergency brake
SF	safe frequency

SF_a	safe frequency (arrival)
SF_b	safe frequency (departure)
TCO	Traction CEM-Oerlikon
TSC	Transportation Systems Center
UD	ultrasonic detector
UMTA	Urban Mass Transportation Administration
VAL	Véhicules Automatiques Légers or Light Automated Vehicle
VC	commanded speed
V_F	filter voltage
V_p	programmed speed
VR	real vehicle speed
WCCU	Wayside Control and Communications Unit

EXECUTIVE SUMMARY

INTRODUCTION

The objective of this interim assessment of the VAL (Véhicules Automatiques Légers or Light Automated Vehicle) system which is currently under construction in Lille, France was to determine the state of technological advancement; review problems and solutions encountered during design, development and implementation; obtain preliminary engineering and economic information; and provide urban planners with information on applicability of this system to their specific transportation problems. To make this determination, an extensive series of tests was performed at the test track in Lille with the first two production vehicles. These first two vehicles are to be used for engineering development. In the development cycle, they are currently undergoing systems integration tests. This integration testing is to be completed by June 1981, when qualification tests will be performed. Hence, this interim assessment is an investigation of the technological development as of August 1980. (See Figure ES-1.)

BACKGROUND

In 1970, EPALE, the public office for the development of East Lille under the French Government, and CUDL, the Lille local community development authority, determined that there was a requirement for a short headway system with a capacity of about 6000 passengers per hour per lane, with frequent service and a high ratio of seated-to-standing passengers. After EPALE's release of a request for proposal and a competitive design effort, MATRA was selected in February 1972 as the system manager and developer of the command and control system. Associated with MATRA were CIMT and TCO, who were responsible for development of the vehicle and propulsion systems, respectively. MATRA won the competition with a medium-sized fully-automated system with pneumatic tires. This was to be the first implementation of a fully-automated system in an urban environment in France.

From 1971 to 1975 a prototype development program was conducted which included the design, development and testing of two prototype vehicles on a 1.7-km test track in Lille. This development phase cost 45 million French francs (approximately $9 million).

FIGURE ES-1. VAL SYSTEM

After numerous studies and public inquiry, final authorization was granted in December 1976 for the 12.7-kilometer Line 1 shown in Figure ES-2. In April 1977, MATRA was awarded a contract for the engineering and production of rolling stock, the command and control, and the fixed equipment including the track, electrification, and the maintenance and test facilities. All civil engineering and construction of the guideway was the responsibility of CUDL.

The first 2 of 38 production vehicles were delivered in July 1979. These first two vehicles were to be used for engineering development. Testing and development of all components and subsystems had been completed. Currently, VAL is undergoing system level tests to assure integration of all subsystems. Any modifications resulting from these tests will be incorporated in the later production vehicles. System qualification tests, analogous to aircraft acceptance tests, are to be performed with 4 production vehicles in October 1981. Revenue operation is to be initiated on the first section of line with 4 stations in January 1982, and expanded to 13 stations in March 1983. Full line operation with all 17 stations is to be initiated in December 1983.

The overall cost of the VAL Lille system is 1650 million French francs ($387.75 million in 1979 dollars). The total MATRA contract is approximately 532 million French francs ($108.2 million in 1977 dollars). MATRA also has a fixed-cost contract for maintenance of the system during the first 5 years of operation. In addition, MATRA also has a cost-plus-incentive contract to maintain the established operating cost over the 5 years. Because MATRA is not a transit operator, COMELI, a 50-percent owned subsidiary, was established to operate the system. TRANSEXEL, a bus and metro system operator, owns the other 50 percent.

TECHNICAL DESCRIPTION

The VAL Lille Metro is a fully-automated, urban public transit system designed to transport passengers between the new town of East Lille, the Lille city center and the Regional Hospital Center. This Automated Guideway Transit (AGT) system operates at grade, elevated, and in tunnels on an exclusive concrete dual-lane guideway that is 12.7 kilometers long. The configuration of the system is a push-pull loop operating between 17 on-line stations.

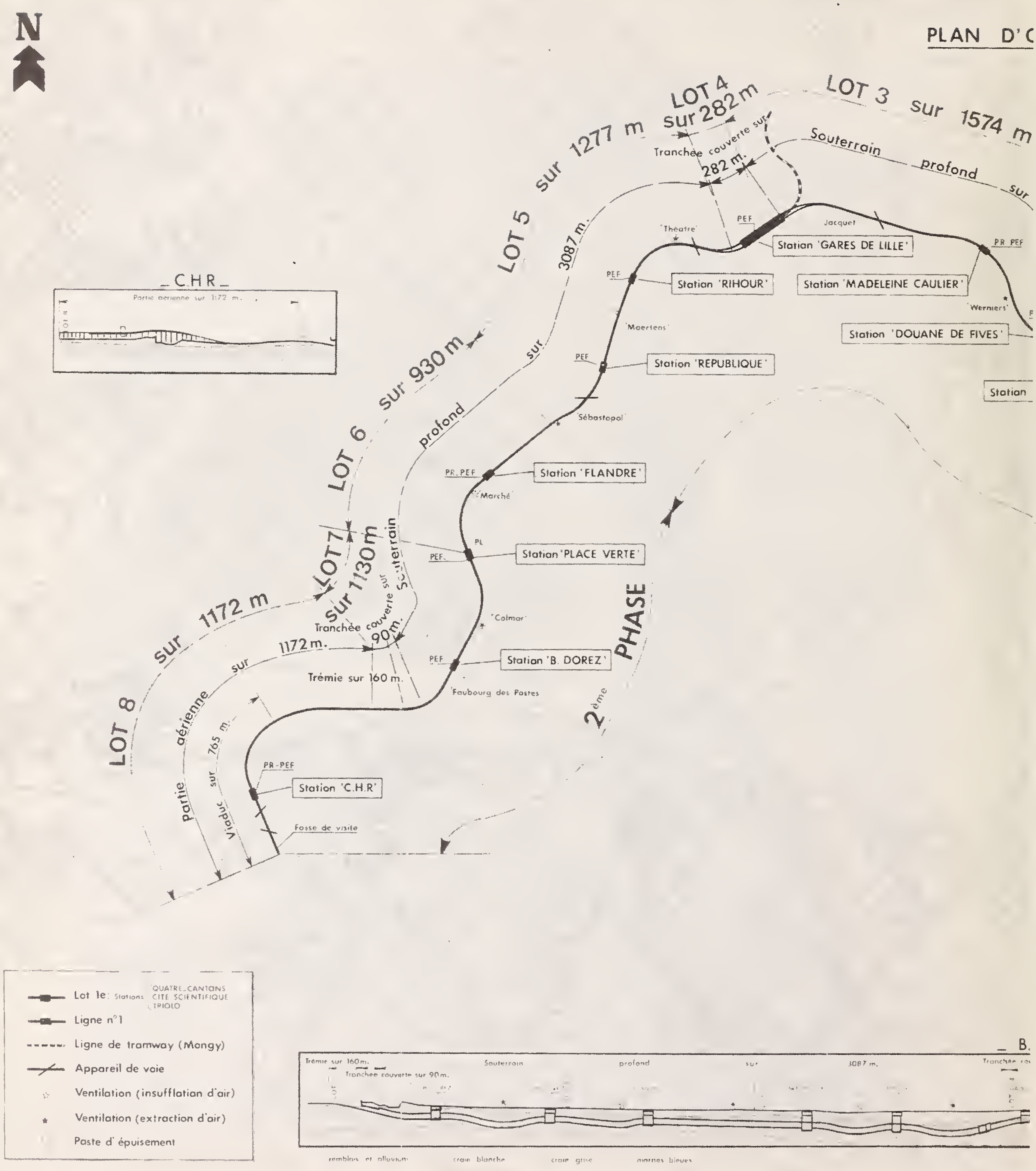


FIGURE ES-2. LILLE METRO PLAN -- LINE 1

D' ORIENTATION

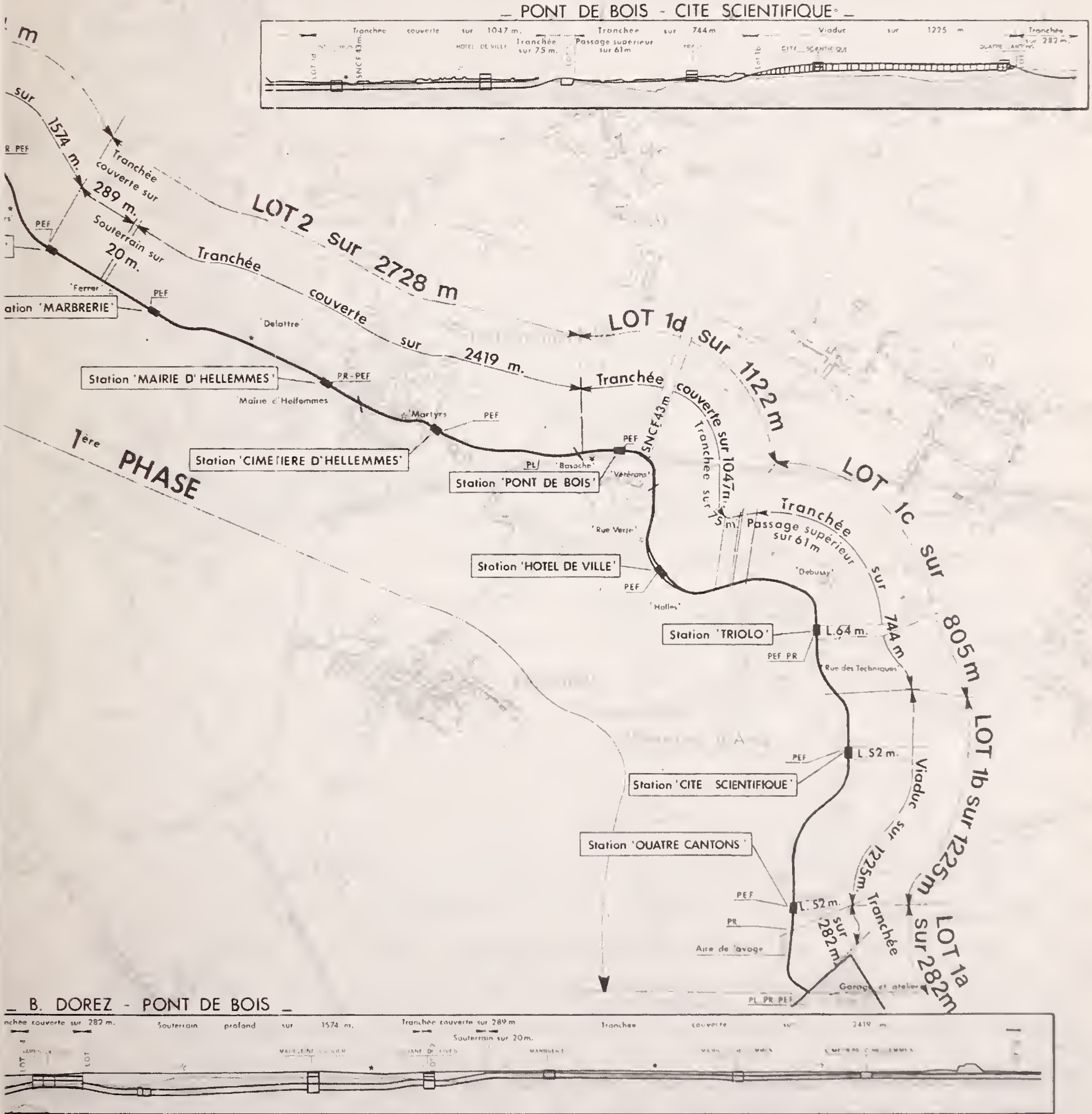


FIGURE ES-2. CONTINUED

Each vehicle unit is a narrow (2 meters wide), light-weight structure 12.7 meters in length. Two vehicle units are permanently coupled together into a vehicle capable of reverse operation. This "married pair" is made up of a chopper (HR) unit and a control (PA) unit. The chopper unit contains the essential propulsion control equipment for the vehicle (married pair) and the control unit contains the automatic control equipment for the vehicle (married pair).

Each vehicle unit is supported on four pneumatic rubber tires. It is equipped with two pivoting axles that are guided laterally by a set of four rubber-tired guidance wheels which run between two steel steering rails. The vehicle suspension is a variable pressure, air bag suspension.

Switching is performed by an auxiliary system with two vertical steel guidewheels which function only in the switch area. The switching wheels interface with two steel rails mounted in the guideway. Switching is effected by a wayside actuator that bends two cantilevered sections of rail laterally (see Figure 3-6). Switching lock-to-lock is accomplished within 3 seconds.

Two 120-kilowatt dc motors propel each vehicle unit through a differential in each axle. The motors are mounted to the body to reduce the unsprung weight.

Automatic control of the vehicle is by Central Control of a conventional fixed block system with an added level of safety electronics on board the vehicle to provide speed control. A hardwired inductive loop system provides presence detection of each vehicle. A second inductive loop system with regulated crossovers provides a reference for speed regulation. The control system consists of three major functional subsystems: Automatic Vehicle Protection (AVP); Automatic Vehicle Operation (AVO) and Automatic Vehicle Supervision (AVS). The Automatic Vehicle Protection system ensures safety of all Automatic Vehicle Operation functions under all conditions. The AVS provides the means to manage system operations.

The system is designed to provide operation at 1-minute headways during peak hours and 5-minute headways during off-peak hours. This is based on an average speed of 35 km/hr which includes a station stop of 14 seconds. The normal one-way design capacity is 7440 passengers per hour per direction with 55 percent of the passengers seated. The normal seating capacity of each vehicle unit is 34 seated and 28 standees for a vehicle unit total of 62 and a vehicle total of 124.

Some of the more important technical and operational characteristics of the VAL system are summarized in Table ES-1.

Assessment

The Lille-VAL system is the first fully-automated, driverless, urban transportation system of the AGT type to be implemented in France. The system has been under development for roughly 10 years. This has resulted in a high level of developmental maturity. High level of developmental maturity is defined as a system development that: 1) has completed the prototype development stage; 2) has completed development of a production system for urban deployment; and 3) is based on hardware and software deployed elsewhere in an urban application. The overall developmental approach has been conservative to minimize risk. Where possible, tried and proven hardware that has been in use in other transportation systems has been selected; e.g., the drive motors and associated chopper controls. Where proven hardware was not available, an approach was taken that was a small evolutionary advance beyond the state-of-the-art. For example, the control system is a conventional fixed block system for presence detection supplemented by a higher level of electronics to provide the speed regulation function and to ensure control system safety. The latter represent functions normally performed by the driver.

To determine the system performance capabilities of the VAL system an extensive series of tests was performed in August 1980 with the first two production vehicles at the Lille Metro Test and Maintenance Facility. The tests were oriented at determining the system characteristics of the Lille Metro related to safety, dependability and performance. The following is a summary of the assessment and major findings of the test program.

- All system functions and operations, including individual vehicle control, were accomplished satisfactorily and without major problems. A comparison of the test results with the VAL published operational capacity and technical specifications indicated good agreement.
- Safety of the system has been studied extensively. Numerous tests were performed for verification. The safety systems in all instances of the test program performed successfully. No mishap or incident was recorded or observed. The VAL system has been designed to be safe and appears to meet all U.S. safety standards with the exception of the door closing force, which is approximately seven times greater than the U.S. maximum.

TABLE ES-1. SUMMARY OF VAL SYSTEM CHARACTERISTICS

Automation	Fully Automated
Type of Service	Line haul
Maximum Theoretical One-Way Capacity	12480 pass/hr
Maximum Practical One-Way Capacity	9600 pass/hr
Normal One-Way Capacity	7440 pass/hr
Headway (min)	35-40 sec
Normal Operating Speed	60 km/hr
Average Speed	35 km/hr
Max Grade	7%
Traveling Unit	married pair
Vehicle Capacity	68 seated; 56 standees
Vehicle Crush Capacity	44 seated; 164 standees
Availability	20 hrs; scheduled
Stations	17 on-line stations
Guideway	12.7 km; elevated; at grade; and tunneled
Switches	Wayside; bending of cantilevered rail
Capital Cost	1650 million French francs ($387.75 million in 1979 dollars)

- Evacuation is through the normal side exit doors onto a guideway platform level with the floor. Evacuation of a fully-loaded vehicle is possible within 20 seconds, providing an adequate and reasonable margin of time in the event of a fire. This configuration makes possible easy evacuation for elderly and handicapped in wheelchairs.
- Fire retardant materials have been used throughout the vehicle. Differences between French and American material standards have not been examined in detail. Overall, they appear to be similar.
- The door closing force was found to be about 980 newtons. This is approximately seven times greater than the U.S. maximum of 133.4 newtons (30 pounds). Redesign of the door closing mechanism is necessary to meet U.S. standards.
- The interior of the vehicle unit is narrow (1.96 m or 6.43 ft). This approach was taken to decrease civil engineering costs and to increase the number of seated passengers. Some inconvenience has been experienced in sitting in the center seats. However, this inconvenience is greatly offset by a large number of wide doors that provides rapid entry and egress, minimizing station dwell time and waiting time.
- Entry and egress presented no problem to a handicapped person in a wheelchair.
- A 20-hour per day, 100-hour dependability test was conducted entirely in an automated mode with a single vehicle. The objective of these tests was to obtain preliminary dependability data on the VAL system.

  Because the system integration phase was not completed, only an indication of the potential performance of the system was concluded. The average availability for the 100-hour test was 0.959. On the final day of testing an availability of 0.997 was achieved.

  The principal cause of malfunctions was attributable to poor communications between the vehicle and station. In all instances the condition was cleared by Central Control through restart, retransmission of commands, and reinitiation of procedures. This demonstrated the flexibility of the software and the flexibility given to the Central Control operator to remotely circumvent problems in real time.

- The maximum vehicle interior noise level of 75 dbA at 60 km/hr was higher than desirable (70 dbA). The noise level was attributed to universal joints in the drive line. A change has been designed that is expected to reduce the noise to an acceptable level.

- Braking in the final station stopping loop was found to be somewhat erratic. A redesign of this brake loop has been completed, but was not implemented at this time.

- Aesthetically the elevated guideway appears more massive than necessary. This is due to the high concrete parapet walls. These were used in Lyon and Marseilles. Their acceptability in these locations was a prime determinant for their use in Lille in spite of questions raised over aesthetics.

- The command and control system represents an evolutionary step beyond rapid rail automatic vehicles with manual override. A more extensive Automatic Vehicle Protection system has been developed to take the place of the manual override. The safety system was extensively tested. The control system's performance was satisfactory. Headways of less than 60 seconds were satisfactorily demonstrated.

- Automatic coupling and push recovery were successfully demonstrated. This capability will enhance system availability.

RESUME D'ENSEMBLE

INTRODUCTION

L'objectif de cette évaluation intermédiaire du système VAL (Véhicules Automatiques Légers *) actuellement en construction à Lille, France, était le suivant :

- Déterminer l'état d'avancement technologique
- Faire le point des problèmes et des solutions aparus au cours de la conception, du développement et de la réalisation
- Obtenir les premières informations techniques et économiques
- Fournir aux urbanistes des renseignements sur l'adaptation du système à leurs problèmes de transport spécifiques.

Pour atteindre ce but une importante série d'essais a été effectuée sur la piste d'essais de Lille, à l'aide des deux premiers éléments de série. Ces deux premiers éléments serviront au développement industriel. Dans le cycle de développement ils subissent actuellement les essais d'intégration. Ceux-ci seront terminés en juin 1981, lorsque l'on effectuera les essais de qualification. En conséquence cette évaluation intermédiaire est une estimation de l'état de développement technologique à l'instant présent. (Voir fig. ES 1.)

PRESENTATION

En 1970, l'EPALE, Etablissement Publique pour le développement de Lille- Est, sous la tutelle du gouvernement français et des autorités locales de développement de la communauté urbaine (CUDL), détermina qu'il existait un besoin pour un système à faible période caractérisé par une capacité d'environ 6000 passagers par heure et par sens, une fréquence élevée et une bonne proportion de places assises par rapport aux places debout. Suite à l'appel d'offre lancé par l'EPALE et à un concours, MATRA fut sélectionné en février 1972 comme ensemblier et chargé du développement du système de commande et contrôle. CIMT et TCO furent associés à MATRA en tant que responsables respectifs du développement du véhicule et des systèmes de propulsion. MATRA gagna le concours avec un véhicule de taille moyenne, entièrement automatisé, et sur pneus. Ce sera la première implantation d'un système entièrement automatique en milieu urbain en France.

---

* A l'origine Villeneuve d'Ascq-Lille.

Un programme de développement incluant la conception, la construction et les essais de deux véhicules prototypes (sur une piste d'essais de 1,7 km à Lille) fut exécuté de 1971 à 1975. Cette phase de développement a coûté 45 millions de francs français (approximativement $ 9 millions).

Après de nombreuses études et une enquête publique la décision finale fut accordée en décembre 1976 pour les 12,7 km de la ligne 1 montrée sur la fig. ES.2. En avril 1977 un contrat fut adjugé à MATRA pour l'ingénièrie et la production du matériel roulant, de la partie commande et contrôle, et des équipements fixes incluant la voie, l'électrification, et les installations de maintenance et d'essai. L'ensemble du génie civil et de la construction de la voie est sous la responsabilité de la CUDL.

Les deux premiers des 38 éléments de série ont été fournis en juillet 79. Ces deux premiers éléments ont été utilisés pour le développement industriel. Le développement et les essais de tous les composants et sous-systèmes sont terminés. Actuellement le VAL subit les essais d'ensemble du système pour assurer l'intégration de tous les sous-systèmes. Toutes les modifications résultant de ces essais seront incorporées dans les futures éléments de série. Les essais de qualification du système, similaires aux essais de réception des avions, seront exécutés avec 4 éléments de série en octobre 1981. L'exploitation commerciale commencera en janvier 1982 (4 stations), mars 1983 (13 stations) et decembre 1983 (17 stations - ligne complete).

Le coût total du système VAL de Lille est de 1.500 millions de francs français (300 millions de dollars). Le montant du contrat MATRA s'élève approximativement à 450 millions de francs (90 millions de dollars). MATRA a également un contrat à coût fixe pour la maintenance du système pendant les cinq premières années d'exploitation. En plus, MATRA a aussi un contrat avec incitation pour maintenir les coûts d'exploitation établis pour les cinq premières années. Puisque MATRA n'est pas un exploitant, COMELI filiale à 50 % a été créée pour exploiter le système. TRANSEXEL exploitant de bus et métros possède les 50 % restant.

DESCRIPTION TECHNIQUE

Le métro de Lille VAL est un système de transport public urbain entièrement automatique conçu pour transporter des passagers entre la ville nouvelle de Lille-Est, le centre ville de Lille et le centre hospitalier régional. Ce système automatique guidé (en anglais AGT) fonctionne au niveau du sol, en aérien et en tunnel sur une voie double en béton longue de 12,7 km. La configuration du système est une exploitation en circuit va et vient entre les 17 stations en ligne.

Le véhicule est d'une structure étroite (2 mètres de largeur) et légère, longue de 12,7 mètres. Deux véhicules sont en permanence couplés l'un à l'autre pour former un "élément passagers" capable d'une marche réversible. Cet "élément double" est constitué d'une unité hacheur (HR) et d'une unité pilotage automatique (PA). L'unité hacheur contient l essentiel de l'équipement de commande de la propulsion pour les deux véhicules, et l'unité pilotage automatique contient l'équipement de pilotage automatique pour les deux véhicules.

Chaque véhicule est porté par quatre roues à pneumatiques caoutchouc. Il est équipé de deux axes pivotants guidés latéralement par un jeu de quatre roues à pneumatiques caoutchouc qui roulent entre deux rails de guidage en acier. La suspension est assurée par un volume d'air à pression variable.

L'aiguillage est réalisé par un système auxiliaire composé de deux roues de guidage en acier verticales qui ne sont utilisées que dans les zones d'aiguillage. Les roues d'aiguillage sont en interface avec deux rails acier fixés dans la voie. L'aiguillage est effectué par un appareil de voie qui courbe latéralement deux portions de rail (fig. 3.2.5.) ; il s'accomplit en trois secondes de verrouillage à verrouillage.

Chaque véhicule est propulsé par deux moteurs à courant continu de 120 kW par l'intermédiaire d'un différentiel dans chaque axe. Les moteurs sont fixés à la caisse afin de réduire les masses non suspendues.

Le contrôle automatique de l'élément passagers s'effectue par contrôle centralisé d'un système à cantons fixes conventionnels auquel s'ajoute une électronique de sécurité à bord du véhicule pour assurer le contrôle de vitesse. Un système câblé à boucle inductive assure la détection de présence de chaque élément passagers. Un deuxième système à boucle inductive avec des croisements à distances déterminées fournit une référence pour la régulation de vitesse. Le système de contrôle est constitué de trois sous-systèmes fonctionnels principaux : Protection Automatique du Véhicule (en anglais AVP), Commande Automatique du Véhicule (AVO) et Surveillance Automatique du Véhicule (AVS). La Protection Automatique du Véhicule assure la sécurité de toutes les fonctions de Commande Automatique du véhicule dans toutes les conditions. La Surveillance Automatique du Véhicule fournit les moyens d'effectuer la coordination de la commande du système.

Le système est conçu pour fonctionner avec des périodes de une minute pendant les heures de pointe et des périodes de cinq minutes pendant les heures creuses. Ceci est basé sur une vitesse moyenne de 35 km/h avec un arrêt en station de 14 secondes. Le système est conçu pour un débit nominal de 7.440 passagers par heure et par sens avec 55 pourcent de passagers assis. La capacité nominale de chaque véhicule est de 34 places assises et 28 places debout ce qui fait un total de 62, ou de 124 par élément passagers.

Quelques unes des plus importantes caractéristiques du système VAL, d'ordre technique ou d'exploitation sont rassemblées dans le tableau ES.1.

EVALUATION

Le système VAL de Lille est le premier système urbain entièrement automatique sans conducteur de type AGT à être installé en France. Le système est en développement depuis environ 10 ans. Il en résulte un haut niveau de maturité de développement.

Le haut niveau de maturité de développement se définit comme le développement d'un système qui :

1) a passé le stade de développement du prototype
2) a terminé le développement du système en production pour une application urbaine
3) est basé sur des "hardware" et "software" utilisés ailleurs en transport urbain.

La philosophie d'ensemble du développement a été conservatrice pour minimiser les risques. Où c'est possible, c'est une technologie ayant fait ses preuves et déjà en usage dans d'autres systèmes de transport qui a été choisie, par exemple les moteurs de traction et les hacheurs associés. Où une technologie éprouvée n'était pas disponible, la solution choisie représentait une petite avance dans l'évolution technologique par rapport à l'état actuel de la technique. Par exemple le système de pilotage est un système à cantons fixes conventionnel pour la détection de présence, complété par un plus haut niveau d'électronique pour remplire la fonction régulation de vitesse et pour assurer la sécurité du système de contrôle. Ce complément d'électronique correspond aux fonctions qui sont normalement remplies par le conducteur.

Pour déterminer les possibilités de performance du système VAL une importante série d'essais a été effectuée avec les deux premiers éléments de série sur le site de maintenance et d'essais du métro de Lille. Les essais étaient orientés dans le but de déterminer les caractéristiques d'exploitation du métro de Lille en ce qui concerne la sécurité, la disponibilité et les performances. Ce qui suit est un résumé de l'évaluation et des principales conclusions du programme d'essais.

Toutes les fonctions et commandes, y compris le contrôle individuel du véhicule ont été accomplies de manière satisfaisante et sans problèmes majeurs. La comparaison des résultats d'essais avec les caractéristiques d'exploitation et spécifications techniques publiées pour le VAL montre une bonne conformité.

- La sécurité du système a été étudiée de manière approfondie. De nombreux essais ont été effectués comme vérification. Les systèmes de sécurité ont fonctionné de manière satisfaisante dans tous les cas du programme d'essais. Aumun avatar ni incident n'a été enregistré ou observé. Le système VAL a été conçu pour être sûr et il apparait satisfaire à toutes les normes de sécurité américaines à l'exception de la force de fermeture des portes qui est approximativement cinq fois supérieure au maximum permis aux Etat-Unis.

- L'évacuation d'urgence s'effectue sur une plateforme fixée sur la voie au niveau du plancher du véhicule par l'intermédiaire des portes normales. L'évacuation d'un véhicule en pleine charge s'effectue en 20 secondes ce qui donne une marge de temps suffisante et raisonnable en cas de feu. Cette configuration rend facile l'évacuation des personnes agées et des handicapés en fauteuil roulant.

- Des matériaux difficilement enflammables ont été utilisés dans l'ensemble du véhicule. Les différences entre les normes françaises et américaines n'ont pas été examinées dans le détail. Dans l'ensemble elles sont comparables.

- La force de fermeture des portes est de 100 kilos. C'est approximativement cinq fois plus que le maximum permis aux Etats-Unis soit 30 pounds. Une modification du mécanisme de fermeture des portes est nécessaire pour correspondre aux normes américaines.

- L'intérieur du véhicule est étroit (1,96 m ou 6,43 pieds). Cette solution a été choisie pour réduire les coûts de génie civil et pour augmenter le nombre de passagers assis. Un peu d'incommodité a pu être constaté lorsque l'on est assis sur les dièges situés au centre. Cependant cette incommodité est largement compensée par le fait que les portes nombreuses et larges permettent un accès et une sortie plus rapides, ce qui minimise le temps de stationnement et le temps d'attente.

- Un handicappé en fauteuil roulant ne rencontre aucun problème pour entrer et sortir du véhicule.

- Un essai d'endurance de 100 heures, à raison de 20 heures par jour a été effectué en mode entièrement automatique, pour un seul élément (de deux véhicules couplés). L'objectif de cet essai était d'obtenir les données préliminaires de disponibilité du système VAL.

La disponibilité du système était déterminée non comme la disponibilité finale du système mais comme une indication pour les possibilités potentielles du système. La disponibilité moyenne au cours du test de 100 heures était de 0,959. Pour le dernier jour de test la disponibilité de 0,997 a été atteinte.

TABLEAU ES 1 : RESUME DES CARACTERISTIQUES DU SYSTEME VAL

Automatisation	Entièrement automatique
Type de service	Stationsen ligne
Débit maximum théorique par sens	12.480 passagers/heure
Débit maximum pratique par sens	9.600 passagers/heure
Débit nominal par sens	7.440 passagers/heure
Période (minimum)	35-40 s
Vitesse de croisière	60 km/h
Vitesse commerciale	35 km/h
Pente maximum	7 %
Elément de transport	2 véhicules couplés indissociables
Capacité de l'élément voyageur	68 assis, 56 debout
Capacité en charge exceptionnelle	44 assis, 164 debout
Utilisation	20 heures/jour, horaire fixe
Stations	17 stations en ligne
Voie	12,7 km, aérien, au sol et tunnel
Aiguillage	Au sol, flexion d'une portion de rail
Coûts d'investissement	1.650 millions de francs (387.75 millions de dollars)

========================

La principale cause de défauts provenait d'une faiblesse de communication entre le véhicule et la station. Dans tous les cas la situation fut clarifiée par le contrôle central à l'aide d'un redémarrage, d'une retransmission de la commande et d'une réinitialisation des procédures. Ceci démontra la souplesse du software, et la souplesse dont dispose l'opérateur du poste central de commande pour résoudre à distance n'importe quel problème en temps réel.

- Le niveau de bruit maximum à l'intérieur du véhicule 75 dBa à 60 km/h était plus élevé que l'objectif (70 dBa). Le niveau de bruit a été attribué au joint universel de la transmission. Un changement a été prévu et devrait réduire le bruit à un niveau acceptable.

- Le freinage à la chaine d'arrêt final en station s'est révélé quelque peu irrégulier. Une nouvelle conception de cette chaine a été étudiée mais n'est pas encore mise en oeuvre actuellement.

- Du point de vue esthétique la voie aérienne apparait plus massive que ce qui est nécessaire. Ceci est dû à la hauteur relativement importante des parapets en béton. Ces derniers ont été utilisés à Lyon et Marseille. C'est leur acceptation dans ces localités qui a été un facteur déterminant pour leur utilisation à Lille malgré l'aspect esthétique.

Le système de commande et contrôle représente un pas d'évolution supplémentaire par rapport à celui des véhicules automatiques rapides sur rail à conduite manuelle. Un système de protection automatique des véhicules (AVP) plus important a été mis au point pour prendre la place de la conduite manuelle. Le système de sécurité a été essayé de manière complète. Les performances du système de commande ont été satisfaisantes. La démonstration de périodes inférieures à 60 secondes a été effectuée.

- L'accouplement automatique et la procédure de poussette ont été démontrés avec succès. Cette possibilité augmente beaucoup la disponibilité du système.

1.0 INTRODUCTION

1.1 BACKGROUND

This report is the result of an interim investigation of the Véhicules Automatiques Légers (VAL) system, a 12.7-kilometer automated system, which is currently under construction in Lille, France. The study was conducted under a bilateral agreement between the U.S. Department of Transportation (DOT) and the French Ministry of Transportation and was conducted by DOT's Transportation Systems Center, under Urban Mass Transportation Administration (UMTA) sponsorship. In the United States, this study is part of a series of assessments of transit technologies, both domestic and foreign, being conducted by the Office of Socio-Economic and Special Projects of UMTA's Office of Technology Development and Deployment. The purposes of these assessments are to:

1. Gather and exchange information on transit technologies to better understand the state of technological advancement and to obtain synergistic improvements for future development;

2. Review problems and solutions encountered during the design, development, implementation, and operation of transit systems in order to improve the process based on experience;

3. Obtain information on engineering, economic, operational performance, and public response which can be used in improving transit systems;

4. Provide urban planners with information which will enable them to determine the applicability of transit technologies to their specific transportation problems.

1.2 SCOPE

The approach taken for this study differs from that of other UMTA assessment activities in that the VAL system is under construction in Lille, France and will not be operational until the beginning of 1982. As a result, operational experience is not available at this time. This type of information will be provided in the final assessment report.

This interim assessment report was based upon an extensive series of tests performed on the first two production vehicles at the test track. These vehicles were used for engineering development. Any modifications are to be incorporated into the next 36 vehicles.

Section 2.0 gives the historical background related to the development of the VAL project from the concept of this transit system to the selection of MATRA as the prime system contractor, and the development of the present system configuration.

Section 3.0 provides a description of the system being constructed in the city of Lille, France including a description of the major elements. The major elements described in the section are the vehicle subsystem; the command, control and communications subsystem in terms of the associated functions of control and safety; the steering and switching subsystems; the propulsion and braking subsystems; the electrification subsystem and the proposed guideway/stations; and the maintenance facility. Performance of the system was derived from data obtained during testing at the test track. The test track located at the east end of the line in the maintenance area was built specifically to test the system being developed for Lille.

Section 4.0 presents the results of the Demonstration Test Program. Section 5.0 System Economics discusses the capital cost of VAL. A summary of the assessment is provided in Section 6.0.

Sections 2.0, 3.0, and 5.0 are a compilation of factual data provided primarily by MATRA and supplemented by EPALE, CUDL, and the IRT. Section 4.0 represents the results of tests conducted by MATRA and witnessed by the DOT team. Section 6.0 represents the opinion of the DOT team.

2.0 BACKGROUND

2.1 PROJECT DEVELOPMENT HISTORY

During the launching of the new "Technologics Priority" program in 1970, the public office for the development of East Lille (EPALE, Establissement Public d'Aménagement de la ville nouvelle de Lille-Est) under the French Government and the Lille local community development authority (CUDL, Communauté Urbaine de Lille) raised the issue of rapid transit service for the new town of Lille-East. EPALE, an industrial and commercial public management company created through the initiative of the French Governement and the Lille local authorities, undertook the first phase of the project, a parametric study of the system requirements for Lille East. An 8-kilometer line with eight stations was considered. One of the stations was located in the center of Lille, two in the existing suburbs, and five in the new town. The plan called for revenue operation by 1975. Expected ridership was approximately 6000 passengers per hour per lane over a long term. The study was performed under the cognizance of the Transport Minister, the Institut de Recherche des Transports (IRT) and the Regional Management Delegation Agency, and was sponsored by the Development Committee for New Urban Transportation Techniques. EPALE was also assisted in this study by SETEC Engineering and Lille University.

For the system to be attractive to riders an excellent quality of service was considered necessary. The basic assumptions of the parametric study were:

- Short headways - as low as possible
- A high ratio of seated to standing passengers
- A high commercial speed.

As a result, the design had to be formulated around four principal criteria:

1) Short headways for low demand levels of riderships are only economical and sensible with small driverless vehicles such that capital cost can be recovered rapidly through fare box earnings;

2) A headway of about 1 minute is desired, and can be accomplished with on-line stations;

3) The highest ratio of seated-to-standees can be obtained economically with a narrow width vehicle which also provides significant savings of civil engineering costs and;

4) A high commercial speed can be obtained by pneumatic tire vehicles with capability for rapid acceleration and large numbers of doors for small dwell time.

In 1970 EPALE requested proposals for the implementation of this project. As a result, SA MATRA Transport Systems Division (MATRA) was selected in February 1972 as the system manager and developer of the command and control system. Associated with MATRA were Compagnie Industrielle de Matériel de Transport (CIMT) responsible for vehicle design and fabrication and Traction CEM-Oerlikon (TCO) for propulsion. INTERELEC, a division of MATRA, was responsible for fabrication of the production command and control electronics.

To accomplish these goals, MATRA designed a medium-sized, light-weight, compact vehicle with an original single-axle pneumatic tire design that has low tire load capacity, reduces the number of wheel sets per square foot of floor and has a low unsprung weight. These basic features remained unchanged throughout the different steps of the Lille project. The conclusions of the 1970 parametric study are given in Table 2-1.

The first phase of development of the VAL (Véhicules Automatiques Légers) system took 4 years - from 1971 to 1975. It consisted of construction and operation of a 1.7-km test loop in Lille with one station, two switched, a command and control center, and electrical substation, and maintenance shop (see Figure 2-1). Experimental testing of two prototype vehicles was conducted until June 1975. This was followed by 3 months of endurance testing during which 30,000 km were logged on each vehicle. This phase of development incurred a cost of 45 million French francs (approximately $9 million) which was subsidized to a large extent by the French Government. Figure 2-2 shows the prototype test vehicle and station at the test track.

In parallel, the CUDL developed and adapted a transit service for the combination of Lille-Roubaix-Tourcoing. The project made provisions for construction of a line-haul network with four lines as shown in Figure 2-3. Line 1 was extended beyond Lille to a length of 12.7 km. Peak traffic on that line was predicted to be between 4000 and 7000 passengers per hour per lane

TABLE 2-1. 1970 PARAMETRIC STUDY RESULTS

Round trip line travel time (16 km)	<30 min
Headway	1 min
Percentage of passengers seated	69%
Number of passengers per vehicle	52
Number of vehicles per unit	2
Maximum acceleration	1.3 m/s^2
Maximum deceleration	1.3 m/s^2
Maximum jerk	0.6 m/s^3
Noise	60 dBA at 6 m from the track edge
Normal operational speed	60 km/h
Maximum regulation speed	80 km/h

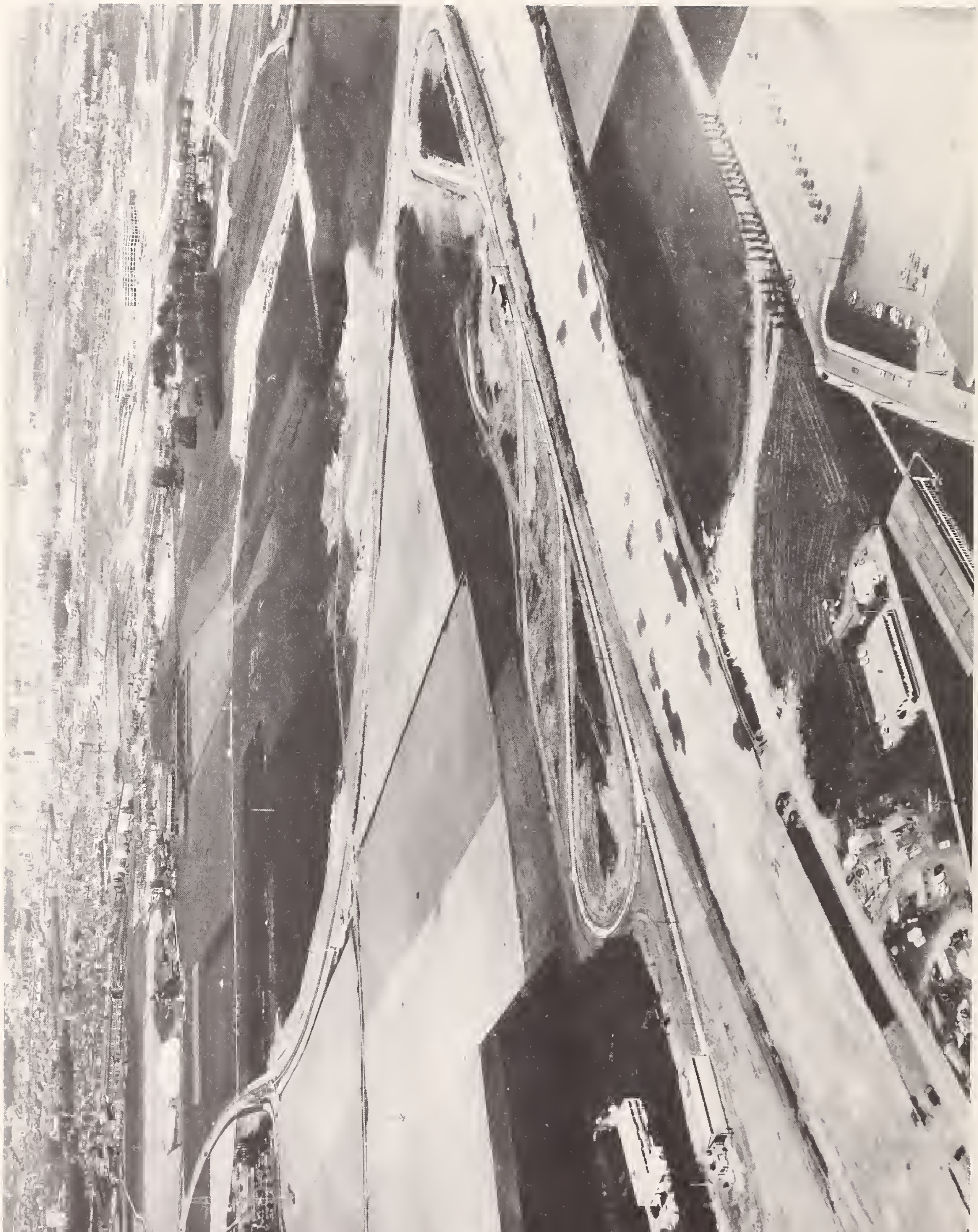


FIGURE 2-1. PROTOTYPE TEST TRACK-LILLE

FIGURE 2-2. PROTOTYPE TEST VEHICLE AND STATION

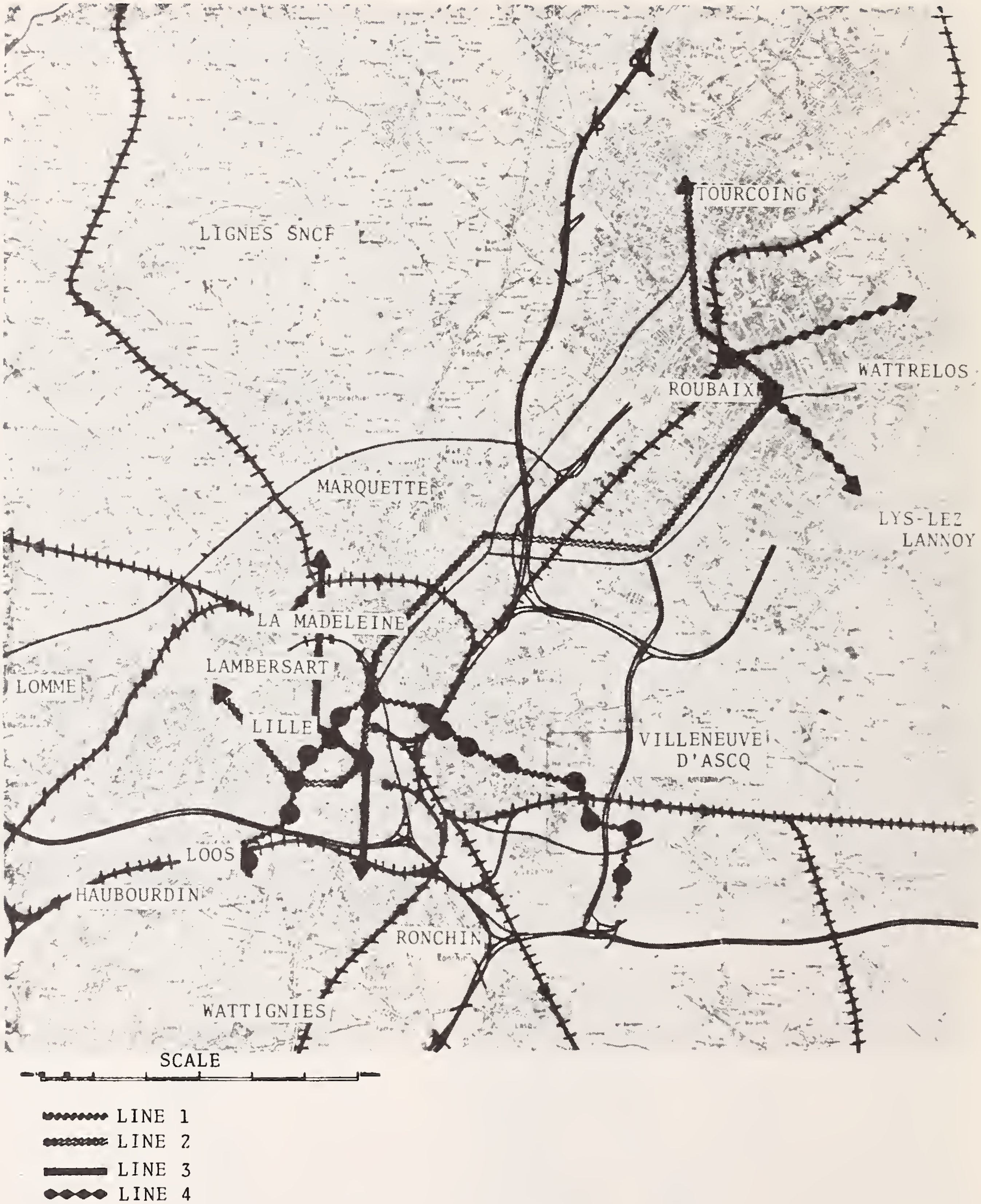


FIGURE 2-3. LILLE METRO NETWORK

by 1990 and expected to grow to around 12,000 to 15,000 at the beginning of the next century.

A study was conducted by MARTRA under the supervision of CUDL and consultants to verify if the VAL concept and hardware was indeed suitable for the project. This study indicated that with few modifications the VAL system was a viable solution. An economic study conducted by the engineering division of RATP (Régie Autonome des Transports Parisiens; the Paris metro operator) compared VAL to conventional metro rapid rail. It showed that the VAL system offered a 15 percent savings in investment and a 30 percent savings in operating costs.

Some modifications to the system were needed to accommodate the even greater ridership expectation than on the original line and increased the length of the line, which necessitated phased construction and modular organization of fixed equipment. This led to the use of the stub-end terminus instead of the original loops. As a result, equipment was made reversible and a new high-speed switch was developed for the high frequency of the stub-end operation. This equipment was tested by the end of 1974.

As a result of many studies on the safety and economic feasibility of VAL as compared to conventional French metro on rubber tires, the French Government approved in principle this innovative system in June 1975. The Government also indicated that it would be inclined to subsidized this operation in similar proportions to the Lyon and Marseille Metros. CUDL voted in favor of this rapid transit program.

At this time procedures were initiated to obtain the Public Service Certification. The corresponding public inquiry was completed at the end of 1975. The final authorization declaring the project to be a public service was granted on December 27, 1976.

In April 1977, MATRA was notified of the contract award for the engineering and production of the rolling stock, the command and control, and the fixed equipment including the track, electrification, test equipment, depot workshop, test track, and some of the station equipment. At the same time CUDL undertook infrastructure studies. CUDL assumed responsibility for all the civil engineering work on the guideway. The first phase of construction was initiated in September 1977. The relationship between CUDL, EPALE, and MATRA and their associated contractors is shown in Figure 2-4.

2.2 PRESENT STATUS AND DEVELOPMENT PHILOSOPHY

Public inquires caused some changes to be made to the line including the addition of two stations and a change of 1 kilometer of elevated guideway to at grade and cut and cover (see Figure 2-5). This incurred a delay of 2 years in the schedule for revenue service. Nevertheless, the system engineering, production, and testing continued. The schedule showing the complete operation is shown in Figure 2-6. Hardware delivery and testing is to be completed with system qualification tests scheduled for October 1981. The VAL civil engineering work is to be completed in three 4-kilometer sections:

1) Quatre Cantons to the Hôtel de Ville station is scheduled for completion by December 1981;

2) Hôtel de Ville to station République is to be operational by March 1983; and

3) République to the CHR station will complete the line in January 1984.

Revenue operation may be tried on section 1 as early as December 1981. Consideration is also being given to making this early operational service free of charge.

The hardware consists of 38 married pairs of vehicles to be delivered in 3 groups; the first consists of two production vehicles that are engineering development models currently in use to test all equipment and subsystems. All rolling stock equipment vehicle testing has been completed (suspension, guidance, and propulsion). Integration of the command and control functions (Automatic Vehicle Operation, Automatic Vehicle Protection, and Automatic Vehicle Supervision) has been completed. Currently VAL is undergoing system level tests to assure integration of all subsystems. The modifications resulting from the testing of these first two production vehicles will be incorporated into the second group: vehicles 3 to 12. Integration testing of these vehicles is scheduled for March 1981. System acceptance tests are to be followed by system qualification testing with four vehicles. System qualification tests are a complete set of detailed tests analogous to aircraft

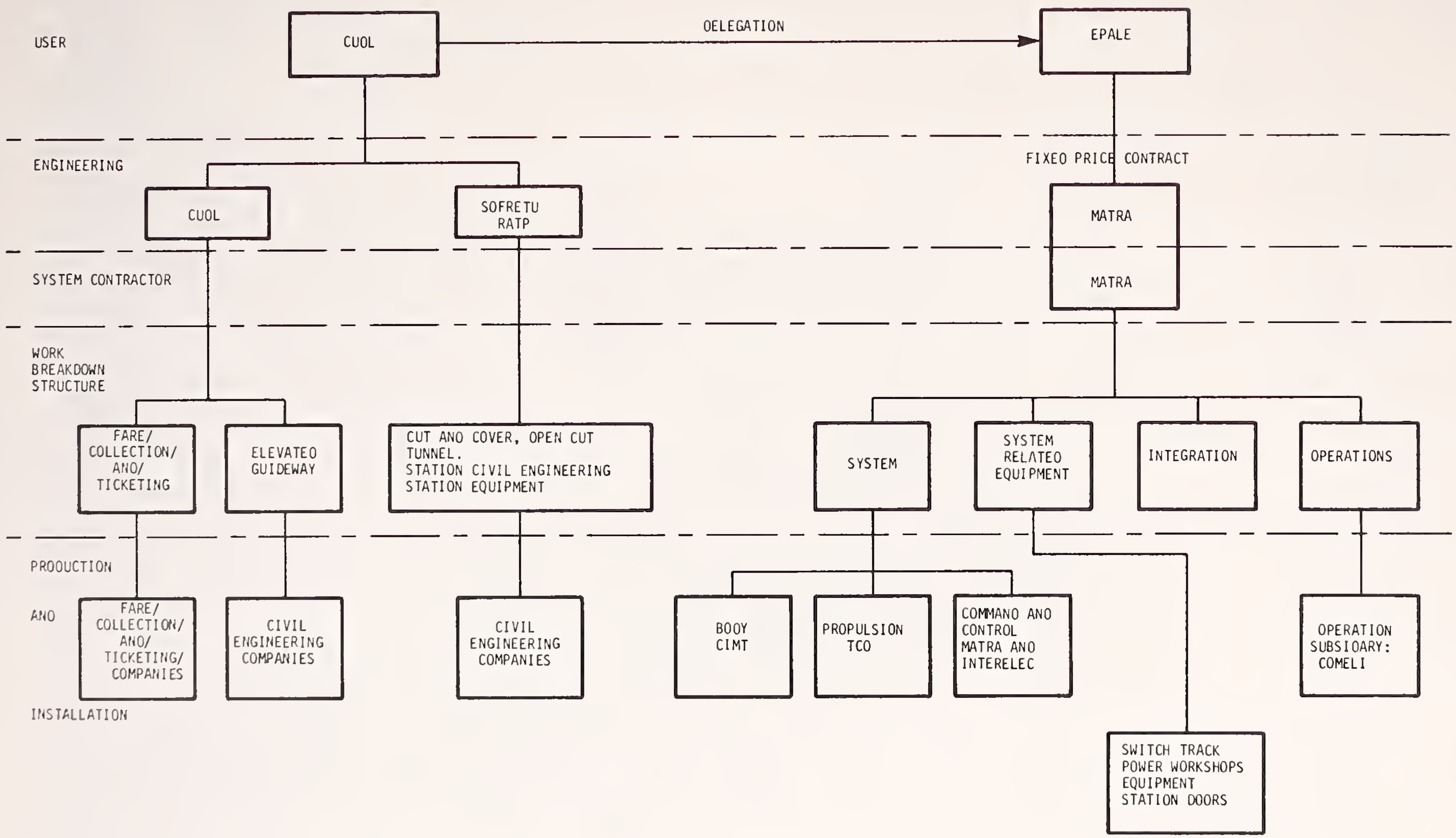


FIGURE 2-4. RELATIONSHIP BETWEEN CUDL, EPALE AND MATRA AND THEIR ASSOCIATED CONTRACTORS

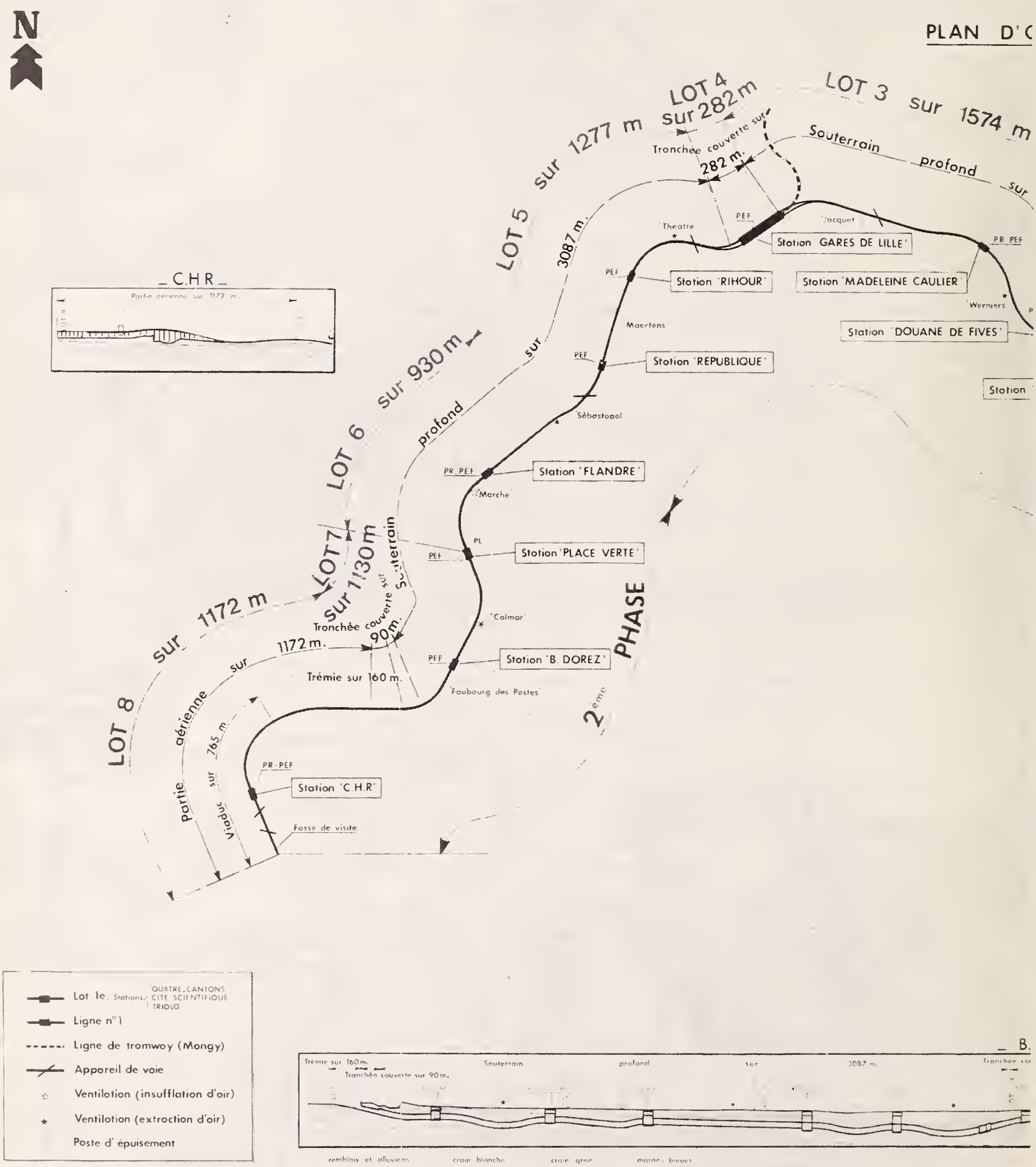


FIGURE 2-5. LILLE METRO PLAN -- LINE 1

D' ORIENTATION

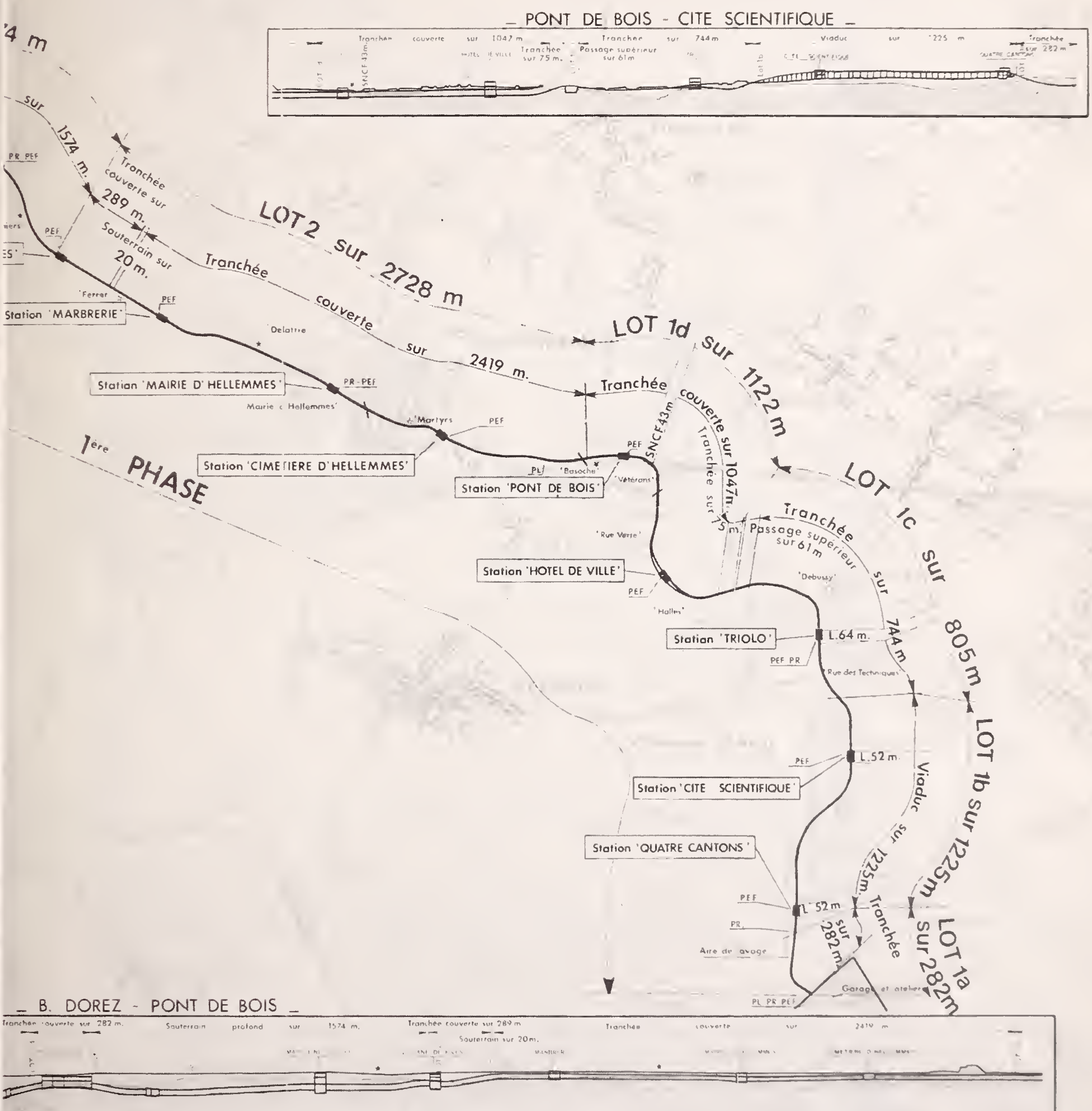


FIGURE 2-5. CONTINUED)

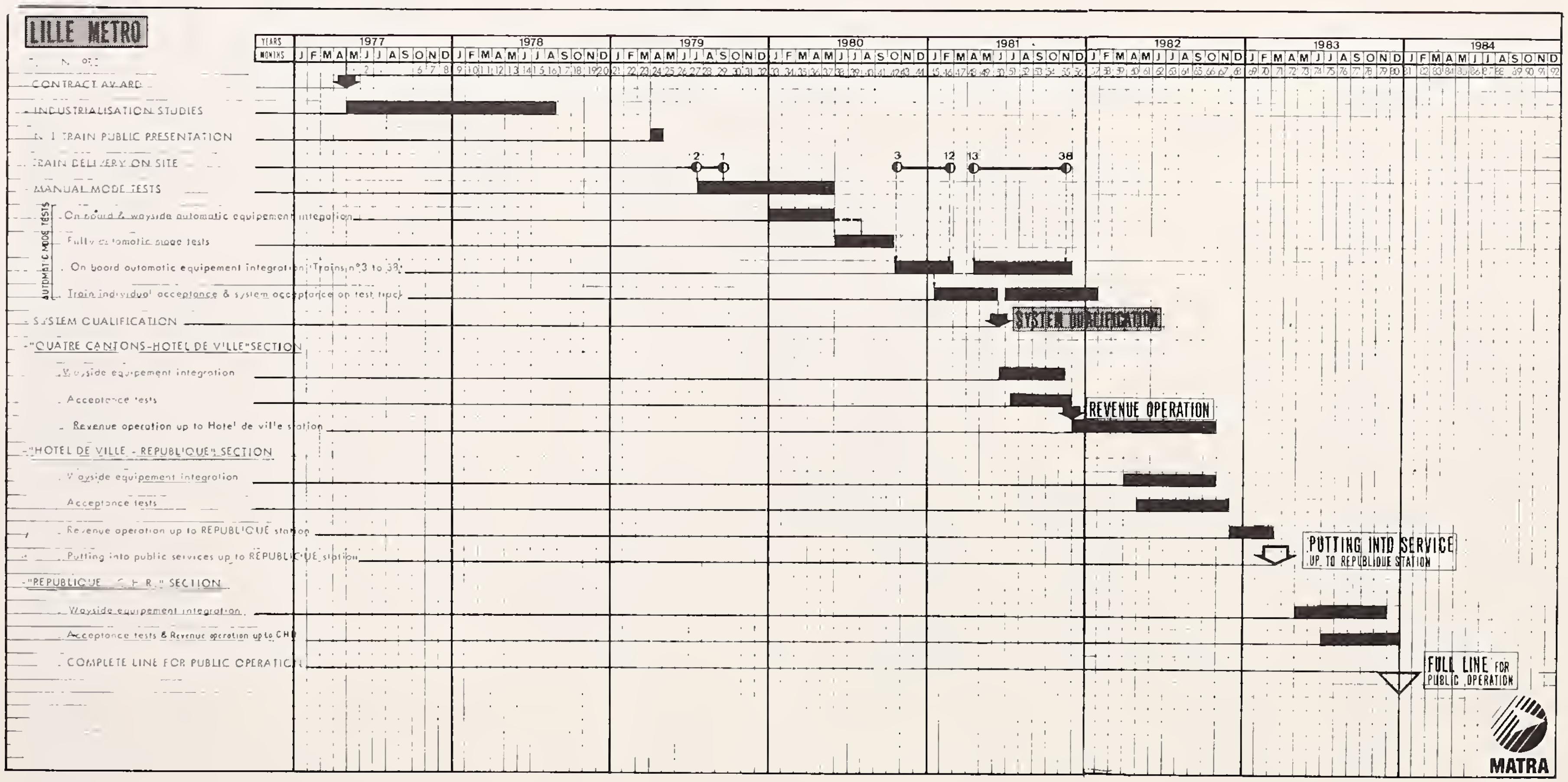


FIGURE 2-6. LILLE DEPLOYMENT IMPLEMENTATION PLAN

acceptance tests; i.e., individual detailed testing of all functions of each subsystem and each system will be conducted. This will be followed by 8 days of reliability tests in which all failures are recorded and used by EPALE to determine the availability factor. Qualification will be followed by 3 months of operational testing.

2.3 CONTRACTUAL IMPLICATIONS

The overall cost of the VAL Lille system is 1650 million French francs ($387.75 million) based on January 1979 price indices and exchange rates. At go ahead in September 1976 MATRA was awarded a fixed-price contract for the system engineering, rolling stock, and command and control equipment for 234 million French francs ($49 million). MATRA accepted this fixed-price contract which specified a system availability of 0.96 at the time of system qualification and 0.98 one year later. MATRA was awarded another contract of approximately 272 million French francs ($55.3 million) in September 1977 for track, electrification, workshop and depot, and some station equipment, bringing the total MATRA contract to approximately 532 French francs ($108.2 million in 1977 dollars). CUDL was awarded the remaining sum to provide all civil engineering and structural elements.

The contract is being closely monitored by CUDL, EPALE, and their consultants. It is also under the control of the French Ministry of Equipment Transport Administration (Ministere des Transports, Direction des Transports Terrestres: DTT) through regular assessment of technology made by the IRT. A safety commission (Groupe Sécurité du Métro de Lille) was also formed with DTT, IRT, RATP, EPALE, CUDL, manufacturers, operators, the Fire and Police Departments, and Consumer representatives. This commission examined the safety of the concepts and design of the first driverless system in France. It gave its approval prior to system qualification. An extensive safety report has been developed in which the details of safety are provided. This report is backed by an extensive series of tests.

The contract also stipulates a fixed-cost contract for MATRA to maintain the system during the first 5 years of operation. In addition, MATRA is also obligated by means of a cost-plus incentive fee contract to maintain the established operating cost over the 5-year period. Because MATRA is not a transit operator, COMELI was established as the operating company. It is owned by TRANSEXEL, a company operating numerous bus systems, including the LILLE-ROUBAIX-TOURCOING network and the LYON Metro, and by MATRA in equal porportions.

3.0 TECHNICAL DESCRIPTION

3.1 SYSTEM DESCRIPTION

The VAL Lille Metro is a fully-automated, supported, Automated Guideway Transit (AGT) system operating at grade, elevated, and in tunnels (see Figure 3-1). The system is an urban public transit system designed to transport passengers between the new town of East Lille, the Lille city center, and the Regional Hospital Center in the city of Lille, France. The configuration of the system is a push-pull loop operating between 17 on-line stations. The exclusive dual-lane guideway is 12.7 kilometers long (see Figure 2-5). Storage, maintenance, inspection, test, and terminus facilities are also provided. An aerial view of the Lille Metro Test and Maintenance Facility at the East Terminus is shown in Figure 3-2.

The system is designed to provide operation at 1-minute headways during peak hours and 5-minute headways during off-peak hours. This is based on an average speed of 35 km/hr which includes an average station stop of 14 seconds. The normal one-way design capacity is 7440 passengers per hour per direction with 55 percent of the passengers seated.

The VAL system operational characteristics are provided in Table 3-1.

3.2 VEHICLE

The vehicle consists of a bi-directional two-car unit (or "married pair"). The vehicle comprises a chopper (HR) unit and a Pilot Automatic (PA) or control unit. The chopper unit contains the essential propulsion control equipment for both vehicle units, and the Pilot Automatic unit contains the automatic control equipment for both vehicle units. The vehicle units are coupled with a connecting bar and can be separated only in the workshop. The vehicle has two automatic couplers located at each end which permits two vehicles to be joined (i.e., two two-car units). Automatic coupling of two vehicles can be accomplished either in the maintenance area or on the guideway in either a manually-operated mode or a fully-automatic mode of control.

3.2.1 Vehicle Body

The vehicle body utilizes an integral body and frame monocoque construction technique. It is fabricated with an aluminum alloy (ALUM 6061-T6) that is

FIGURE 3-1. VAL SYSTEM

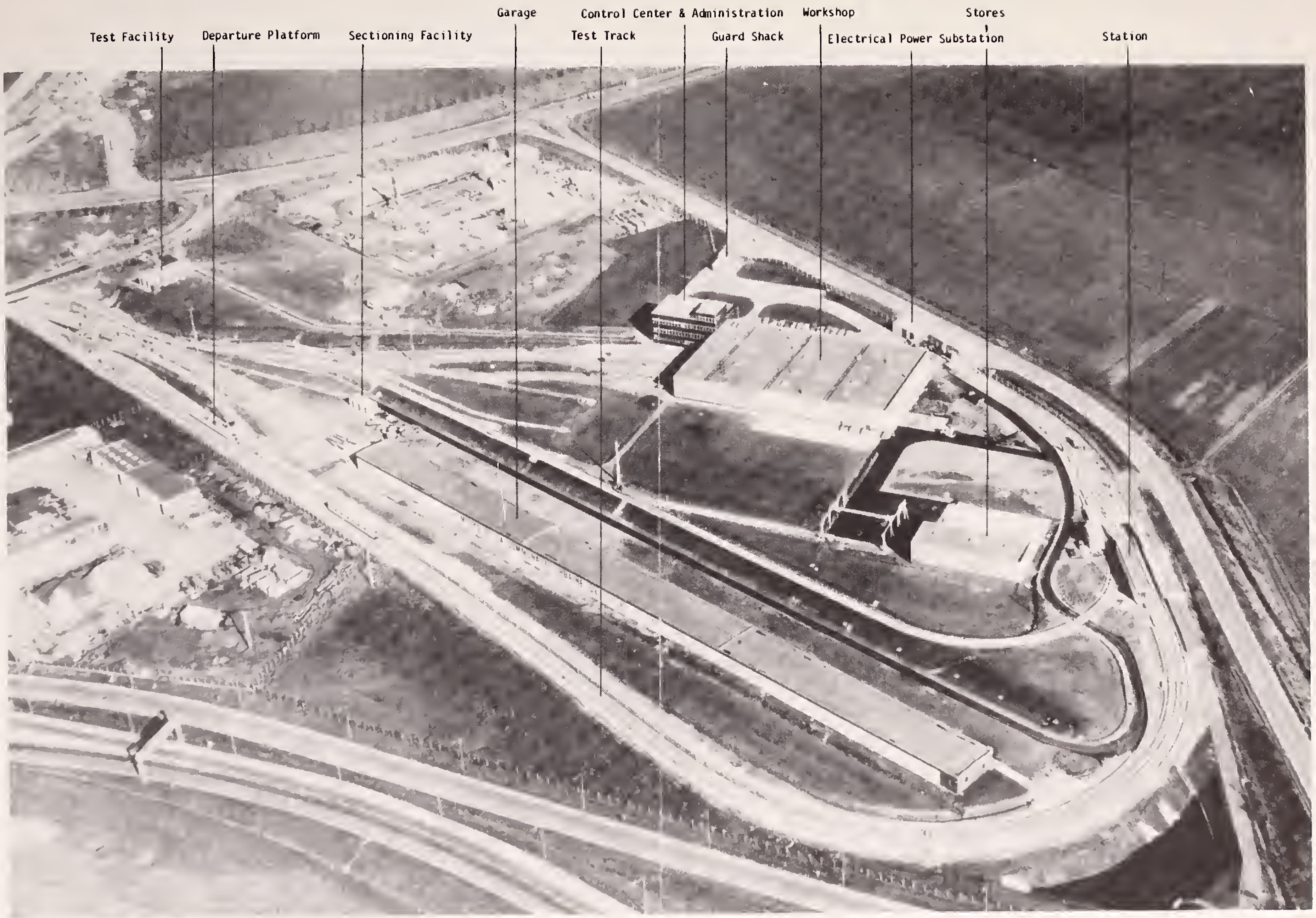


FIGURE 3-2. AERIAL VIEW OF LILLE METRO TEST AND MAINTENANCE FACILITY

TABLE 3-1. VAL SYSTEM OPERATIONAL CHARACTERISTICS

System Performance:	
Max. theoretical one-way capacity (1)	12480 pass/hr
Max. practical one-way capacity (2)	9600 pass/hr
Normal one-way design capacity	7440 pass/hr
Min. theoretical headway (3)	35-40 sec
Practical headway with on-line stations	60 sec
Service availability	Scheduled; 20 hrs/day
Type of service	Line-haul; on-line stations
Type of network	Line-haul
Traveling unit	married pair
Interior noise	75 db A
Exterior noise (4)	72 db A
Vehicle Performance:	
Max. speed	80 km/hr (50 mph)
Average speed	34 km/hr (21.75 mph)
Normal operating speed	60 km/hr (37.28 mph)
Max. grade	7%
Average acceleration/deceleration	1.3 m/sec^2 (0.132 g)
Max. jerk	0.65 m/sec^3 (0.66 g/sec)
Min. emergency deceleration	1.8 m/sec^2 (0.183 g)
Max. emergency deceleration	2.4 m/sec^2 (0.244 g)
Stopping precesion in station	0.3 m
Degredation if guideway is wet	None
Degredation for ice & snow	None - electrically heated
Vehicle design capacity	68 seated and 56 standees
Vehicle crush capacity	44 seated and 164 standees
Energy consumption (5)	4.5 kW-hr/km

Notes:

(1) With 6 pass/m^2 and jump seats up
(2) With 4 pass/m^2 and jump seats up
(3) Includes 30-sec dwell time and time for switch command and verification
(4) At 60 km/hr; at 7.5 m distance from track
(5) Of a single vehicle unit without regenerative braking

TABLE 3-1. VAL SYSTEM OPERATIONAL CHARACTERISTICS (CONTINUED)

Stations:	
Type	On-line, 1-berth (6)
Type boarding	Level
Tickets & fare collection	Automatic fare collection with honor system
Security	Closed circuit TV; police
Boarding capacity	
Deboarding capacity	
Max. wait time (off-peak)	5 min
Min. wait time	36 sec
Vehicle in-station dwell time	10-30 sec
Station spacing (average)	0.85 km
Individual Service:	
Privacy	Multiple party
Transfers required	None
Stops	At every station
Accomodations	seated & standing
Security	TV mon. in stations and a police team
Instruction	Signs
Passenger articles	Small packages & luggage
Comfort	Heating & ventilation
Cargo Capability:	
Accomodations	None
Reliability & Safety:	
Fail-safe features	Components individually fail safe
Strategy for passenger evacuation	Walkways
Strategy for removal of failed vehicle	Automatic push capability; manual backup; & small recover deisel vehicles

Notes:

(6) The concrete for a second berth has been included, but station equipment is not installed.

(7) Platform-to-platform transfers are provided to a street car system in station "Gares" which is intended to become line number 2 in the future.

TABLE 3-1. VAL SYSTEM OPERATIONAL CHARACTERISTICS (CONTINUED)

System lifetime	Design goal 30 yrs
Vehicle	Design goal 30 yrs
Operational life	-
System Mean Time Between Failure (MTBF)	42 hrs (est.) (8)
System restore time after failure (MTTR)	-
System availability	Design 98%
Vehicle MTBF	-
Guideway MTBF	-
Command & control MTBF	-

Personnel Requirements	Per Shift	Total Staff
Vehicles & stations	Unmanned	-
Central control	2-6	28
Maintenance	45 (9)	45
Roving teams	6-12	45
Administrative	11	12
		130

VAL SYSTEM PHYSICAL DESCRIPTION

Vehicle	
Unit length, overall	25840 mm
Width, outside	2022 mm
Height, clear inside	2045 mm
Width, clear inside	1960 mm
Height, overall	3250 mm
Weight, empty	29600 kg
Weight, gross	45200 kg

Suspension	
Supported, verticle	Air cushion (4 per vehicle) elastomeric series suspension with 4 pneumatic tires per vehicle mounted on 2 axles
Axle	Steerable
Lateral Guidance	8 pneumatic horizontally-mounted rubber tires per vehicle
in switching area	4 vertically-mounted steel wheels
roll	4 hydraulic shock absorbers

Notes:

(8) With 32 vehicle units on-line
(9) Exclusive of cleaning

TABLE 3-1. VAL SYSTEM OPERATIONAL CHARACTERISTICS (CONTINUED)

Propulsion & Braking:	
Type & no. of motors	2 dc rotary 380 V motors in series
Motor rating	120 kV
Type drive	Mechanical coupling through a differential
Type power	750 V dc
Power collection	Sliding contact shoes on steel power rails; 4 shoes per vehicle (+, -, & ground)
Type service brakes	Conjugated regenerative braking and pneumatic friction disks
Type emergency brakes	Pneumatic friction disks
Switching:	
Type	Lateral transfer of cantilevered steel rail within a steel rail channel
Switch time (lock-to-lock)	3 sec
Speed through switch	25 km/hr
Guideway:	
Type	2 running pads for vertical supported running tires; lateral steel "I" guidance beams mounted on insulators
• At grade	Concrete pad
• Width	2.41 m (10)
• Length	0.867 km
• Elevated	Concrete box "T" beam
• Supports	Concrete
• Width	6.4 m (11)
• Length	2.38 km

Notes:

(10) Single lane width

TABLE 3-1. VAL SYSTEM OPERATIONAL CHARACTERISTICS (CONTINUED)

• Cut & cover	Concrete box beam
• Width	7.3 m (11)
• Length	4.216 km
• Tunneled	Concrete vaulted section
• Width	6.4 m (12)
• Length	4.571 km
• Total guideway length	12.7 km (13)
• Average height of vehicle floor above running pad	950 mm
• Max. grade	6.9%
• Min. turn radius	100 m (at 60 km/hr) 40 m (at reduced speed)
• Min. vertical curve radius	1050 m

Notes:

(11) Width for dual lane guideway.
See Fig 3-17 Guideway Infrastructure.
(12) Inside Diameter for dual lane guideway.
See Fig 3-17 Guideway Infrastructure.
(13) Including storage maintenance and turnouts.

welded, resulting in a light-weight body of only 2 tons. The ends of the vehicle body are made of reinforced fiberglass impregnated with polyester resins. The windows are made of laminated high-resistant glass (V.H.R.).

Each vehicle unit has three 1.3-meter wide by 1.9-meter (74.8 inches) high doors on either side. The bi-parting doors will open or close within 4 seconds. This average kinetic energy during closing does not exceed 10 joules (7.4 foot-pounds).

The bi-parting sliding doors are externally suspended on ball bearing hangers running in upper and lower tracks, but are not of the plug type. An overhanging cover protects the actuator mechanism from the environment. This approach was taken to simplify the door opening mechanism, and to minimize the gap between the station platform and the vehicle (maximum of 35 mm). Thus, with the vehicle floor located at the platform level, easy access is achieved by the handicapped in wheelchairs.

The door actuator is powered hydraulically. Door opening is synchronized by a belt interconnecting the matching bi-parting doors.

In normal operation, the vehicle doors are controlled automatically. Control and supervision of the doors are safety critical. At the station, doors can not open until the vehicle is stopped. Similarly, the vehicle is not allowed to leave until the doors are closed and confirmation signals have been received by the Dwell Operational Control Unit (DOCU).

Manual door operation by maintenance personnel is possible either from the operator's panel or by means of service key. In the event of an emergency, passengers can open the side doors by an emergency handle located in the ceiling over the door. Actuation of this emergency handle initiates emergency brakes, cuts off the power, unlocks the door, and releases the hydraulic force which keeps the door closed. In this state, doors are easily opened manually with a force of about 22 newtons (5 pounds).

Doors are equipped with an obstacle detection system that will detect objects down to 5 cm. In case an obstruction is encountered during door closing, the door motion stops and the closing force is removed so the the doors can easily be pushed open. After an adjustable delay time, the closing circuit is again energized and door closing resumes.

3.2.2 Interior

The normal seating capacity of each vehicle unit is 34 seated and 28 standees for a vehicle unit total of 62. See Figures 3-3 and 3-4 for the vehicle layout and dimensions. This includes occupation of 12 jump seats. The total normal seating capacity of a vehicle is 124 (based on 4 standing passengers per square meter). This provides a 55 percent ratio of seated to standing passengers. With jump seats (12 in each vehicle unit) folded-up, the normal capacity is increased to 160. The crush loading capacity of the vehicle is 262 passengers, based on 8 standing passengers per square meter.

The seats are reinforced fiberglass with foam backed inserts. The seats are mounted longitudinally along the sides of the vehicle. The fiberglass seats contain fire retardant additives. The emergency battery is mounted under the central seats of the chopper unit and is vented externally.

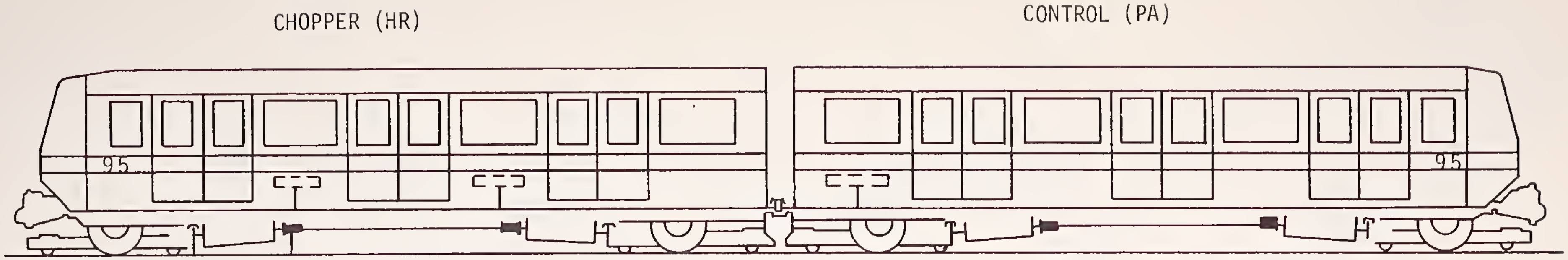
The ventilation system provides a maximum flow that will change the air every 30 seconds. Air conditioning is not provided on VAL. Heating is by means of electrical radiators.

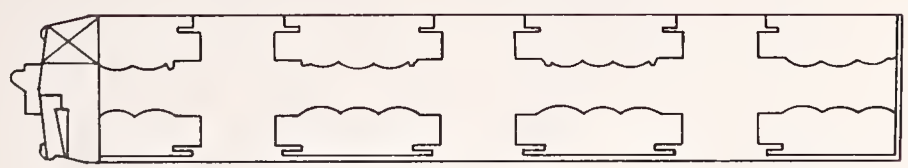
3.2.3 Suspension

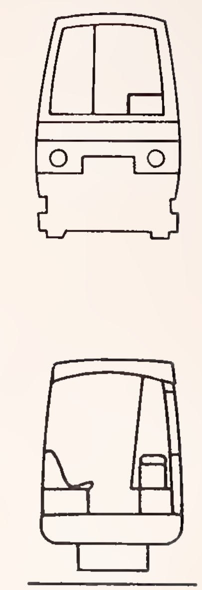
The vehicle runs on rubber pneumatic tires. Each vehicle unit is equipped with two pivoting axles. Each axle is guided laterally by a set of four rubber-tired guidance wheels which run between two steel steering rails. Figure 3-5 shows a cut-away of the vehicle. The four guidance wheels and two switching wheels are mounted to an "H" frame which is in turn mounted to the axle. Figure 3-6 shows this running gear. The axle is fitted with a differential. This steering and suspension arrangement and the use of a differential produces more direct kinematic forces that permit curves to be negotiated without slapping or sliding.

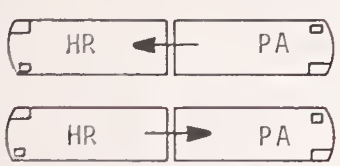
The wheels have Michelin Radial tires (13.50/85R 16x VGE) which are approximately 1 meter in diameter. A metal rim has been added to the inside of the wheel to prevent total collapse in the event of deflation.

The axle is connected to a bolster by a pivot pin. The vertical vehicle loads are reacted against two sliding surfaces on the axle with a Telfon-like material. The bolster is, in turn, mounted to the vehicle by two air bag springs. A series of drag links maintain the axle in proper alignment and transmit traction and braking forces to the body.









CAPACITY	CAR seats	CAR standees	CAR total	MARRIED PAIR total
Normal load*	34	28	62	124
Normal load°	22	58	80	160
Peak load°	22	82	104	208
Fixed seats			22	44
Jump seats			12	24

°: jump seat folded
*: jump seats occupied

FIGURE 3-3. VEHICLE LAYOUT

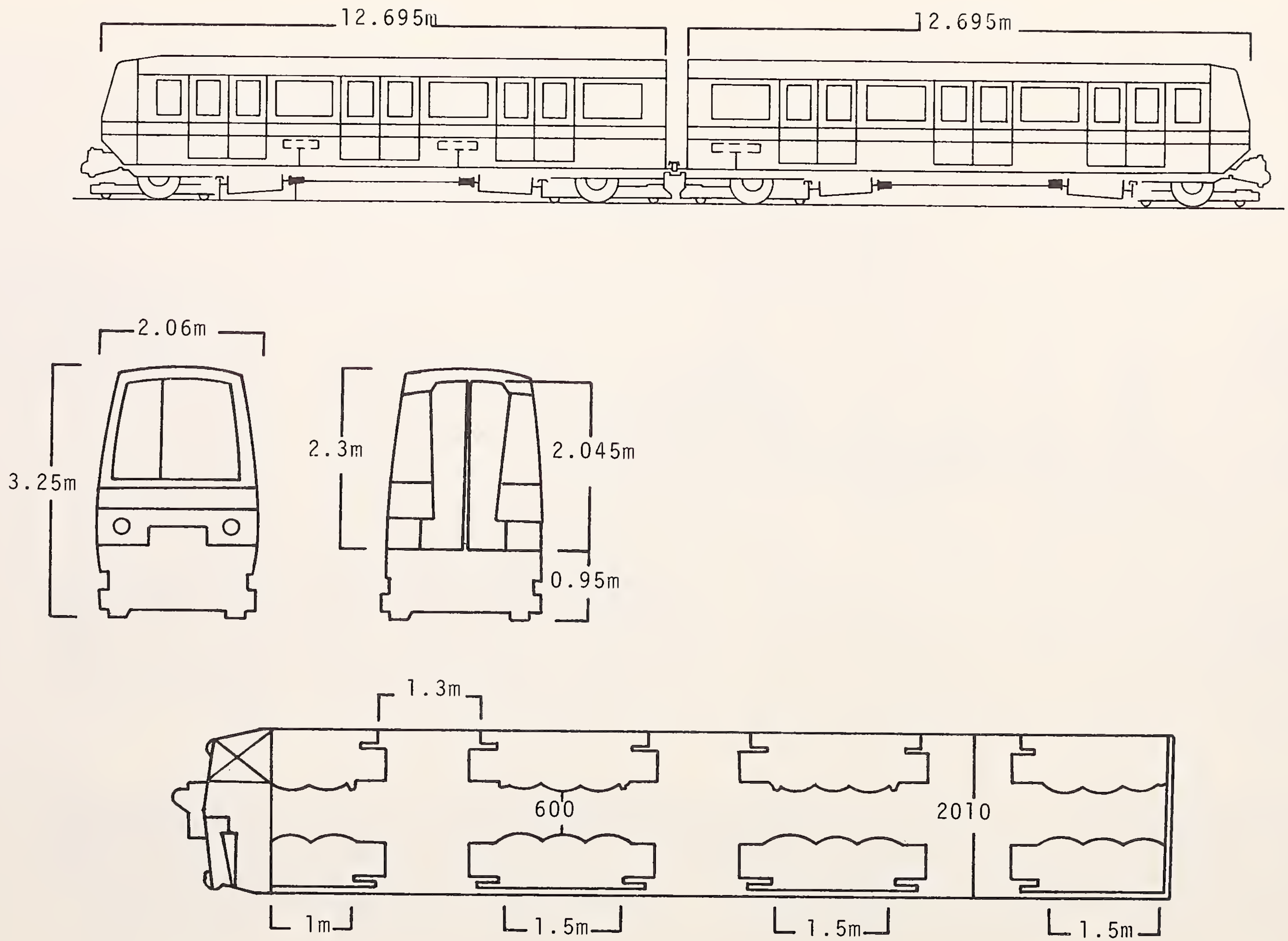


FIGURE 3-4. VEHICLE DIMENSIONS

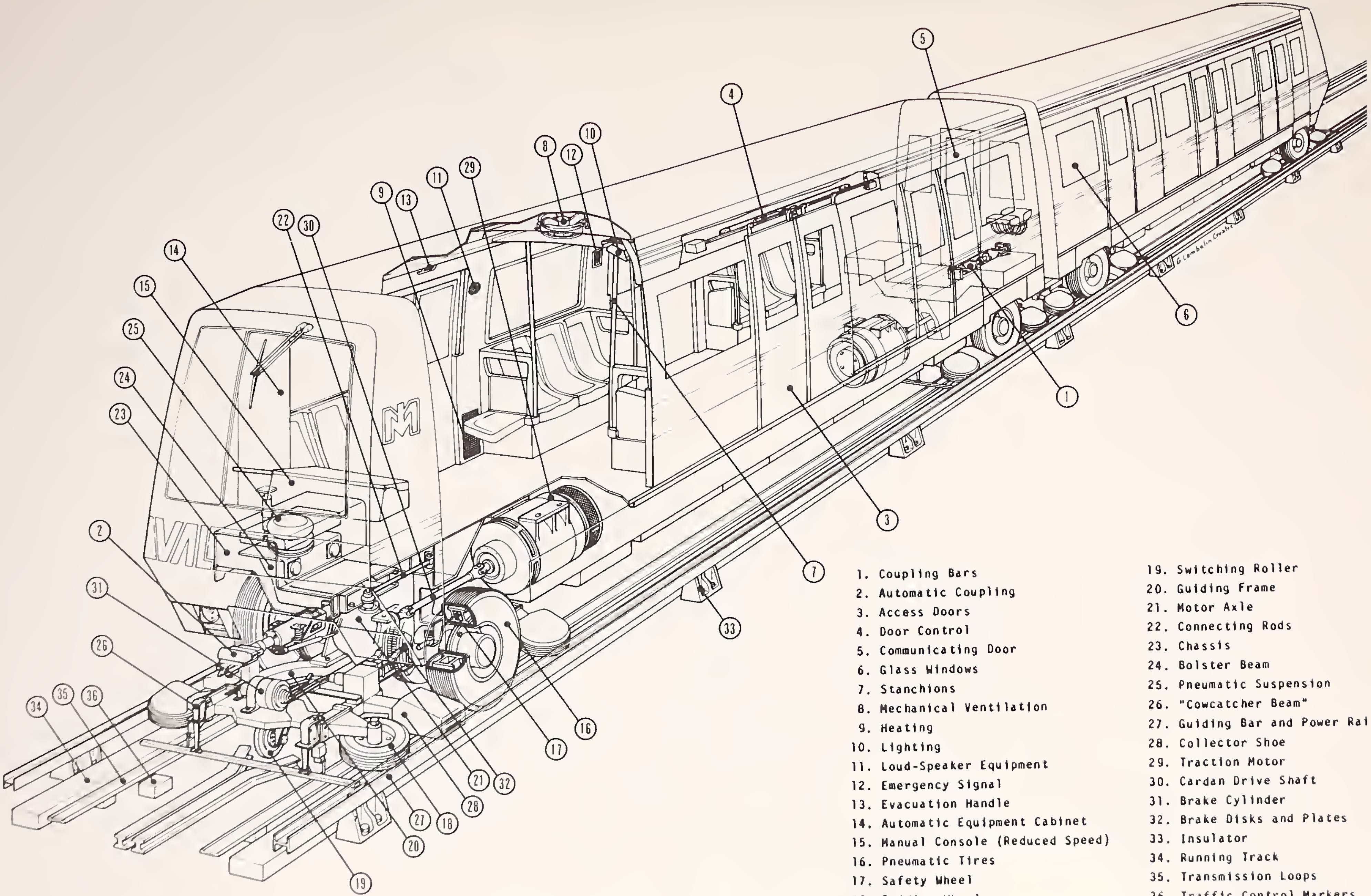


FIGURE 3-5. VEHICLE CUT-AWAY

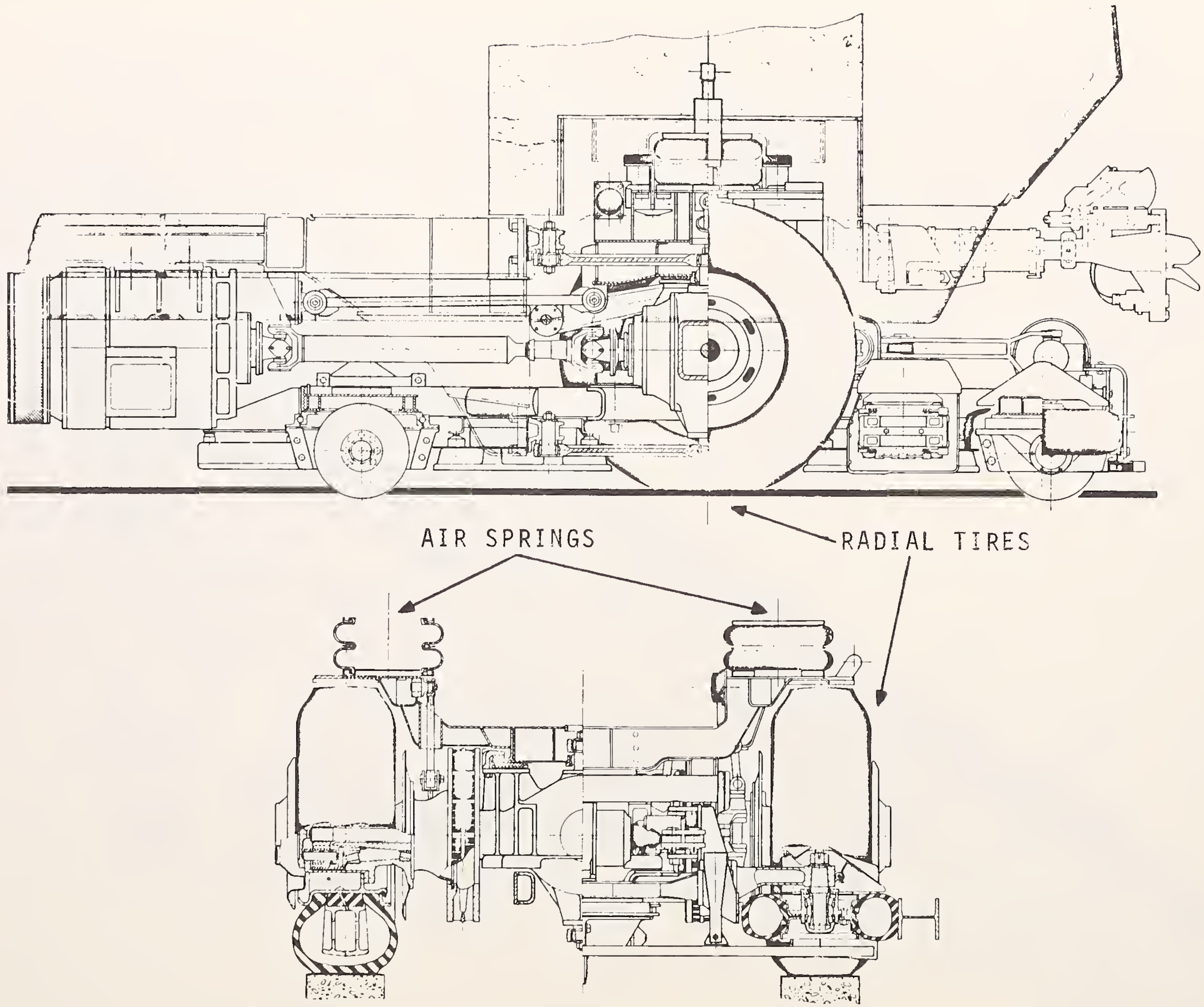


FIGURE 3-6. RUNNING GEAR ASSEMBLY SHOWING AIR SUSPENSION SYSTEM

The air bag suspension system has an automatic levelling device that keeps the floor height constant. This control device also changes the spring constant to maintain a constant suspension frequency. It is normally adjusted to its optimum value of 1.30 Hz which corresponds to an effective value of acceleration of approximately 0.5 m/sec^2.

The electric drive motor is mounted to the body and is connected to the differential by a drive shaft with single Cardan joints at each end. This has been done to reduce the unsprung weight.

3.2.4 Switching

Two steel guidewheels 0.32 meters in diameter, mounted fore and aft of each axle on the "H" frame interact with a steel rail track in the guideway to produce steering forces in the switching area (see Figure 3-7). The dual-rail track provides positive lateral restraint. Switching is accomplished by a wayside actuator that bends a cantilevered rail laterally.

3.2.5 Propulsion

Each vehicle unit is propelled by two 114-kW (continuous rating) dc series wound motors. These two traction motors are connected in series in each vehicle. This limits motor voltage and balances torque between the front and rear axles. The propulsion system configuration is illustrated in Figure 3-8.

The series wound motors have been designed and manufactured in accordance with French and international regulations for traction equipment IEC 349. This type of motor has been in service for more than 10 years in Montreal, Marseilles and Santiago. The propulsion motor characteristics are shown in Figure 3-9.

The propulsion systems in the chopper vehicle unit and the control vehicle unit are coupled in parallel (see Figure 3-10). Each of these propulsion systems is capable of moving the vehicle at line speed when the vehicle is empty and at a reduced (0.9 velocity) speed when fully loaded. Even with only one propulsion system operating, the vehicle is able to accelerate up a 7-percent grade at 0.1 m/sec^2 from a standing start. Because of redundant propulsion systems, a vehicle with a failed propulsion system can complete its assigned trip at a speed in accordance with decreased torque available. In the event

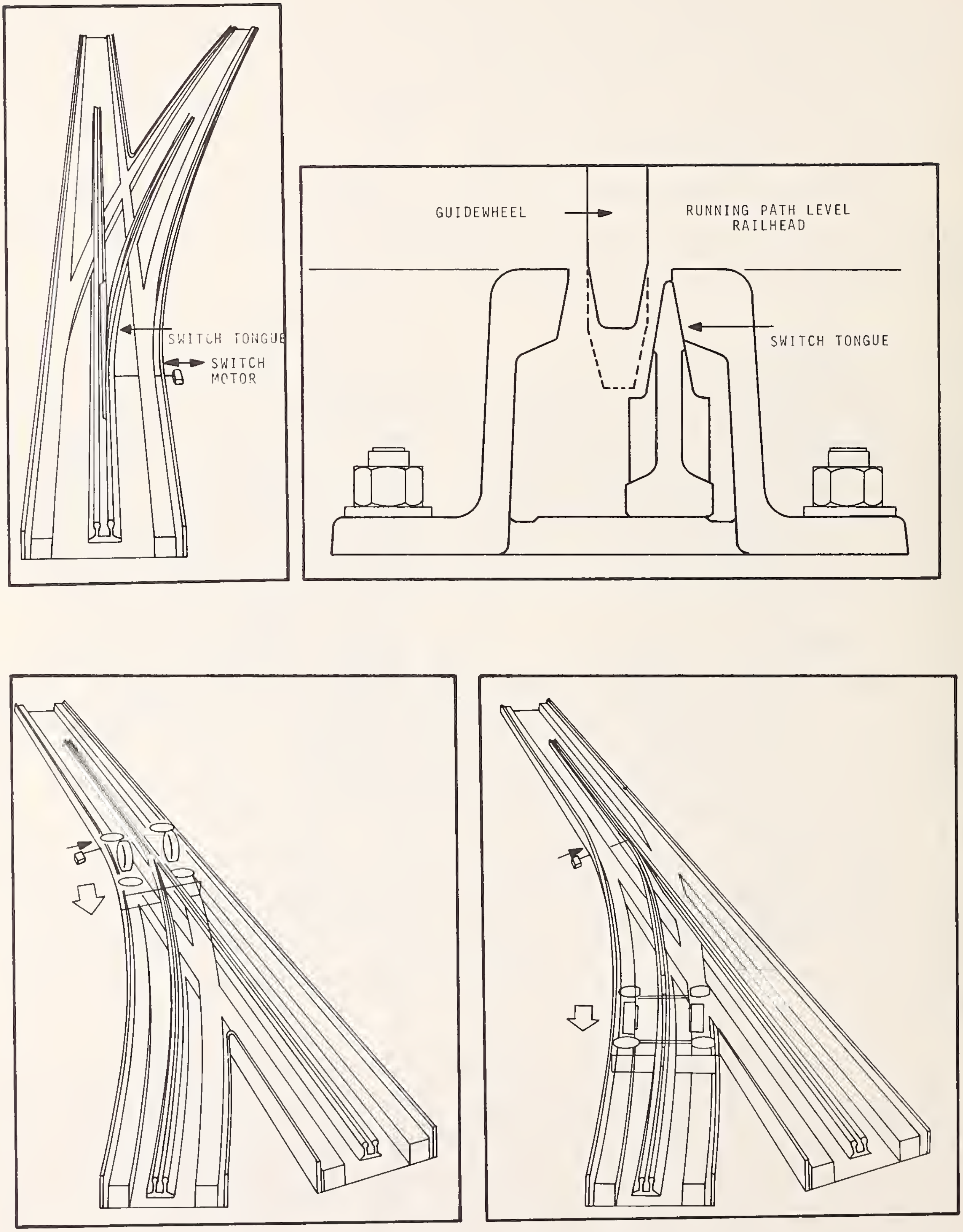


FIGURE 3-7. SWITCHING SCHEMATIC

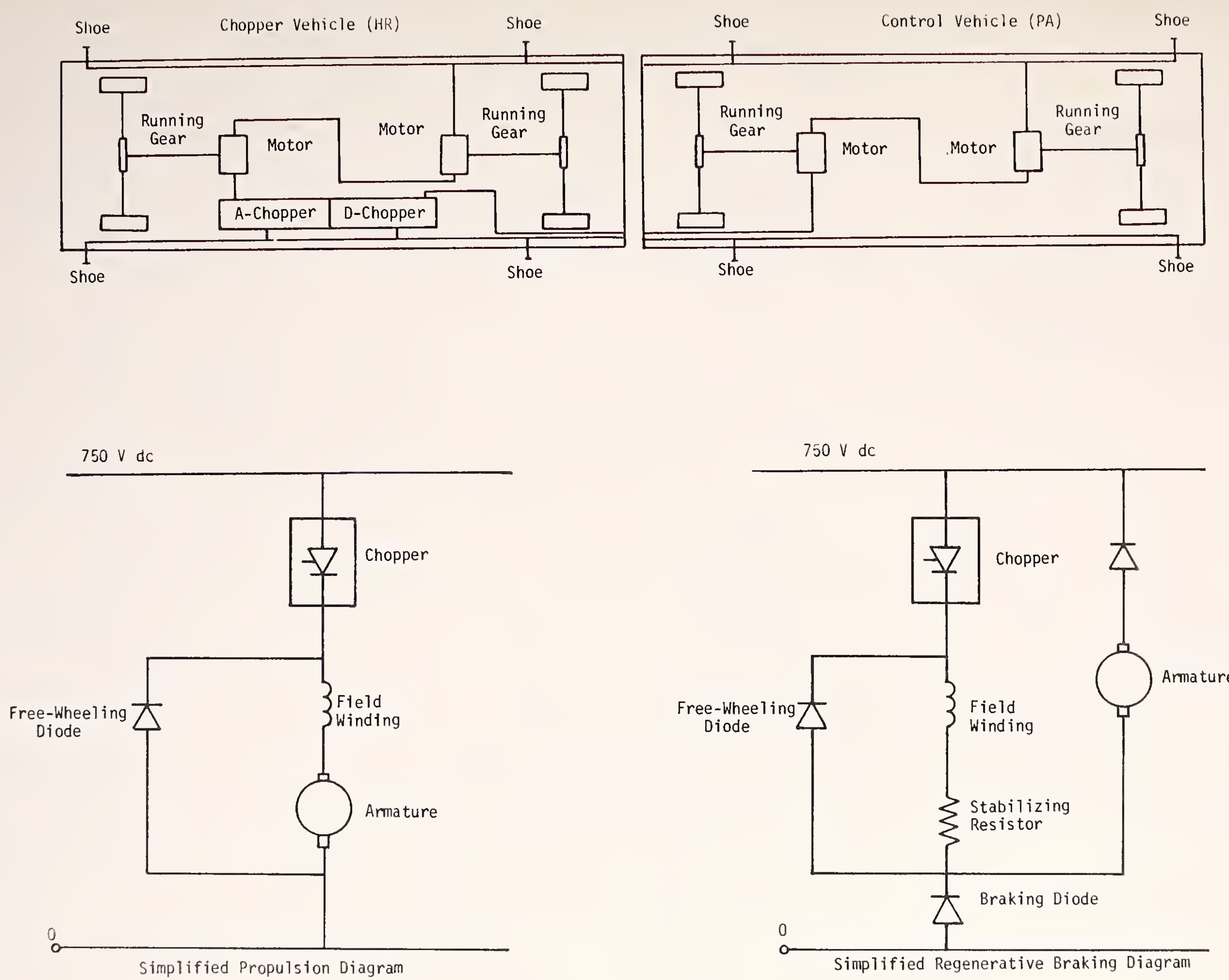


FIGURE 3-8. PROPULSION SYSTEM CONFIGURATION AND FUNCTIONAL SCHEMATICS

MOTOR RATING AS PER IEC 349

	Continuous	one hour	Max.
Mechanical power at shaft	114 KW	123 KW	
Voltage	345 V	360 V	560 V
Armature Current	370 A	400 A	550 A
Field Current	340 A	400 A	550 A
Rotating Speed	1556 RPM	1520 RPM	3806 RPM

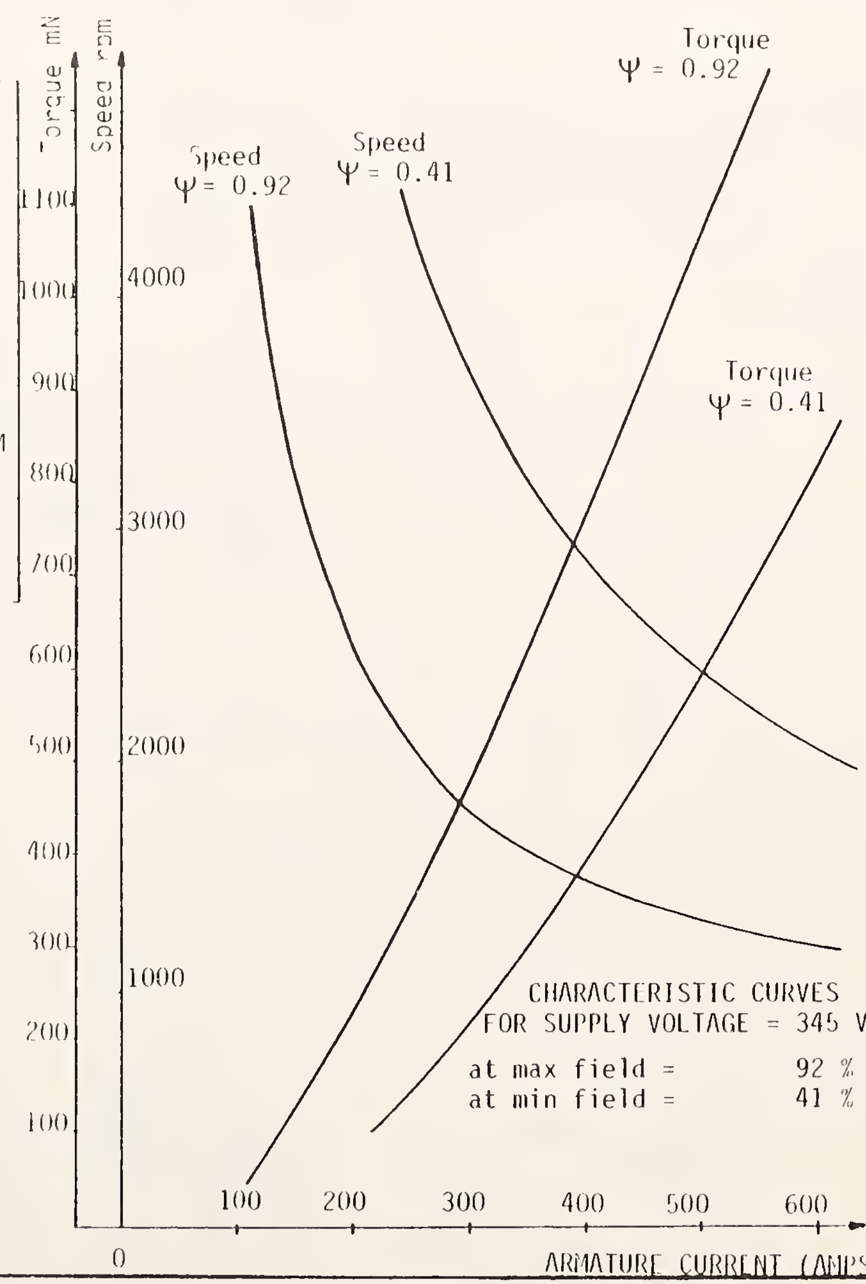


FIGURE 3-9. PROPULSION SYSTEM CHARACTERISTICS

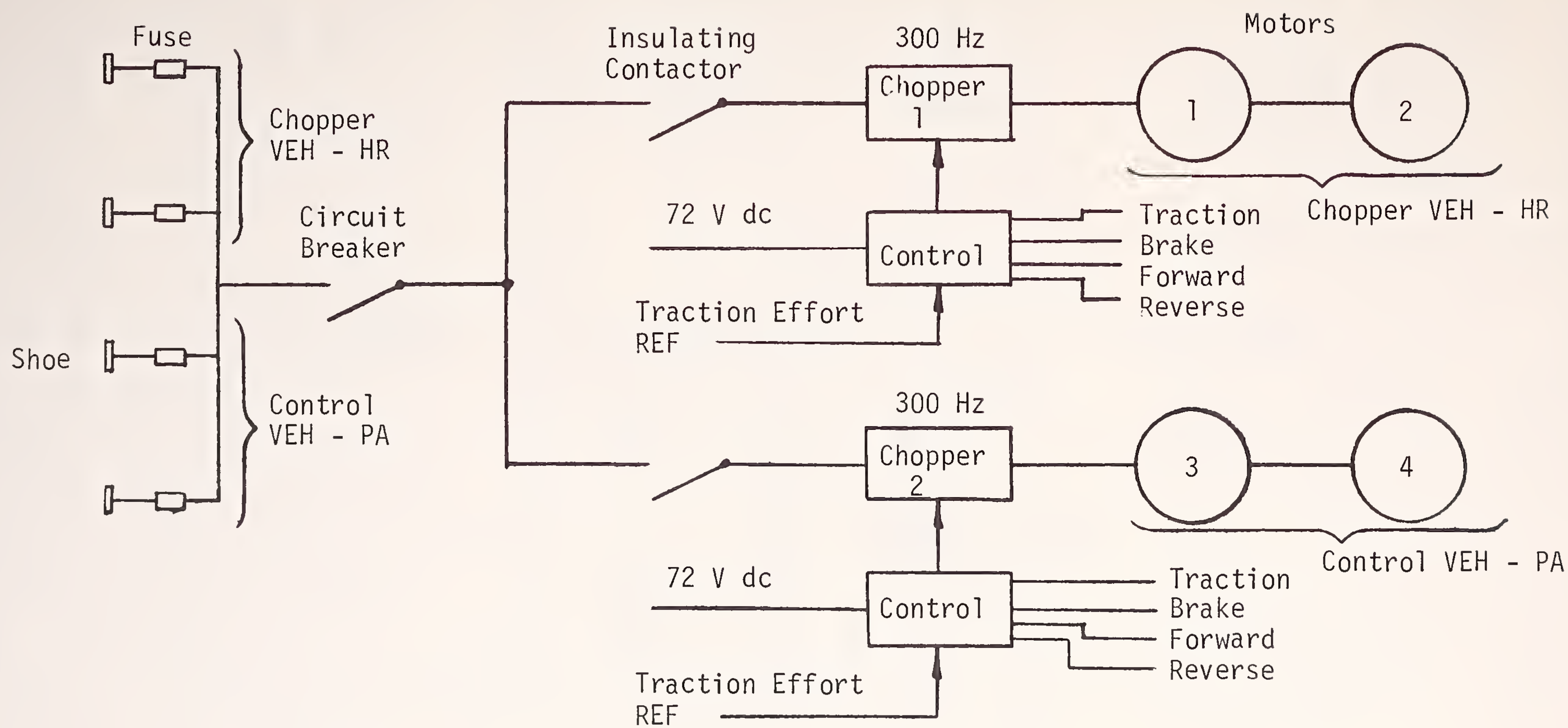


FIGURE 3-10. PROPULSION SYSTEM SCHEMATIC

that a vehicle is disabled by a failure, the propulsion system of a following vehicle is designed with sufficient torque capacity to push the failed vehicle, even when the trailing vehicle is fully loaded.

Each group of two motors is supplied by a chopper based on a thyristor design. The choppers operate at a constant frequency of 300 Hz and are 180 degrees out of phase with one another, thus providing for low-ripple current and minimum spurious harmonics, a significant factor in controlling electromagnetic interference. The schematic of the traction configuration is shown in Figure 3-11. The chopper uses field weakening for control at higher speeds. The chopper performance is illustrated in Figure 3-12.

3.2.6 Braking

The chopper also provides a means of regenerative braking at the higher speeds. The schematic of the regenerative braking configuration us shown in Figure 3-13. Braking is provided by regenerative braking at high speeds, a blending of mechanical and electrical brakes in the mid-speed region, and by mechanical brakes at low speeds. This is illustrated in Figure 3-14. The acceleration and jerk commands, and therefore the associated longitudinal ride quality, are constrained by blending the automatic vehicle commands, which are jerk limited, with linear performance characteristics of the chopper-controlled propulsion system. This jerk filtering network provides for brake control blending at each end of a velocity transition.

In the regenerative mode, field weakening is not used. Rather, current in the field coils are controlled by the chopper. This allows braking down to 5-6 km/hr (see Figure 3-15).

When a vehicle is coming to a stop in a station area, jerk, at these low speeds, is controlled by reducing mechanical brake force as a function of distance to the platform stopping point. This braking is initiated by a beacon located in the near vicinity of a station. Hence, a smooth and continuous blending of both electrical and mechanical brake modes is achieved in the transition from one speed region to the other. A simplified mechanical brake system schematic is illustrated in Figure 3-16.

Mechanical braking is effected by two 590-mm diameter, 110-mm thick air-cooled disk brakes per axle. The disk brake caliper assemblies are operated by a single spring. The spring force is released by an air cylinder operating

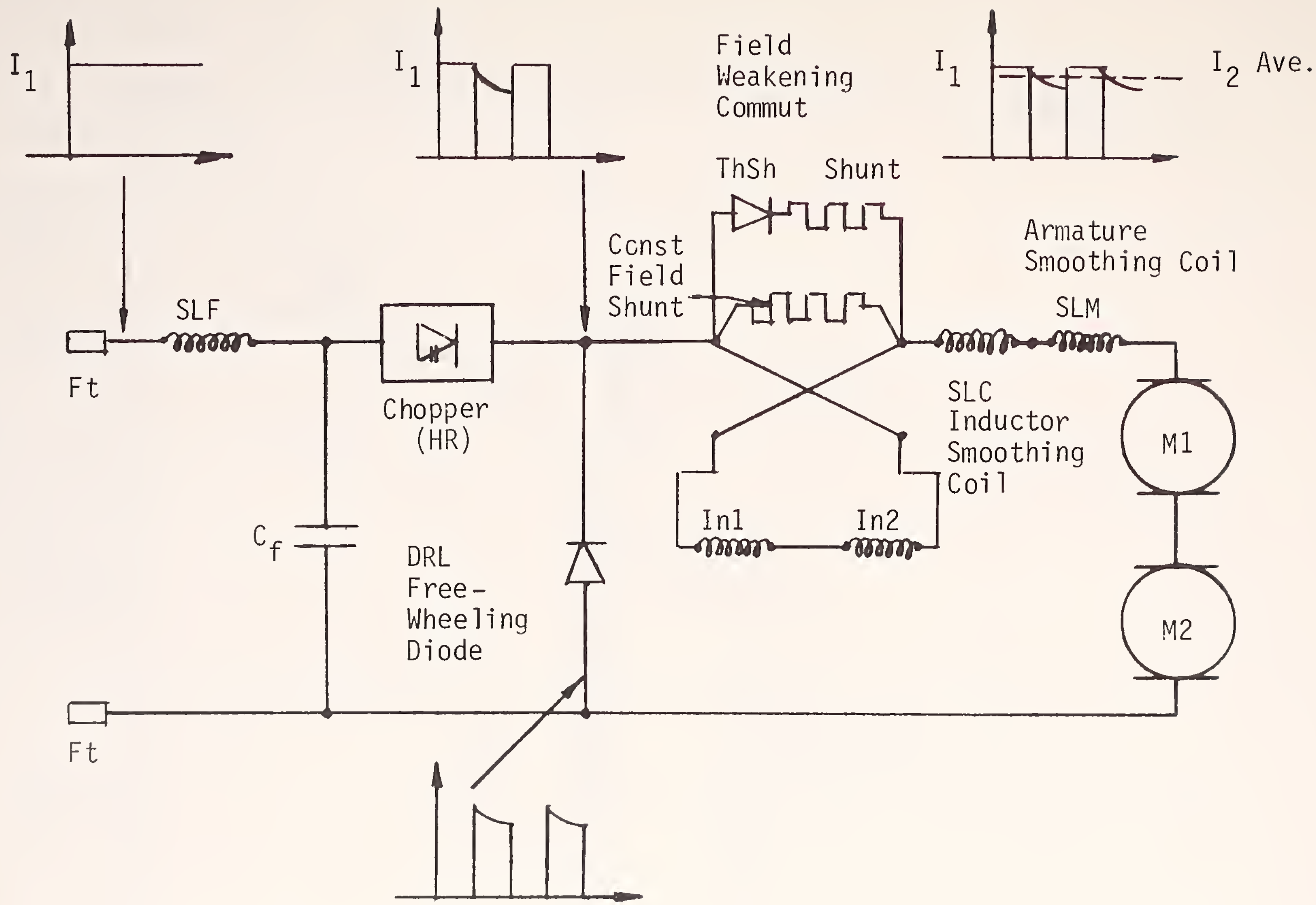


FIGURE 3-11. TRACTION CONFIGURATION

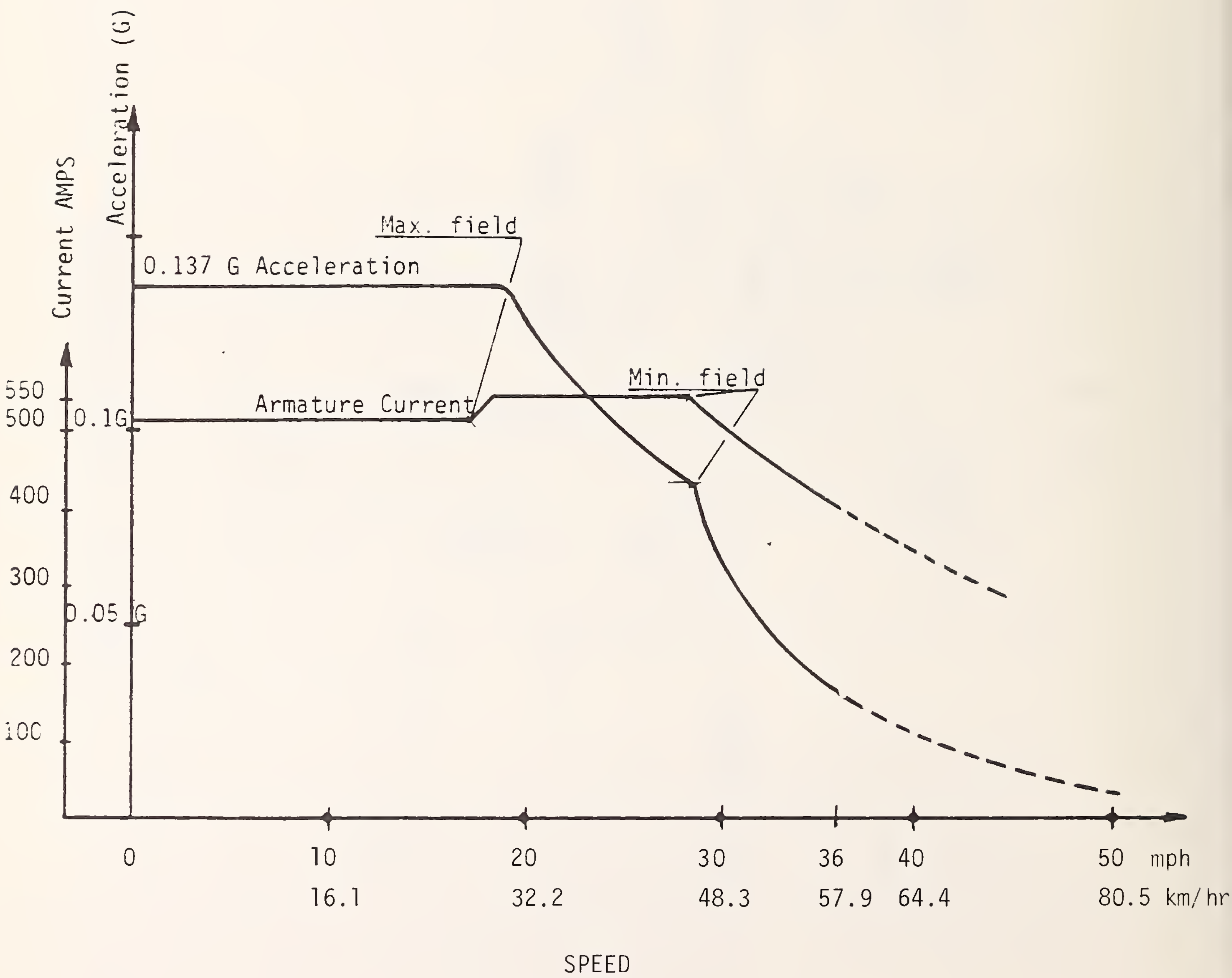


FIGURE 3-12. CHOPPER CONSERVATIVE APPLICATION OF THE STATE-OF-THE-ART

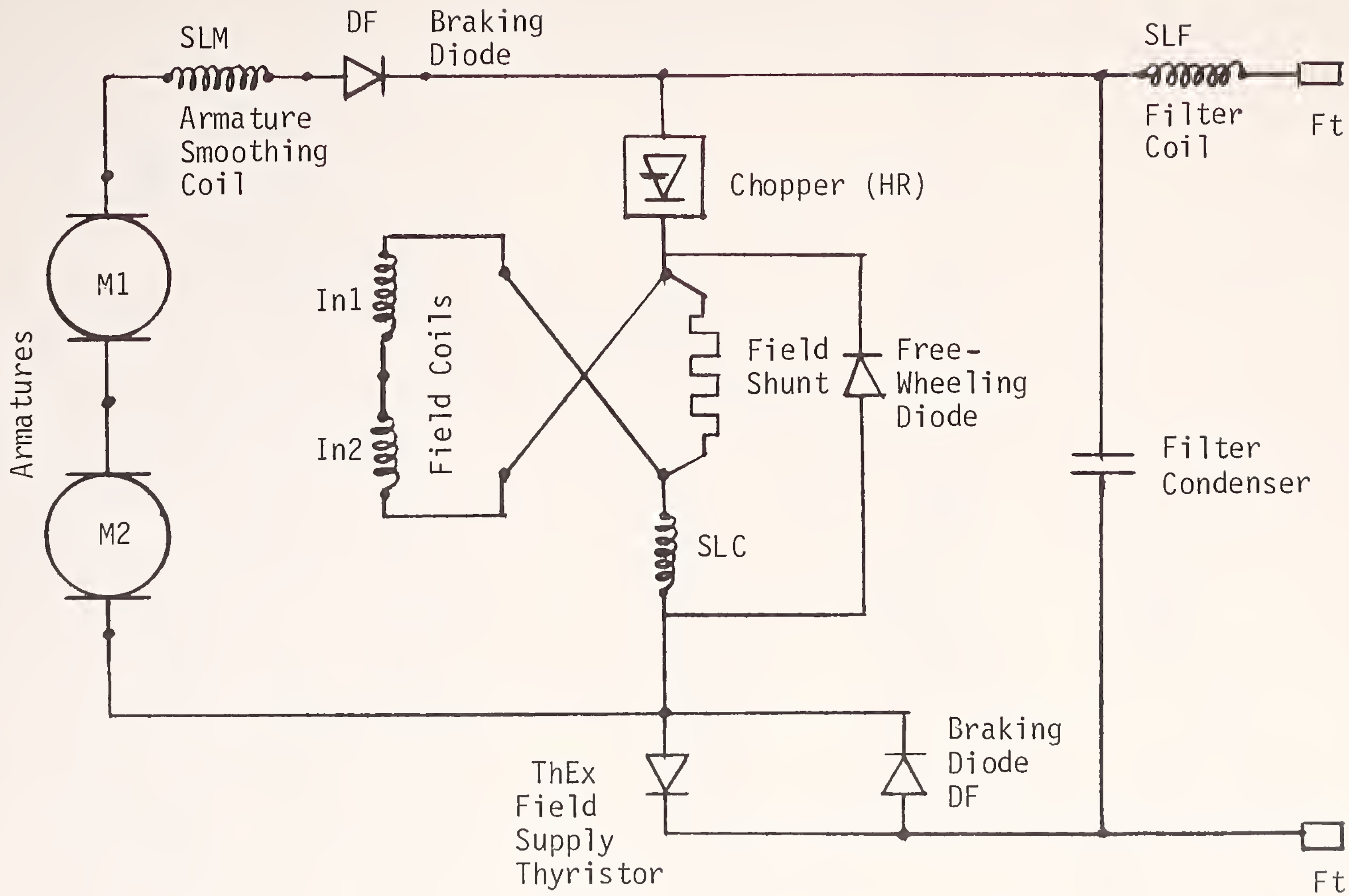
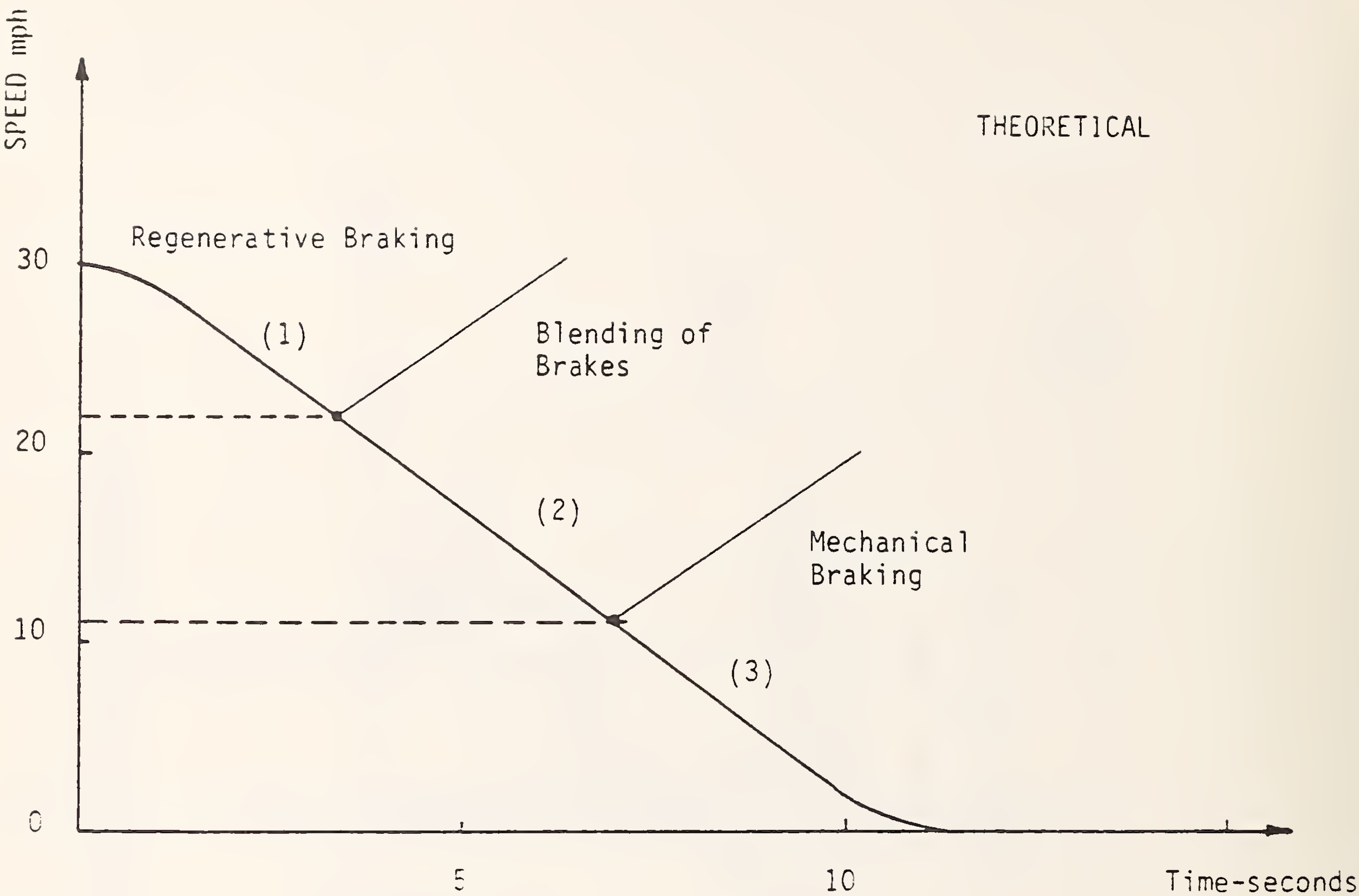


FIGURE 3-13. REGENERATIVE BRAKING CONFIGURATION



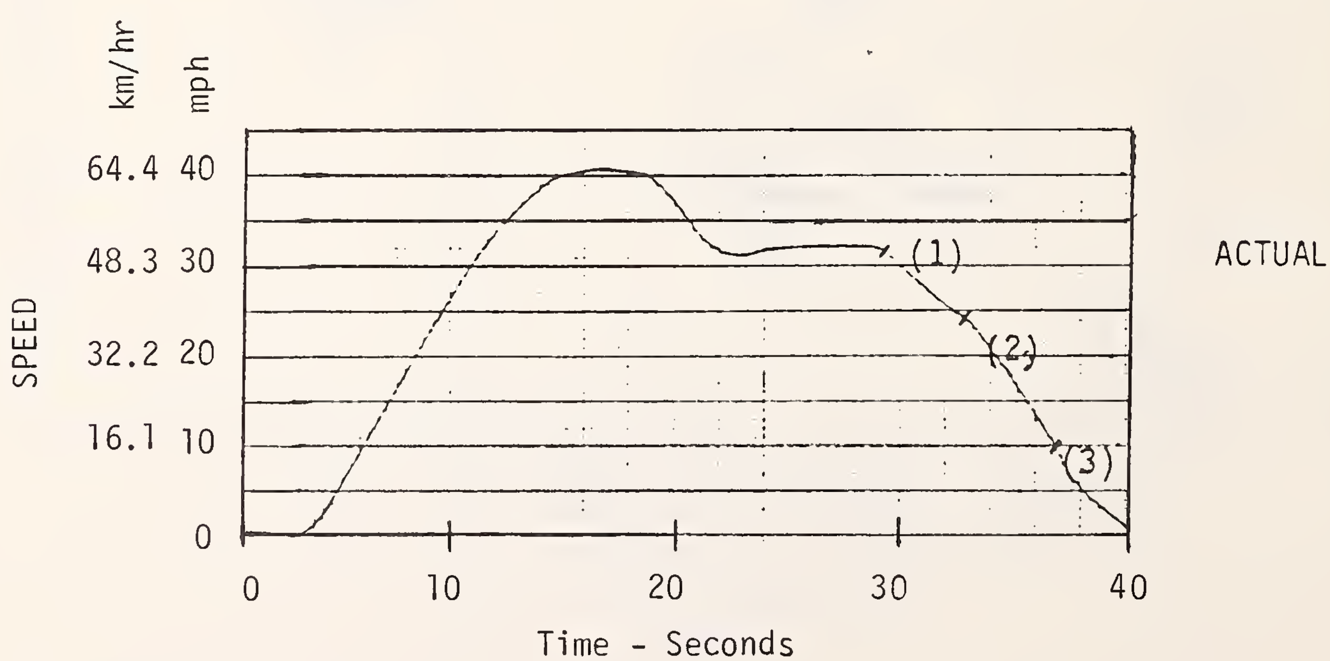


FIGURE 3-14. TYPICAL SPEED PROFILE RECORDED ON LILLE TEST TRACK

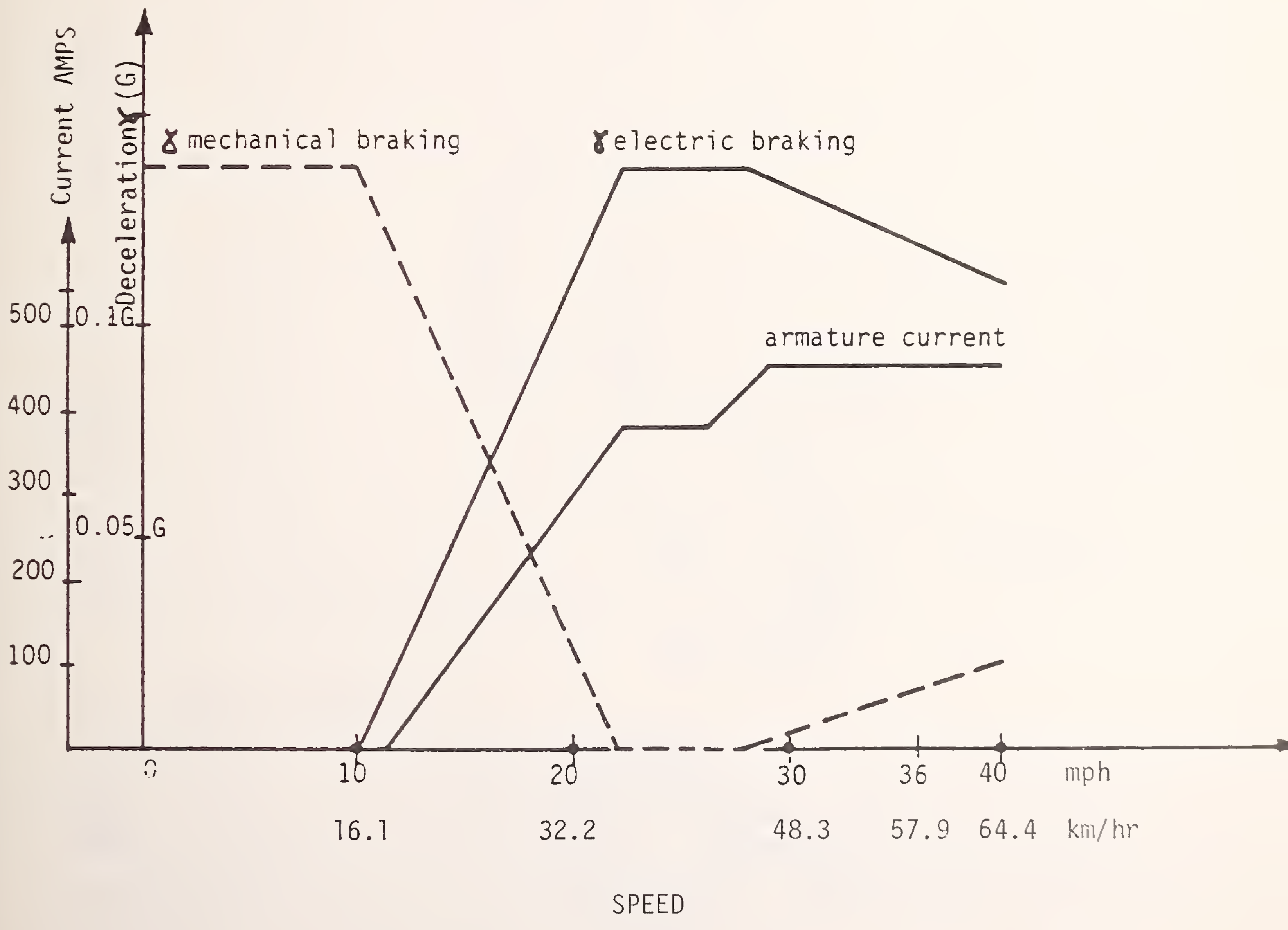


FIGURE 3-15. BRAKING ACCOMPLISHED BY BLENDING OF ELECTRICAL/MECHANICAL SYSTEMS

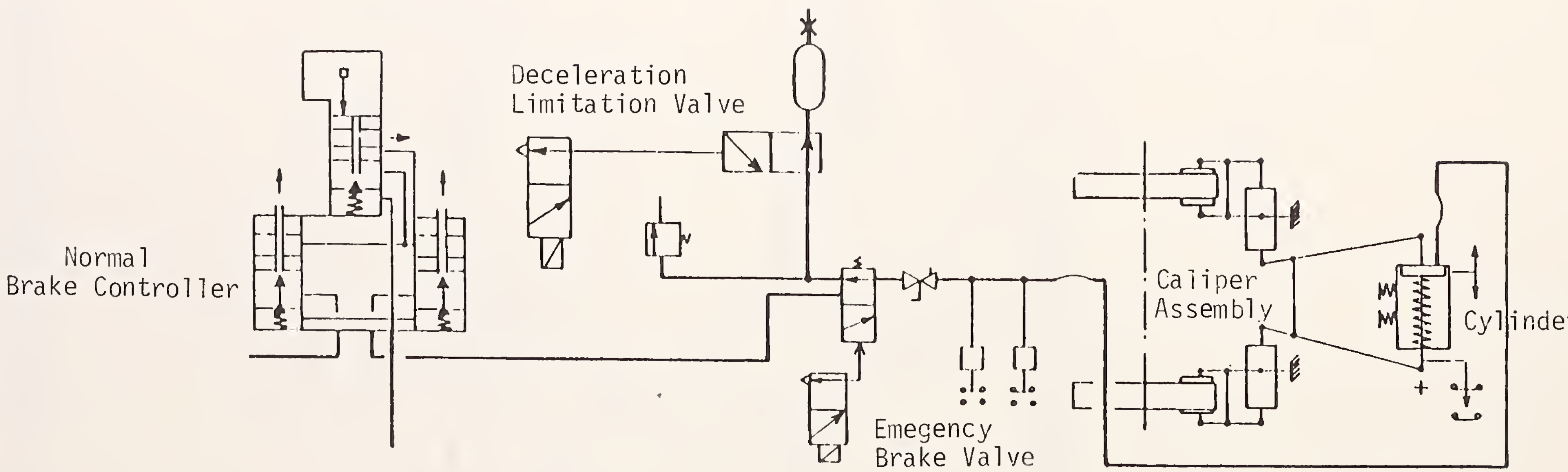


FIGURE 3-16. SIMPLIFIED MECHANICAL BRAKE SYSTEM SCHEMATIC

at 130 psi. The air cylinder supply is provided by a single compressor mounted on the control (PA) vehicle unit. The air supply is sufficient for the vehicle to operate to the nearest terminal in the event of a compressor failure.

The caliper assembly including the actuating cylinder is common to both the service and emergency brake systems. However, each function is controlled separately. For service braking an air-activated proportional controller overrides the mechanical spring force to provide the desired braking effort. For emergency braking, the air supply to the caliper is closed and the caliper is vented until the vehicle deceleration, which is determined by a mercury accelerometer, closes the primary caliper vent. Thereafter, the brake forces increase slowly with time until the entire spring force is available to the caliper. To effect fail-safe emergency brake operation, an electrical command removes power from the traction motor system, and if residual power is detectable, the primary circuit braker is opened.

Electrical braking is operational at line voltages between 450 and 825 volts. Above 825 V braking effectiveness is reduced as a function of the voltage which becomes zero when it reaches 1000 V. When no net power demand exists on the traction power distribution system, braking is accomplished with mechanical brakes. When the chopper senses that line voltage is above predetermined values, it decreases regenerative current and increases the mechanical braking effort. Regenerative braking can reduce the traction power requirements during peak periods by as much as 20 percent. Concomitantly, wear rates on the mechanical friction brakes are minimized.

3.2.7 Emergency Brakes

Only the mechanical, self-ventilated disk brakes with a diameter of 590 mm and a thickness of of 110 mm are used for emergency braking. The mechanical brakes are designed in a fail-safe manner. This is achieved by holding off a spring actuated brake with a pneumatic cylinder. The mechanical brake system consists of the following elements:

- An air compressor and tank which also supplies air to the suspension system and door pistons. The air compressor system normally maintains a pressure between 8.5 and 9.5 bars (atm.) in one main tank and two auxiliary tanks per vehicle;

- A direct electropneumatic pilot (PEPD) or controller per vehicle that supplies air pressure proportional to the current. The current through the PEPD is controlled by a system which combines the effort from both the electrical brake and the mechanical brake. The normal service brake deceleration is 1.3 m/sec^2;
- A pneumatic relay to supply a volume of air proportional to the output pressure from PEPD;
- A receiver cylinder per axle that controls the calipers of the disk brakes. These cylinders are equipped with springs which, when there is no air from the pneumatic relay, will exert a force on the calipers that will decelerate the vehicle at more than 1.8 m/sec^2; and
- A disk pad wear regulator.

The air supply from the pneumatic relay is used to release the brakes by compressing the springs in the receiver cylinders. In the emergency brake mode, the air supply of the PEPD is cut off, and air in the receiver cylinders is dumped by a solenoid valve permitting the springs to apply maximum force to the brake pads.

3.2.8 Electrical Auxiliaries

The systems for controlling and monitoring the various electrical devices in the vehicle unit include the following:

- Control and monitoring of normal and emergency lighting. The two emergency lighting circuits are powered by a 72 V battery.
- Control and monitoring of ventilation and heating. Heating is provided by the 750 V supply whereas ventilation is provided by a 72 V, 52 cell, 70 amp-hr battery. Therefore, if the dc to dc converter fails, the ventilation system will continue to operate.
- Control and monitoring the compressor, air tanks and brake circuit.
- Control and monitoring of door status. The safe state of the doors is in the closed position. The open position will neither allow the vehicle to move from the station, nor will it initiate an emergency stop when it is on line.

- Monitoring of the status of the mechanical coupling bar and electrical connector between two vehicles of a passenger unit. Uncoupling causes an application of emergency brakes on each of the set of two vehicles. After the monitoring signals are transmitted to the Control Center, they are processed by the Automatic Vehicle Supervision system. In certain cases, monitoring signals can exert an immediate and direct influence on the passenger unit (e.g., overheating of the compressor initiates compressor shutdown, and a serious leak in either the main or auxiliary accumulators initiates mechanical braking).

The primary low voltage (750 V dc) power is stepped down by a solid-state converter to 85 V dc to supply the electrical auxiliaries. To achieve high system availability, power to the emergency electrical lighting, ventilation, door controls, vehicle automatic control system, and the emergency traction drive is supplied by a backup 72 V nickel-cadmium battery system; this is supplied by the dc to dc converter through a battery charger.

The operating status of the converter and battery are continuously monitored. Failure of the converter will not prevent operation. If the 750 V supply is cut out, some of the auxiliaries will be turned off, permitting the battery to supply the remaining auxiliaries for about 40 minutes. If the primary 750 V dc or the converter fails, the battery has sufficient capacity to move the vehicle approximately 25 kilometers; this is a round trip time of 36 minutes. In this case, lighting and ventilation are turned off. The primary function is to move the vehicle to the next station.

3.2.9 Power Collection

The lateral guidance rails on the guideway supply the vehicles with 750 V dc power. One rail serves as the positive contact rail, and the other rail is the negative.

Each vehicle has two collector shoes per side (i.e., four per passenger unit side). Each collector shoe has a continuous rating of 500 amps which corresponds to the maximum rms current required for 2 hours of continuous normal operation at crush load weight. The peak rating is 1100 amps per shoe which is sufficient to start moving a vehicle.

The distance between the fore- and aftmost collector shoes on the vehicle (24.4 meters or 80 feet) is longer than the opening of lateral guidance rails in crossover areas. A vehicle stopped in a crossover can restart with the current on one shoe on each side. An electrical schematic of the power collection system is shown in Figure 3-17.

In accordance with IFC and UIC standards and regulations, motors, choppers, and other vehicle electrical components will operate with voltage variations of +20 percent and -30 percent without damage. The motors are conservatively rated at 690 V dc. Voltage limiters protect the propulsion equipment to 1000 V dc. At higher voltages, circuit breakers are tripped. With supply voltages as low as 450 V dc, all systems will continue to operate, but with possible degraded performance. Below 450 V dc circuits are automatically disconnected. In the event of a short duration high voltage variation, circuit breakers open after a prescribed time delay and automatically reset. If the power supply remains out of tolerance, the breakers reopen and must then either be reset from Central Control or manually.

In the maintenance area the power to the vehicle is supplied through an umbilical line with a connector. For safety purposes, power can not be supplied through the umbilical unless: the vehicle control panel is manually switched to the "plug" condition; and the connector is properly seated on the vehicle side, thus overriding a shorting strap in the control circuit.

Under no circumstances are collector shoes energized in the shop. Vehicle electrical systems are protected by: high power fuses physically located very close to the shoes; a differential relay which clocks equality between inbound and outbound currents; and a shoe-plug switch. Power (750 V dc) is distributed to the:

- High voltage auxiliaries such as the compressor and heating system which are individually fused;
- Traction motors and choppers - the two choppers have a common electric filter and rapid circuit breakers;
- 12 kW static converter which supplies auxiliary power at 85 V dc for the battery charger, vehicle control system, and lights. The battery is used in the event of loss of 750 V dc power or static converter failure. The battery will provide emergency traction power for 40 minutes.

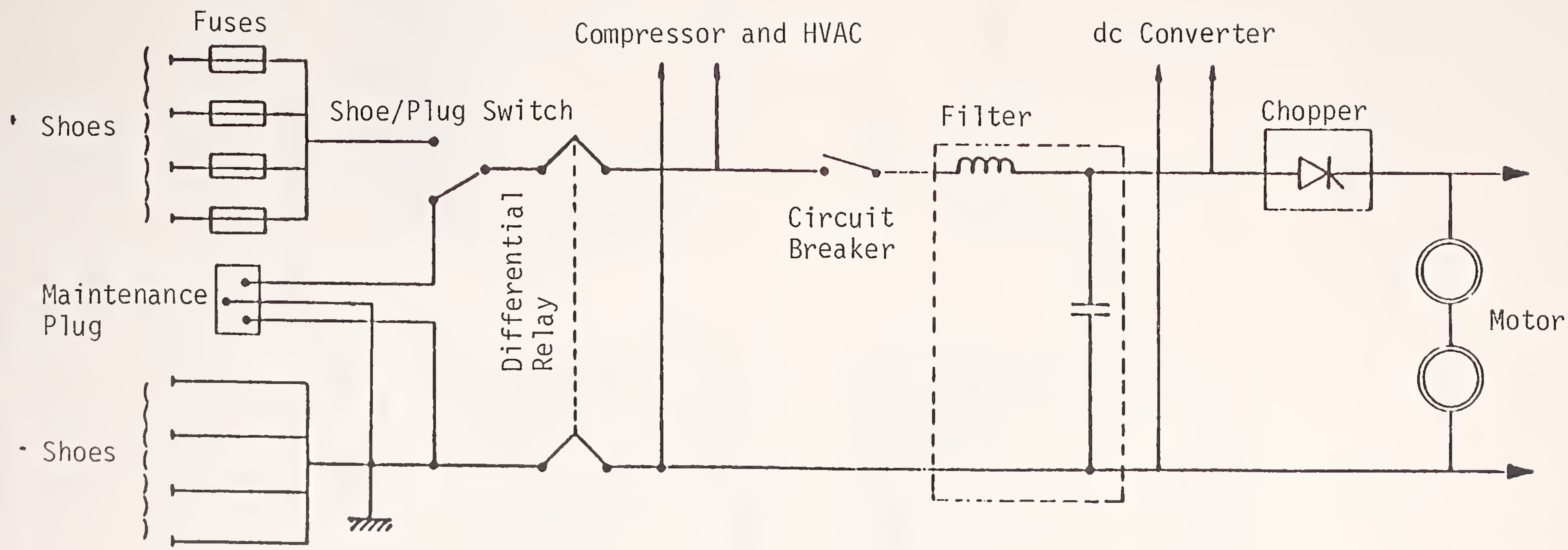


FIGURE 3-17. POWER COLLECTION AND CONTROL DIAGRAM

3.3 GUIDEWAY AND STATIONS

3.3.1 Guideway

The VAL system in Lille utilizes four types of guideway elements: elevated, at grade, cut ans cover, and tunnels. Three of these configurations are shown in Figure 3-18. In each case, the concrete running surfaces are supported by a concrete structure.

The running surfaces are made of two prefabricated reinforced concrete beams, 5.20 meters long, 270 mm wide, and 140 mm thick (see Figure 3-19). The running surface gage is 1610 mm. The running surface beams are fastened to the concerte bed with bolts making replacement easy (see Figure 3-20). The separation for expansion between these longitudinal beams is 5 mm.

A concerte running surface was selected to allow 7 percent grades to be climbed even from a standing start, and high deceleration levels (1.8 to 2.4 m/sec^2 under emergency brakes). A special coating is used on elevated structures to provide adequate adhesion in the rain without being abrasive to the tires.

Lateral guidance is provided by two steel H sections (HEB 140) located on either side of the guideway. The lateral guidance wheels run on the side of this H section, 200 mm above the running surface. They are located by molded polyester electrical insulating supports spaced at 3.5-meter intervals on straight sections and 3.0 meters on curves (see Figures 3-21 and 3-22). The electrical insulating supports are necessary because the lateral guidance beams are also used to simultaneously provide propulsion power. One rail serves as a positive while the other serves as a negative. The upper and outer face of the positive power rail is covered with an insulator. Bayonet type expansion joints are used in the power and lateral guidance rails (see Figure 3-23). Section insulators permit entire sections of the line to be cut thereby providing a means of isolation (see Figure 3-24). The laterial guidance rails are mounted in place first and all other surfaces are referenced to the lateral guidance rails (see Figure 3-25).

The winter climate in the Lille area has necessitated heating of the running surface and power rails of elevated guideway sections to provide good adhesion and power collection in the presence of frost and ice. Heating is

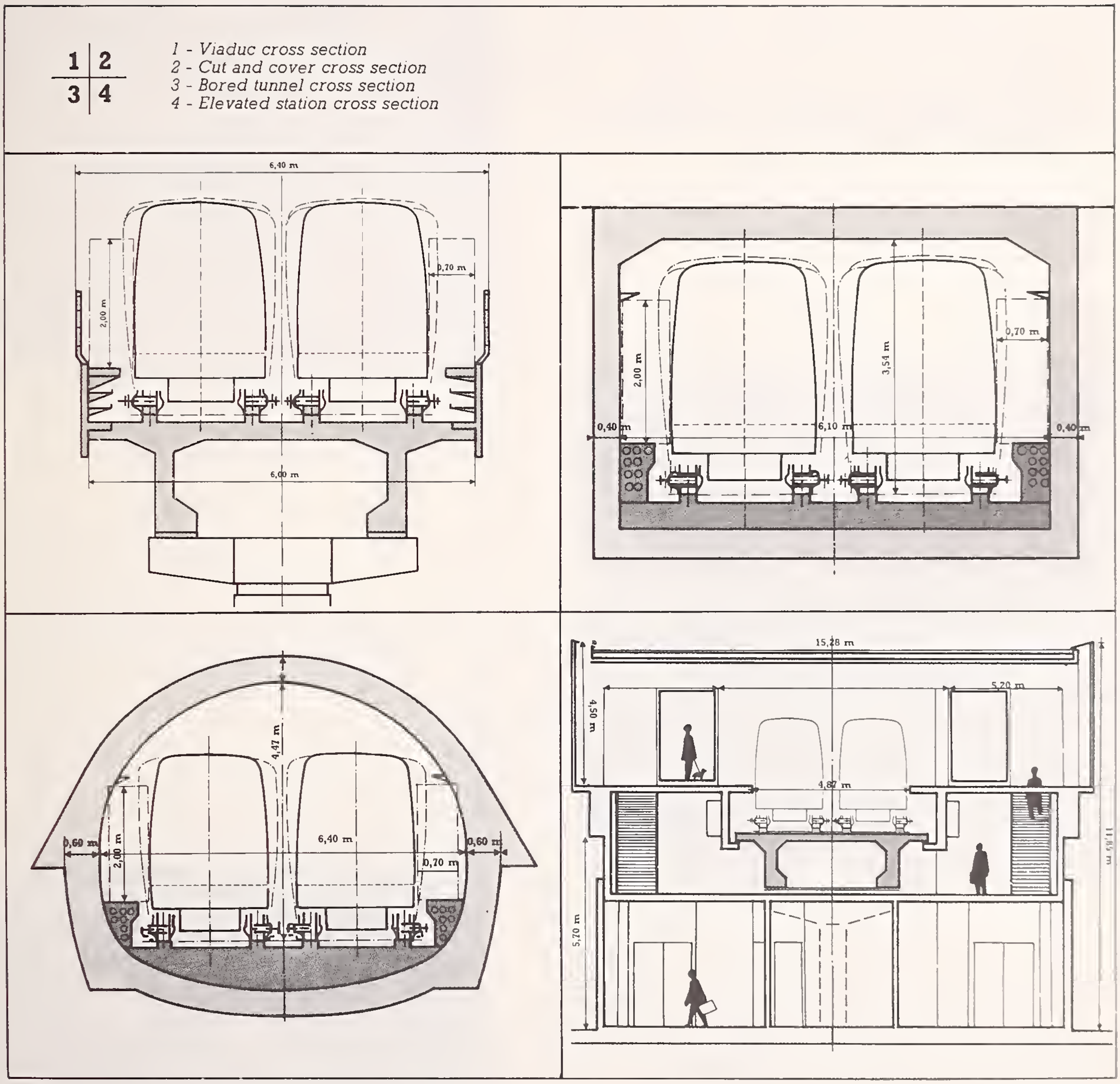
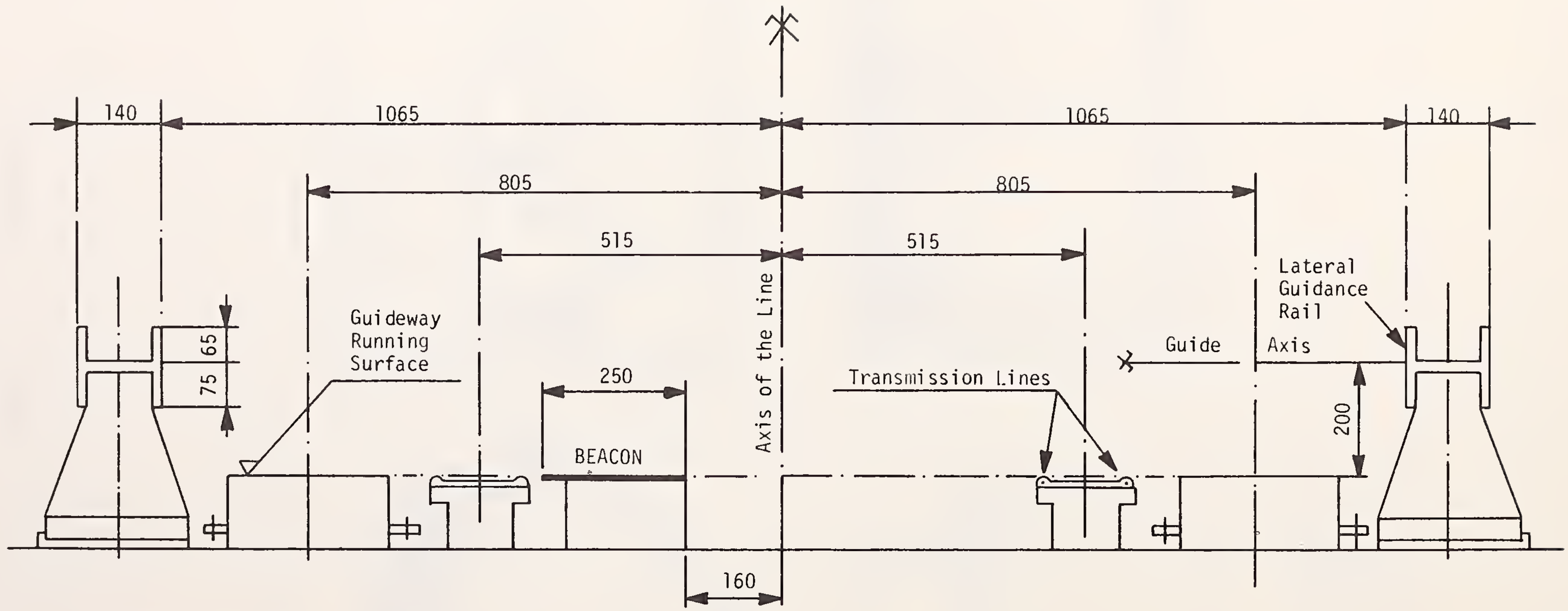


FIGURE 3-18. GUIDEWAY INFRASTRUCTURES



Note: Dimensions in millimeters.

FIGURE 3-19. CROSS SECTION THROUGH A SINGLE-TRACK SECTION OF GUIDEWAY

FIGURE 3-20. RUNNING SURFACE BEAMS

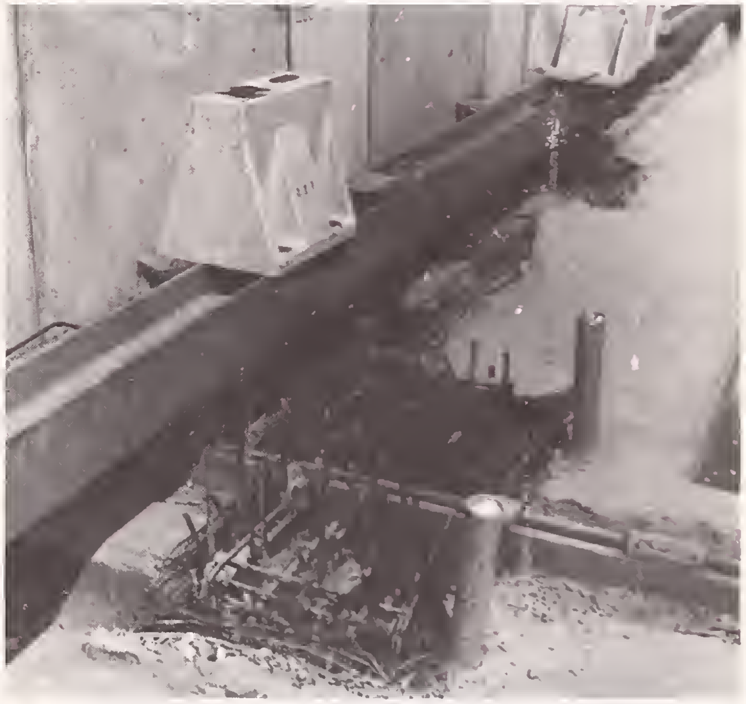


FIGURE 3-21. ELECTRICAL INSULATING SUPPORTS

FIGURE 3-22. LATERAL GUIDANCE RAILS ON INSULATING SUPPORTS

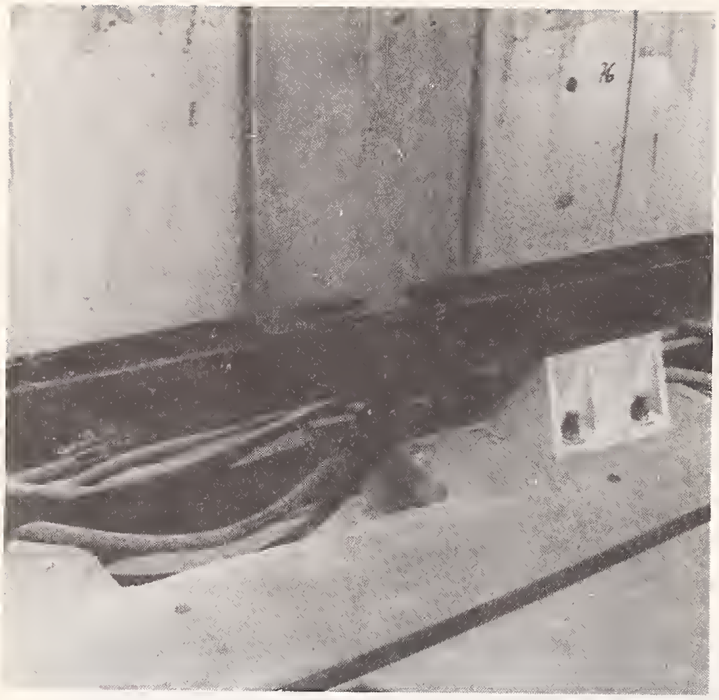
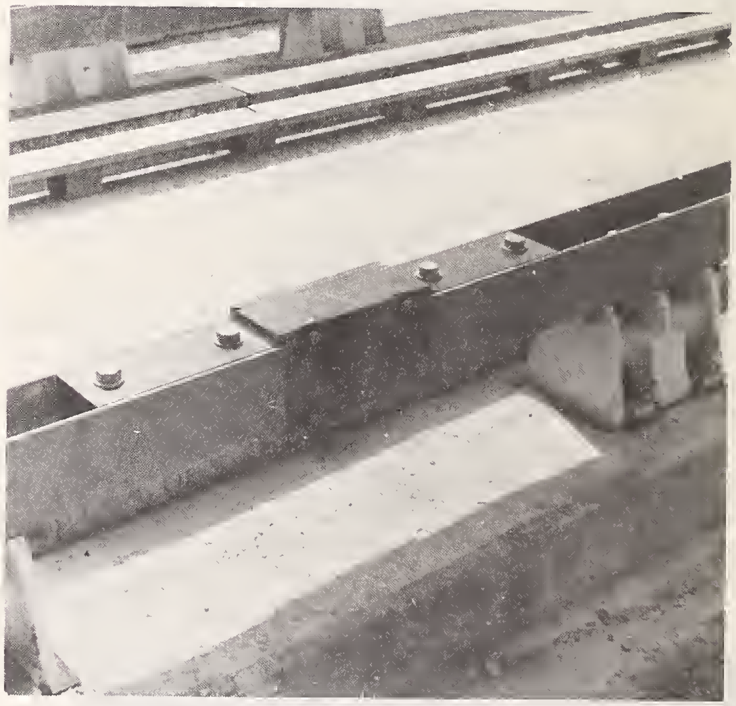


FIGURE 3-23. BAYONET EXPANSION JOINT

FIGURE 3-24. SECTION INSULATOR



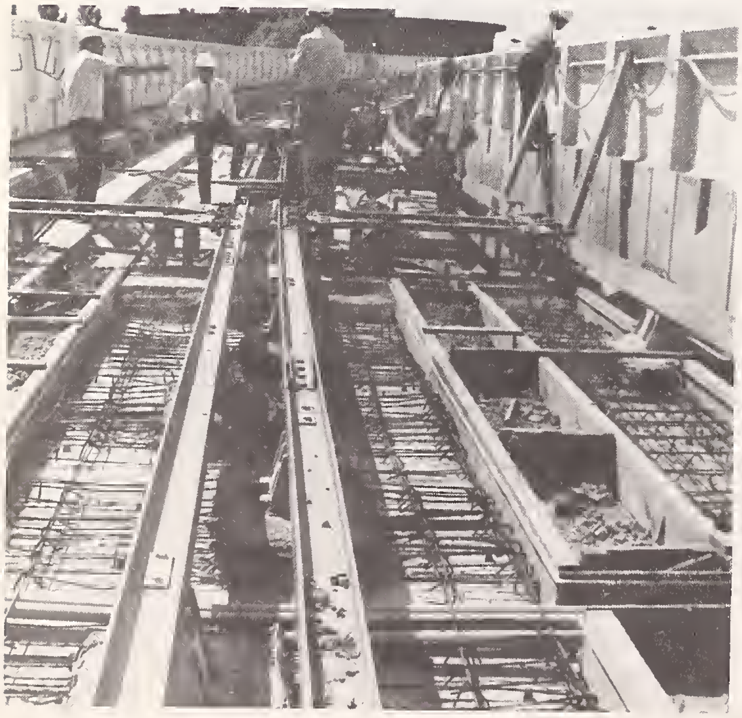


FIGURE 3-25. LATERAL GUIDANCE GAGE

provided by electrical wires submerged in the running surface beams and attached to the back of the lateral guideance running surface. Heater wires are supplied with 750 V dc power.

3.3.2 Wayside Equipment

The two-wire inductive loop transmission lines which permit reception of signals transmitted to and from the vehicle are also shown in Figure 3-17. These transmission loops are located in a plastic-coated wrapping termed a "mat," which has two potential parallel channels that carry the transmission wires (see Figure 3-26).

Aluminum studs or beacons are also located on the guideway. The act as synchronizing markers for the traffic control and as initiators of stopping programs.

Ultrasonic detectors are shown in Figure 3-27. They consist of a redundant transmitter and receiver pairs. They provide a negative detection signal when a vehicle breaks the beam.

Wayside switches consist of an electrical actuator connected to a cantilevered rail weighing 56 kg/m and a 50-mm wide guide channel formed by two T-head rails weighing 36 kg/m (Figure 3-28).

Each end of the channel is provided with a converging opening 200 mm wide to admit the vehicle switching guidewheel in the event of a flat tire. The switch is located on the centerline of the guideway and flush with the guideway running surface. The tires roll over the guide channel.

The operating time of the switch is 3 seconds including all position checks. A delay of 5 seconds prevents a second actuation until the first is completed. The operating speeds over switches are 80 km/hr in straight sections and 40 km/hr in curved sections.

From the safety standpoint, the switch is designed for unusual transverse forces exerted by the rolling stock. The vehicle can traverse a switch backward without damaging the switch.

Under normal conditions, all switches are remotely controlled by the Wayside Control and Communications Unit. In the event of a transmission malfunction, the switch can be operated either electrically from the control center or manually by maintenance personnel.

FIGURE 3-26. INDUCTIVE LOOP TRANSMISSION LINES

FIGURE 3-27. ULTRASONIC DETECTORS

FIGURE 3-28. WAYSIDE SWITCH

Switches that are exposed to weather elements are provided with a 300 watt/m heating system to permit operation in ice and snow.

3.4 POWER DISTRIBUTION

Electrical power is distributed in two grids from the medium voltage network of the French Electrical System at two points on the line (Balson or Marbrerie and Flandre) and at the maintenance facility. The two grids include lighting and power to feed the auxiliary equipment at the stations and on the line, and traction power supplied to the substations to feed 750 V dc to the power buses.

The lighting and power stations are located at all the stations on the line; they are connected in a loop with 3-phase, 20 kV, 50 Hz and transform this medium voltage to 3-phase, 380 V/220 V, 50 Hz and distribute it to all stations and line auxiliaries. Each station consists of two half-stations which are separate; i.e., two medium voltage-to-low voltage transformers. Each half-station is designed to power all the priority equipment at the station, nearby ventilating equipment, and line illumination stations. In addition, the power and illumination stations are equipped with Nicad batteries to power the emergency equipment with 110 V, 48 V, and 24 V dc. The low voltage power to the maintenance area is supplied by a separate transformer.

Six Power Rectifier (PR) substations are located along the line at Quarte Cantons, Triole, Hellemmes, Caulier, Flandre, and C.H.R. Each power rectifier is supplied with 3-phase, 20-kV, 50-Hz input from one of the two distribution points. The 750 V dc from the PR substation is distributed to the guiderails which also serve as the power rails. One rail serves as the positive and the other the negative. This 750 V dc also powers the guideway heaters used for winterization.

In the normal mode, all of the PRs feed all sections of the line in parallel. Each of these sections can be isolated. Under overload conditions, when it is necessary to turn off the voltage on the line or to isolate a section, the control center initiates the opening of the 20-kV circuit breakers at the outputs of the distribution stations, causing the power rectifier output circuit breakers to open which in turn open the isolating switches. Without a load the isolator switches are normally open. The power rails in the isolated section are short-circuited and grounded.

An emergency power cut-off loop makes it possible to turn off the 750 V dc power from the vehicle or the Control Center. This achieved by operating the output circuit breakers remotely at the distribution station. These in turn open the appropriate isolation circuits.

Line fault detectors actuate the opening of the 750 V power rectifier high-speed circuit breakers in the event of a failure or short circuit. This isolates and grounds the section where the fault is located.

To feed back regenerated voltage from the vehicle electrical braking system into the line, a high speed automatic switch directs 750 V dc to the power rectifier output.

3.5 COMMAND AND CONTROL

3.5.1 System Description

The VAL command and control system is designed to operate normally in a fully-automatic mode. Fundamentally, it is a fixed block control system. The command and control system consists of the hardware and software necessary to provide the following functions:

- Automatic Vehicle Protection (AVP)
- Automatic Vehicle Operation (AVO)
- Automatic Vehicle Supervision (AVS)
- Manual Back-up Mode Operations.

The AVP functions perform all automatic action necessary to provide safe operations regardless of malfunctions. The AVO functions perform all automatic vehicle operations that are non-safety related. The AVS functions provide a capability to change modes of operations. Manual back-up mode operations are utilized in the event of a malfunction which cannot be safely resumed in an automatic mode.

The AVP, AVO, and AVS functions are performed by control system equipment distributed at three locations: the control center, the wayside, and on-board the vehicle. A block diagram of the control system equipment is given in Figure 3-29. In addition, Table 3-2 shows the allocation of command and control functions among the control system hardware:

1) Control Center Equipment consists of control consoles display panels, computers, and data communications equipment.

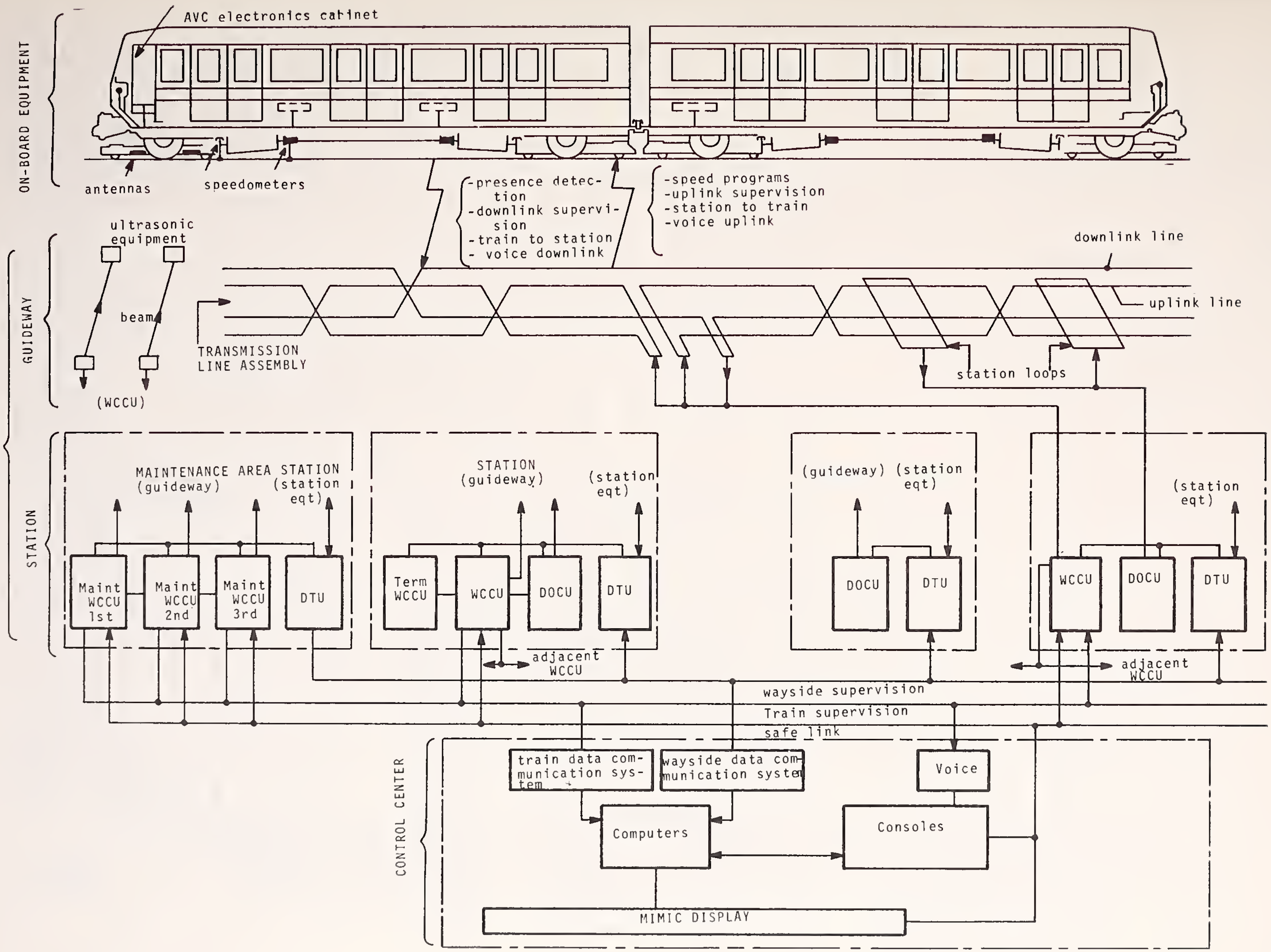


FIGURE 3-29. BLOCK DIAGRAM OF CONTROL SYSTEM EQUIPMENT

TABLE 3-2. ALLOCATION OF COMMAND AND CONTROL FUNCTIONS

CONTROL SYSTEM EQUIPMENT \ FUNCTIONS	AUTOMATIC VEHICLE PROTECTION (AVP)											AUTOMATIC VEHICLE OPERATION (AVO)				AUTOMATIC VEHICLE SUPERVISION (AVS)					
	VEHICLE DETECTION	COLLISION AVOIDANCE	OVERSPEED	SWITCH INTERLOCKING	DIRECTION CONTROL	VEHICLE DOOR CONTROL	PLATFORM DOOR CONTROL	VEHICLE INTEGRITY	ALARM FROM PASSENGERS	DETECTION OF OBSTACLE	GENERAL VEHICLE STOP	SPEED REGULATION	DWELL OPERATION	SWITCH OPERATION	VEHICLE REVERSAL	GENERAL VEHICLE DATA COMMUNICATION	ADDITIONAL VEHICLE DATA COMMUNICATION IN STATION	WAYSIDE DATA COMMUNICATION	VOICE COMMUNICATION	TRAFFIC REGULATION	VEHICLE MANAGEMENT
VEHICLE CONTROL EQUIP. AVP ELECTRONICS		x	x	x	x	x	x				x	x									x
AVO ELECTRONICS												x	x		x					x	x
AVS ELECTRONICS																x	x		x		x
TACHOMETER					x							x			x						x
PHONIC WHEEL			x									x									x
RECEIVERS		x	x	x	x	x					x	x	x		x	x	x		x	x	x
PRESENCE TRANSMITTERS	x								x												x
DOWNLINK TRANSMITTER																x					x
VEHICLE TO STATION TRANSMITTER						x	x						x				x				x
VOICE COMMUNICATION TRANSMITTER																					x
TRAIN-LINE/INTERFACES	x	x	x	x	x	x		x	x	x	x	x	x		x	x			x		x
GUIDEWAY EQUIPMENT TRANSMISSION LINE ASSEMBLY	x	x	x	x	x	x	x		x			x	x		x	x	x		x	x	x
ULTRASONIC EQUIPMENT	x			x																	
STATION BASED EQUIP. WAYSIDE CONTROL COMMUNICATION UNIT (WCCU) (MAINLINE)	x	x	x		x		x		x		x	x				x		x	x		x
WCCU (TERMINAL)	x	x	x	x	x						x	x		x	x			x			x
WCCU (MAINTENANCE AREA)	x	x	x	x	x						x	x		x	x	x		x	x		x
DWELL OPERATION CONTROL UNIT (DOCU)		SPEED RESTRICTION	x			x	x					x	x				x	x		x	x
DATA TRANSMISSION UNIT (DTU)			x															x		x	x
CONTROL CENTER			x						x		x					x	x	x	x	x	x

2) Wayside Control Equipment consists of Wayside Control and Communications Units (WCCU), Dwell Operation Control Unit (DOCU), Data Transmission Units (DTU), Transmission Lines, Ultrasonic Detectors (UD) and visual signals. This equipment is located both in the station and along the guideway. Table 3-3 shows the allocation of wayside control equipment. Wayside Control and Communication Units are located in selected stations. They perform all wayside safety functions such as collision avoidance and overspeed protection, and they provide all wayside uplink and downlink signalling functions. Each WCCU consists of two similar equipment consoles, one of which is for redundancy (see Figure 3-29).

Dwell Operation Control Units (DOCU) are provided in each station to manage station operations including dwell control. DOCU's consist of one console which contains two redundant sets of equipment, each of which can manage both station platforms.

Data Transmission Units (DTU) are located at each station and provide communication between the Control Center and all wayside equipment.

Transmission Lines are provided for two-way link between wayside and vehicle equipment. Certain transmission lines utilize physically encoded speed limit crossover indicators (see Figure 3-29).

Ultrasonic Detection Equipment consists of redundant transmitter and receiver pairs placed on opposite sides of the track in terminal areas and at section boundaries for detection of vehicles.

Visual Signals are located at particular points along the guideway to indicate plaftorm door status, departure authorization, and switch status during manual back-up operations.

3) Vehicle On-Board Control System Equipment is shown in Figure 3-30 and its physical location is shown in Figure 3-31. The safety and control equipment includes redundant AVP and AVO electronics and power supplies. Uplink Receivers are provided to receive vehicle speed commands, remote commands, and voice communications via the guidwway transmission line. The vehicle is provided with two receivers (left and right) allowing two possible locations of the uplink transmission lines. Two redundant Downlink Transmitters are provided for passenger unit presence detection signals. There is also one downlink transmitter for AVS and one transmitter for voice communications. Each vehicle unit is provided with two redundant tachometers gene-

TABLE 3-3. ALLOCATION OF WAYSIDE CONTROL EQUIPMENT

EQUIPMENT / STATIONS	DOCU	LINE WCCU	TERMINAL WCCU	MAINTENANCE WCCU	DTU (T 200)	STATION CONSOLE	TERMINAL CONSOLE	
QUATRE CANTONS	1 (*)	1 X 2	1 (*)		1	2	1	
CITE SCIENTIFIQUE	1 (*)				1	2		( ) 1 BAY WITH TWO REDUNDANT PIECES OF EQUIPMENT
TRIOLO	1 (*)				1	2		
HOTEL DE VILLE	1 (*)	1 X 2	1		1	2	1	
PONT DE BOIS	1 (*)	1 X 2			1	2		
LEZENNES	1 (*)				1	2		
HELEMMES	1 (*)				1	2		
MARBRERIE	1 (*)	1 X 2			1	2		
FIVES	1 (*)	1 X 2	1		1	2	1	
CAULIER	1 (*)				1	2		
GARES	1 (*)	1 X 2			1	2		
RIHOUR	1 (*)				1	2		
REPUBLIQUE	1 (*)	1 X 2	2		1	2	2	
GAMBETTA	1 (*)	1 X 2			1	2		
WAZEMMES	1 (*)				1	2		
DOREZ	1 (*)				1	2		
CHR	1 (*)	1 X 2	1 (*)		1	2		
MAINTENANCE AREA				2 X 2 + 2	2			
TEST TRACK	2 (*)	1 X 2	2 (*)		1	1	2	

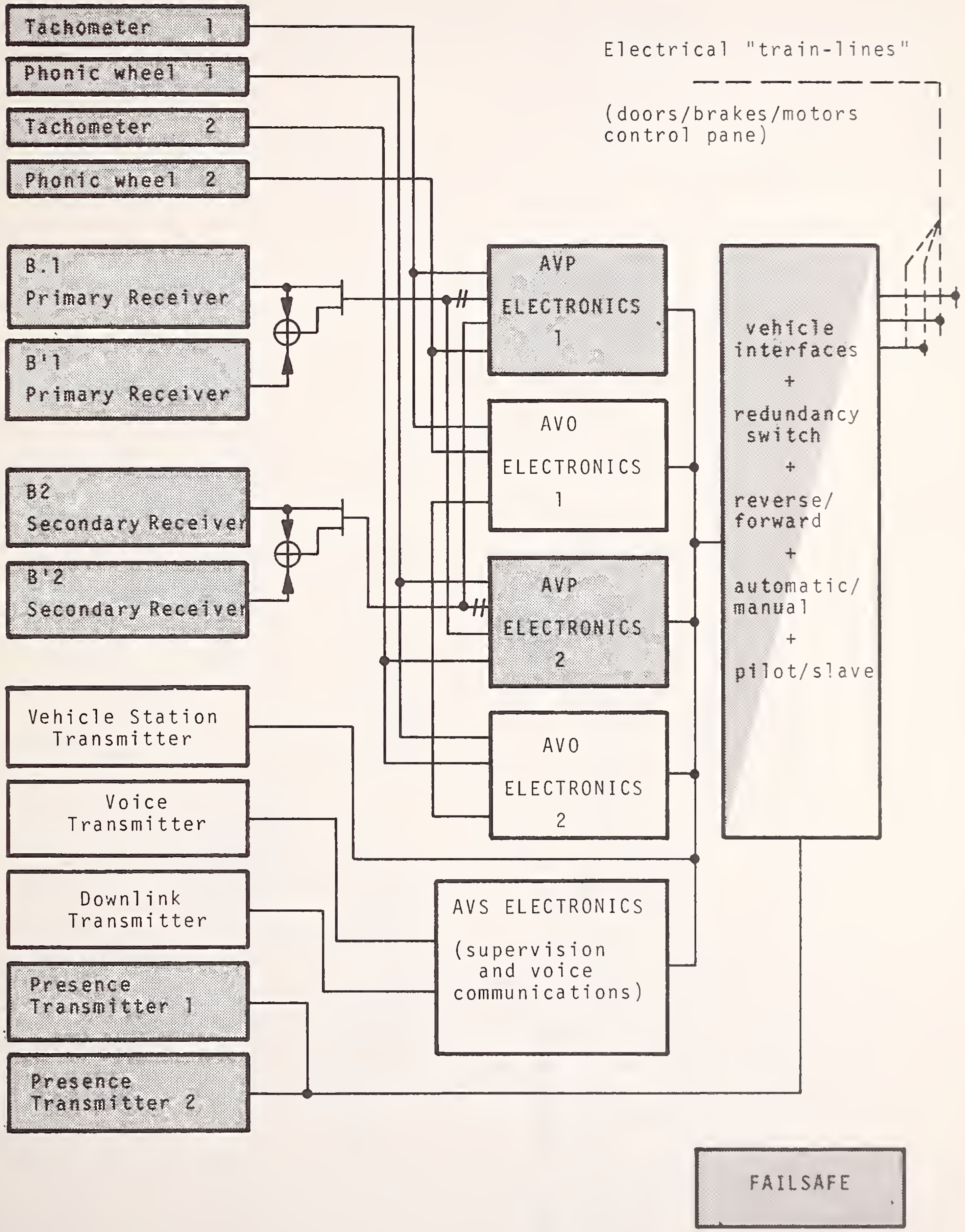


FIGURE 3-30. VEHICLE ON-BOARD CONTROL SYSTEM EQUIPMENT

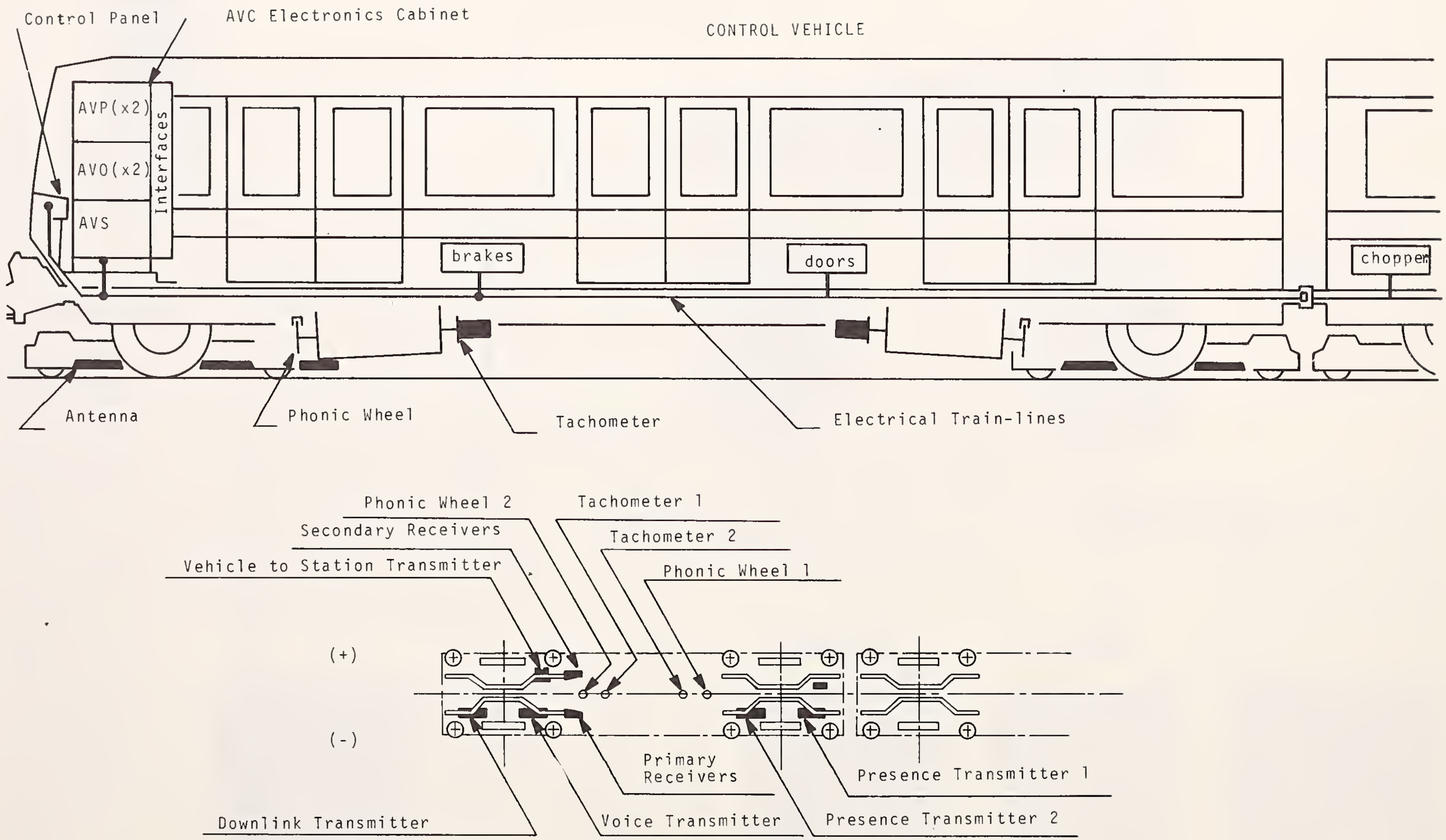


FIGURE 3-31. CONTROL SYSTEM LOCATION ON VAL

rating a voltage proportional to speed, and two redundant phonic wheels producing pulses for each 3.81-mm (0.15-inch) advancement of the vehicle. A tachometer and a phonic wheel pair are associated with each of the two vehicle control channels.

3.5.2 Automatic Vehicle Protection (AVP)

The Automatic Vehicle Protection functions are preformed by the vehicle control and communications and the wayside control and communications subsystems. The AVP initiates two types of actions:

1) It will apply the service brakes of any vehicle to avoid collision with the leading vehicle, and

2) The system will stop any or all vehicles with emergency brakes when service brakes are not sufficient to avoid collision between vehicles, or when the following events occur:

- Overspeed
- Lack of Safe Frequency Detection
  - . remote control from Control Center
  - . opened platform doors in station
  - . detection system alarm
  - . loss of isolation between guideway transmission lines
- Roll back
- Unlocked Vehicle Doors
- Vehicle Unit Separation
- Detection of Obstacles on Guideway
- Overpassing the Stopping Point.

Emergency braking is "held-off" by the fail-safe generation of positive data. This is based upon the determination by all on-board AVP equipment that it is safe to proceed. Although emergency braking is initiated directly by on-board equipment, it can also be initiated by wayside or Central Control equipment.

3.5.2.1 Collision Avoidance - Collision avoidance is based on a fixed block system; the line is divided into blocks and the occupancy of a block prevents any other vehicle from entering that block. It provides vehicle detection and safe stopping commands.

Four or five consecutive blocks in each direction are grouped into sections. Each section is controlled by a WCCU. VAL is divided into nine bi-directional sections as indicated in Table 3-3.

3.5.2.2 Vehicle Dectection - Vehicle detection employs a fail-safe, check-in/check-out sequential process. At the termini, stations, and section boundaries, ultrasonic transmitter and receiver combinations are placed on each side of the track and detect the crossing of any passenger unit into or out of the station or section by cutting the ultrasonic beam. The results in negative detection (ND) data. In addition, continuous positive detection (PD) data are available due to the continuous transmission of presence signals by each vehicle. These signals are magnetically coupled to the wayside via the transmission line. Then the presence of each vehicle in the section is located within a specific block.

A downlink loop is provided throughout each block for continuous detection. These loops are crossed periodically to minimize crosstalk with other transmission lines. In addition, small loops are placed at the section and block boundaries for the sequential detection of vehicles. The sequentially-received PD and ND data are used by the AVP equipment to safely detect the occupancy of the blocks and to identify any anomalies that require emergency braking, such as loss of PD signal, penetration of a vehicle into an already occupied block, or rollback block entry. The sequential presence detection process is illustrated in Figure 3-32.

3.5.2.3 Safe Stopping Commands - These commands are determined by vehicle detection of antenna crossovers which are separated physically in proportion to the speed in that block. A phase change of the induced signal is detected by the on-board safety equipment when passing each crossover.

Each block is either categorized as an interstation block or a station block. The predetermined safe speed limits for each block is enforced through detection of crossovers of the guideway-mounted transmission line assembly containing multiple antenna sections. For interstation blocks two physical speed programs, "normal" and "perturbed," are encoded which will allow the vehicle to continue into the next block or actuate service brakes at a safe distance before the next block boundary.

The safe stopping distance used in the perturbed program is based on the following worst case conditions occurring simultaneously:

Note: PD: presence detection loop
ND: negative detection by ultrasonic equipment

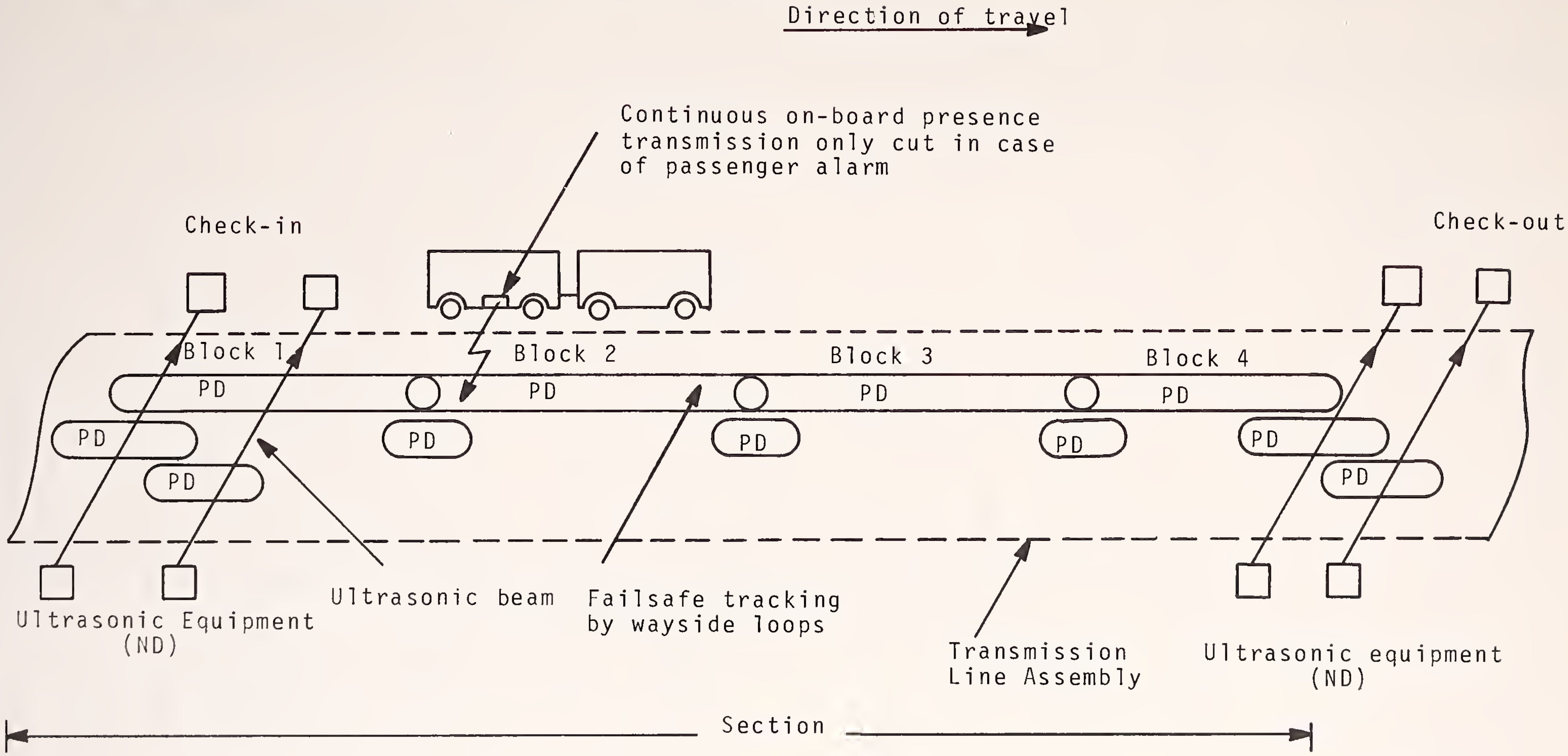


FIGURE 3-32. SEQUENTIAL PRESENCE DETECTION PROCESS

- Maximum train length of two vehicles (two married pairs), allowing for push recovery;
- Exceeding overspeed limitation at maximum acceleration;
- A maximum delay of one crossover before overspeed detection;
- A maximum delay prior to actuation cf emergency brakes;
- Application of minimum emergency deceleration rate, considering all critical environmental conditions.

The normal speed program is selected for a vehicle when the downstream block is unoccupied. This speed program is implemented by a transmission line with crossings that are normally detected at regular intervals of 0.3 seconds. The normal program transmission line carries the safe carrier frequency (SF) essential to safe operation of the system.

The perturbed stopping program is selected for a vehicle when the next downstream block is occupied. This stopping program is implemented by a second transmission line with crossovers which, when detected by the vehicle at intervals of 0.3 seconds, results in the vehicle following a perturbed stop.

Figure 3-33 illustrates the normal and perturbed stopping programs. Both wayside signals are permanently energized. The perturbed stopping program (PP) carrier frequency signal is not modulated. The normal stopping program (SF) carrier frequency is phase modulated by two audio signals, one each from the following two groups:

Group 1: f1 or f2 or f3

- f1 (572 Hz) indicates that the vehicle must follow the nominal speed program.
- f2 (463.5 Hz) indicates that the vehicle must follow the perturbed speed program (used when the next downstream block is occupied).
- f3 (405.5 Hz) indicates a push-recovery mode is to be used.
- No modulation results in a 0.8 m/sec (2 mph) maximum speed limit in the areas where the perturbed stopping program is implemented and emergency braking elsewhere.

Group 2: f4 or f5

- f4 (440.5 Hz) indicates direction 1.
- f5 (532 Hz) indicates direction 2.
- No modulation results in initiation of emergency brakes.

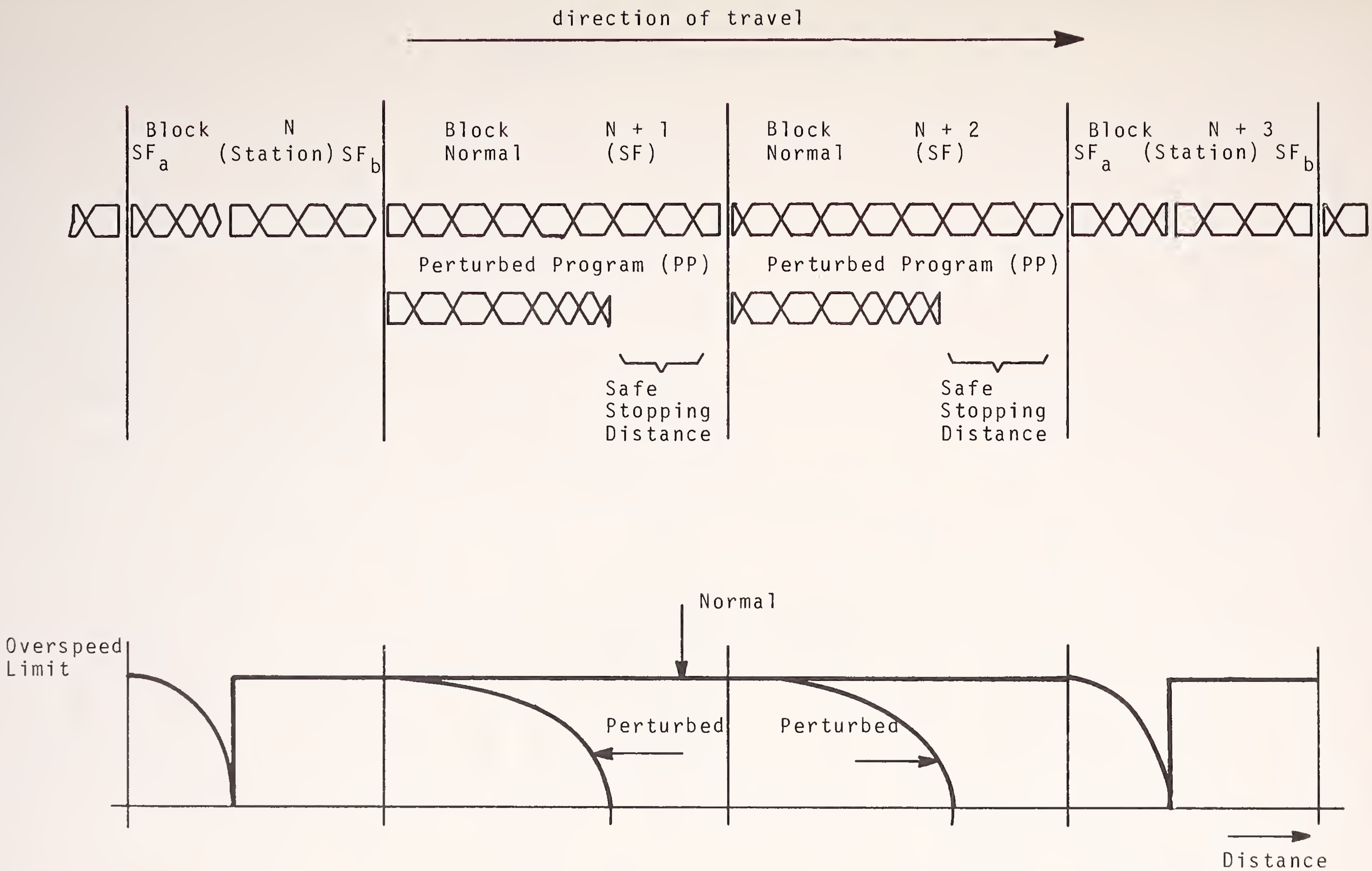


FIGURE 3-33. NORMAL AND PERTURBED STOPPING PROGRAMS

In each intersection block the WCCU selects the speed program which must be followed by the vehicle and transmits the corresponding frequency modulation of the SF carrier.

As shown in Figure 3-33, station blocks are designed without the PP program, but with two successive SF lines; SF_a (arrival) and SF_b (departure). Thus, if the next downstream block is occupied, the SF_a may be energized to permit access into the station while the SF_b remains unenergized. Vehicle departure from the station will not be authorized by the Dwell Operation Control Unit when the downstream block is occupied. The SF_a and SF_b are both unenergized when the platform doors are opened. The SF_a and SF_b carry only the f1 or f3 frequencies of Group 1, and the f4 or f5 frequencies of Group 2.

3.5.2.4 Control System Communications - These communications are divided into three links:

1) Wayside-to-vehicle signalling
2) Vehicle data
3) Wayside data.

All the transmission lines for links (1) and (2) relating to the vehicle are assembled in the guideway transmission line. Table 3-4 gives the frequency transmission characteristics of each of these links.

The wayside-to-vehicle signalling consists of two links: an uplink and a downlink. Uplink transmission links energized by the WCCU contain the speed profile programs for normal perturbed stopping conditions. Downlink presence detection loops in the transmission line assembly are used for the safe detection of the passenger units at wayside.

The Vehicle Data Link provides a continuous two-way link between the Control Center and the vehicles via the WCCU. This link uses the same transmission lines that are used for presence detection (downlink) and normal speed program (uplink). These two links include:

- Uplink - remote control commands and voice
- Downlink - vehicle status data for AVS functions and voice.

Additional data are transmitted between vehicle and wayside in stations by means of special small communication loop in the stations.

The Wayside Data Link provides a two channel for control of the wayside control equipment, power distribution equipment, and all auxiliary station equipment. A Data Transmission Unit (DTU) is located in each station and is

TABLE 3-4. FREQUENCY TRANSMISSION CHARACTERISTICS OF CONTROL SYSTEM COMMUNICATIONS

COMMUNICATIONS LINK	WAYSIDE TO VEHICLE (UPLINK)	VEHICLE TO WAYSIDE (DOWNLINK)	FREQUENCY Hz	MODULATION	REMARKS
PRESENCE		X	69,000	NONE	REMOVED BY PASSENGER ALARM
SPEED PROGRAMS . NORMAL	X	X	42,000	PHASE MODULATION	ONE AUDIO FREQ. Gp.1:1 OF 3 ONE AUDIO FREQ. Gp.2:1 OF 2
. PERTURBED	X		33,000	NONE	
UPLINK			135,000	PHASE MODULATION	
DATA	X			DATA FSK ON SUBCARRIER AT 5.5 KHz	DATA IS Bi Ø AT 192 bps
VOICE	X				VOICE CUTOFF IS 4,000 Hz (-6 db)
VEHICLE STATUS		X	80,000	AMPLITUDE MODULATION (OOK)	DATA IS RZ 384 bps
VOICE DOWNLINK		X	100,000	PHASE MODULATION	VOICE CUTOFF IS 3,000 Hz (-6 db)
STATION TO VEHICLE DATA	X		36,250	FSK	DATA IS Bi Ø AT 256 bps
VEHICLE TO STATION DATA		X	55,250	FSK	DATA IS Bi Ø AT 128 bps

GROUP 1: f_1 = 572 Hz - NORMAL
f_2 = 463.5 Hz - PERTURBED
f_3 = 405.5 Hz - PUSH RECOVERY

GROUP 2: f_4 = 440.5 Hz - DIRECTION 1
f_5 = 532 Hz - DIRECTION 2

connected to the Control Center. It decodes and distributes all control tasks from the Control Center to the wayside system.

3.5.2.5 Overspeed Protection - The AVP system shown in Figure 3-34 ensures protection from overspeed by initiation of emergency brakes by on-board equipment when a vehicle attains a speed greater than the safe margin above the minimum of the following three speed limits:

- The selected speed program (normal or perturbed);
- A speed restriction selected remotely from the Control Center;
- The push-recovery speed limit when applicable.

3.5.2.6 Speed Programs - The on-board safety ensures that the time between crossovers is never less than 0.27 seconds. The maximum velocity is proportional to the crossover spacing which varies along the guideway and is tailored to the specific guideway location. Two redundant on-board overspeed devices operate in parallel for normal and preturbed stopping speed program. If a crossover is detected in less than 0.27 seconds, emergency braking will be initiated.

In a similar manner, the on-board AVO system regulates the vehicle speed such that the crossover times are 0.30 seconds. The difference between the AVP 0.27 seconds and the AVO 0.30 seconds provides a 10 percent margin. Two dissimilar redundant digital clocks provide the reference signal.

3.5.2.7 Speed Restriction - The AVP system provides one temporary speed limit restriction which can be requested from the Central Control. One is a proportional speed restriction and the other two are constant speed limits.

The proportional speed restriction used the normal and perturbed program overspeed limits with a constant reduction factor of 0.9. This safe restriction can be actuated automatically on-board during push-recovery when the consist is composed of two vehicles (two married pairs) or after a weight overload has been detected. This will be the greatest push-recovery speed.

3.5.2.8 Push-Recovery Speed Limit - During push-recovery, when an operational vehicle is coupled to a disabled vehicle, the speed of the operational vehicle is safely limited to 0.8 m/sec (2 mph). Overspeed protection is accomplished with the "phonic wheel." The command for the push-recovery procedure is detected when the f3 modulation on the SF carrier signal is

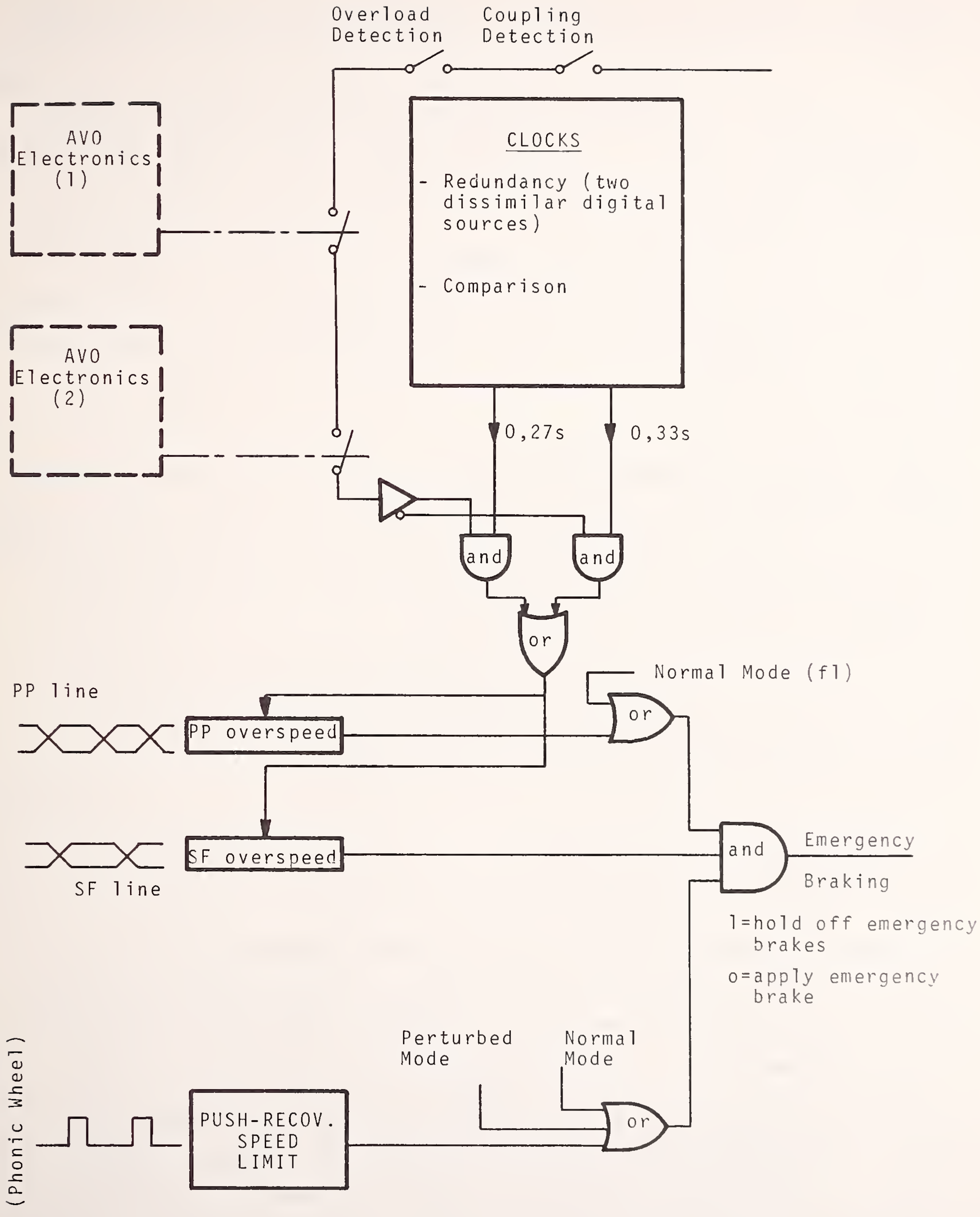


FIGURE 3-34. AUTOMATIC VEHICLE PROTECTION (AVP) SYSTEM

present and if the vehicle has received a specific remote control command from Central.

3.5.2.9 Switching Interlocking & Collision Avoidance in Switch in Zones - In terminal station areas and in the maintenance area, the WCCU provides for switch interlocking when the vehicles are in the switching zones. Vehicles cannot enter a switching zone unless all active switch elements are locked. The detection of an unlocked switch element causes a safe stop before the switch location by commanding the perturbed stopping modes, or if a critical distance has been reached the emergency braking signal is initiated. Switch lock status is derived from switch position detectors and motor position detectors.

In crossover areas where bi-directional operation is possible, vehicle presence detection is effected only with ultrasonic detectors. The distance between two successive detector pairs is maintained less than the length of a vehicle (married pair) to ensure continuous detection within these areas.

AVP equipment safety ensures that no route will be selected which will lead to a collision and that vehicles will not converge or conflict to a switch in any way. Thus, automatic control around switches can only be effected if the following conditions are satisfied:

- The route corresponding to the SF program is electronically enabled;
- The switch status is correct;
- The downstream guideway is clear of a vehicle.

In the manual back-up mode, switches can be positioned individually. In this case, the SF carrier frequency signal is automatically cut off and vehicles must be controlled manually. A wayside visual signal indicates the switch status.

3.5.2.10 Direction Control and Roll Back - The direction command (D_1 or D_2) is implemented using the f_4 and f_5 modulation of the SF carrier frequency. In the event of a disagreement between the commanded direction and the actual direction measured by the vehicle tachometers, emergency braking is actuated on-board in a fail-safe manner.

In the event of roll back penetration into an aft block the WCCU generates an alarm and automatically shuts off the SF carrier frequency, causing emergency braking.

In bi-directional switching zones two SF carrier frequency signals are generated; each one is modulated by the correct Group 2 direction modulation signal. Only one direction can be implemented at any time.

3.5.2.11 Vehicle Door Control - AVP equipment controls the operation of vehicle doors. If any door on a moving vehicle is detected in an unlocked state, emergency braking is initiated. This is accomplished by means of an electrical "train line" which connects all door contactors on each side of the vehicle in series. If any one door is unlocked, the "train line" is broken initiating emergency braking and an alarm which is transmitted to the Control Center.

In stations, vehicle doors can only be opened if the AVP on-board equipment detects zero speed and proper position. Zero speed is detected by the fail-safe tachometer, whereas proper position is verified by receipt of a carrier frequency transmitted by the DOCU. The side of the vehicle on which the doors are to open in indicated by two means which must agree.

- The detection of left or right position of the station to vehicle antenna loop; the loop is provided on only one side of the guideway;
- The data transmitted by the DOCU.

After the station dwell is completed, the AVP system will authorize the vehicle to leave the station only if all the doors are closed and locked.

The AVP system also provides the following station platform door interlocking functions:

- When the station doors are opened, the station block is registered as being occupied;
- Authorization to open the platform doors is given only if a vehicle is stopped at its proper location in the station;
- When the station doors are opened, the SF_a and SF_b station safety signals are both off disabling the vehicle from leaving the station.

In the back-up manual mode, the station console allows the manual operation of the platform doors and the manual authorization of a vehicle to depart with station doors open. Two wayside visual signals are provided at each station before the platform indicating whether the doors are opened or closed, and at the end of the platform to indicate departure authorization.

The Dwell Operation Control Unit detects any vehicle or station door malfunctions and transmits an alarm to the Control Center.

3.5.2.12 Vehicle Integrity - Although unintentional uncoupling of a "married pair" of vehicle units can be considered mechanically impossible without failure of a mechanical link, a break of the train line signal which passes through the coupling device will initiate emergency brakes of both vehicles. This train line signal is also enabled when two vehicles are coupled for normal operation or push recovery. An uncoupling of the automatic coupler will again initiate emergency brakes.

3.2.2.13 On-Board Emergency Switch - An on-board emergency switch located inside the vehicle over each door allows passengers to signal for assistance. Actuation of this alarm initiates six functions:

- Application of emergency brakes;
- Unlocking of vehicle doors after a time delay that accounts for stopping time;
- Fail-safe cut off of the vehicle presence signal to the wayside which initiates an alarm to the WCCU by the wayside block occupancy detection equipment;
- Fail-safe transmission of an alarm to the Control Central by the WCCU;
- Withdrawal of the safe carrier frequency for all guideway sections resulting in an emergency stop of all vehicles;
- Removal of guideway power throughout the affected sections.

3.5.2.14 Obstacle Detection - The vehicle is provided with a pressure sensitive bar on the extremity of each vehicle to detect obstacles on the guideway. In the event of a collision with an obstacle on the guideway, the sensor will be tripped and emergency brakes applied.

3.5.2.15 Redundancy of AVP Functions - The on-board and wayside AVP equipment is fail safe and redundant. Two strings of equipment process data in parallel. These strings can be used in either the OR or AND configuration. Each configuration can be selected remotely from the Control Center.

For all emergency braking functions commanded on-board the vehicle, the signals from both redundant strings are continuously compared and any discrepancy is transmitted through the vehicle data channel. Redundant signals for block occupancy in the WCCU are also continually compared. A warning signal is transmitted to the Control Center in the event of a discrepancy.

3.5.3 Automatic Vehicle Operation (AVO)

Automatic Vehicle Operation is performed by both wayside and on-board equipment and includes speed regulation, dwell control, switch operation and vehicle reversal. While AVO functions are controlled by the wayside with resident parameters that can be modified from Central Control, these functions are not dependent upon the Central Control and can function without parameter modification from the AVS. All AVO station and on-board equipment is redundant. Switching between two identical equipment strings can be accomplished by a Control Center command.

3.5.3.1 Speed Regulation - Figure 3-35 schematically shows the components of the on-board AVO control equipment which provide speed control of the vehicle. It consists principally of two major components, a microprocessor unit used to compute the speed commands, and an analog speed regulator which implements closed-loop propulsion and braking control within speed regulation comfort constraints.

The microprocessor unit calculates the speed commands from the following data:

- The maximum operating speed of the vehicle in alternative guideway sections; this speed is determined from the distance between two successive crossovers of the normal or perturbed guideway transmission line speed program.
- Divided by a constant 0.3-second time coefficient; the crossover distance is measured by the phonic wheel.
- The proportional speed which imposes a limit to the maximum operating speed of 0.9

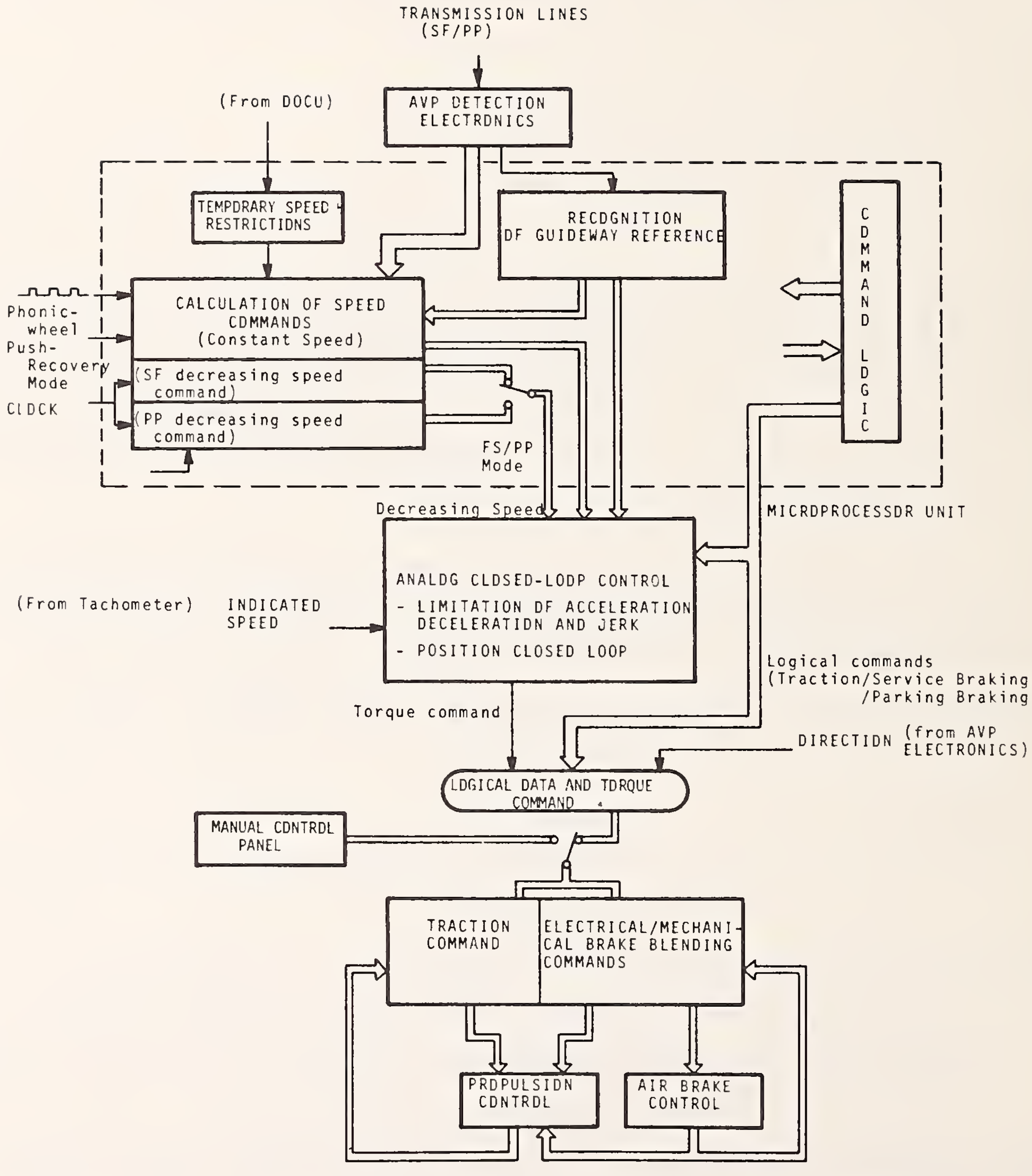


FIGURE 3-35. ON-BOARD SPEED REGULATION EQUIPMENT

The microprocessor selects the appropriate constant or proportional speed command for the analog speed regulator to follow.

The AVO system also requires three specific reference marks or beacons (B1, B2, and B3) on the guideway to:

- B1 - initiate the start of deceleration
- B2 - initiate the end of deceleration
- B3 - initiate a closed-loop precision stopping process at the station.

The beacons are aluminum plates separated by three different distances: B1 is 0.6 meters, B2 is 1.02 meters, and B3 is 1.44 meters.

The analog closed-loop speed controller consists of linear and non-linear circuits. It receives speed commands from the microprocessor unit and compares them with the acutal vehicle speed measured by the tachometer. It performs speed regulation within a range of ±5 percent of a commanded constant speed and limits the acceleration, deceleration, and jerk in accordance with the following requirements:

- Acceleration - 0.137 g
- Service deceleration - 0.137 g
- Jerk - 0.068 g/sec.

The outputs of the analog speed controller are commands to the vehicle's propulsion and braking subsystems, the chopper and mechanical brakes. The direction of this tractive effort (propulsion or braking) is provided by the microprocessor.

During the application of service braking, the brake control system blends the efforts of both the electrical regenerative and mechanical braking systems within the service deceleration constraints. The closed-loop process allows a stopping position accuracy of ±30 cm regardless of variation in the approach speed, road surface or weather condition.

Propulsion and braking commands can be provided manually from the driving panel of the vehicle when the vehicle is switched to a manual mode of operation.

3.5.3.2 Dwell Control - The Dwell Operational Control Unit (DOCU) manages the station stopping sequence. It consists of a microprocessor and associated data transmission devices which are schematically shown in Figure 3-36. When

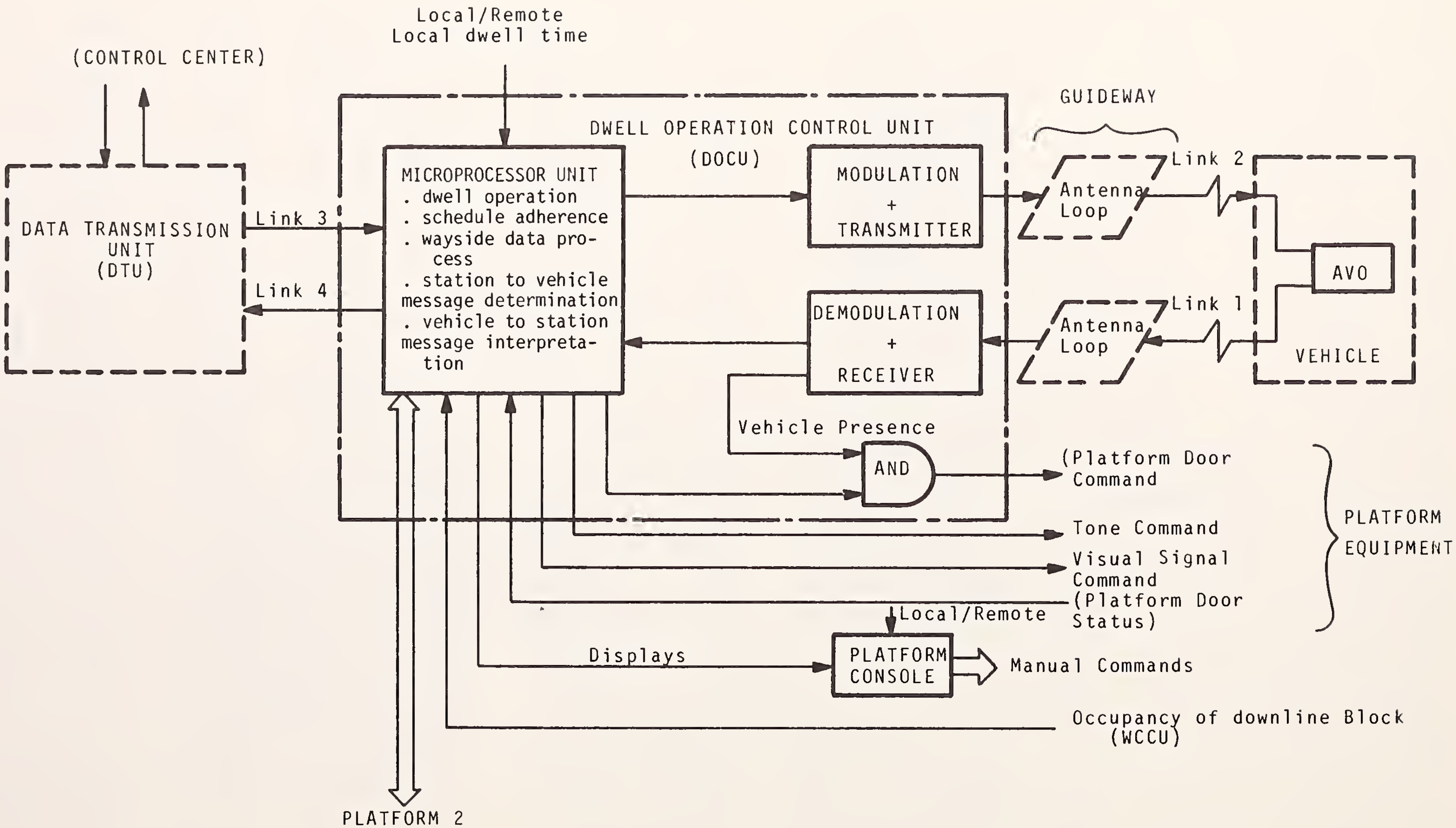


FIGURE 3-36. DWELL OPERATIONAL CONTROL UNIT (DOCU)

the vehicle is stopped at the station platform, a two-way communication link (1 & 2) is established with the station equipment. This link is the means with which the DOCU controls the following station sequence:

1. The Control Center transmits to the DOCU over Links 3 and 4 the scheduled time of arrival of the next vehicle.
2. Upon arrival, the vehicle communicates its number and status parameters to the DOCU.
3. The DOCU commands the simultaneous opening of vehicle doors and platform doors.
4. The dwell time is determined in the DOCU or is set manually on a control panel.
5. The DOCU transmits the regulation speed limit for the next inter-station trip to the vehicle.
6. A tone detectable within 3.1 meters of the station platform is emitted and a visual signal at the wayside is given 3 seconds prior to closing the doors.
7. The DOCU commands the departure of the vehicle at the end of dwell cycle.

The information transmitted over the four principal data links is shown in Figure 3-37. The Dwell Transmission Unit (DTU) functions between the DOCU and the Control Center.

The door open time is adjustable between zero seconds and indefinite hold. If no instruction is received from the AVS equipment, the AVO will revert to a predetermined dwell time previously selected on the DOCU control panel.

In response to a specific AVS command, the AVO can perform a stopping sequence which eliminates door opening and provides for immediate departure.

3.5.3.3 Switch Operation and Vehicle Reversal - The AVO system makes the route selection for operations in station and maintenance areas. This selection is made under the direction of the AVS system and with the permission of the AVP system. The direction of travel and switch position commands are implemented by the appropriate WCCU.

Two levels of back-up are provided for these switch reversal functions. If the AVP equipment is operational, automatic routing commands may be initiated locally via the back-up consoles provided in the WCCU located in the

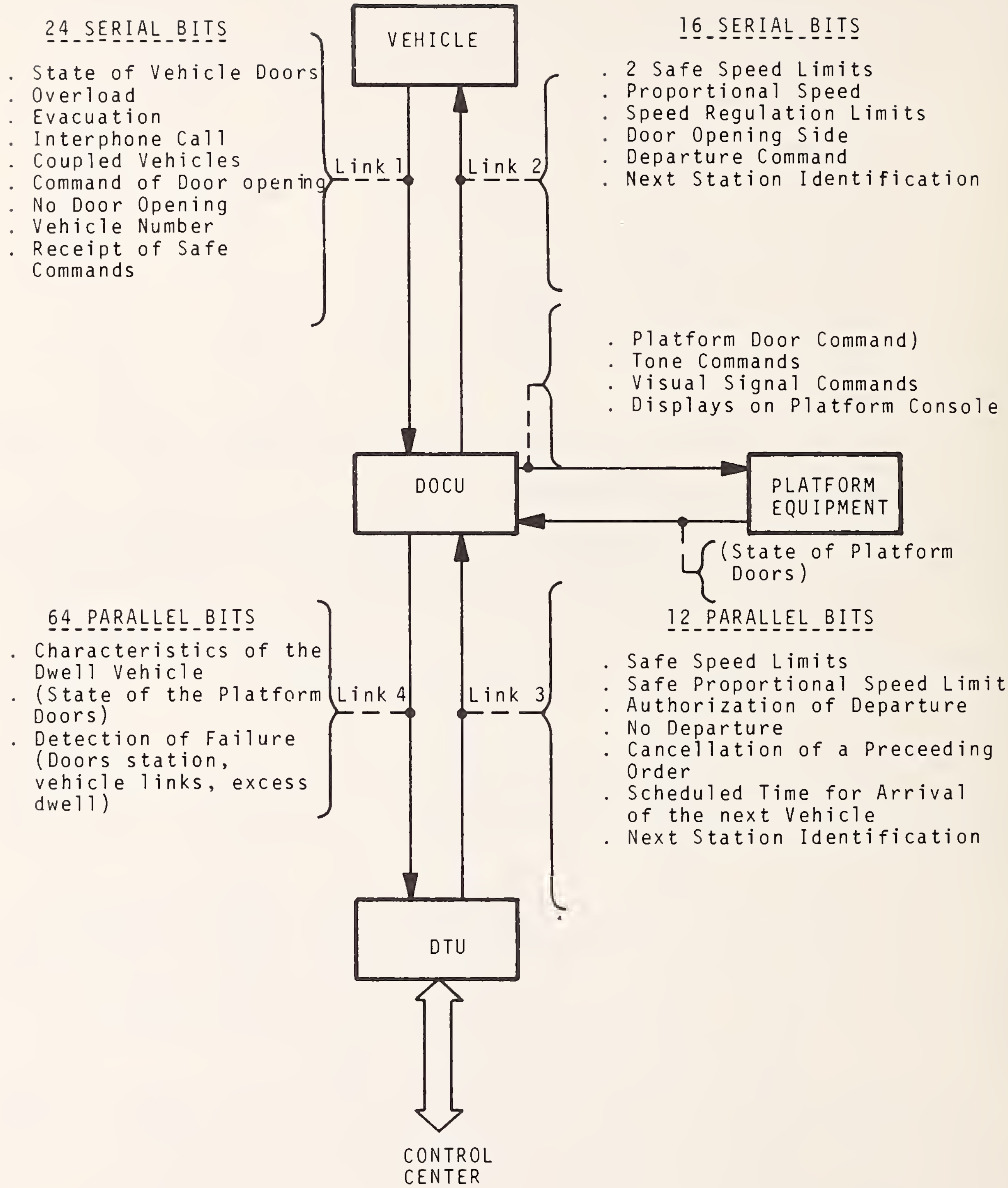


FIGURE 3-37. DWELL OPERATION CONTROL UNIT (DOCU) DATA COMMUNICATIONS

terminal stations or at the maintenance facility. If the WCCU is not functioning, the switches can be commanded at their guideway location. In that case, the safe frequency is shut off in this area and the vehicle must be driven manually through the switches. For this back-up mode, switch position and route selection are provided by a single wayside visual signal and collision avoidance is ensured by the on-board operator.

The functional capability for automatic route operations at terminals is schematically indicated in Figure 3-38. This is given for two cases, a mainline-to-maintenance and a terminus. The terminals are provided with a single crossover behind each station. Turnback operation is completely automatic. The maintenance area is provided with crossovers and switches for automatic operation between the workshop, storage area, wash stand, test area, and the mainline. Insertion and withdrawal of vehicles from the mainline to maintenance is also completely automatic. This operation is initiated and supervised by Central Control.

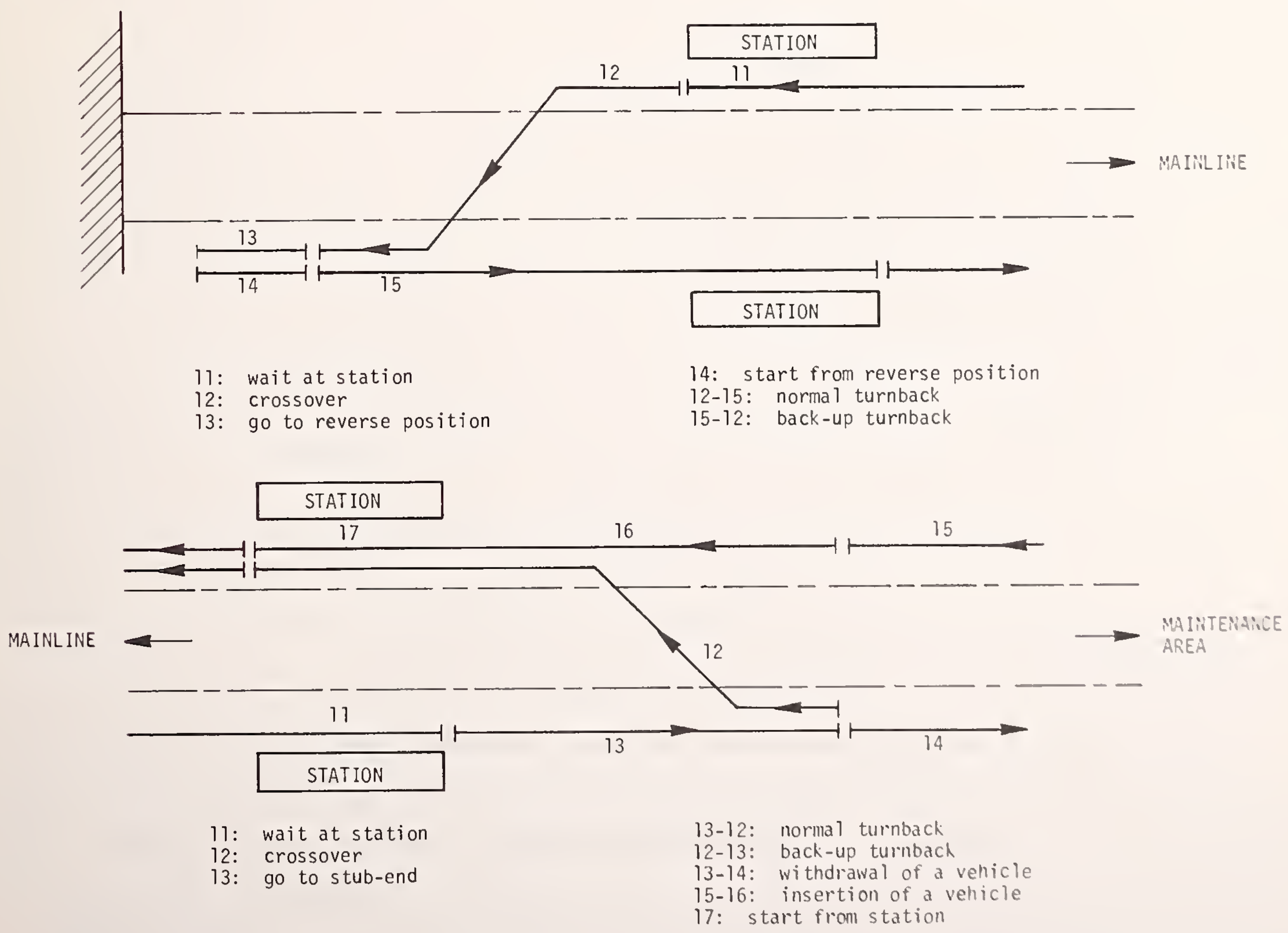


FIGURE 3-38. AUTOMATIC ROUTE OPTIONS AT TERMINALS

3.5.4 Automatic Vehicle Supervision (AVS)

The Automatic Vehicle Supervision functions are provided to manage system operations is response to both system events and central control commands. The AVS collects the data required to perform its functions, provides the interface with operating personnel through the Control Center displays and consoles, initiates and implements failure management strategies under the supervision of system operators, controls selected facility equipment, and records operating data. AVS data is processed by digital computers which are part of the Control Center.

Commands from the AVS are subordinate to the AVP system. In no case can the AVS system initiate a series of maneuvers which bypass safety functions.

The AVS uses the Dwell Operation Control Unit and its link with the vehicle dwelling in the station to modify AVO parameters. These modifications yield the most efficient level of service through regulation of the spacing of vehicles along the guideway. The AVS can adjust dwell time, modify operating speeds between stations, or hold a vehicle in a station.

The AVS also gives commands to the AVO system to insert and remove vehicles, thereby changing the operating fleet size. During vehicle insertion, for example, it accepts vehicles from the departure test area and adjusts the spacing among all vehicles to allow the insertion of each new vehicle. During vehicle removal, the AVS allows the operator to select vehicles for removal from service based on a set of priorities including the need of maintenance, time allocated for changes, and accumulated vehicle miles.

Computer software in the Control Center processes all the data concerning the actual state of the system (position and number of each vehicle, operating schedules, etc.) and selects appropriate system management policies and strategies.

Vehicle status information is collected from each vehicle via a data communication link with the Wayside Communication Control Unit and the guideway transmission line assembly. Vehicle remote control uplink commands are communicated in the same way. These uplink data are transmitted with a time frame of 1.333 seconds, at a 192 bps rate. The format uses 8 bits per byte with 8 lines of 4 bytes, i.e., 256 bits.

These uplink transmissions can command on-board equipment to:

- Send the vehicle status downlink;
- Remotely control operation of specific vehicles; this control command includes the selection of three vehicles for voice communications, one remote push-recovery command, and one other remote control command (on/off speed limit, zero speed, receipt of alarm, no door opening, switch redundancy).

To execute an individual remote control command the computer sends the identification number of the affected vehicle and the code of the remote control. The uplink message can also execute a universal remote control command to all vehicles.

Downlink vehicle status messages are continuously transmitted by each vehicle. These messages are synchronized on-board the vehicles by the reception of the first uplink line, which is a synchronization frame. Each downlink frame contains 64 bytes and has a 1.333-second frame time. The transmission rate is 384 bytes per second.

Two downlink vehicle status messages are provided: (1) a general status message is given for each vehicle each 1.333 seconds, and (2) a detailed message from one vehicle can be given each 1.333 seconds upon request by Central Control or automatically after an alarm has been detected on-board the vehicle and sent as part of the general message. The former includes information indicating receipt of speed limits, passenger initiated call waiting, failure flag, evacuation warning and the forthcoming transmission of a detailed message. The later status message gives the vehicle number and the status of all equipment and warnings. Table 3-5 lists the status data and warnings provided to the Control Center in the detailed message.

An additional data communication link is employed for polling status and control of wayside and station equipment via the DTU. This link provides the Control Center with AVS equipment status. AVO parameter modification and the remote switching of redundant wayside equipment are commended via this data link. These communication links are illustrated in Figure 3-39.

This wayside data channel uses the DTU which communicates serially at 1200 baud with the Control Center, and in parallel with the different station equipments which are supervised.

TABLE 3-5. DETAILED DOWNLINK STATUS MESSAGE DATA

EQUIPMENT \ DATA	STATUS	ALARMS
GENERAL	VEHICLE ID NUMBER	
VEHICLE CONFIGURATION	SINGLE OR DUAL (FOR PUSH-RECOVERY)	DRIVING CONSOLE UNLOCKED INTERNAL SPEED LIMIT ACTIVATED (FOR OVERLOAD, PUSH-RECOVERY, ETC.) - OVERLOAD FLAG
CONTROL SYSTEM	CONTROL MODE (AUTOMATIC, MANUAL, BACK-UP MANUAL) OPERATING CONTROL EQUIPMENT STRING (1 OR 2) RECEIPT OF SPEED RESTRICTION COMMAND RECEIPT OF "NO DOOR OPENING" COMMAND DIRECTION (FORWARD RESERVE) COMMANDED PROPULSION CONTROL (TRACTION/BRAKING) EMERGENCY BRAKING FLAG CONTROL SYSTEM READY CONTROL EQUIPMENT STATUS (DATA FOR EACH EQMT. STRING): ZERO SPEED, SF RECEPTION, NORMAL MODE, PP RECEPTION, PERTURBED MODE EMERGENCY BRAKING COMMAND, PUSH RECOVERY MODE, DIRECTION MODE	DISCREPANCY OF STRING 1 AND 2 EMERGENCY BRAKE COMMAND DETECTED SLIPPING OR SKIDDING EMERGENCY BRAKING (PASSENGER ACTIVATED) EMERGENCY BRAKING (DUE TO OBSTACLE ON GUIDEWAY) EMERGENCY BRAKING (DUE TO UNCOUPLING) EQUIPMENT ALARMS (DATA FOR EACH EQUIPMENT STRING) . AVO ALARM FLAG . MORE THAN TWO SUCCESSIVE EMERGENCY BRAKINGS . STARTING SEQUENCE FAILED . ELECTRICAL BRAKING FAILED . STATION COMMUNICATION LINK FAILED
PROPULSION SYSTEM	CHOPPER STATUS (AT LEAST 1 OF 2 STRINGS IN SERVICE)	CHOPPER MALFUNCTION (AT LEAST 1 OF 2 STRINGS FAILED) PROPULSION SYSTEM OVER-TEMPERATURE FLAG PROPULSION SYSTEM MALFUNCTION (AT LEAST 1 OF 2 FAILED)
MECHANICAL BRAKING SYSTEM		DEFECTIVE EMERGENCY BRAKING SYSTEM DEFECTIVE SERVICE BRAKING SYSTEM DEFECTIVE BRAKE RELEASE
AIR CONDITIONING		CABIN TEMPERATURE OUT OF THE TOLERANCE FLAG AIR CONDITIONING EQUIPMENT MALFUNCTION
DOORS	COMMENDED DOOR OPENING (FOR EACH EQUIPMENT STRING)	DOOR OPEN ON LINE (DATA FOR EACH OF TWO STRINGS)
PNEUMATIC EQUIPMENT		COMPRESSOR LOW-PRESSURE FLAG SUSPENSION LOW-PRESSURE FLAG COMPRESSOR OVER-TEMPERATURE FLAG
ELECTRICAL AND AUXILIARY EQUIPMENT	BATTERY CHARGE STATUS	CONVERTER MALFUNCTION-LIGHTING MALFUNCTION BATTERY MALFUNCTION-NO HIGH VOLTAGE FLAG = LOW VOLTAGE LOAD REDUCTION ACTIVATED-ELECTRICAL SYSTEM NOT READY FLAG.

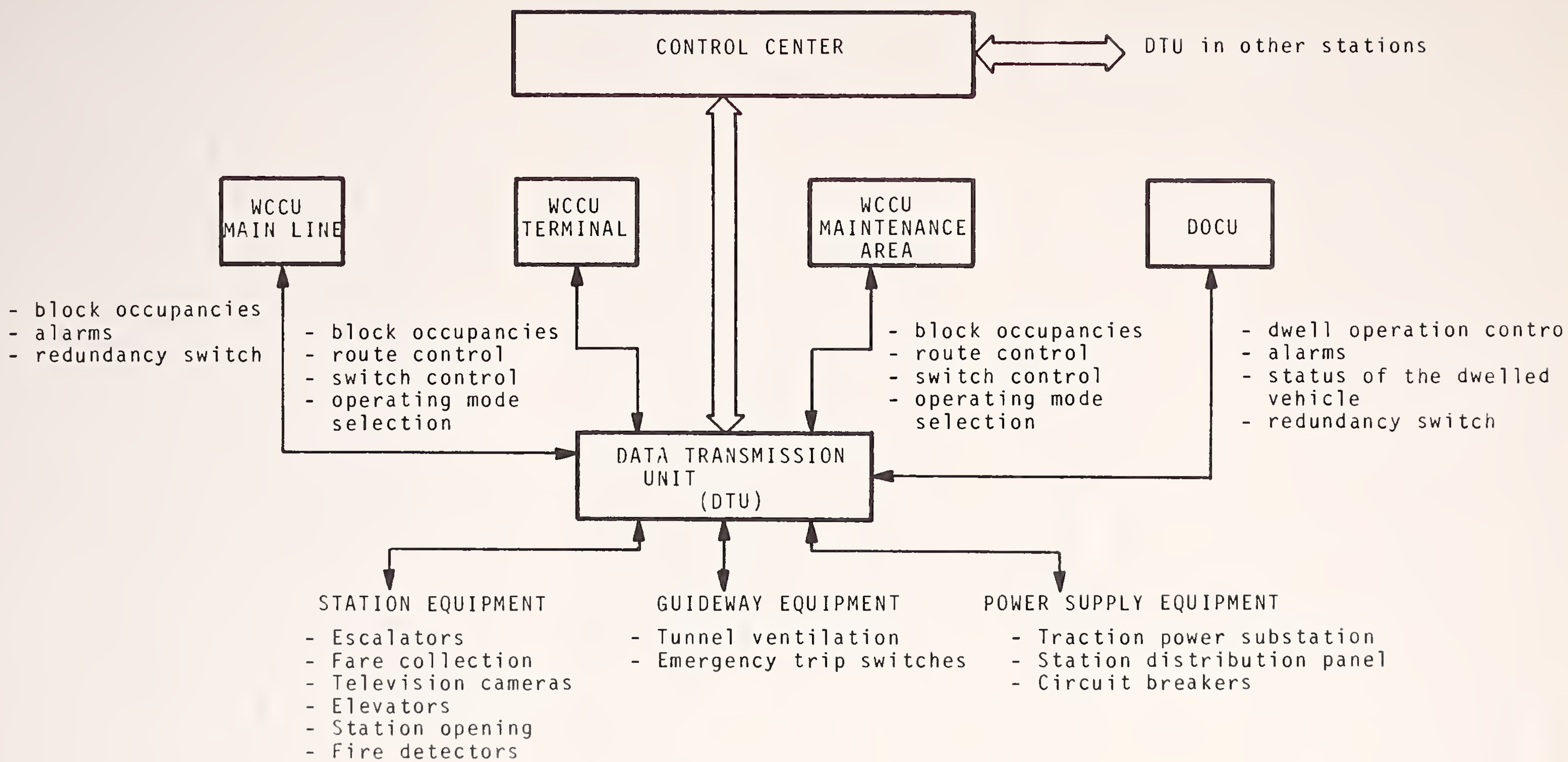


FIGURE 3-39. DATA TRANSMISION UNIT (DTU) COMMUNICATION LINKS

3.6 SYSTEM OPERATION

3.6.1 Normal Operation

In normal service the VAL system vehicles will be operated in a completely automatic mode between the stations shown in Figure 2-5 without intervention of any operating staff. During peak periods each of the 32 vehicles will stop at each station. A headway of 60 seconds will be maintained. Six vehicles will either be in maintenance or held in reserve for immediate insertion in the event of a failure.

The transitional phases resulting from introduction or withdrawal of vehicles from the line are managed by the Control Center. The operation of vehicles is fully automated everywhere on the line, including the termini, depot, and vehicle-washing machine located on a shunt off the maintenance depot access sidings.

In the event of an anomalous condition, control can be assumed by Central Control personnel and subsequently by personnel on the line who are distributed as follows: 1) depending on the time of day, from one to three teams of two technicians will be based in the major stations; 2) two to four mobile inspectors; and 3) two inspectors located at the termini.

Accounting for the amplitude of service and operation 20 hours per day the total operational and maintenance labor force will be approximately 80 persons. In addition, provision has been made for a squad of specially assigned local police.

3.6.2 Failure Management

Regardless of equipment reliability, failures and unplanned events will occur. The VAL system has been designed to minimize the frequency and the resulting effects of handling these events.

The design philosophies and priorities embodied in the VAL system are to always keep the system safe; whenever possible, to keep passengers moving to minimize passenger inconvenience during reduced performance periods; and to restore the system to normal operation as quickly as possible. Accordingly, the VAL system is able to be operated under a wide range of very different conditions, especially under failure conditions, with a minimum number of effective operating personnel. This is done within all safety constraints and with maximum flexibility given to failure management operators.

This flexibility is available through the Control System, which has been designed to perform the principal Failure Management functions:

- Fault Detection
- Automatic Responses
- Failure Diagnosis
- Recovery Strategy Selection and Implementation.

To implement these Failure Management functions, the following are necessary:

- Information - from diagnostic aids or other data transmitted to the operators
- Means of action - pre-programmed reactions, and recovery sequences chosen either by the system or the operators.

3.6.2.1 Fault Detection - The diagnostic aids allow the operator and the system to be aware of a failure as soon as it occurs.

The majority of the possible failures induces a status change to remote sensings resulting in a warning transmission to the Control Center. These warnings identify the failed equipment, its nature, and its location. This information is displayed to the operator, either on the consoles or on the mimic displays.

3.6.2.2 Automatic Responses - Each remote sensing sequence, which is related to a state which may lead to an unsafe result or to a failure that may result in a greater future failure, induces an automatic response in the vehicle equipment. This automatic response is performed through on-board automatic sequences; the choice of the sequence corresponds to the nature of the failure. For example, a power convertor fault which may lead to insufficient electrical autonomy induces a power load reduction sequence.

3.6.2.3 Failure Diagnosis - For the great majority of failures, the analysis of status reports leads to a single and simple diagnosis (e.g., a convertor fault). For the remaining failures, the operator is able to make a judgment based on all the available status reports.

These reports make possible a classification of failure types. After classification, to the extent possible, each type of failure results in a single line of action. Since it is not possible to have one single status change for each single failure, one part of the failure diagnosis may be a result of an unsuccessful recovery sequence.

However, because the recovery modes are generally easy and rapid, the possible multiple diagnosis is not a severe penalty. Operator judgment is also used for failure diagnosis since that person is able to integrate such information as previous recorded failures on one specific vehicle or equipment, particular operating conditions, or information available through the CCTV or voice communications systems.

3.6.2.4 Recovery Strategy Selection and Implementation - As soon as the diagnosis has been performed, the choice of strategy is made. For each diagnosis, a strategy has been defined after a preliminary analysis of failure effects on operation. As previously indicated, each strategy is a succession of sequences, which are chosen and initiated by the operator, and then implemented by the AVS system through the AVO system. Substantial flexibility is given to the operator to increase system operability in implementing the succession of sequences.

a. Strategies Related to Vehicle

These strategies may be classified according to their basic characterics.

1. Removal of vehicle at the terminal:

In this case, the failure has not precluded movement of the vehicle; that is, the vehicle is removed only because the passenger comfort level is lowered or because a redundant or non-essential piece of equipment has failed. According to the remaining functional capability, removal will be conducted either at the Maintenance Terminal or at the first terminal encountered.

To maintain the level of service, the removed vehicle will be replaced whenever possible by a reserve vehicle located in one of the terminals.

2. Evacuation of passengers at the next station and removal of a vehicle:

This action is taken when the status of the vehicle or vehicle unit may lead to a perturbation of system operation greater than permissible (e.g., too low a pneumatic pressure).

This procedure may initiate an automatic low speed on the vehicle. The vehicle is removed at one of the terminals (according to the same conditions as in the previous case). The trip between the evacuation station and the terminals is completed without dwelling in the stations.

3. Automatic push recovery:

This procedure may be needed, for example, in case of a failure of both redundant parts of the on-board AVO equipment leading to the complete inability of the vehicle to move.

Evacuation may be performed at the next station with confirmation of the previous action (no stops and removal).

4. Operator intervention on failure site:

This intervention is required in case of blockage due to an obstacle on the guideway, or a mechanical breakdown of a train. The intervention of system personnel may also be required in case a vehicle cannot restart.
After on-site inspection, a decision will be made to:

- Resume normal traffic
- Initiate push recovery
- Perturb normal traffic.

5. On-Line passenger evacuation:

Two types of evacuation may occur:

- Non-emergency evacuation - Wherein there is no high voltage or a greater impending failure of the vehicle preventing it from restarting.

  An evacuation order is given by operator and is performed under personnel supervision.

- Emergency evaluation - This is performed only after an on-board emergency passenger alarm (pulling the "emergency control"). High voltage power is immediately cut off and doors can be opened after a delay to be certain the vehicle comes to complete stop following emergency braking. Passengers then evacuate the vehicle using the evacuation platform along the side of the guideway and proceed to the nearest station.

6. Miscellaneous strategies:

   These actions include such sequences as limited speed orders given either by AVS system, or by operators (e.g., in the event of vehicle overload.

b. Strategies Related to Stations

Three types of strategies are related to stations:

- Failure of station equipment that has no effect on vehicle movement of safety. These failures will lead to a deactivation of equipment until the intervention of operating personnel (e.g., shutdown of an escalator).

- Failure of station equipment that has an effect on vehicle movement but not on safety. The number of failures leading to disruption on a station platform is low because of the use of redundant equipment on the great part of station electronics. The procedure to be employed, in most of the cases, is to switch to the redundant equipment when system personnel intervene. This eliminates disruption of the traffic.

  In the event of a failure when alternate equipment cannot be employed, and when the time to repair is expected to be high, passengers may be directed via the public address system or displays to be rerouted.

- Failure which has an effect on safety - This is mainly the case of station door failure.

  In addition to the actions which are automatically taken to prevent further vehicle movement, on-site sequences are initiated, such as transferring the door automatic safety to the on-site operator, or giving departure orders from the platform.

c. Strategies Related to Power Units

Power units are protected by circuit breakers fitted with "automatic reset" devices (circuit braking due to overload is followed by two automatic attempts to reset at 5-second intervals). If the reset fails, intervention of system personnel is required. In case of failure of one unit, power will be supplied to the failed portion by the next sub-stations. During off-peak periods, this will have no effect on operation. During peak periods, it may be necessary to reduce the performance of vehicle (i.e., lower operating speed).

In case of failue of two units, a strategy for limiting simultaneous acceleration of vehicles permits the system to maintain normal service levels.

d. Strategies Related to the Wayside and Transmission Equipment

This equipment has built into it switch redundancy so that, in the event of a failure, a switch is made automatically to redundant equipment. A failure status is automatically reported to Central Control. Repair of the failed unit is initiated by the controller.

In some cases, the failure may lead to on-site intervention, for operation of a particular element of the system (e.g., the operation of a crossover switch is performed). This may be conducted from the local terminal console, if the transmission unit is out of order or from the electrical cabinet switch, if the wayside equipment has failed.

e. Strategies Related to the Guideway Equipment

These strategies include such schemes as bypassing the switch or operating with the second switch if the primary switch is out of order.

f. Strategies Related to Maintenance and Storage Areas

The breakdown of a part of the transmission lines, lateral guidance rails, or switches may lead to a perturbation of main line operation during the insertion periods. The insertion can still continue but at a lower rate with the following actions:

- Manual operation of the switches
- Manual operation of the vehicles
- Use of only one part or a single lane of the tracks.

3.6.2.5 Information

a. Diagnostic Aids

These aids are mainly remote sensing systems giving the complete status of equipment by section. The complete status of all sensors for one specific vehicle or equipment element is available on request at the control consoles and is updated every 1.3 seconds.

Some specific sensor outputs are considered as warnings and are automatically displayed to operators at each change of status. After a warning occurs, the operator may request the complete status report.

The principal status reports are:

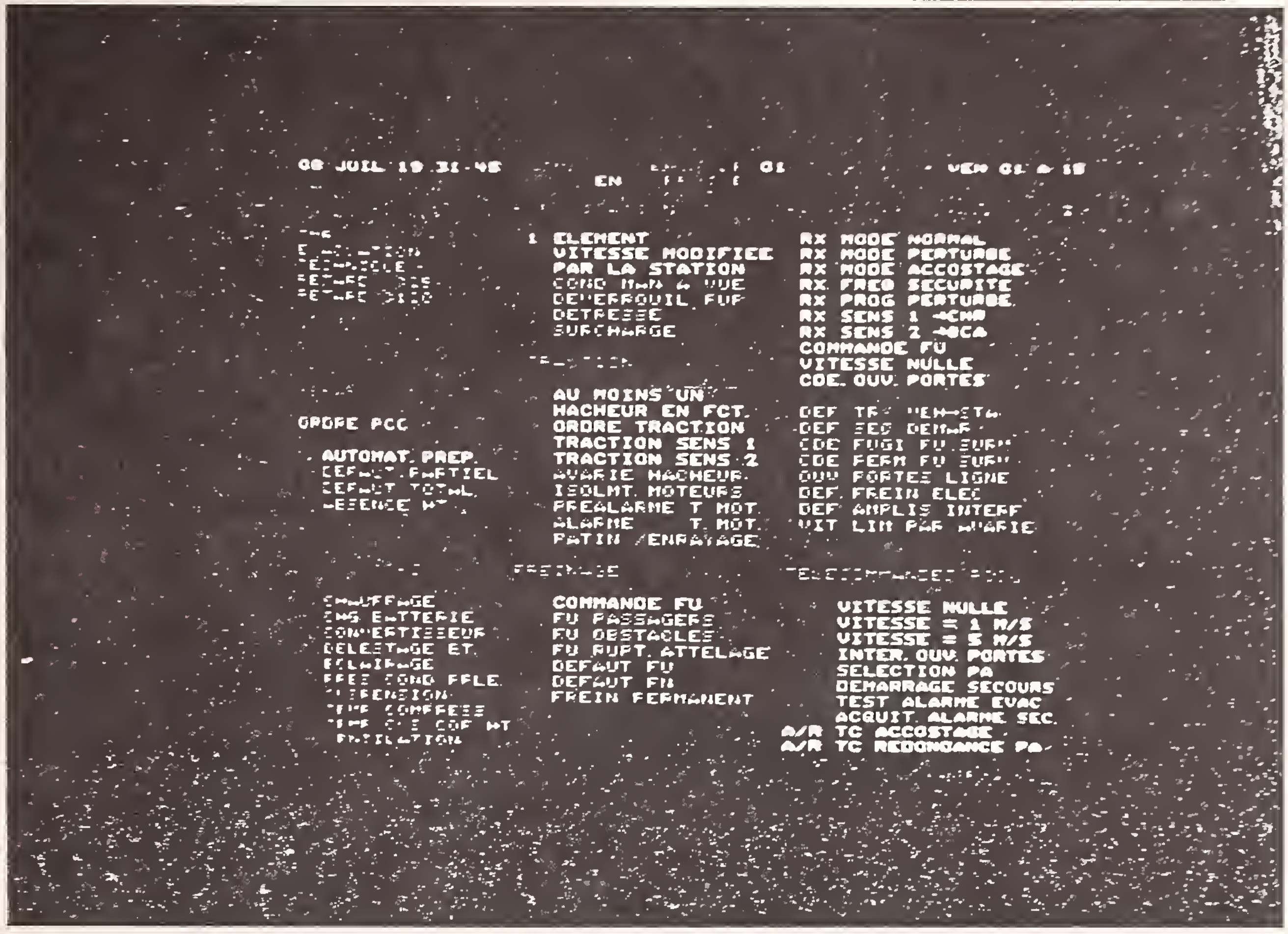
1. Vehicle equipment status, include:
   - Technical faults
   - Passenger or operator call on Voice Communications System
   - Emergency evacuation demand ("emergency handle" in the vehicle)
   - Technical fault reset not valid.
2. Wayside and transmission equipment status, giving the technical state of AVO fixed equipment, dwell units, and data transmission units.
3. Station equipment status, for such items as doors, fare collection, escalators, lights, displays, etc.
4. Power supply equipment status including power substations, and circuit breakers.
5. Guideway equipment status including the state of crossovers.

An example of the detailed status is shown in Figure 3-40 for the 01 vehicle where the upper portion of the figure shows the actual CRT display and the lower portion is an English translation of the display.

b. Other Data Available

A list of data is available to the operator, principally through the Control Center Equipment.

1. Information from the mimic displays (guideway, stations, power system) giving the location of units, of failures;



08 July 19:31:45 — STATUS REPORT: PASSENGER UNIT 01 ON LINE — PU 01 TO 15

ALARMS

Remote Sensing YES
Evacuation NO
Technical NO
Lost Time > 25 NO
Lost Time > 120

POSITION

PREPARATION OF UNIT

CONTROL CENTER COMMAND OP 0

\+ On-board Equip. Prepared
☐ Partial Default
☐ Total Default
☐ No High Voltage

AUXILIARIES

☐ Heating
☐ Battery Charge
☐ Converter
☐ Power Load Reduction
☐ Lighting
\+ Pneumatic Pressure
\+ Suspension
☐ Compressor Temp.
☐ Converter Temp.
☐ Ventilation

OPERATION

1 Married-Pair
☐ Speed Modified by the Station
\+ Manual Mode (Visual Obs.)
\+ Manual Console Open
☐ Coupled Units (After Failure)
☐ Vehicle Overload

PROPULSION

☐ One Chopper on line (at least)
☐ Propulsion Command
☐ Propulsion Direction 1
☐ Propulsion Direction 2
☐ Chopper Fault
☐ Chopper Disconnection
☐ Motor Temperature Prelim-Alarm
☐ Motor Temperature Alarm
☐ Slipping/Skidding

BRAKING

☐ Emergency Brake E.B. Command
☐ E.B. Passenger Demand
\+ E.B. Obstacle Detection
☐ E.B. Coupling Bar Broken
☐ E.B. Default
☐ Normal Braking Default
☐ Permanent Braking

AVC EQUIPMENT ON-LINE 2

Normal Mode	☐	☐
Perturbed Mode	☐	☐
Push Mode	☐	☐
Safety Frequency	☐	☐
Perturbed Frequency	☐	☐
Direction 1 → CHR Station	☐	☐
Direction 2 → OCA Station	☐	☐
Emergency Brake Command	☐	☐
Zero Speed	+	☐
Doors Open Command	☐	☐
Veh. → Station Link Fault	☐	☐
Start Sequence Fault	☐	☐
Sporadic Overspeed E.B. Command	☐	☐
Permanent Overspeed E.B. Command	☐	☐
Doors Open on Guideway	☐	☐
Electrical Brake Fault	☐	☐
E. B. Interfacing Fault		☐
Speed Limited		+

REMOTE COMMANDS

Y N	Zero Speed	☐
Y N	Speed = 1 M/S	☐
Y N	Speed = 5 M/S	+
Y N	No Door Opening	+
1 2	AVC Equip. Switch	
Y	Start Seq. Recover	
Y	Evac. Alarm Reset	
Y	Alarm Reset	
REC	Push Command	☐
REC.	And On Switch Command	☐

FIGURE 3-40. CRT DISPLAY OF EQUIPMENT STATUS

2. Visual information from the CCTV System, e.g., such as state of a station platform;

3. Information from the Voice Communications System with maintenance or intervention personnel or with patrons;

4. Data recording of prior incidents.

3.6.2.6 Means of Action - All failure management strategies are a succession of many basic sequences. Each of these sequences or "operating tools" may be used in any one of several failure management strategies in order to add greater flexibility to system operation.

The Recovery Sequences are:

- On-board automatic sequences
- Remotely initiated automatic sequences
- On-site manual sequences.

The primary sequences are basically summaried in the following paragraphs.

a. On-Board Automatic Sequences

These sequences are auto-responses, initiated by the vehicle on-board equipment to selected faults which may, in most cases, affect passenger safety comfort or might have affected the vehicle autonomy.

Each of the sequence activations is transmitted to the Control Center through the Vehicle Status report.

The sequences are:

1. Automatic speed reduction
   Maximum speed is limited to 11.2 mph (5m/sec).

2. Automatic speed and deceleration reduction
   The maximum civil speed is multiplied by a constant 0.9 factor and the deceleration rate by a constant $0.9^2 = 0.81$ factor.

3. No re-start at the next station
   The doors will remain open and the unit will not re-start until the order is given by the operator.

   If the equipment state requires it, the vehicle will remain stopped even if the diagnosis has not yet been fully completed at the Control Center.

4. Initiation of propulsion effort

   The vehicle cancels any propulsive effort and either the deceleration program applies brakes or the vehicle coasts to a stop.

5. Propulsion effort reduction

   The propulsive effort transmitted to wheels is limited to reducing the current in propulsion motors.

6. Power load reduction

   Auxiliaries on board the vehicle are cut out in order to diminish power consumption. This is accomplished in two steps: first by reducing secondary loads and second by eliminating cooling to the chopper control.

7. Inhibition of electrical braking

   The passenger unit uses only its mechanical braking for service braking.

8. Stop compressor

9. Chopper isolation

   One of the two choppers is isolated thereby removing power from the affected vehicle.

10. Emergency braking

b. Remotely Initiated Automatic Sequences

These sequences are chosen after the failure has been diagnosed. They are initiated through the operator's control console. These sequences are performed by the AVS system subject to the safety constraints of the AVP system.

Subsequent implementation is automatically controlled by the AVS system under operating personnel supervision. Operators can modify or cancel the implementation by means of console controls except in those cases where safety requires that the sequence must be fully completed before any further action, e.g., push recovery.

Once the mode of action has been chosen and the principal inputs have been given to the system, the only intervention which is required from the operator is to authorize the sequence and supervise it.

The remotely initiated automatic sequences are:

1. Speed reduction

2. Speed and acceleration reduction

3. No re-start of a vehicle at the next station - These three sequences have the same effect as the corresponsing automatic ones on-board. The capability to initate them from the Control Center provides added flexibility to the system.

4. Switch to a redundant equipment - When a failure occurs on an actively redundant set of equipment, switching to the alternative equipment may be performed automatically by the AVS system.

   This switching to alternate equipment is not only possible on vehicles but also on some of the fixed wayside equipment.

   Switching of particular equipment may be performed through special control if they have an impact on vital functions which must be switched in accordance with the AVP safety requirements. Otherwise, they are initiated by the operating personnel using the control console.

5. Evacuation of passengers in the next station - This procedure requires the use of the Public Address and the CCTV systems.

6. No dwell operations in the next station - Once this action has been initiated the vehicle will not dwell at any station. The vehicle slows down and stops in a station and resumes moving at once without opening its doors. This procedure remains the same until the vehicle reaches the next terminal, unless it is cancelled by system personnel.

7. Removal of a vehicle at the next terminal - This may be the terminal opposite the workshops. The operator may choose the location and initiates the procedure which is automatically implemented by wayside equipment.

8. Removal at the terminus on the same side as workshop - This includes removal to the maintenance area or the storage area.

9. Insertion of reserve units - This may be done at each end of the line according to the location of the failure, the available reserve, and the need for replacement.

10. Push recovery - Once it has been initiated by operating personnel through special controls in the Control Center, automatic coupling is performed between a failed vehicle and the following vehicle. This procedure complies with all the safety criteria, since the system is specifically designed with an automatic retrieval capability. Following successful coupling, the two vehicles (two married pairs) move the 0.9 speed and 0.81 deceleration reduction to the nearest station.

11. Power supply failures procedures - These procedures include automatic check of emergency switches, and attempts to reset cirucit breakers according to a certain set of safety checks. These actions are initiated through operator's console in the Control Center.

12. Miscellaneous - Includes such procedures are resetting an escalator after emergency stop.

The use of these primary sequences may be adapted to special events. The operating personnel are given adequate flexibility to add such actions to these sequences as sending special messages over the public address system.

c. On-Site Sequences

These sequences are mainly performed through the dispatch of system personnel to the site of the failure. They may have different levels of automation according to the nature of the failure.

1. Operation of equipment from local consoles
   (Transmission units out of order)

   - Operation of switches from terminal console
   - Operation of station console

2. Operation of equipment from local cabinet
   (Fixed equipment out of order)

   - Operation of switches from a switch in the electrical cabinet

3. Manual operation of equipment

- Manual operation of switches
- Manual driving of a train

4. On-Site interventions (Other)

- Such as passengers evacuation monitoring on guideway

These actions may be performed with constant links between the personnel on site and the Control Center through the communications system.

3.6.3 Information and Data Recording

The system is designed to provide information to the operating personnel both in real time and for future off-line analysis.

3.6.4 Traffic Regulation

The anti-bunching and schedule recovery functions of the AVS system operate around the failure in order to keep the system operable to the maximum extent. The schedule recovery capability of the operation allows it to return quickly to normal operation as soon as the failed vehicle has been reset, repaired, or removed. This failed vehicle is replaced by a reserve vehicle which then allows the system to maintain the level of service capability.

3.7 TEST AND MAINTENANCE FACILITY

A schematic of the Operational Test and Maintenance Facility is shown in Figure 3-41. It is located at eastern extremity of the Lille VAL system (see (Figure 2-1). The demonstration tests reported on herein were all conducted at this facility. The test track consists of two stations, 710 meters apart, and two sub-end terminals, which permits a quasi-loop operation. The total length around the entire loop is 1.4 km. The test track is used to perform development testing, qualification testing, and acceptance testing. The East station departure is a complete station with doors, whereas the East arrival and West arrival and departure are simply open platforms.

The Control Center for the test track and the Line 1 Lille Metro are housed in the Central Control and Administration facility. This is joined to

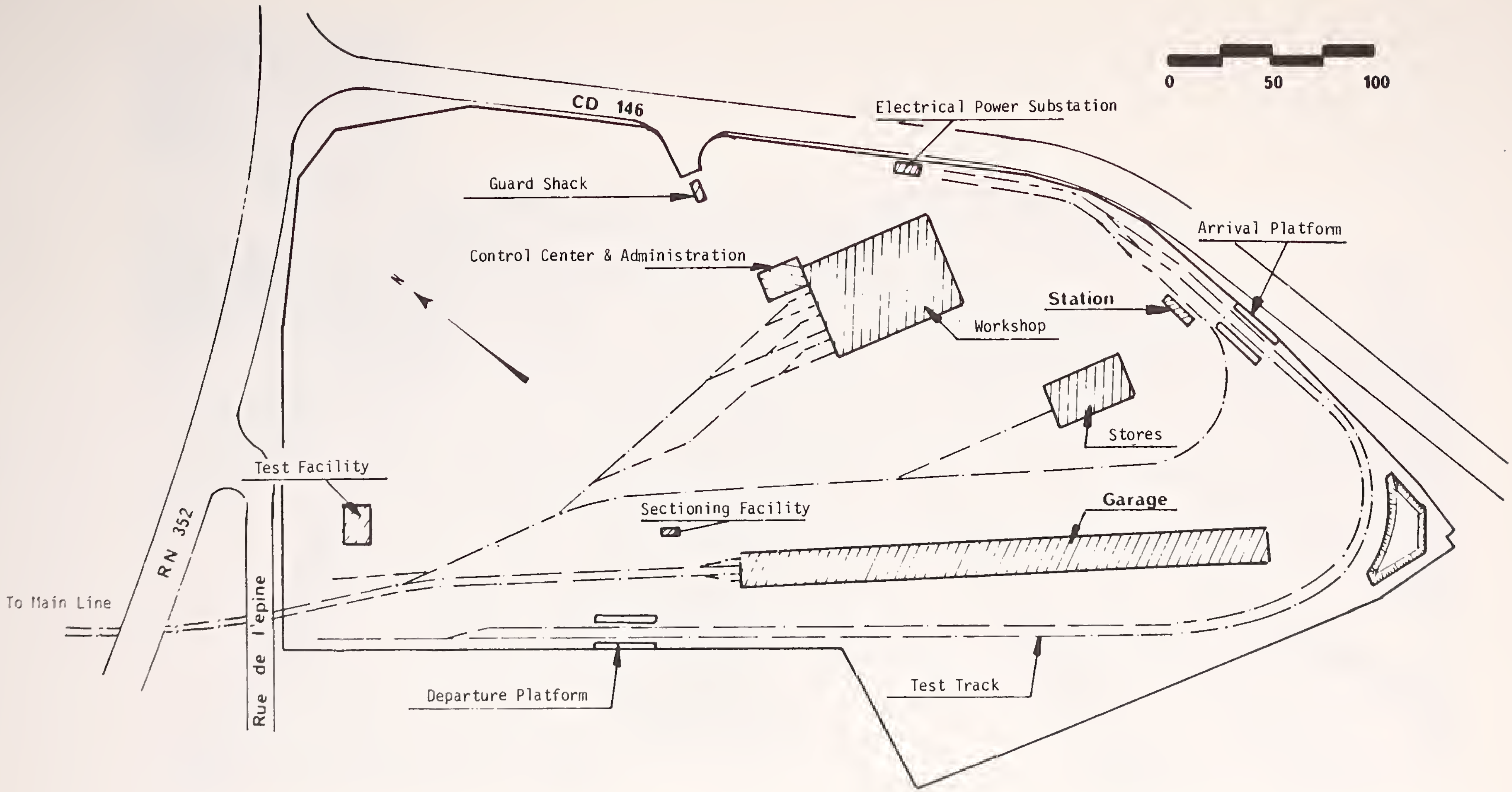


FIGURE 3-41. SCHEMATIC OF OPERATIONAL TEST AND MAINTENANCE FACILITY

a workshop with six bays (see Figure 3-42). Each bay has eight synchronized lifts that lift the entire vehicle unit (see Figure 3-43). This allows easy access for maintenance personnel and equipment without restrictions.

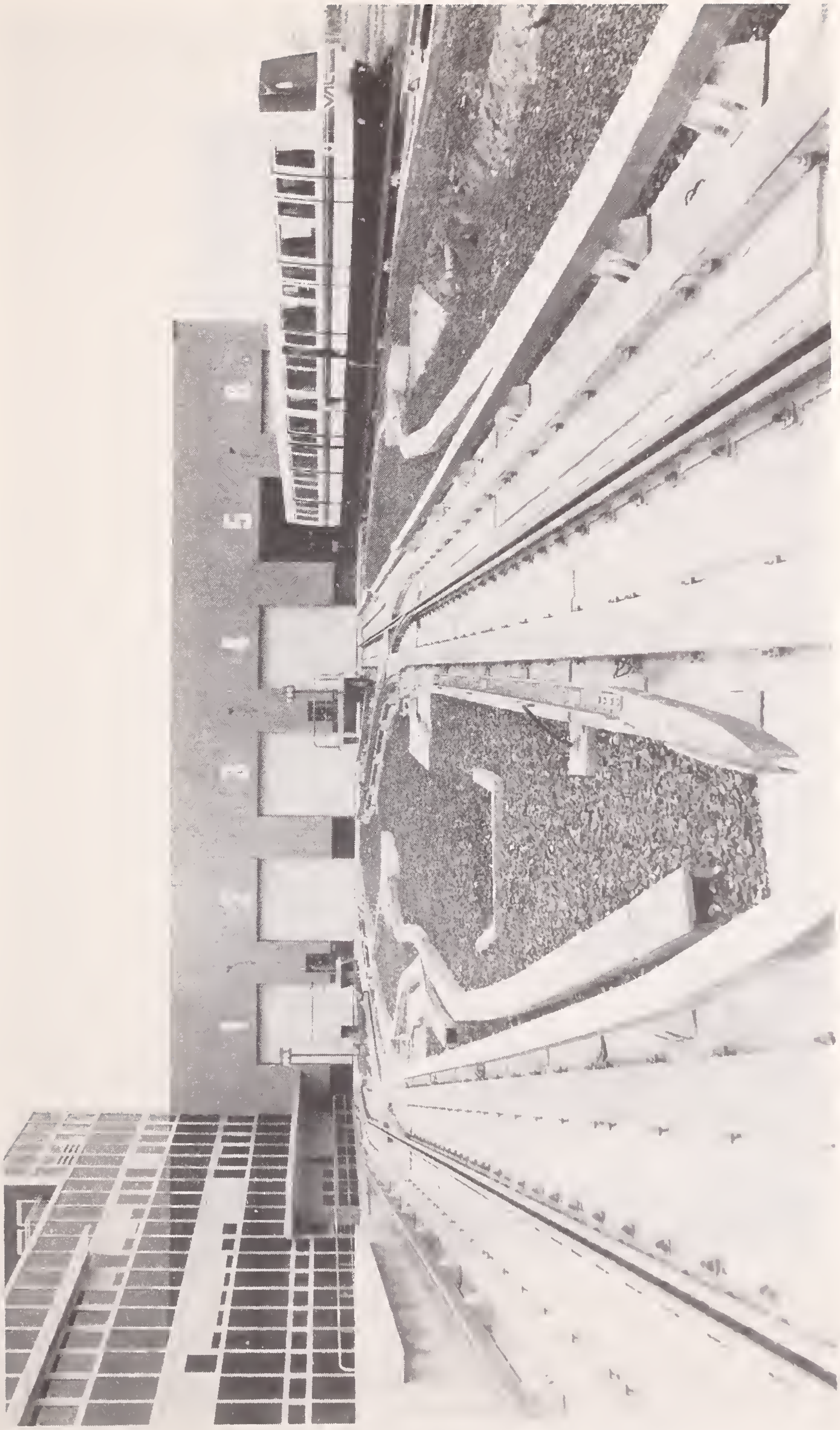


FIGURE 3-42. WORKSHOP

FIGURE 3-43. VEHICLE ON LIFT

4.0 DEMONSTRATION TEST PROGRAM

A series of demonstration tests of the VAL system were performed at the Operational Test and Maintenance Facility in Lille to determine the performance characteristics of VAL.

To this end, 13 categories of tests were performed between 4 to 25 August 1980 at the test track in Lille, France. A summary of these tests is presented in Section 4.1 through Section 4.13.

The tests were, in general, oriented to determining the system characteristics as related to safety, dependability, and performance in the framework of the Lille Metro and a conceptualized urban transit system. The primary consideration was to determine the safety performance of the Val system. The secondary consideration was to obtain preliminary data on the system dependability. An all-up and complete dependability test program was not intended during this demonstration test program. Rather, it was intended to perform a preliminary dependability test to obtain a general idea of the level of dependability; that is, to assess the potential of VAL meeting its dependability goals. A complete dependability program was not performed because the system integration phase was not completed. Integration of the rolling stock (vehicle, propulsion, brakes, and suspension), however, was completed. As such, any failures in these subsystems were weighted more heavily than in the automatic control system which was not integrated. The third consideration was to verify to the extent possible the performance characteristics. Because time was greatly constrained for these demonstration tests, the focus was on the vehicle system and the command and control system.

The safety aspects of the system were carefully and extensively examined. This was a primary consideration. Numerous artificial faults were created to determine the system response in the presence of malfunctions. These tests essentially provide a measure of the Automated Vehicle Protection (AVP) capability. Finally, the performance characteristics were measured, providing a measure of the capability of the Automatic Vehicle Operation (AVO) system. The capabilities of the Automatic Vehicle Supervision (AVS) system were principally determined during the course of safety or AVP testing.

The following is a summary of the 13 categories of demonstration tests conducted and a brief explanation of each objective.

Test Category

C1 - Dependability Tests

- One vehicle
- Two vehicles

Objective - to obtain preliminary data on the VAL system dependability. A simulated revenue operation was to be performed on the Lille Test Track for a total of 100 hours - 20 hours per day without major failures.

D1 - Emergency Braking and Addendum

Objective - to demonstrate the performance of emergency brakes.

D2 - Propulsion and Service Braking

Objective - to demonstrate the capabilities of the propulsion and service braking capabilities. Service brakes will be tested with regeneration only and with combined friction and regenerative braking.

D3 - Coupling of Vehicles

Objective - to demonstrate the capability of coupling of the two vehicles in both a manually-driven mode and a fully-automated mode.

E1 - Collision Avoidance

Objective - to demonstrate that the safe spacing between two vehicles is automatically maintained.

E2 - Overspeed Avoidance

Objective - to demonstrate that the vehicles are prevented from exceeding the speed limits.

E3 - Direction Control

Objective - to demonstrate: 1) that the reverse direction is only possible in the reversal switches; 2) that the vehicles are prevented from rollback.

E4 - Switch Interlocking

Objective - to demonstrate route selection capability and the safety associated with switch operation.

E5 - Station Safety

Objective - to demonstrate the control and operation of the vehicle and station doors by the AVP.

F1 - Speed Control and Ride Comfort

Objective - to demonstrate that the vehicle speed closely follows the commanded speed and to demonstrate longitudinal ride comfort.

F2 - Programmed Stops

Objective - to demonstrate the stopping accuracy at each station.

F3 - Dwell Adjustments

Objective - to demonstrate the capability to adjust dwell time for each station.

F4 - Headway Measurement

Objective - to demonstrate the minimum headway capability.

Two production vehicles, referred to as the 01 vehicle and the 02 vehicle, were used during the course of the test program. Each vehicle consists of a Pilot Automatic (PA) or control unit and a chopper (HR) unit. During the course of the demostration test program, the 01 vehicle accumulated 280 kilometers of travel and the 02 vehicle accumulated 1685 kilometers. There are two switches in the loop that were operated twice per cycle. These two switches performed approximately 5000 switching operations.

4.1 DEPENDABILITY TESTS

A series of dependability tests were conducted to obtain preliminary dependability data on the VAL system. The tests were conducted entirely in an automated mode by a single vehicle simulating revenue operation; that is, the vehicle stopped at each station on the test track, doors were opened for a predetermined dwell, and a switch-back reversing direction was performed at the terminals of the test track. The objective of this test was to operate the vehicle without major failure. Failures are classified as to:

- Minor failures - can be cleared in less than 10 minutes:

- Major failures - require more than 10 minutes to correct and may require removal of the vehicle.

These tests were conducted for 100 hours - 20 hours per day. Observers rode the vehicle periodically to determine whether the vehicle was functioning properly.

The dependability tests were performed on the 02 vehicle (the second of the series production vehicle units) before integration testing of the control system was completed, and prior to any endurance testing of the system. Thus, this test represented the first of the system dependability tests.

The test track was designed so that tests are more severe than on the line because of shorter interstation spacing, i.e., two terminals per round trip of 1.3 kilometers. Therefore, equipment such as brakes, doors and control systems were submitted to a higher utilization rate than on line.

A summary of dependability test data is given in Table 4-1, in terms of the days of operation. A total of 100 hours of testing was performed. The total distance traveled was 1363 kilometers and the number of cycles or round trips around the test track was 1091. The overall down time accumulated daily decreased from 1.828 hours to 0.067 hours over the 5-day period. The down time is subdivided into the down time attributable.

TABLE 4-1. SUMMARY OF DEPENDABILITY TEST DATA

Day	Test Duration (hrs)	Distance (km)	No. of Cycles (1)	Down Time (hrs)	Repetitive Malfunctions (hrs)	Intermittent Malfunctions (hrs)	Availability
1	20	266	213	1.828	1.222	0.606	0.909
2	20	254	203	0.98	0.697	0.283 (2)	0.951
3	20	285	228	0.575	0.544	0.031	0.971
4	20	273	218	0.629	0.414	0.215	0.969
5	20	287	229	0.067	0.058	0.008	0.997
Total	100	1363	1091	4.079	2.935	1.144	0.959 (3)

Note: (1) Calculated
(2) Estimated
(3) 5-day average

to repetitive malfunctions and intermittent malfunctions. The availability of the system with a single vehicle in operation is also given for each day.

The malfunction categories and their effects are given in Table 4-2. Table 4-3 summarizes the number of malfunctions per category experienced on a daily basis.

Item 1 malfunction was eliminated after the first day of operation by shortening the transmission line in the East Terminal. Items 2 and 4 were repetitive malfunctions. The remaining items are intermittemt. The exact cause of the malfunctions in each instance was not determined because the test vehicle was in a revenue service configuration and did not have any measurement equipment installed. However, the principal cause of malfunctions was attributable to poor communications between the vehicle and stations. They are possibly related to either on-board software malfuncitons, on-board electronics shifts in characteristics with temperature, or spurious signals. However, in all instances the condition was cleared by the Control Center through restart, retransmission, and reinitiation procedures.

The total number of malfunctions contributing to down time was 198. If the 36 malfunctions associated with item 1 are excluded, since a corrective action was taken after the first 20 hours of operation, then 162 malfunctions cause the remaining down time. Of these a poor communication link between the vehicle and the station was the cause of 95 item 2 and 18 item 6 malfunctions, or about 70 percent of the malfunctions. The emergency braking, item 4 malfunctions which had the effect of decreasing comfort, was reported 37 times or about 23 percent of the time. The remaining 12 or 7 percent of the malfunction were split over the 6 remaining items.

It is important to observe that no failure occurred in the vehicle rolling stock equipment which had completed system integration testing. Furthermore, throughout the entire period of testing not one malfunction was experienced with the running gear.

The system availability for single vehicle operation was determined not as a definitive system availability but as an indication of the potential performance of the system. The availability increased from 0.909 to 0.997 with an average for the 5 days of 0.959. On the final day of testing the total down time was 4 minutes out of 20 hours of continuous operation. If it is assumed that the majority of malfunctions experienced can be corrected during

TABLE 4-2. MALFUNCTION CATEGORIES

Item	Category	Effect
1	Too short a stopping sequence in the East Terminal	The vehicle did not automatically restart from the East Terminal stub end.
2	Station-to-vehicle communication malfunction	No door operation, correct stopping sequence ineffective. Vehicle only restarts in the ASMD mode until it reached the next station. The vehicle did not recover at the next station. The vehicle restarted but did not stop at stations during a complete round trip.
3	The vehicle remains stopped in the West Terminal	The vehicle did not automatically restart from the West Terminal stub end.
4	Emergency braking	The vehicle stopped after departure from the East and West stations. The vehicle stopped at the exit of the East and West Terminals. The vehicle applied emergency brakes at the station arrival platform and missed the station.
5	Telecommand loss	Telecommands were not executed.
6	Too short a stopping sequence at the East Station Arrival platform	The vehicle restarted automatically in the ASMD mode and remained it it only for a few seconds.
7	On-line emergency braking	The vehicle applied emergency brakes and automatically restarted in a normal mode.
8	Assumption: a slow down beacon was mistaken by the vehicle as a station beacon.	The vehicle stopped according to the disturbed program service braking, restarted in the ASMD mode, and continued until the next station.
9	Dwell Unit malfunction	The station doors remained open. The vehicle could not restart.

TABLE 4-3. NUMBER OF MALFUNCTIONS

ITEM \ DAY	1		2		3		4		5	
	Minor	Major	Minor	Major	Minor	Major	Minor	Major	Minor	Major
1	36	0	0	0	0	0	0	0	0	0
2	11	8	27	1	11	2	25	0	10	0
3	1	0	0	0	0	0	0	0	0	0
4	10	0	13	0	4	0	6	0	4	0
5	2	0	2	0	1	0	1	0	0	0
6	2	0	3	0	4	0	9	0	0	0
7	0	0	2	0	0	0	1	0	0	0
8	0	0	0	0	1	0	0	0	0	0
9	0	0	0	0	0	0	1	0	0	0
TOTAL	62	8	47	1	21	2	43	0	14	0
Including malfunctions without Down Time	15	/	28	/	11	/	12	/	7	/

system integration of the command and control system and that an availability of 0.997 for single vehicle operation can be achieved regularly, then the system availability of 0.98 with four vehicles on the test track can be achieved. The Lille Metro system requires that an availability of 0.96 must be achieved with simultaneous operation of four vehicles on the test track for qualification. An availability of 0.98 is to be achieved in operation 1 year later.

4.2 EMERGENCY BRAKING

A series of 30 tests were conducted to determine the emergency stopping distance and the maximum acceleration and jerk. The tests were performed on the straight portion of track with a 2.5 percent down grade just prior to the west arrival platform. The debris guard (or cow catcher) switch was actuated by a fixed block on the track. Stopping distance was measured from this point.

The forward chopper vehicle was loaded with 2926 kg (6450 lbs) and the control vehicle was loaded with 3311 kg (7300 lbs) simulating passenger loading of 39 and 44 passengers, respectively, at the extreme front of each vehicle. The latter assumed an average weight of passenger of 75 kg (165 lbs) occupying 0.14 square meter (1.5 square feet) or (7.5 passengers/m^2).

The stopping distance and initial velocity is shown in Figure 4-1. The stopping distance closely follows the velocity variations. The vehicle was manually driven to facilitate testing. The maximum acceleration was measured at 2.18 m/sec^2. The maximum jerk was 1.5 m/sec^3. See Figure 4-2.

The maximum temperature of the disk brake measured immediately after the last emergency brake test was approximately 130°C.

To demonstrate the performance of the emergency braking system in an automatic mode, a series of tests were conducted with simulation of a safe frequency cut off. At a speed of 58.3 km/hr (36.2 mph), a maximum acceleration of 2.13 m/sec^2 and a maximum jerk of 1.78 m/sec^3 were achieved. This is depicted in Figure 4-3, where the velocity (V) and acceleration (α) profiles, the emergency brake command (FU), and the programmed or commanded speed (V_p) are shown.

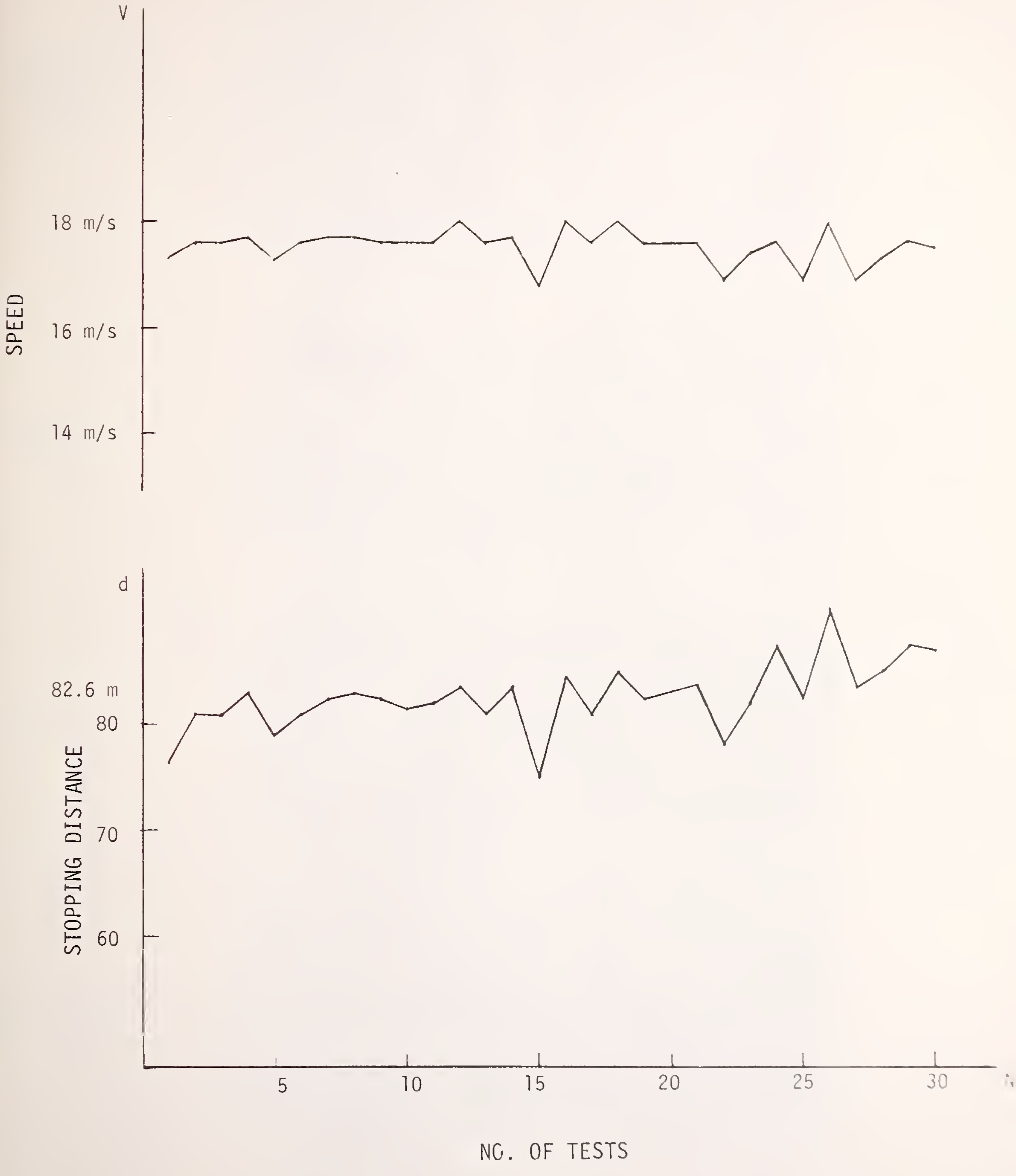


FIGURE 4-1. EMERGENCY STOPPING DISTANCE

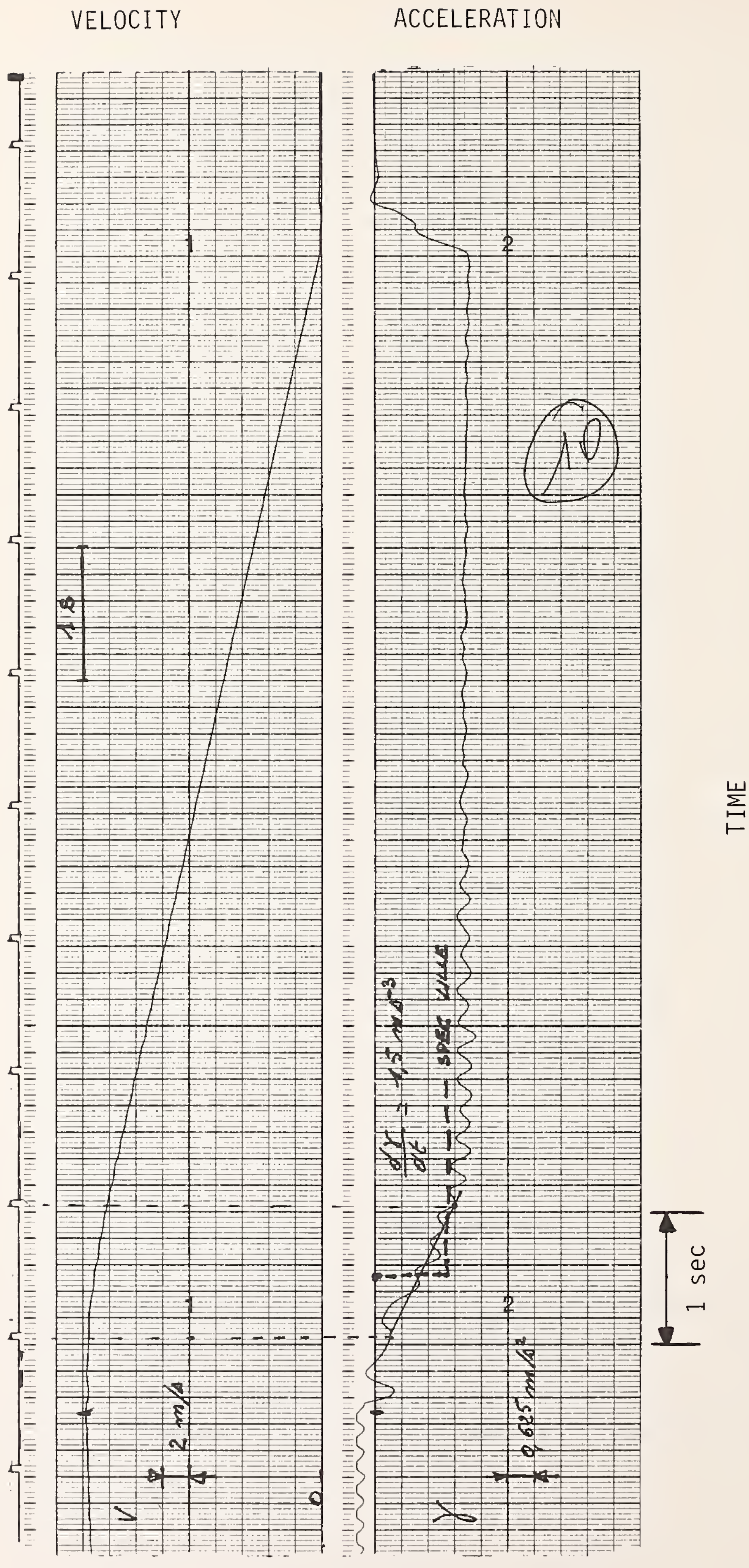


FIGURE 4-2. EMERGENCY BRAKING: SPEED AND DECELERATION PROFILES - MANUAL

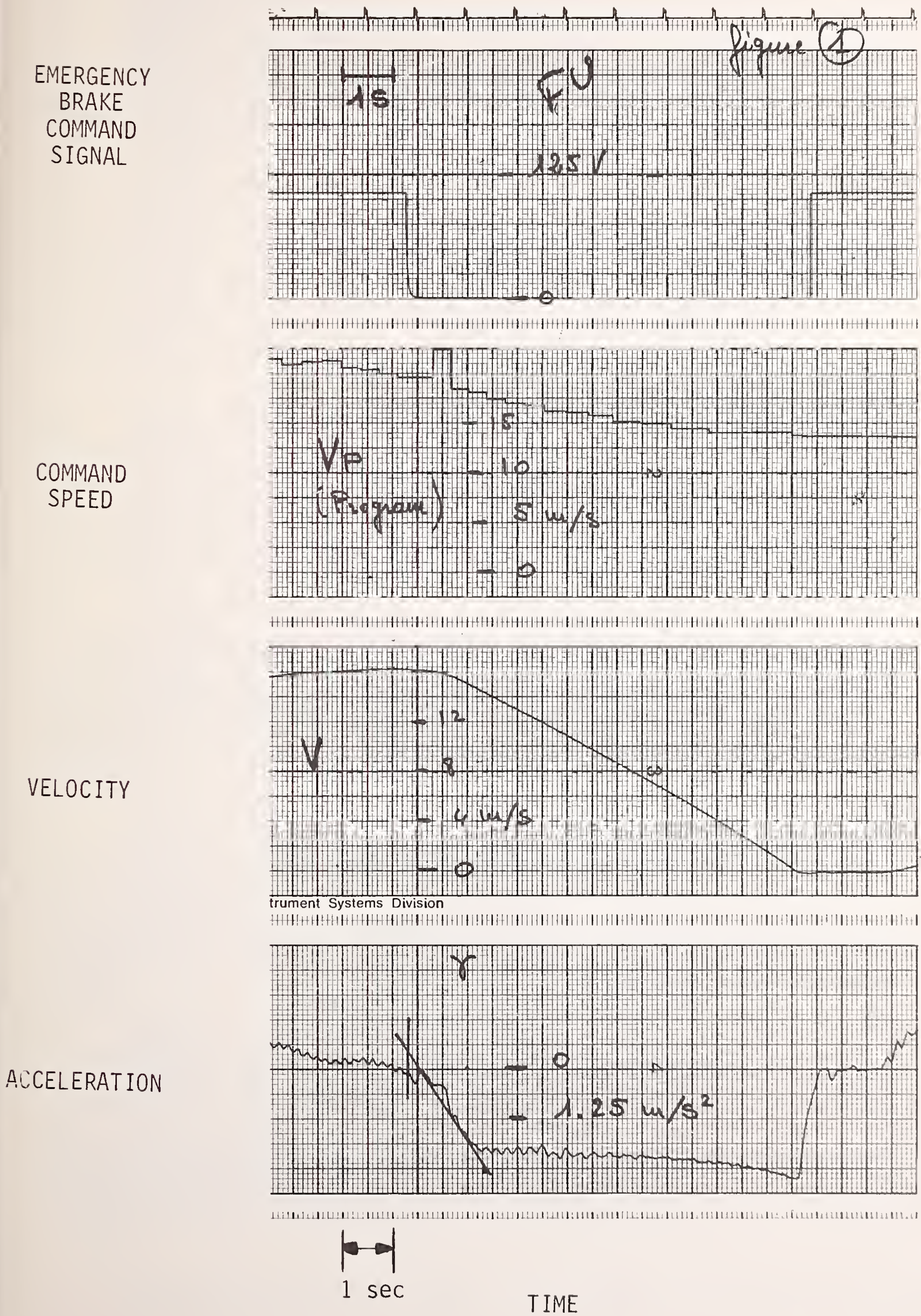


FIGURE 4-3. EMERGENCY BRAKING: SPEED AND DECELERATION PROFILES - AUTOMATIC

In the first series of tests the vehicle weight and loadings were:

	29,000 kg	- empty vehicle
	6,000 kg	- simulated load
	6,000 kg	- inertial masses
Total	41,000 kg	

In the second series of tests the total weight of the empty vehicle was about:

29,000 kg	- empty vehicle
6,000 kg	- inertial masses
35,000 kg	

4.3 PROPULSION AND SERVICE BRAKING

Propulsion and service braking tests were performed with the 02 vehicle under manual control with 10 people on board and about 200 kg of measurement equipment. The propulsion performance is shown in Figures 4-4 and 4-5 where the filter voltage, V_F; acceleration, α; velocity, v; induced current of the vehicle control unit, J2; the induced current of the vehicle chopper unit, J1; and the inductor current of the chopper vehicle, I1 are shown. The maximum induced currents in both chopper and control vehicle was measured at 560 amps. The acceleration is a two-way average, thus giving the acceleration on a level grade. Accelerations of 2.18 m/sec^2 and 0.75 m/sec^2 were achieved at a speed of 20 km/hr and 60 km/hr, respectively.

The same parameters were measured for regenerative braking performance and are shown in Figures 4-6 and 4-7. The maximum induced currents J1 and J2 were measured at 450 amps. The maximum acceleration after voltage and slope adjustment was 1.45 m/sec^2.

Figures 4-8 and 4-9 show the effects of combined friction and regenerative braking. The maximum induced currents J1 and J2 were 470 amps.

The vehicle power consumption of a single vehicle included the line losses, rectifier losses, load resistor consumption and guideway losses. The maximum power consumption was measured at 476 kW.

The premeasured traction motor (type 4 ELG, 2330) characteristics are shown in Figure 4-10.

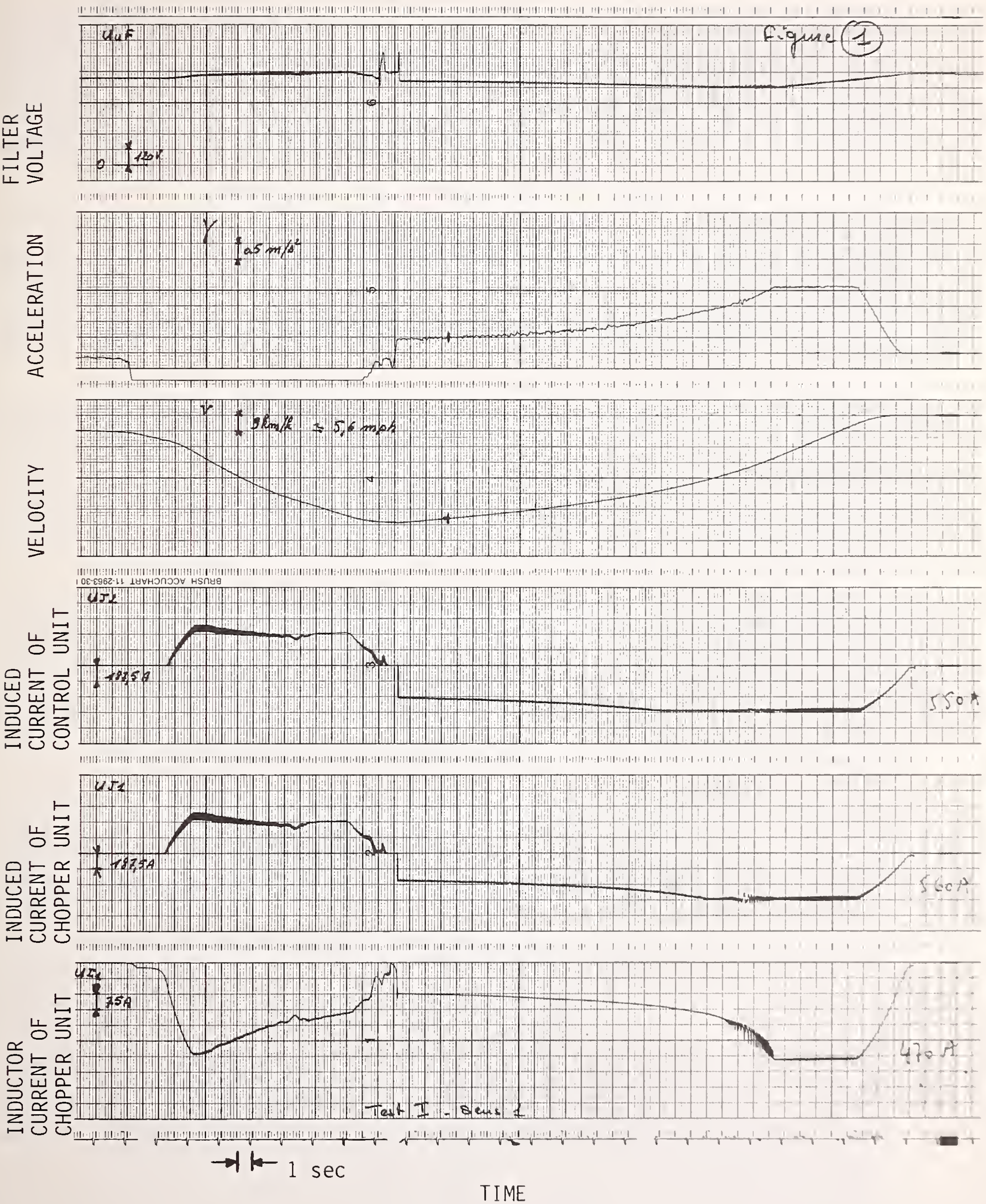


FIGURE 4-4. PROPULSION PERFORMANCE - 20 km/hr

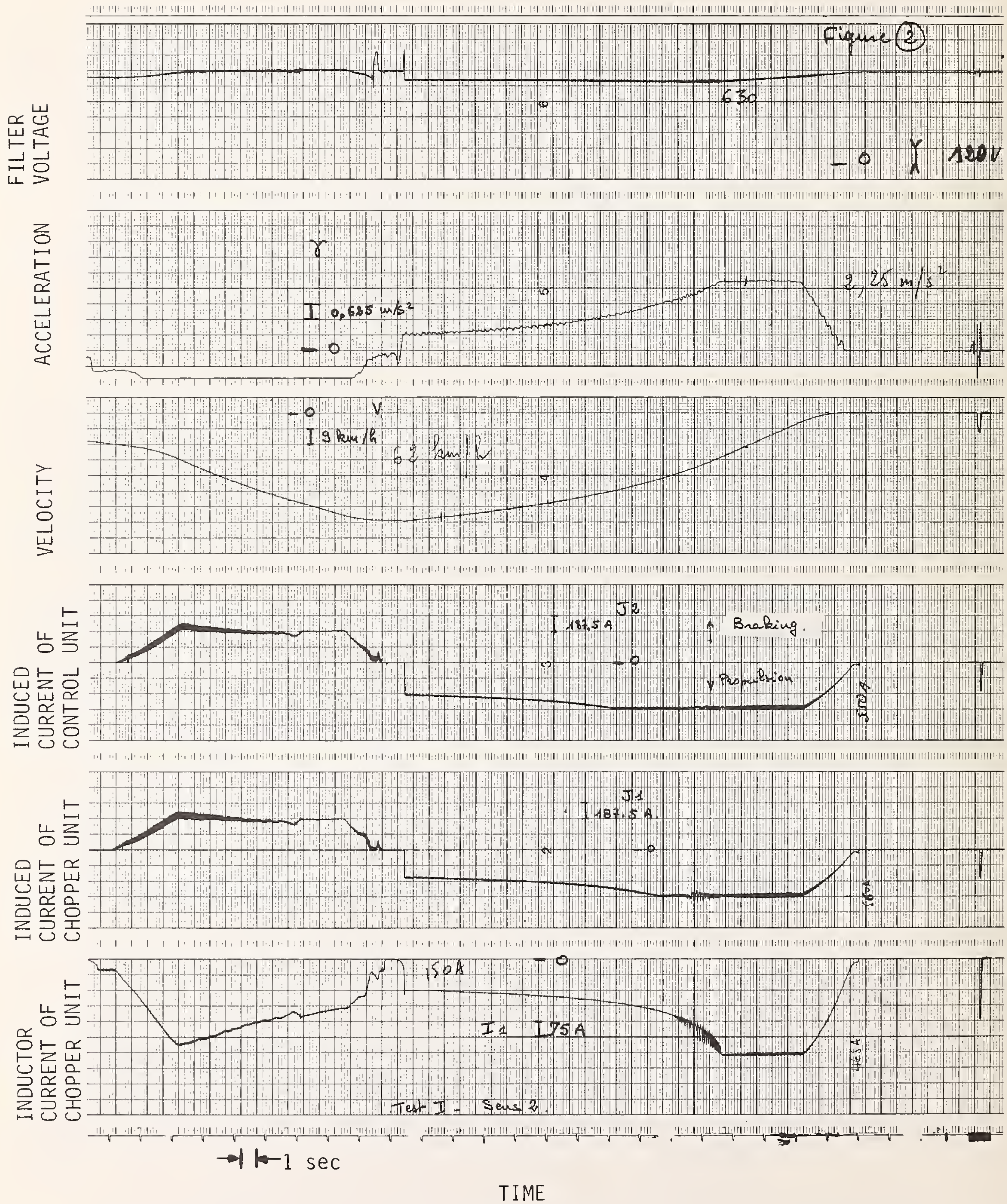


FIGURE 4-5. PROPULSION PERFORMANCE - 60 km/hr

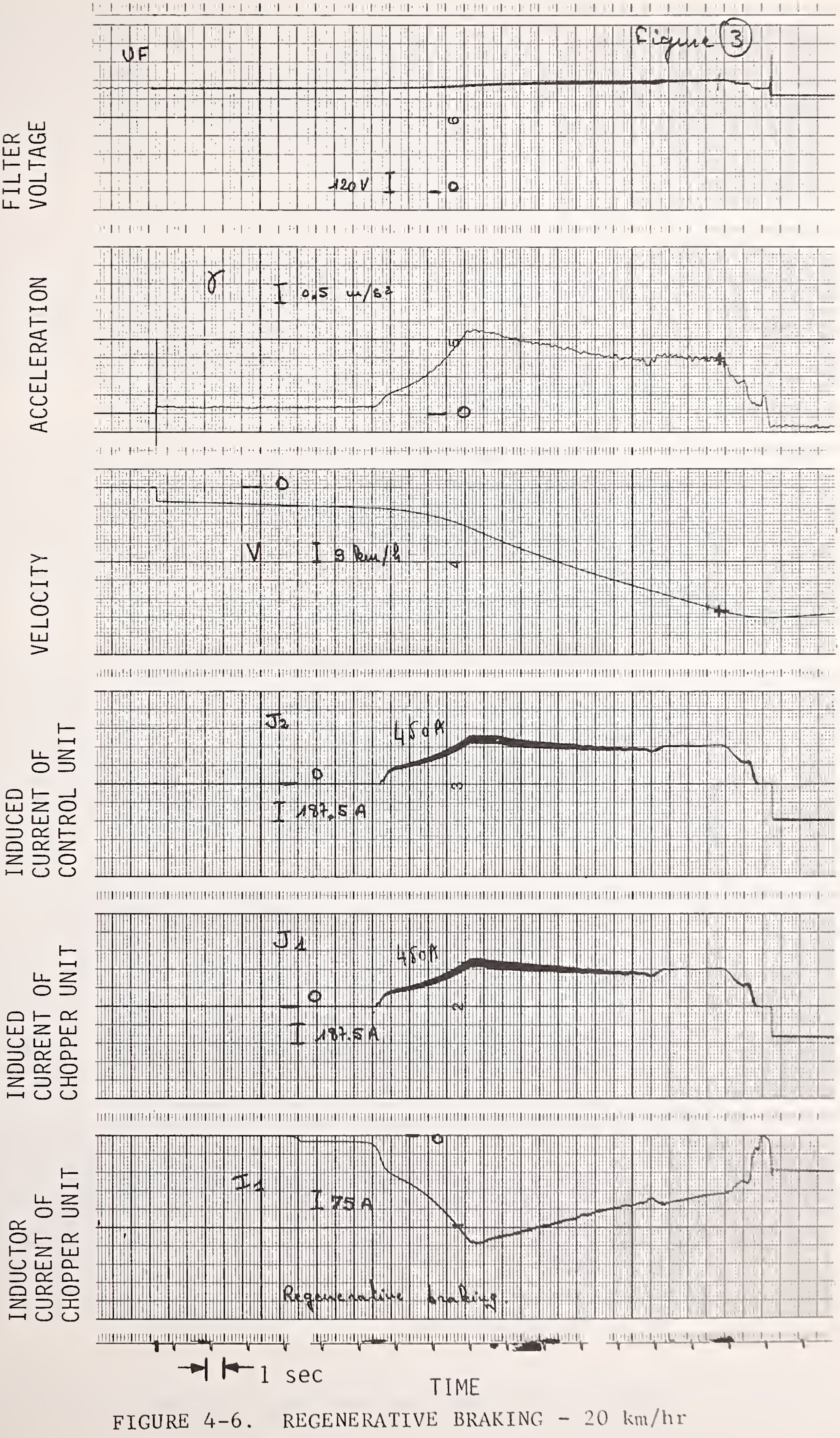


FIGURE 4-6. REGENERATIVE BRAKING - 20 km/hr

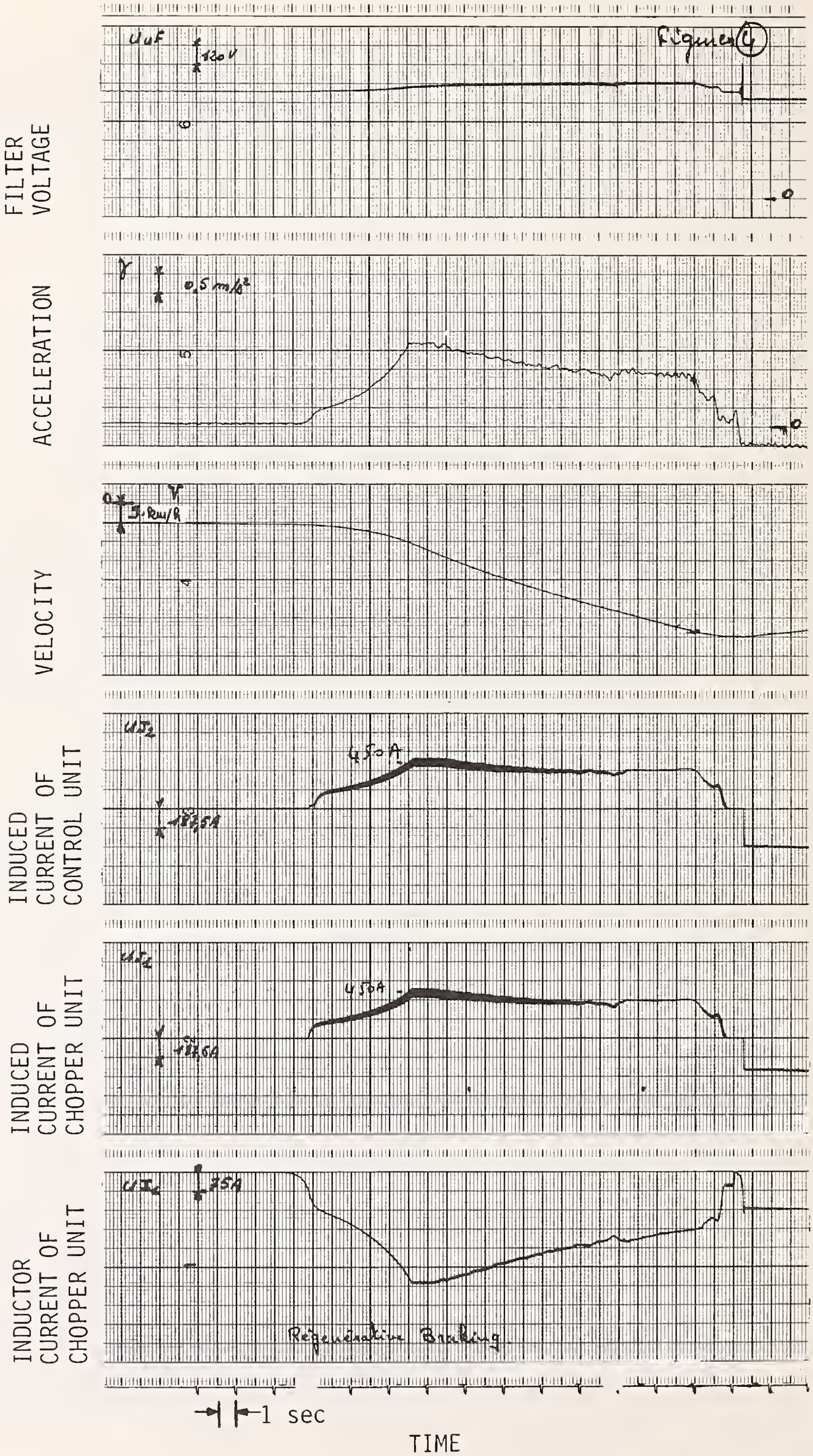


FIGURE 4-7. REGENERATIVE BRAKING -- 60 km/hr

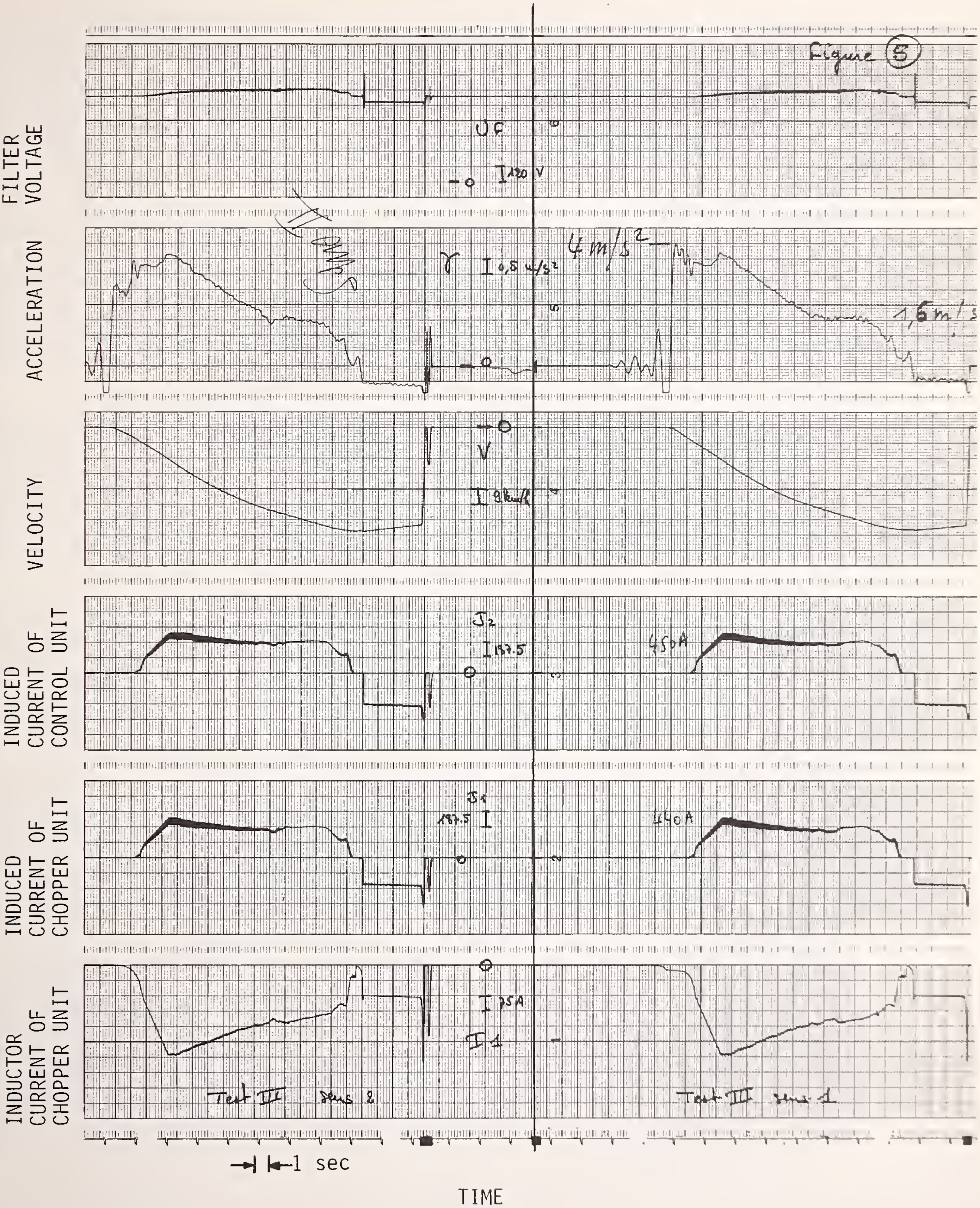


FIGURE 4-8. COMBINED FRICTION AND REGENERATIVE BRAKING - 20 km/hr

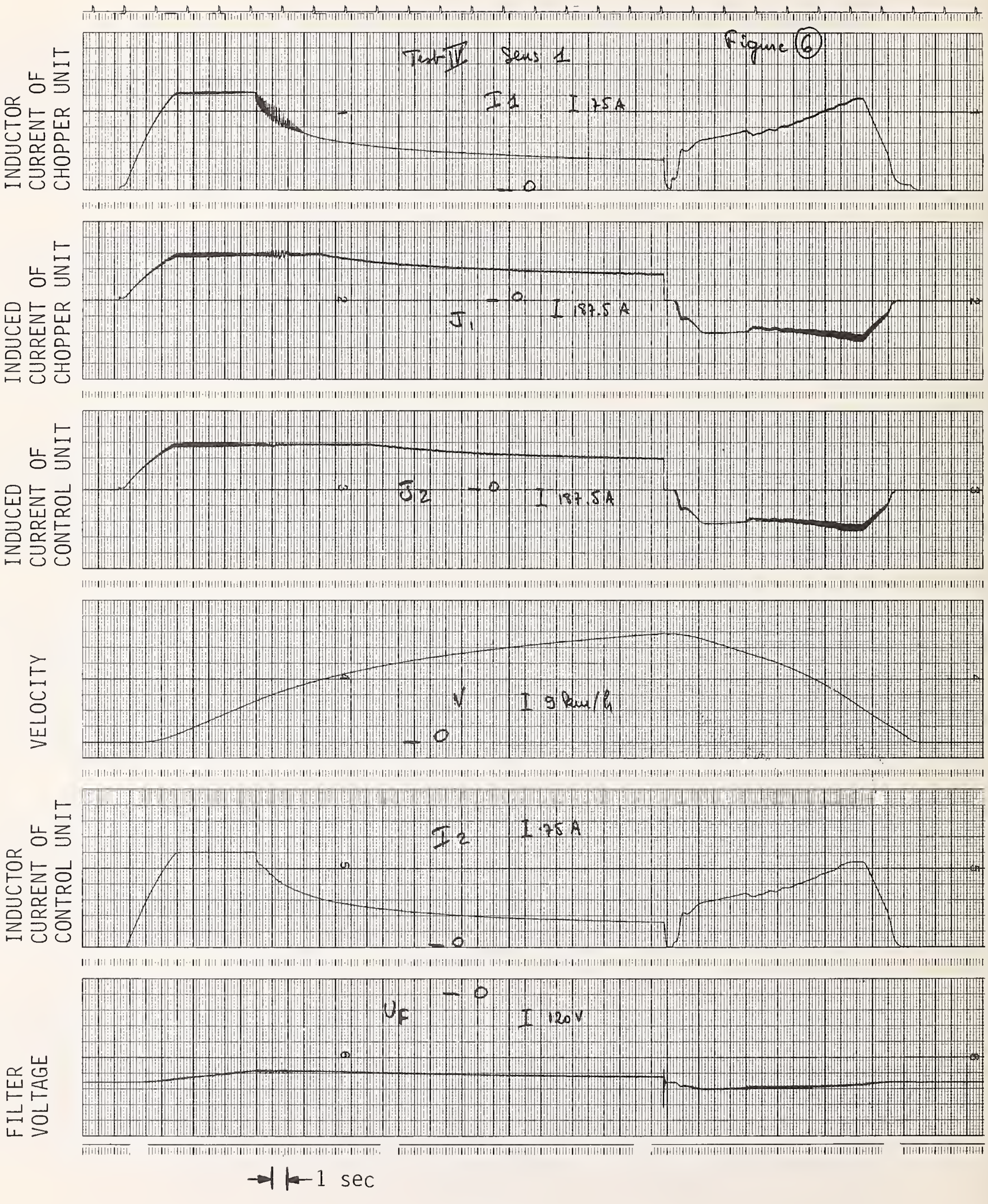


FIGURE 4-9. COMBINED FRICTION AND REGENERATIVE BRAKING - 60 km/hr

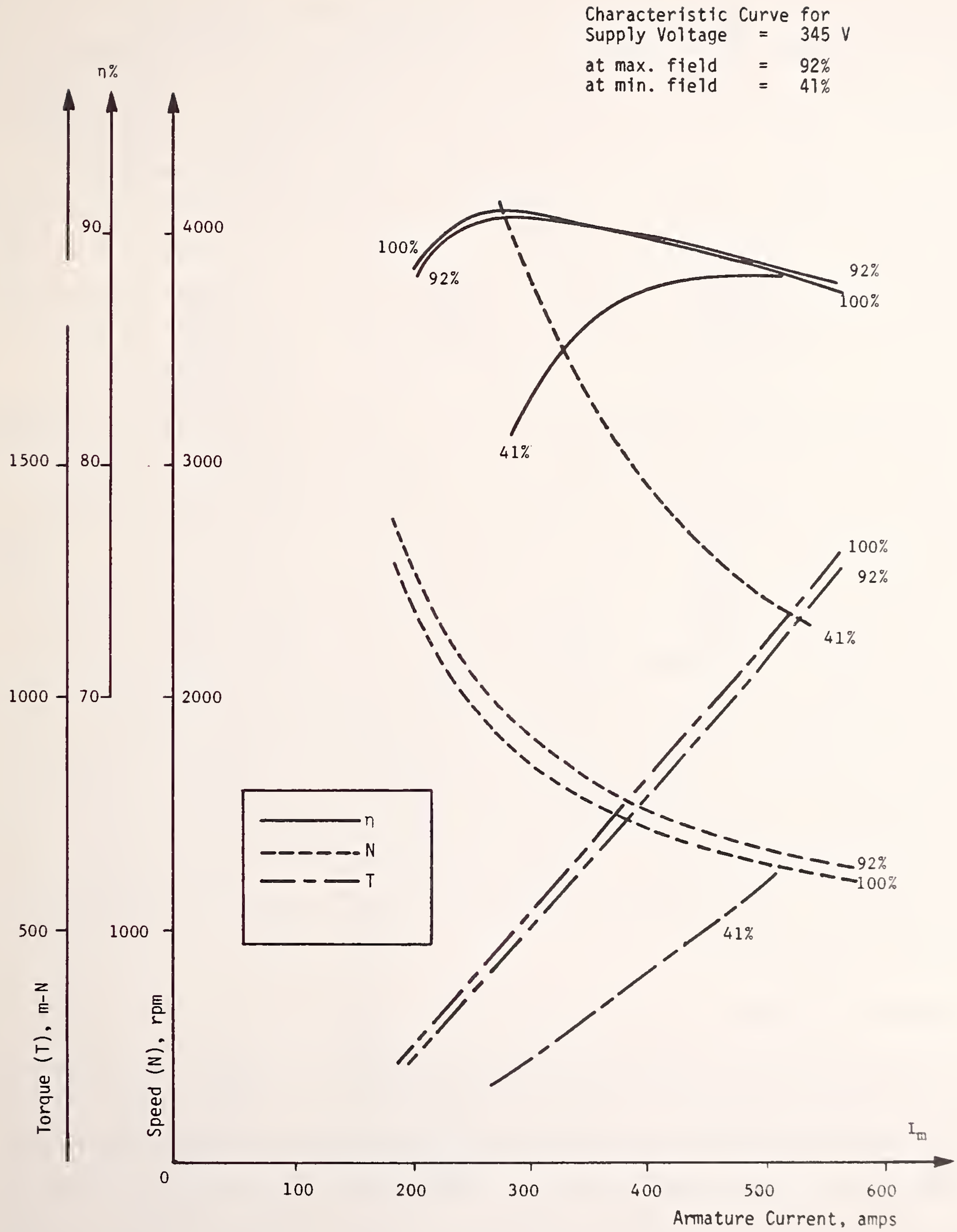


FIGURE 4-10. TRACTION MOTOR CHARACTERISTICS

4.4 AUTOMATIC COUPLING

Automatic coupling of two vehicles was demonstrated in both the manual and automatic mode. Coupling in the manual mode was performed on a straight section, a 40-meter radius curve, and an "S" section. The 01 vehicle was disabled (with emergency brakes applied) in each of these areas. The 02 vehicle was manually driven up to the disabled vehicle and successfully accomplished automatic coupling. A check was made to determine that the services of the failed 01 vehicle were functional (i.e., lights, air, brakes, and door operations). The 02 pushing vehicle was then put into an automatic mode and push out of the failed vehicle was accomplished. The two coupled 01 and 02 vehicles were brought to a stop and automatic separation was demonstrated.

Coupling was also demonstrated with both vehicles in an entirely automatic mode. The 01 vehicle was disabled on the straight section of track with a 4.5 percent grade heading toward the West Arrival platform. Vehicle 02 was brought around the loop in an entirely automatic mode. When it tried to leave the West Departure platform, the vehicle would not proceed because the block ahead was occupied. A remote command was given from Central Control for the vehicle to proceed in the ASMD mode (0.8 m/s) and couple automatically with the vehicle ahead. This action was successfully accomplished. The power, air, brakes, and door operation were restored to the failed vehicle. Push out of the failed vehicle up a 4.5 percent grade was then successfully accomplished. A stop was made at the next station. The 01 and 02 vehicles were then uncoupled in the East Terminal. It should be noted that the chopper and control units are connected by a connecting bar and can only be separated in maintenance (See page 3-1).

4.5 COLLISION AVOIDANCE

The objective of the collision avoidance tests was to demonstrate that safe spacing between two vehicles is maintained over the entire test track. The collision avoidance function is performed by the Automatic Vehicle Protection (AVP) equipment. Thus, these tests are in essence tests of the AVP system.

The two vehicles, 01 and 02, were used in a fully-automated mode. The 02 vehicle was the follower. Continuous tracking of the vehicles, stopping, and data acquisition and warning were the functional tests performed. Figure 4-11 shows a schematic of the test track fixed block control system including the subdivision into blocks.

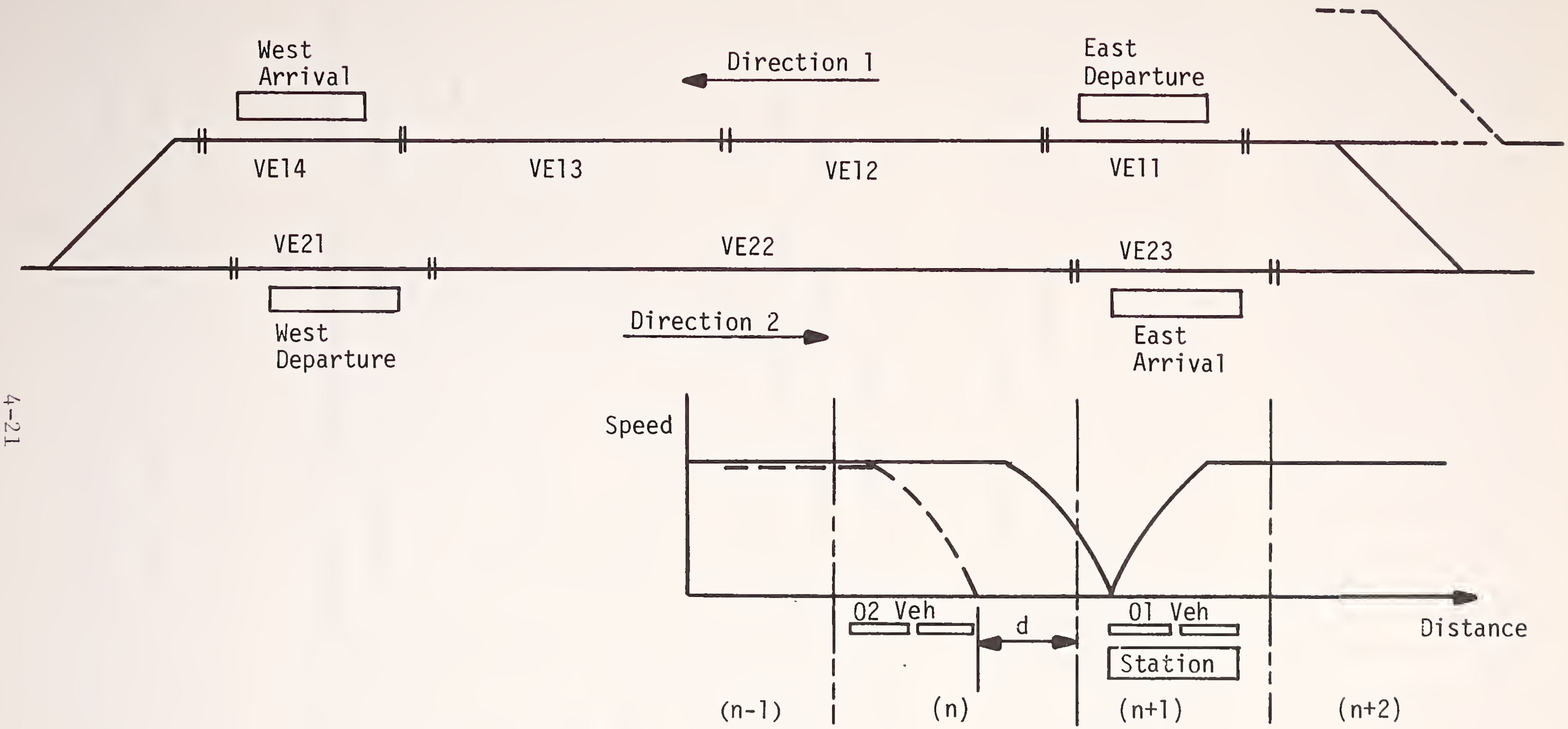


FIGURE 4-11. TEST TRACK FIXED BLOCK CONTROL SCHEMATIC

Safe stopping commands are determined by detection of antenna crossovers which are separated physically in proportion to the speed in that block. A phase change of the induced signal is detected by the on-board safety equipment when passing each crossover. For interstation blocks two physical speed programs, "normal" and "perturbed," are encoded which will allow the vehicle to continue into the next block or actuate service brakes at a safe distance before the next block boundary.

The normal speed program is selected for a vehicle when the downstream block is unoccupied. The purturbed stopping program is selected for a vehicle passenger unit when the next downstream block is occupied. Service brakes are used in all normal circumstances to stop the vehicle passenger unit in the perturbed stopping mode. However, emergency brakes are used if the maximum permissible delay is reached. This delay is determined by the on-board AVO system.

4.5.1 Safe Stopping Program - Service Brakes

The vehicle safe stopping capability with service brakes was demonstrated by stopping the 01 vehicle at typical locations around the test track and observing the stopping performance of the following 02 vehicle. In the first test, the 01 vehicle was stopped in block VE23 (or n+1) at the East Arrival platform by a zero speed order sent by the Control Center (CC). The 02 vehicle stopped in accordance with the perturbed stopping program in block VE22 (or n) using service brakes. It stopped with a proper distance margin (d) to block VE23. This test was repeated with a forbidden departure order to the 01 vehicle. Again, the 02 vehicle stopped in block VE22 (or n) using only service brakes following a perturbed stopping program. The 01 vehicle was stopped in block VE14 and VE13 with a zero speed order. The 02 vehicle stopped using only service brakes on blocks VE13 and VE12 respectively following a perturbed stopping program and with the appropriate distance margin (d) in all cases.

4.5.2 Safe Stopping Program - Emergency Brakes

The vehicle safe stopping capability with emergency brakes was demonstrated by simulating a stopped vehicle at the East Arrival platform in block VE23 and by overriding controls of a following vehicle. The 02 vehicle was brought to a stop in block VE22 about 100 meters before the perturbed stopping program point by successive slower speed commands of 5, 0.8, and 0 m/sec. The MNV (normal mode) and MPV (perturbed mode) orders were reversed by crosswiring test leads. The CC canceled the zero speed command. The 02 vehicle accelerated at 1.3 m/sec^2 and passed through the perturbed stopping program point. At that point the AVP system effected emergency brakes and brought the 02 vehicle to a stop.

A communications check was made. The central control Cathode Ray Tube (CRT) display indicated an emergency brake (EB) command and zero speed. The 02 vehicle telemetry was also checked. The safe frequency modulation carrier (f1) was detected. The perturbed frequency (f2) was not present. With the functional communications check completed, the reversed MNV and MPV orders were put back into their proper state. The simulated vehicle at the East Arrival platform was deleted and the 02 vehicle was restarted automatically.

4.5.3 Normal Stopping Program - Emergency Brakes

This test was made to determine if a following vehicle could violate an occupied block when it is following a normal stopping program. The 01 vehicle was stopped in the East Terminus block (n+2). The 02 vehicle was stopped in block VE22 (or n) by a zero speed command. The input to the tachometers were removed making possible an overspeed condition. A maximum speed signal was sent to the on-board AVO. The zero speed command was cancelled. Vehicle 02 restarted and accelerated at 1.3 m/sec^2. It passed through the point where the normal stopping program would be actuated. Emergency brakes were then applied bringing the 02 vehicle to a stop within block VE23 (or n+1), but beyond the normal station stopping point. The n+2 block was not violated. The 02 vehicle was unable to restart because the 01 vehicle was in n+2. The proper warnings were given on the central control CRT display; that is, emergency brakes and a zero speed were indicated. In addition, the 02 vehicle telemetry indicated that the safe frequency was not present.

4.5.4 Station Stopping

Collision avoidance in a station was tested by stopping the 01 vehicle in the East Terminus or block n+2 and trying to move vehicle 02 from the East Arrival platform in block VE23 (n+1). A signal was sent by the CC to force the 02 vehicle to leave the station. Emergency brakes were applied in less than 5 meters after the vehicles started to move but prior to entering block n+2. Proper emergency brake and zero speed commands were indicated in the CC. The safe frequency (SF_b) was not present. Each station has a safe frequency a and b dividing the station to allow independent departure or arrival. In this case the departure signal was withheld because of downstream occupancy.

4.5.5 Collision Avoidance Frequency Transmission Switched Off

The collision avoidance frequency transmission or safe frequency was switched off when the emergency egress handle was pulled while the 02 vehicle was in block VE23. The on-board equipment initiated emergency brakes and removed the safe frequency and power over the entire track. Appropriate telemetry was sent to the CC. Subsequently the emergency egress command was cancelled and the warning released. The CC was able to reinitiate the system.

This test was repeated in block VE22 with similar results. It was also attempted with vehicle astride the block boundary of VE12 and VE13. In this case, the warning could not be released and the track had to be reinitiated in a manual mode.

4.5.6 Entry Into an Engaged Block

The collision avoidance system was demonstrated simulating a manual failure recovery operation. The 01 vehicle was stopped in block VE22 (n). Vehicle 02 was brought around the track and stopped in the VE21 (n-1) in accordance with the safe stopping program thus engaging both n and n-1 blocks. The 02 vehicle was then manually operated and forced to enter the block (n) at 0.8 m/sec in the ASMD mode. After progressing 10 meters into block (n), the safe frequency and power were removed and emergency brakes were applied. A push command from the CC would be necessary to allow the vehicles to come together.

4.5.7 Operation Without Collision Avoidance Frequency Transmission

As the 02 vehicle left the East Departure terminal, the safe frequency was removed by the CC. Emergency brakes were applied and power was removed.

4.5.8 Rollback Protection

Operation of the system in a rollback mode was demonstrated. The 02 vehicle was stopped in block VE23 (n+1). It was then manually driven in reverse at 0.8 m/sec and forced to enter the block (n). After 5 meters of penetration into block (n), the safe frequency and power were removed, and emergency brakes applied.

4.5.9 Redundancy Check

A demonstration test was performed to ensure that switching from one set of on-board equipment to the redundant equipment can be accomplished safely. Two vehicles 01 and 02 were in full-up automatic operation. A zero speed command was given stopping both vehicles. By a command from the CC a change was made from the on-board control equipment (PA)A to (PA)B. A telemetry check of the tracking equipment was made to ensure that a vehicle was not lost in transfering from A to B control equipment. The zero speed order was cancelled and the two vehicles were restarted. A proper headway was maintained.

4.5.10 "AND" or "OR" Operations

The AND or OR operations have been incorporated to monitor the redundant equipment not in operation. The AND mode compares pieces of B control equipment with A equipment. To demonstrate this the AND mode was selected by the CC for the on guideway AVP with the (PA)A control equipment functioning. Two vehicles 01 and 02 were in automatic operation. A simulated fault was created in the (PA)B equipment of the lead 02 vehicle which stopped the vehicle. The following 01 vehicle also come to a stop. The (PA)B equipment was actuated from the CC. No change was observed. The OR mode was then selected. Again no change was observed. The (PA)A equipment was finally selected. The vehicles restarted automatically. Although the AND mode is safer, the OR permits operation when one of the two redundant pieces of AVP equipment has failed.

4.5.11 On Guideway AVP Initiation

AVP reinitiation was accomplished by driving the vehicle around the test track in a manual mode with the safe frequency switched off. The safe frequency transmission was switched on only after the warnings were released.

4.6 OVERSPEED AVOIDANCE

The objective of the overspeed avoidance tests was to demonstrate that vehicles are prevented from exceeding the established speed limits. The on-board AVO system regulates the vehicle speed such that the antenna crossover times are 0.30 seconds, but never less than 0.27 seconds. If a crossover is detected in less than 0.27 seconds, emergency braking will be initiated.

The tests were conducted to demonstrate that: 1) the overspeed avoidance devices are always actuated for the Normal Program; and 2) the overspeed devices for the Safe Stopping Program are released in the presence of the Normal Program. To demonstrate overspeed, equipment was installed in block VE12 (see Figure 4-11) which simulated a reduction of the antenna crossing distance. This equipment was actuated by the CC by the command "test FU" (emergency brakes). The overspeed avoidance under the Normal Program was demonstrated by starting the 02 vehicle from block VE11, the East Station Departure platform, and running it into block VE13 where it encountered the test section. This resulted in the application of emergency brakes. Figure 4-12 shows a strip chart record of this test in block VE12. Positive and negative detection of crossovers are shown where the crossover prior to overspeed detection is measured at 320 milliseconds and the crossover indicating the overspeed is measured at 260 milliseconds, which is below the minimum of 270 milliseconds. The result was an emergency brake command which is also shown in Figure 4-12. Telemetry from the vehicle to the CC was indicating proper warnings. The vehicle was then restarted automatically.

The overspeed threshold under the Normal Program was determined by simulating an overspeed condition with a 500 K ohm variable resistance which shortened the periodic output of the tachometer. The strip chart data is shown in Figure 4-13 for an overspeed threshold test in block VE14. Upon detection of a crossover of 260 milliseconds, which is less than the threshold of 270 milliseconds, emergency brakes were applied. The emergency brake command was given about 10 milliseconds after overspeed detection. This test was repeated in block VE22. The strip chart data for this test is shown in Figure 4-14 with similar results.

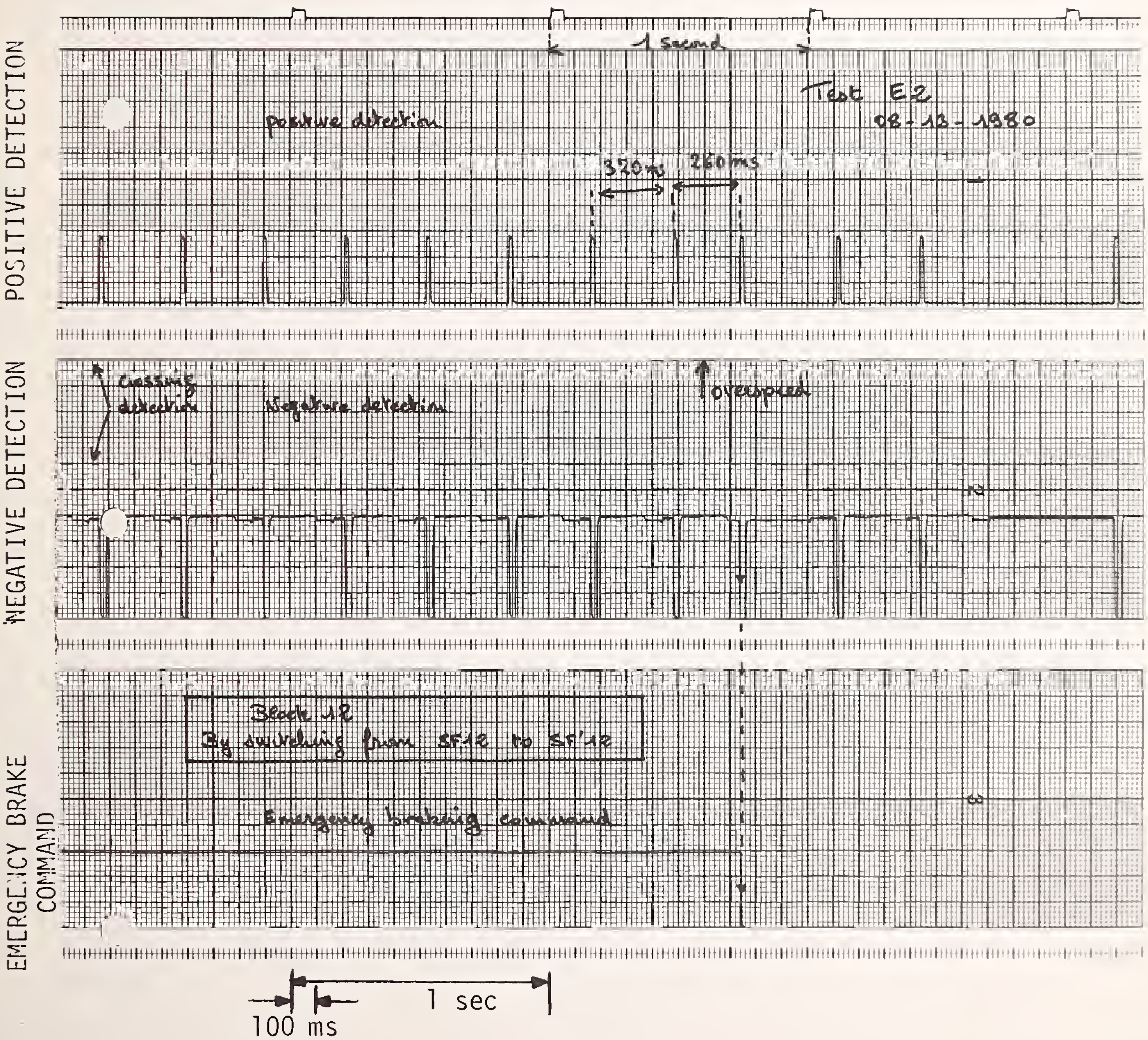


FIGURE 4-12. OVERSPEED AVOIDANCE - NORMAL PROGRAM

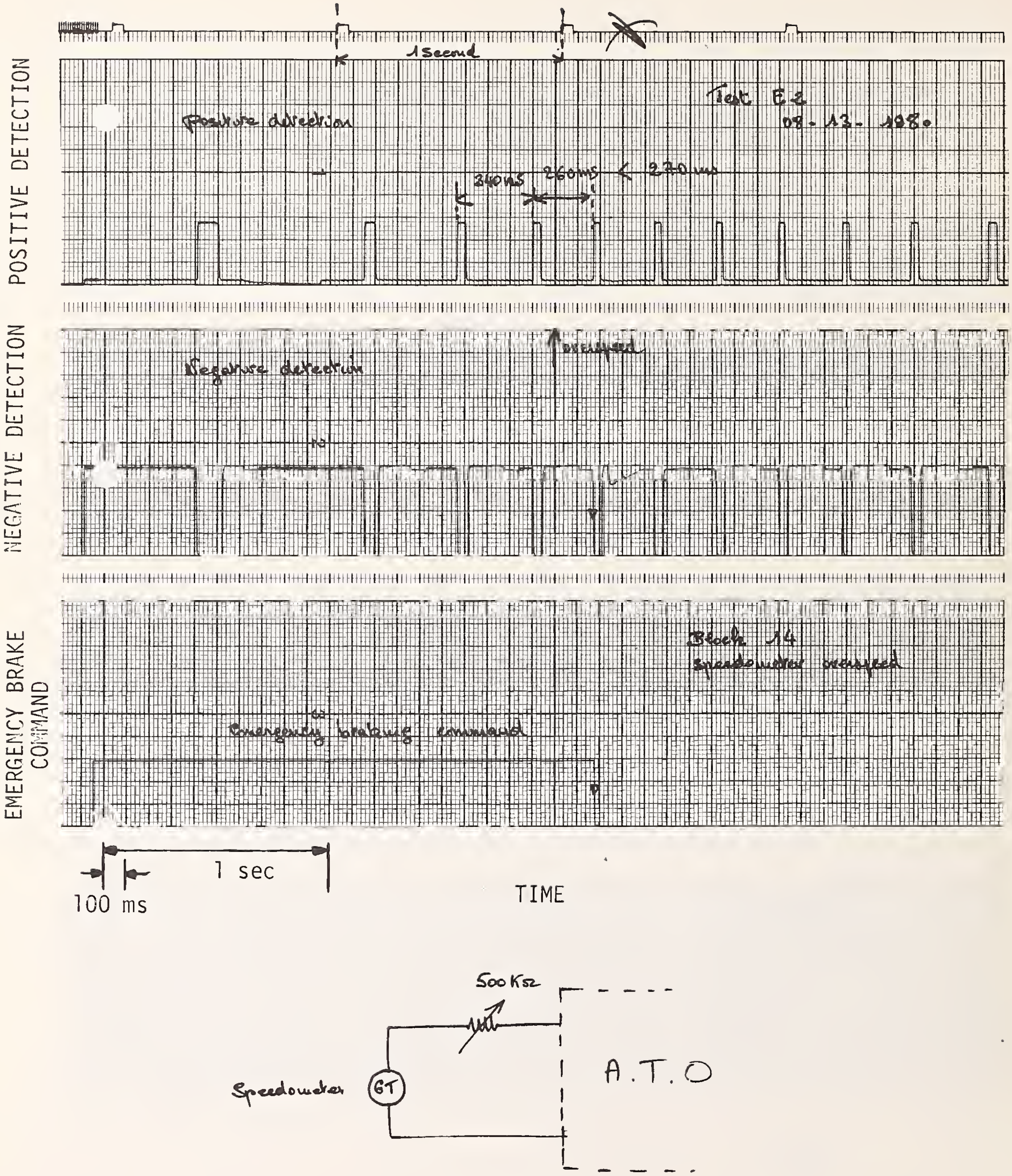


FIGURE 4-13. NORMAL PROGRAM OVERSPEED THRESHOLD - BLOCK 14

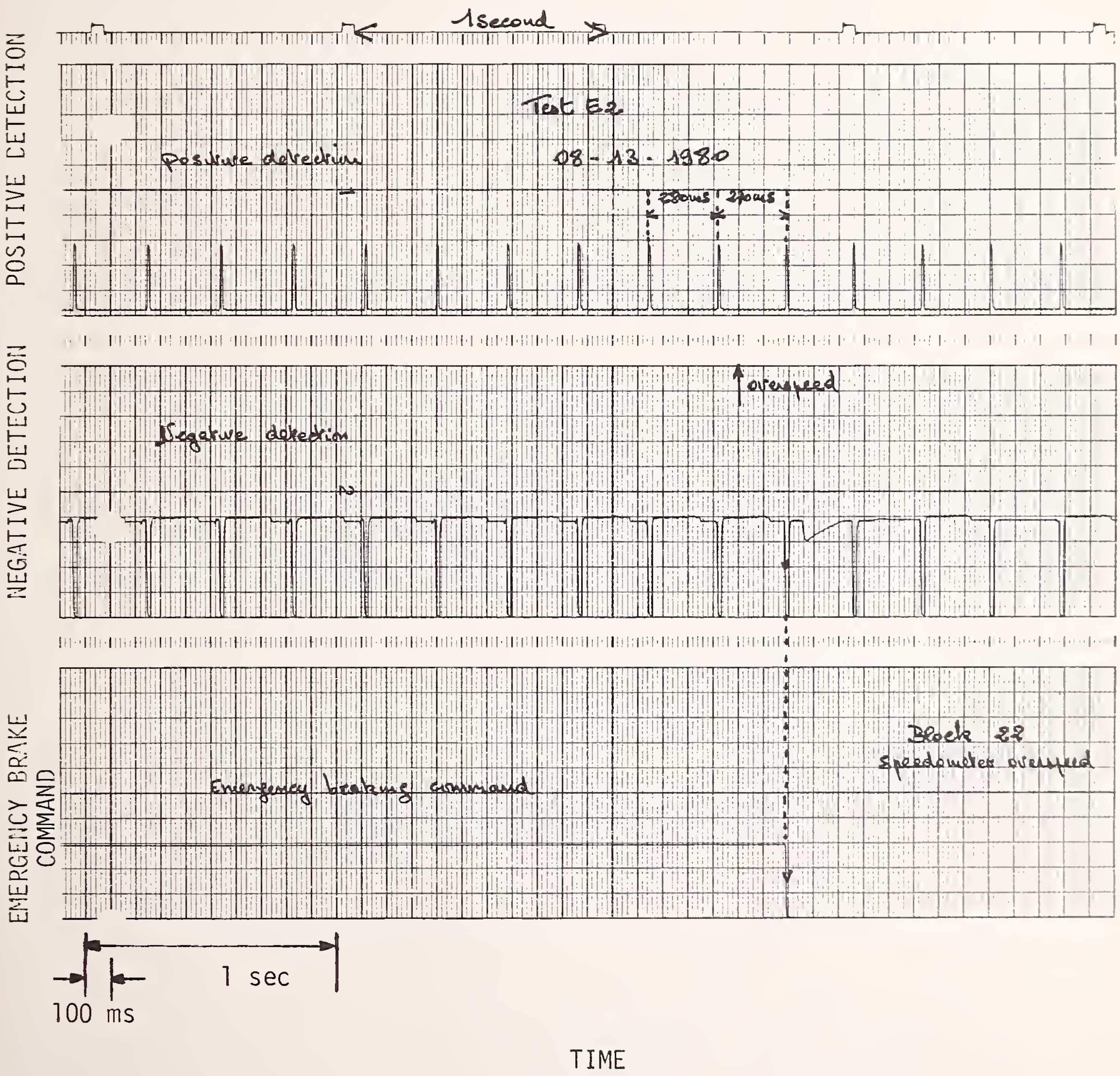


FIGURE 4-14. NORMAL PROGRAM OVERSPEED THRESHOLD - BLOCK 22

4.7 DIRECTION CONTROL

The objective of the direction control tests was to demonstrate that a reversal of vehicle direction is only possible in the reversal switches and that the system prevents vehicle rollback. The reverse direction is obtained in the reversal switches by a change of safety frequency. The AVO system makes the route selection under the direction of the AVS system and with the permission of the AVP system. The direction of travel and switch position commands are implemented by the appropriate Wayside Control and Communications Unit (WCCU).

The direction command (D1 or D2) is implemented by one of two modulations of the group 2 frequencies on the SF carrier frequency. In the event of a dissagreement between the commanded direction and the actual direction measured by the vehicle tachometers, emergency braking is actuated.

The results of the reverse direction demonstration tests in a switch are described in Section 4.8, Switch Interlocking.

The rollback demonstration test was performed with the 02 vehicle. The vehicle was stopped in block VE22 by a zero speed command. The forward and reverse direction signals (D1 and D2) were reversed by crossing test leads. The CC ordered a vehicle restart. Emergency brakes were applied after a small motion (roughly 0.3 meters).

4.8 SWITCH INTERLOCKING

The objective of the switch interlocking tests was to demonstrate the capability to select routes and to safely perform switch operations. A schematic diagram indicating the location of the arrival and departure platforms in relation to the switch and the ultrasonic detectors for the West Terminal is shown in Figure 4-15. Similarly the East Terminal is shown in Figure 4-16. Reversal operations were conducted at the West Terminal. Safety demonstrations and route selection operations were conducted at the East Terminal.

4.8.1 <u>West Terminal Switch</u>

4.8.1.1 Reversal Operations

a. <u>One Vehicle Operation</u>

The 02 vehicle in full-up automatic operation is stopped in block VE14 at the West Arrival platform (see Figure 4-11). An order reversal is given by the CC. Acknowledgement is checked. The ITF1 telemetry signal is received indicating Direction 1. The control console mimic display traffic light SM01 was green, the SM03 was red, and the BE2 switch position was on the left (see Figure 4-17). Thus, entry of a vehicle from Direction 1 or the left side into the terminal was permitted.

The 02 vehicle was started. When the DM01 ultrasonic detectors (UD). were occulted the SM01 traffic signal turned red. The accompanying light on the mimic display also turned red. Between the station platforms and the terminus end UD's are placed at intervals shorter than the vehicle passenger unit length so that the vehicle may be continuously followed and to ensure that the vehicle is not lost.

The switch position was changed automatically within 2-3 seconds of the vehicle clearing UD DN02. The telemetry signal ITF1 disappeared and the ITF2 signal appeared indicating that a switch from Direction 1 to Direction 2 phase modulation was accomplished. The vehicle restarted in the reversed direction after a dwell of less than 5 seconds. Completion of switching changed the SM03 red light to green.

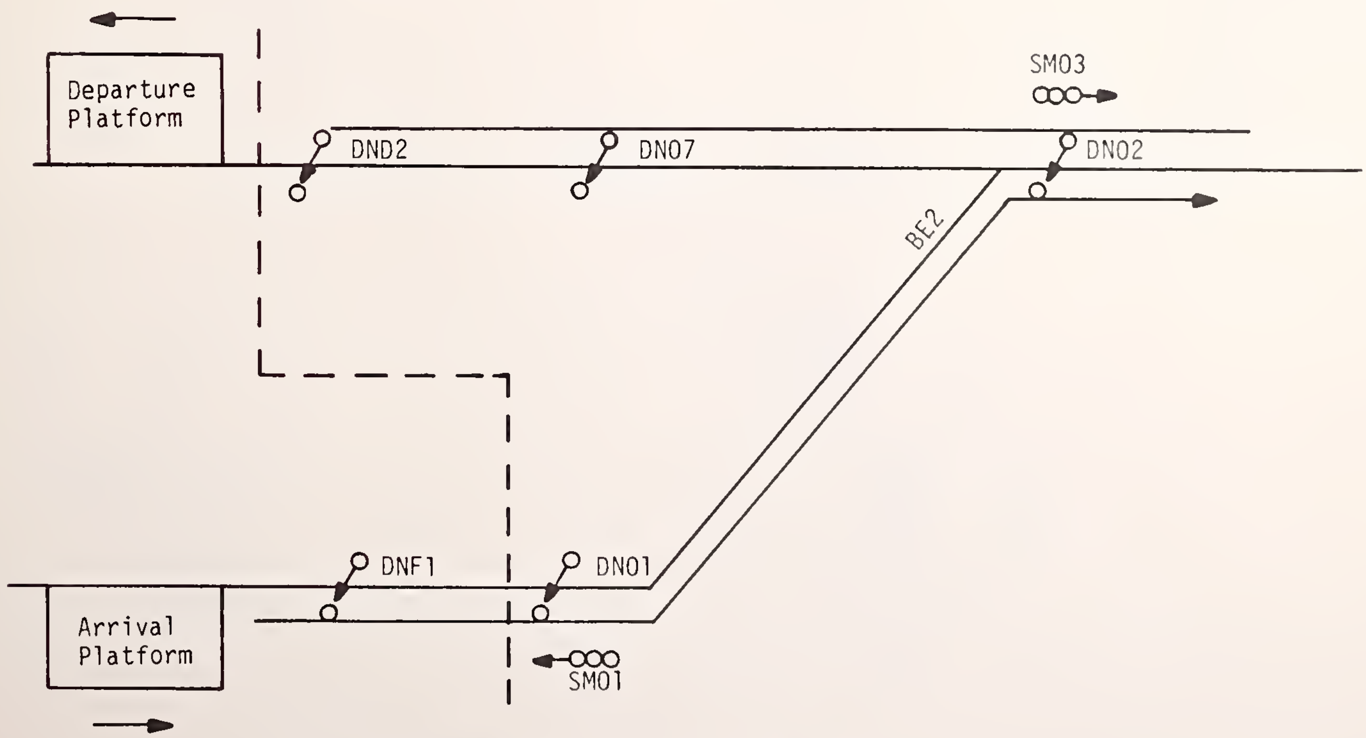


FIGURE 4-15. WEST TERMINAL

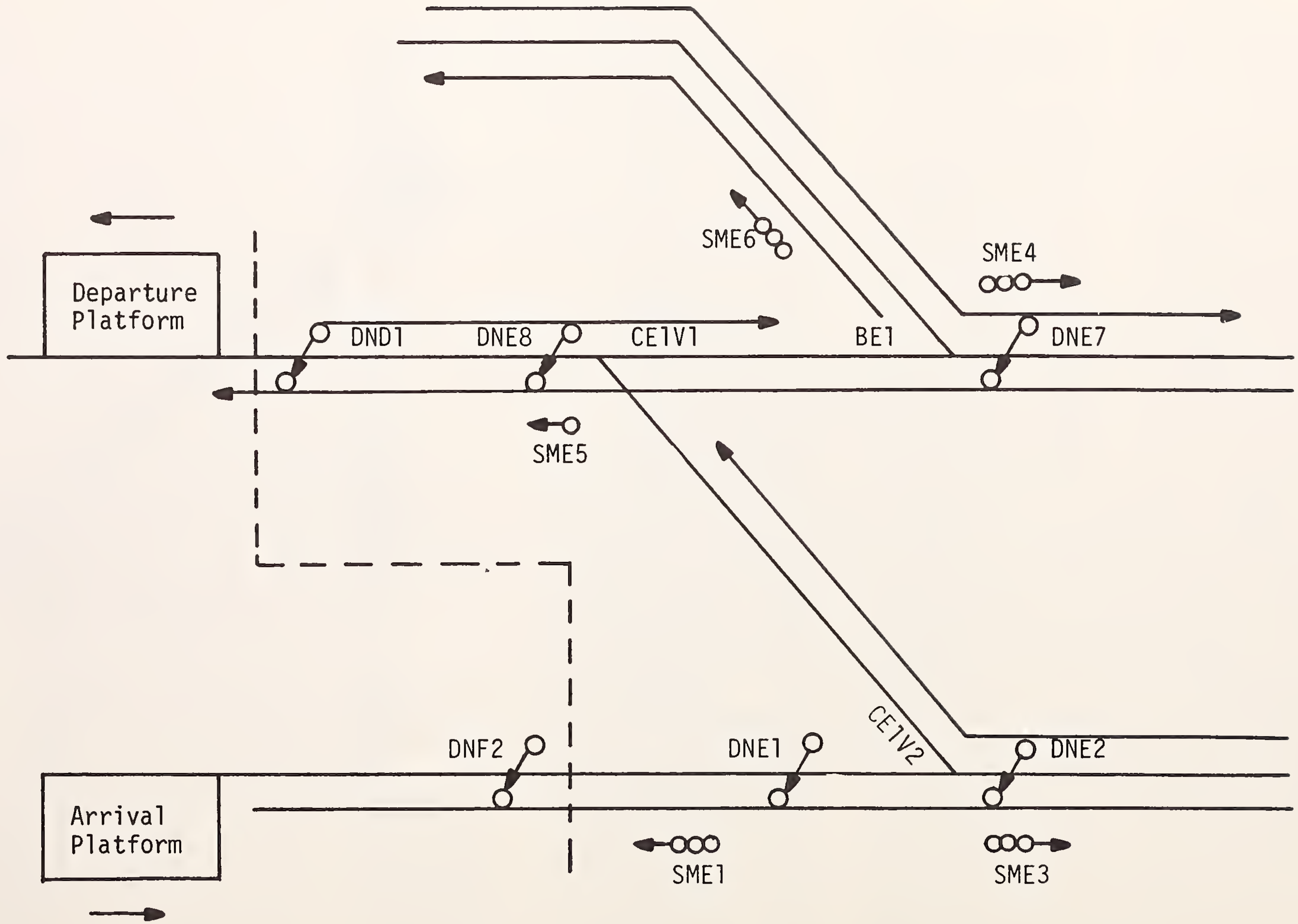


FIGURE 4-16. EAST TERMINAL

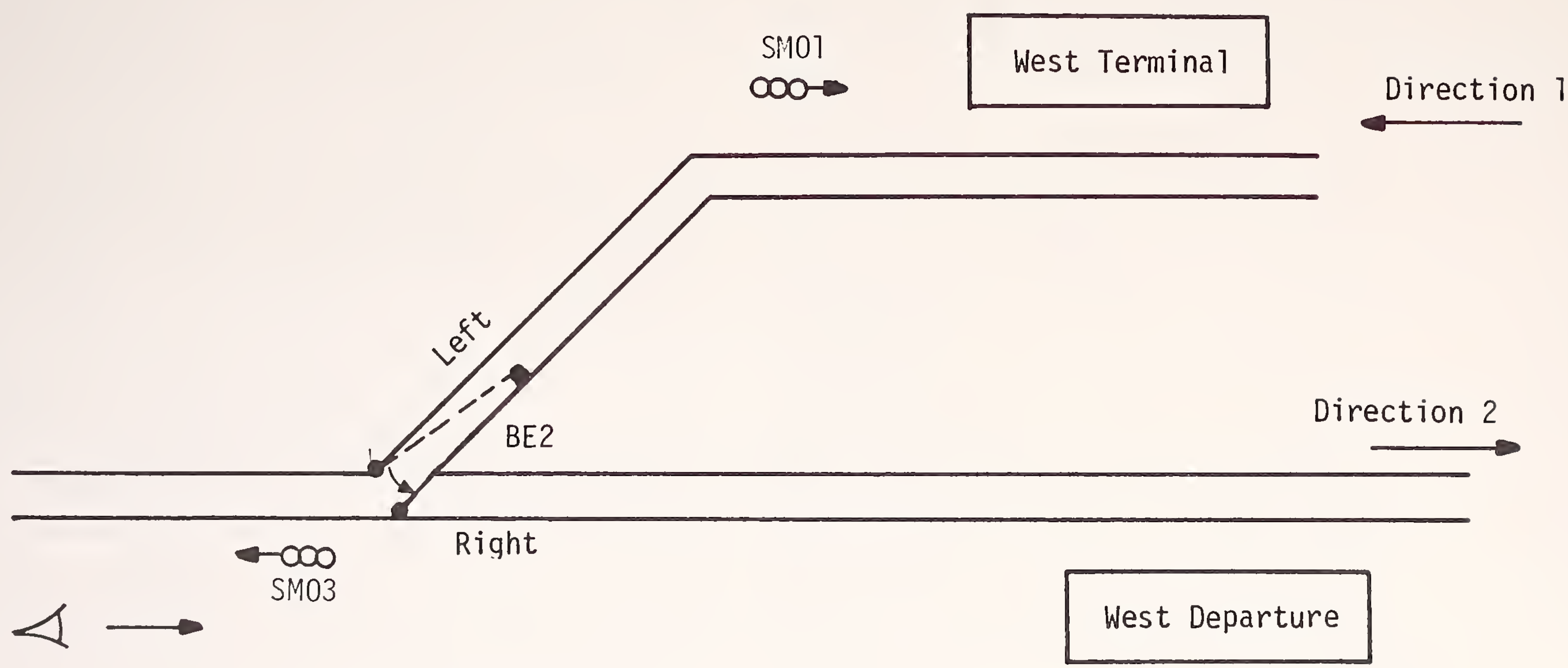


FIGURE 4-17. WEST TERMINAL SWITCH SCHEMATIC

After the UD DND2 was cleared by the vehicle, the BE2 switch position was moved to the left, SM01 was changed from red to green, SM03 was changed from green to red, the ITF2 signal disappeared, and the ITF1 appeared. These actions returned the terminal switch to a state that would accept another vehicle from Direction 1.

b. Two Vehicle Operation

This test was intended to demonstrate that a vehicle in a full-up automatic mode will perform properly when following another vehicle through the stub-end terminus. The 01 vehicle is operated in a manual mode whereas the 02 vehicle is operated automatically. The 01 vehicle was stopped in the stub end. The 02 vehicle moved from the East Departure station and stopped at the proper stopping point at the West Arrival platform in block VE14. The vehicle was then commanded to move forward in the ASMD mode out of the SF_b or departure portion of the block. Emergency brakes (EB) were immediately applied. EB and zero speed were indicated in the CC. The SF_b transmission was cut to not allow restart of the 02 vehicle because of the vehicle ahead. However, the SF_a and the SF transmissions behind this section of the station were not cut allowing a following vehicle to come into the station and disembark passengers.

The manually driven 01 vehicle was then authorized to leave the stub end and stop at the West Departure platform. When the 01 vehicle cleared the UD DND2, the switch was reset permitting entry of a vehicle from the left. The 02 vehicle restarted automatically and stopped in the stub end. The switch was reset permitting motion to the right when the 02 vehicle cleared the UD DN02. Automatic restart was effected when the 01 vehicle moved out of block 21, the West Departure platform. The switch was reset to the left as soon as the 02 vehicle cleared DND2 UD. Thus the stub end and switch were returned to a state that would accept another vehicle from Direction 1.

The vehicles were brought around the test track and returned to the original condition, i.e., vehicle 01 in the stub end and vehicle 02 at the West Arrival platform. The 01 vehicle was moved forward until it occulted UD DN07. The traffic lights and the mimic display for SM01 were red and for SM03 were green. The 02 vehicle was commanded to leave the station in the normal mode. It did not move. It was then forced to leave the station in the ASMD mode. Emergency brakes were applied immediately. The 01 vehicle was moved into the station. Upon clearing the UD DND2, the SM01 traffic signal and associated mimic display at the CC were changed from red to green, the switch was reset for entry from Direction 1, and the 02 vehicle restarted automatically.

c. Parking in the Stub End

The 02 vehicle stopped at the West Arrival platform in a full-up automatic mode. The CC implemented the ITFT command. A telemetry check indicated that the reset emergency brake (REB) signal had disappeared. The vehicle moved into the stub end and stopped. The REB was commanded by Central, and the vehicle restarted automatically.

4.8.2 East Terminal Switches

4.8.2.1 Safety

a. Collision Avoidance in Reversal Operations

Two vehicles in a full-up automatic mode were run through the East Terminal. The 01 vehicle was stopped in the East Terminal stub end. The SME1 traffic light and CC mimic board both indicated red. The 02 vehicle arrived at the East Arrival platform and successfully stopped. The 02 vehicle was then forced to leave the station. Emergency brakes were applied immediately. Proper telemetry warning signals were received at the CC, i.e., EB and zero speed.

The 01 vehicle was commanded to leave the stub end in the ASMD mode (0.8 m/sec). The safe frequency was switched on as soon as the 01 vehicle moved beyond the CE1V1 switch. The SME1 traffic light and mimic board light were changed from red to green, and SME3 was changed from green to red. The CE1V2 switch did not move to the normal position that allows acceptance of a vehicle into the stub end until the DND1 UD was cleared. The 02 vehicle moved into the stub end only after DND1 was clear and the switch reset. The 01 vehicle stopped properly at the East Arrival platform and the SF_a was removed so that the vehicle would not depart. The telemetry from the 02 vehicle was checked. No safe frequency was detected because the SF_b is not monitored. The SME3 lights were still red. The 01 vehicle was then authorized to leave the station. As soon as the block VE11 was cleared, the SME3 lights changed to green and the 02 vehicle restarted automatically.

b. Injection

Vehicles 01 and 02 were prepared for injection into the East Terminal. The 02 vehicle was in an automatic mode and the 01 vehicle was under manual control. The CC sent an injection command check acknowledgement. After receipt of the acknowledgement a GO order was transmitted and acknowledged. The switch BE1 was thrown and SME4 was green. The 02 telemetry was checked and the FS signal was present. It moved into the parking area and stopped. The SME4 light changed to red.

The SME5 traffic light and mimic display indicated blue; it is only used when a vehicle is under manual control. The 01 vehicle was switched to the automatic mode. A GO order was sent from the CC. The 01 vehicle moved automatically and stopped before the BE1 switch and SME4 light which was still red. The 02 vehicle was then authorized to depart from the parking area. SME4 turned green when it cleared. The 01 vehicle automatically restarted and moved to the parking area. It was authorized to leave the parking area after the 02 vehicle cleared the DND1 UD.

c. Route Selection - Reversal Operations

The 02 vehicle was stopped astride the switch CE1V1 during a reversal operation (REB). The CC sent an injection order. SME4 was red, but no acknowledgement was received at the CC. A check was made to determine if the order for reversal operation was still selected, which it was. Therefore, injection safety was shown to be interlocked with the reversal operation.

d. Vehicle and Switch Safety Interfaces

The 02 vehicle was stopped at the East Arrival platform. A reversal order was sent by the CC and acknowledgement was received. The 02 vehicle left the East Arrival platform in the ASMD mode (0.8 m/sec) and was stopped just before switch CE1V2. A green light on the left side of the console mimic display indicated the switch position that would allow entry from the left or the East Arrival platform. A red light on the right indicated a switch position that would not allow a vehicle to leave the stub end. The SME3 traffic signal was red. The vehicle was commanded to continue to the stub end. The switch automatically moved to the left turning the right red light to green and the left green light to red. SME3 was also changed from red to green after the completion of the switch manoeuvre. The vehicle automatically restarted and moved toward the East Departure platform. The CE1V2 switch reverted to the original state so that it could accept another vehicle from the East Arrival platform as soon as the CE1V1 switch and the DND1 UD were free.

e. Emergency Brakes

The 02 vehicle was in the automatic mode at the East Arrival platform. The CC gave a reversal order and canceled the automatic operation of the East Terminal switches. All traffic lights were red. The vehicle was commanded to move. Emergency brakes were applied immediately. The special "peep hole" lights for the manual mode were off with exception of the reversal light.

The CC authorized manual operation of the East Terminal switches and the vehicle. The safe frequency was off and all traffic lights were red. The SME1 peep hole lights showed red and white indicating the driver would have to drive through the switch in the switched mode forcing the switch to move. The switch has been designed so that a vehicle could be driven through the switch in the event of emergencies without damaging the switch. Thus a vehicle could complete a reverse operation even if control is lost in this emergency state. The CE1V2 switch was thrown right allowing a turn out to the East Departure platform and the CE1V1 switch was thrown left allowing the vehicle to force its way through the switch, but to reverse direction for removal.

f. Manual Route Selection - Removal Operation

The CC selected "REVERSAL" operation when the 02 vehicle was at the East Arrival platform. The vehicle proceeded through the terminal and was stopped in front of the traffic light SME5 and just after switch CE1V1. A command for manual operation of the East Terminal switches was given, followed by a "REMOVAL" operation command. The switch CE1V1 was thrown left allowing access to the parking area, and BE1 was thrown left allowing a vehicle to force the switch but to also turn out for removal. The SME5 light eminated a blue light indicating manual operation of the vehicle. The manual mode must be selected to put a vehicle into parking. It can then be returned to the automatic state for completion of the removal process. Meanwhile, the 01 vehicle was brought into the East Arrival. Traffic signal SME1 indicated red. The 01 vehicle was forced to leave the station. Emergency brakes were applied immediately. The 02 vehicle was then moved into the normal ready parking area. Automatic operation of switches was commanded. SME1 was changed from red to green and the safe frequency was switched on. The 01 vehicle restarted automatically and completed the reversal operation.

g. Automatic Removal and Injection

The CC selected automatic operation of switches when the 02 vehicle was in the parking area. The "REMOVAL" command was given to move the vehicle from normal ready parking to off-line parking. The BE1 switch was thrown left allowing the vehicle to turn out to off-line parking. The traffic signal SME4 was green and SME6 was red.

With the 01 vehicle stopped in front of traffic signal SME6, the "INJECTION" command was given. Switch BE1 remained left making it possible for the 01 vehicle to enter the normal ready parking area. Signal light SME6 was green and SME4 was red. After clearing UD DNE7, switch BE1 was thrown right and CE1V1 was thrown left making a clear path to the East Departure station. SME4 was changed from red to green, and SME6 was changed from green to red.

4.9 STATION SAFETY

This series of station safety tests was performed to demonstrate the safe control of vehicle and station door operation by the AVP. Because of the bi-directional capability of the VAL vehicles, the doors on both sides of the vehicle are alternatively used for Directions 1 and 2. Only the doors on the outside of the vehicle facing the station platforms are allowed to open. Proper door unlock authorization and functional operation was checked during the dependability tests.

The door opening threshold of the vehicle and station doors was determined by slowly moving the 02 vehicle to either side of the station theoretical stopping point until the communications link drop out occurred. The threshold is schematically shown in Figure 4-18. The vehicle can open its doors at ± 0.15 meters on either side of the theoretical stopping point or within the station door opening. These maximum and minimum conditions are also shown in Figure 4-18.

The distance on either side of the theoretical stopping point for vehicle and station door authorization is shown in Figure 4-19. The design criteria is also shown in Figure 4-19. Note that the actual authorization threshold

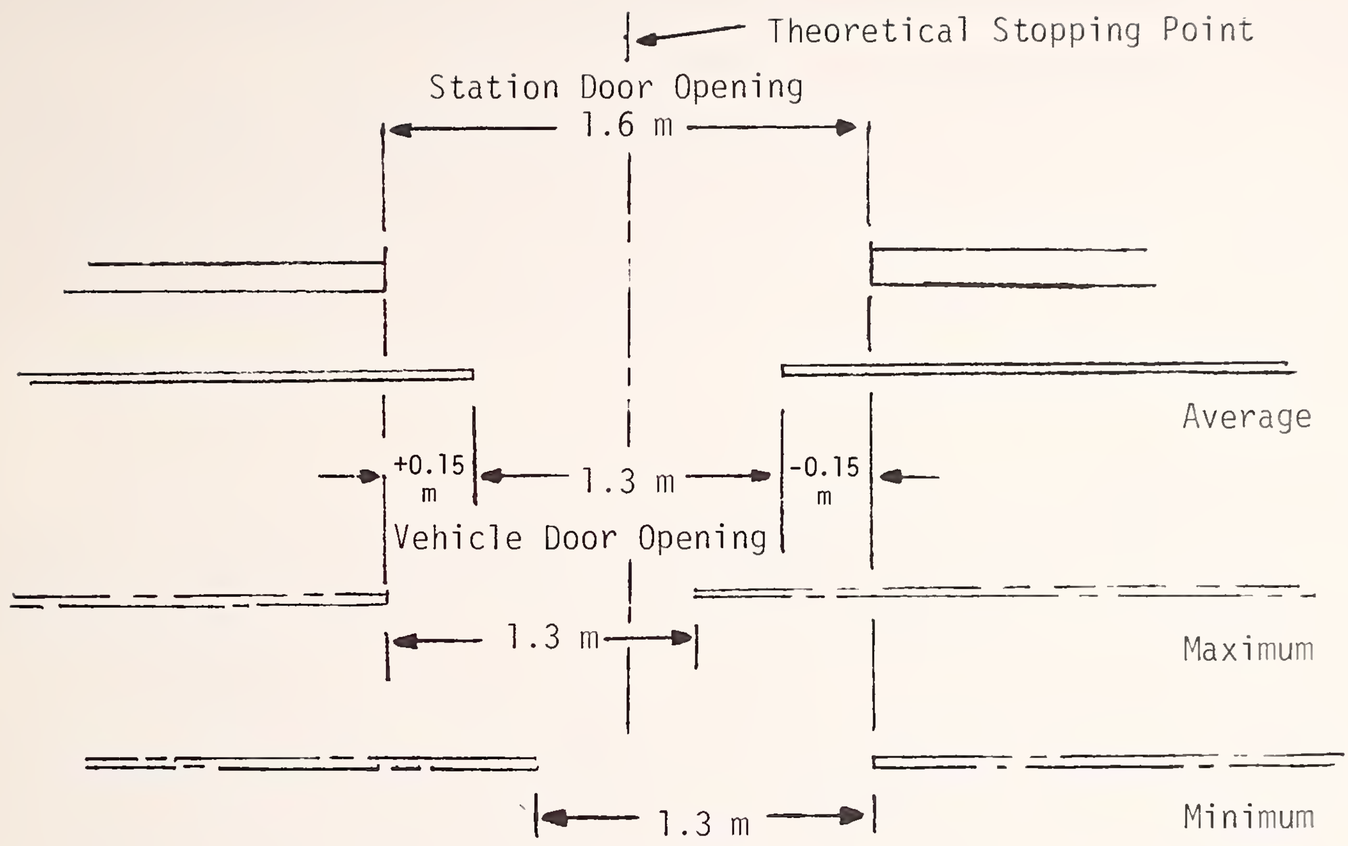


FIGURE 4-18. THRESHOLD TOLERANCE SCHEMATIC

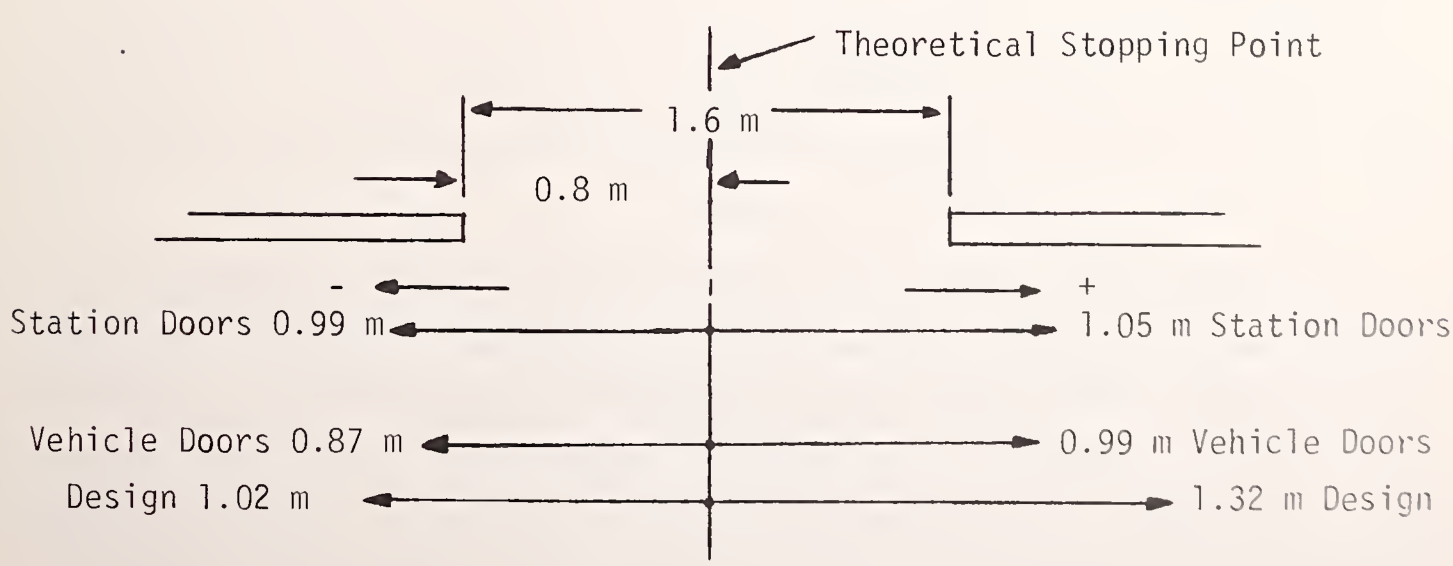


FIGURE 4-19. AUTHORIZATION THRESHOLD

is larger than ±0.15 meters specification on the door opening, but is smaller than the design limits.

The vehicle was subsequently stopped with emergency brakes at ±2.00 meters distance from the theoretical stopping point. The vehicle doors were opened automatically. The station emergency doors were used to disembark into the station. These doors were opened manually by depressing a conventional door release bar.

4.9.1 Station

A station service and emergency door was unlocked as the 02 vehicle approached the East Terminal Departure platform. Emergency braking occurred about 25 meters ahead of the station. The vehicle was unaffected at the East Arrival platform and was able to depart. If a door is unlocked before the vehicle moves through block (n-1), which precedes the station block (n), the vehicle will use the service brakes with a normal stopping program. Emergency brakes are used if the vehicle has entered block (n). Only two emergency stops and restarts are permitted before it is necessary to restart the system from the CC. After two emergency stops the vehicle can only be driven manually after reactivation from the CC, and this must be done each time it subsequently stops. In both cases the station entry and exit traffic lights were red.

4.9.2 Vehicle

The 02 vehicle was moved into the station and a single vehicle door was unlocked. Commands were sent to the vehicle to depart. It would not move. This test was repeated several times with one and several doors on each of the units comprising the vehicle.

The vehicle was backed up and moved into the station and stopped by the vehicle emergency egress handle opposite the station emergency egress doors. The doors were opened with a small mechanical force (estimated to be about 22.6 newtons (5 pounds)). The emergency egress doors in the station were used to exit the vehicle. This emergency exit system was easy to use. The vehicle emergency egress handle was in the ceiling of the vehicle and required that a person be tall enough to reach it. A special tool was needed to reset the emergency system once it was used. Thus maintainance personnel would be required prior to moving the vehicle.

The door closing obstacle detection system was tested by inserting objects of various sizes. The doors reopened with objects as small as 50 mm. It did not open or release with objects the width of a hand or smaller. The door closing force was very high (approximately 980 newtons). This is roughly seven times that of elevator doors (133.4 newtons or 30 pounds)[1]. The Lille specification calls for 10 joules of energy to close the door.

4.10 SPEED CONTROL AND RIDE COMFORT

The speed control tests were performed to demonstrate the agreement between vehicle speed and command speed. Longitudinal ride comfort tests were performed to demonstrate that vehicle acceleration and jerk were within specified limits.

The speed profile for the entire guideway is shown in Figure 4-20. The speed profile for Direction 1 from East Departure to West Arrival is shown in the upper half of the figure. Direction 2 is shown in the lower half. The dotted curve was the speed using the perturbed stopping program.

4.10.1 Speed Control

The 02 vehicle speed profile was recorded for Direction 2 (see Figure 4-21). The following parameters were recorded: command or program speed $(VC)_2$ deceleration order (DVC), real vehicle speed (VR), acceleration command (α_c), real vehicle acceleration-electrical (α_R), and real vehicle acceleration-mechanical (α_R). The real vehicle acceleration-electrical is obtained by recording the output of the tachometer, whereas the real vehicle acceleration-mechanical is obtained from a longitudinally amounted accelerometer.

At constant speed the error shown in Figure 4-21 between the commanded and actual speed was -0.2 m/sec which is within the expected results of ± 3 percent. The error during deceleration was +0.5 m/sec at a command speed of 14 m/sec, +0.5 m/sec at a command speed of 10 m/sec, 0 m/sec at 8 m/sec, and +0.2 m/sec at 6 m/sec. In the transition region between constant speed

[1]ANSI A17 American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks.

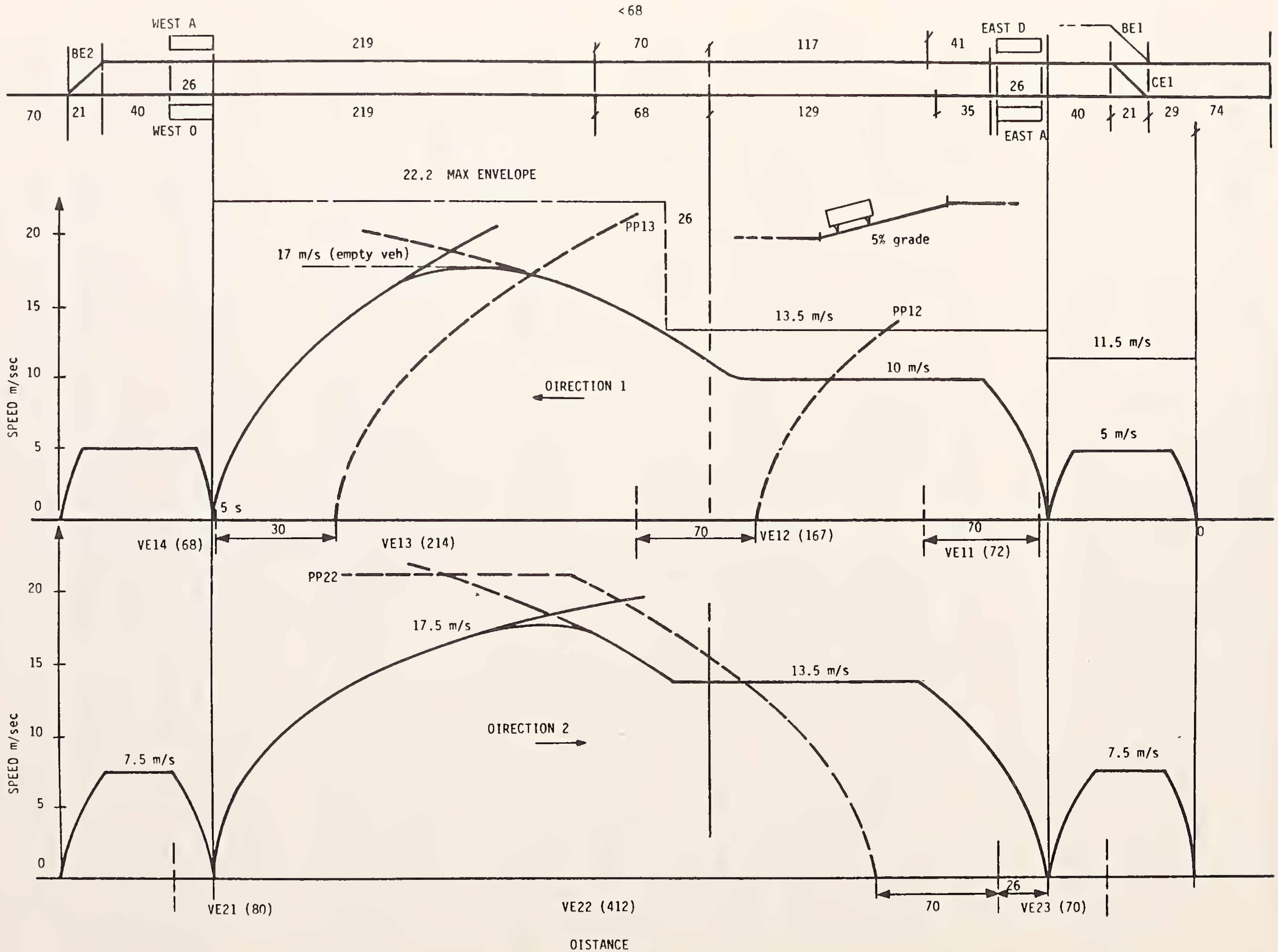


FIGURE 4-20. TEST TRACK SPEED PROFILE

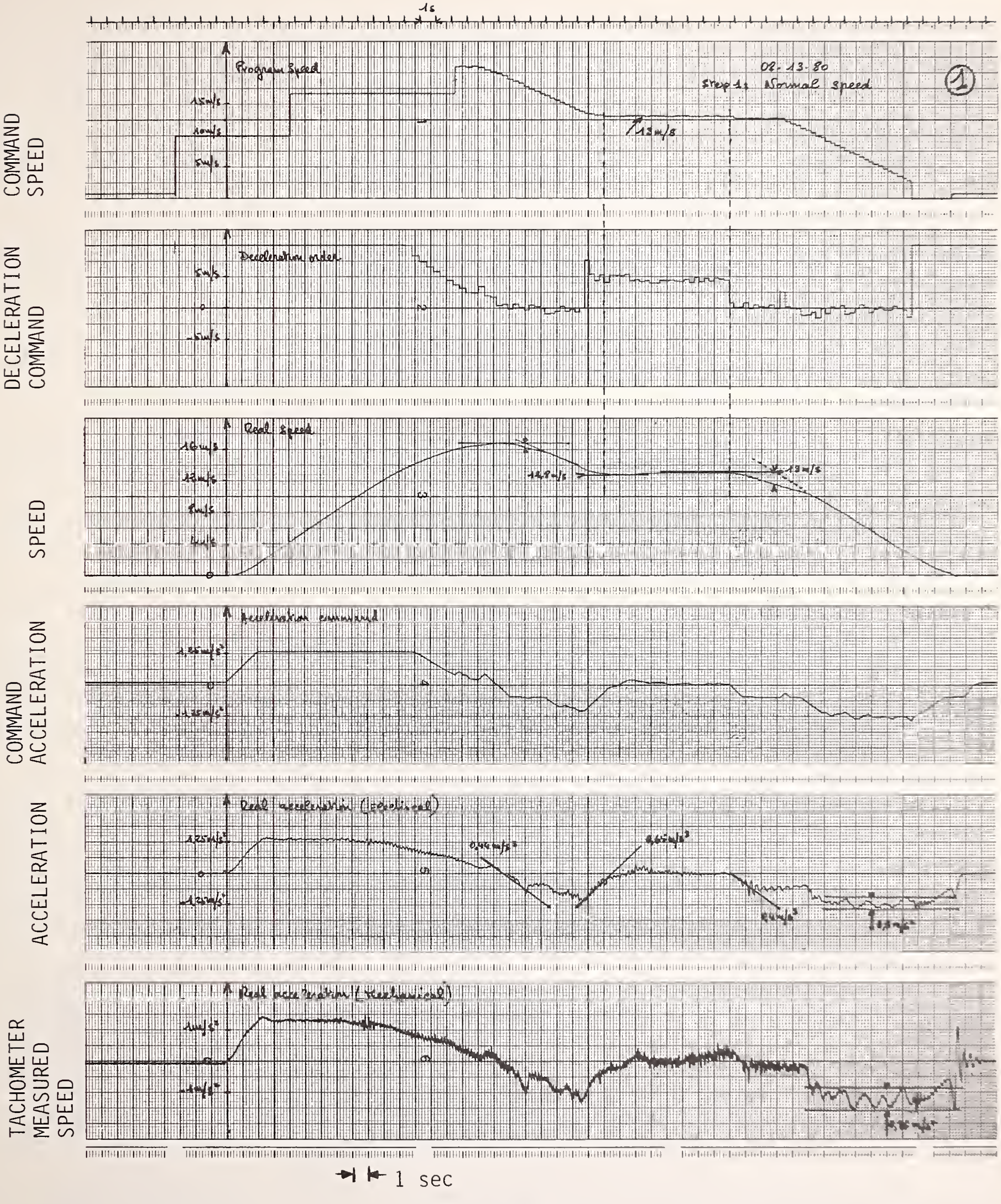


FIGURE 4-21. NORMAL SPEED AND ACCELERATION PROFILES

and deceleration the maximum error was -1.6 m/sec at a command speed of 12.7 m/sec. The deceleration order is the difference between the program speed and the real speed.

The stopping program speed profiles are shown in Figure 4-22. A vehicle was simulated at the East Arrival platform invoking the stopping program. The normal speed deceleration into the station has been approximated by the dashed curve for comparative purposes. The 02 vehicle stopped in block VE22 with a safe distance margin. The velocity and accelerations were very much the same as recorded in the normal program mode, only deceleration occurred earlier.

Figure 4-23 shows the speed profiles of the 02 vehicle when commanded by the CC to proceed at 5 m/sec. The actual speed of the vehicle was measured at 4.8 m/sec.

The speed profiles of the 02 vehicle in the coupling mode are shown in Figure 4-24. The nominal command speed during coupling operations is 0.8 m/sec. The command speed was 0.83 m/sec. The actual speed was 0.7 m/sec. This is lower than the ± 0.3 m/sec speed tolerance.

The speed profiles for the 02 vehicle in a reduced speed mode are shown in Figure 4-25. The vehicle speed was modified to 0.9 of normal speed. A reduced speed of 11.7 m/sec was commanded. The real speed was 11.6 m/sec.

4.10.2 Ride Comfort

The system specifications limit the longitudinal acceleration to ± 1.3 m/sec^2 and the jerk to ± 0.65 m/sec^3. From Figure 4-20 it can be seen that the maximum acceleration reached was $+1.4$ m/sec^2. The maximum deceleration was -1.3 m/sec^2 for the normal operating portion of the trajectory. However, 1.6 m/sec^2 was shown for the region of final braking when arriving in the East Station. A variation of 0.75 m/sec^2 is shown indicating erratic operation of the final feed back brake loop. Corrective action of the gains have been prepared but were not implemented at this time.

The maximum jerk during acceleration was 0.7 m/sec^3. The maximum jerk during a transition phase was 0.9 m/sec^3. These are somewhat above the Lille specification.

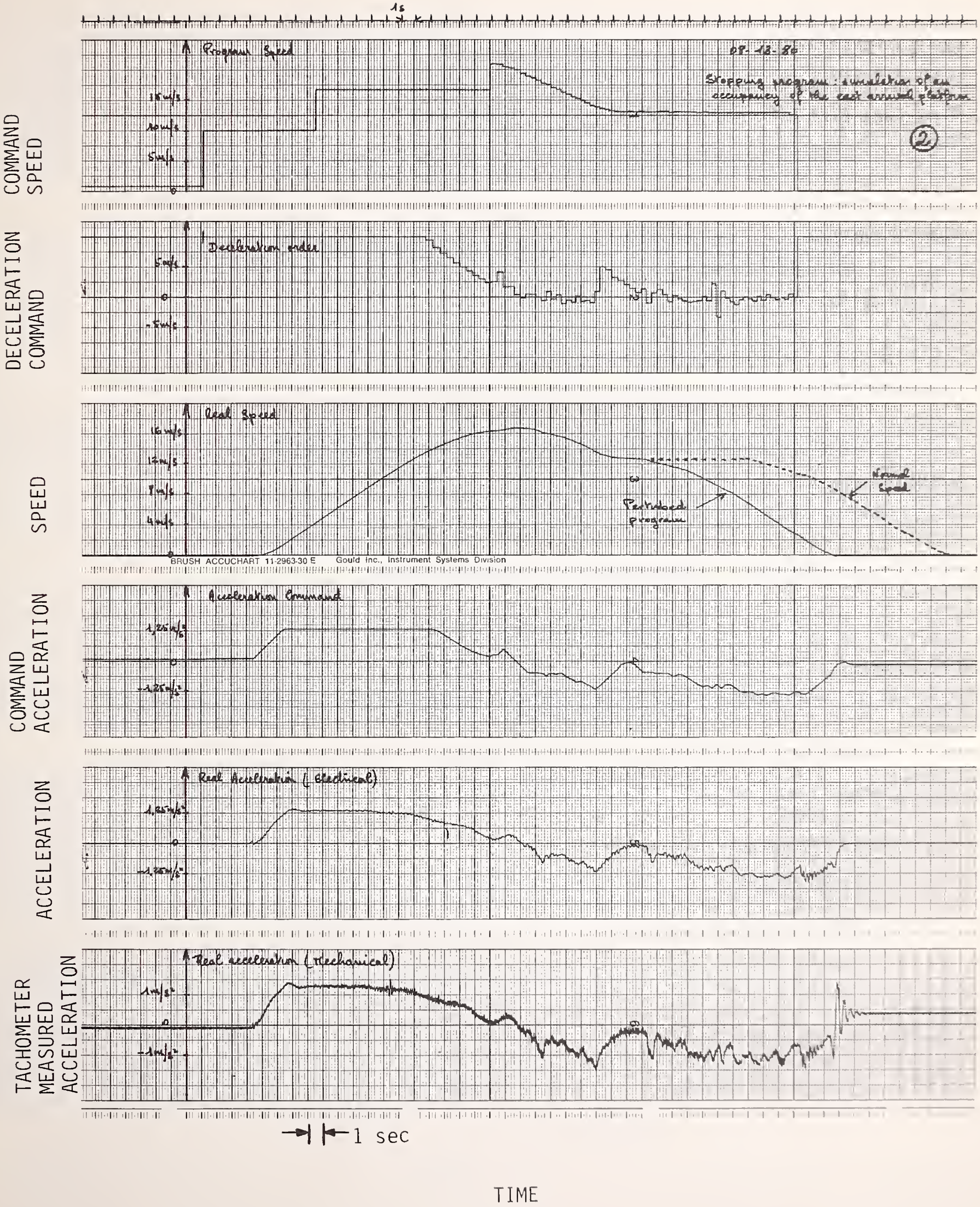


FIGURE 4-22. STOPPING PROGRAM SPEED AND ACCELERATION PROFILES

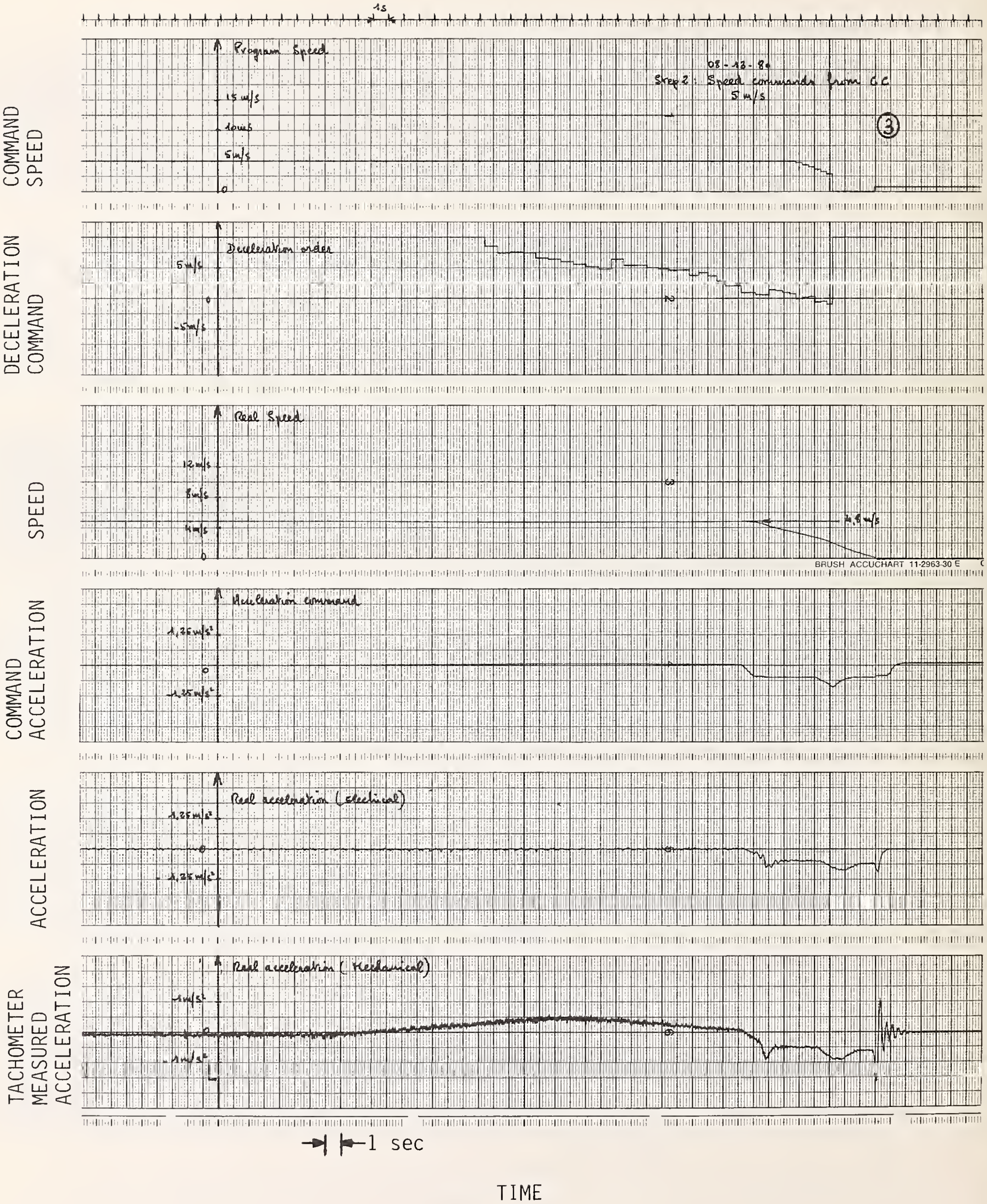


FIGURE 4-23. SPEED AND ACCELERATION PROFILES - 5 m/sec Commanded by CC

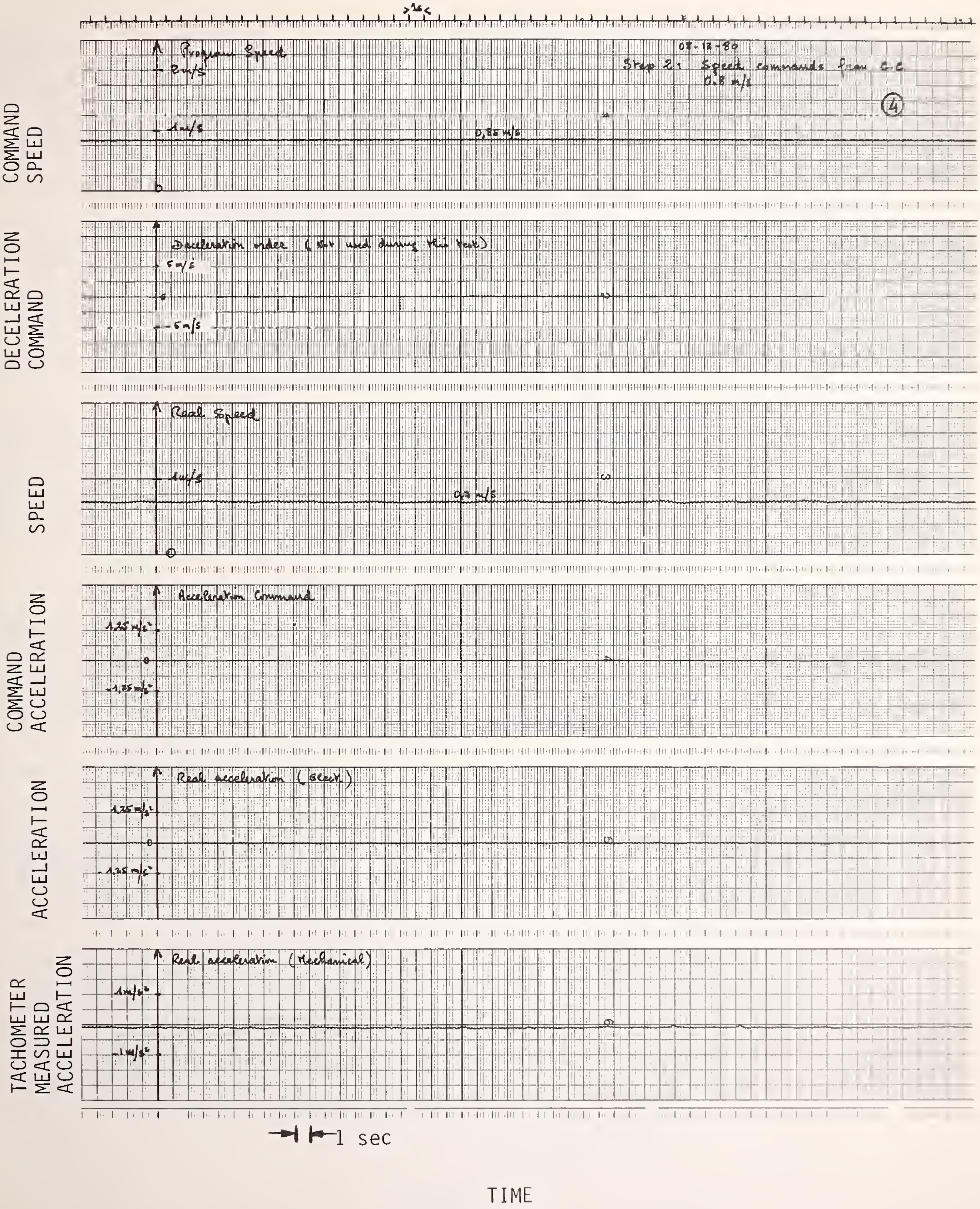


FIGURE 4-24. SPEED AND ACCELERATION PROFILES - 0.8 m/sec Coomanded by CC

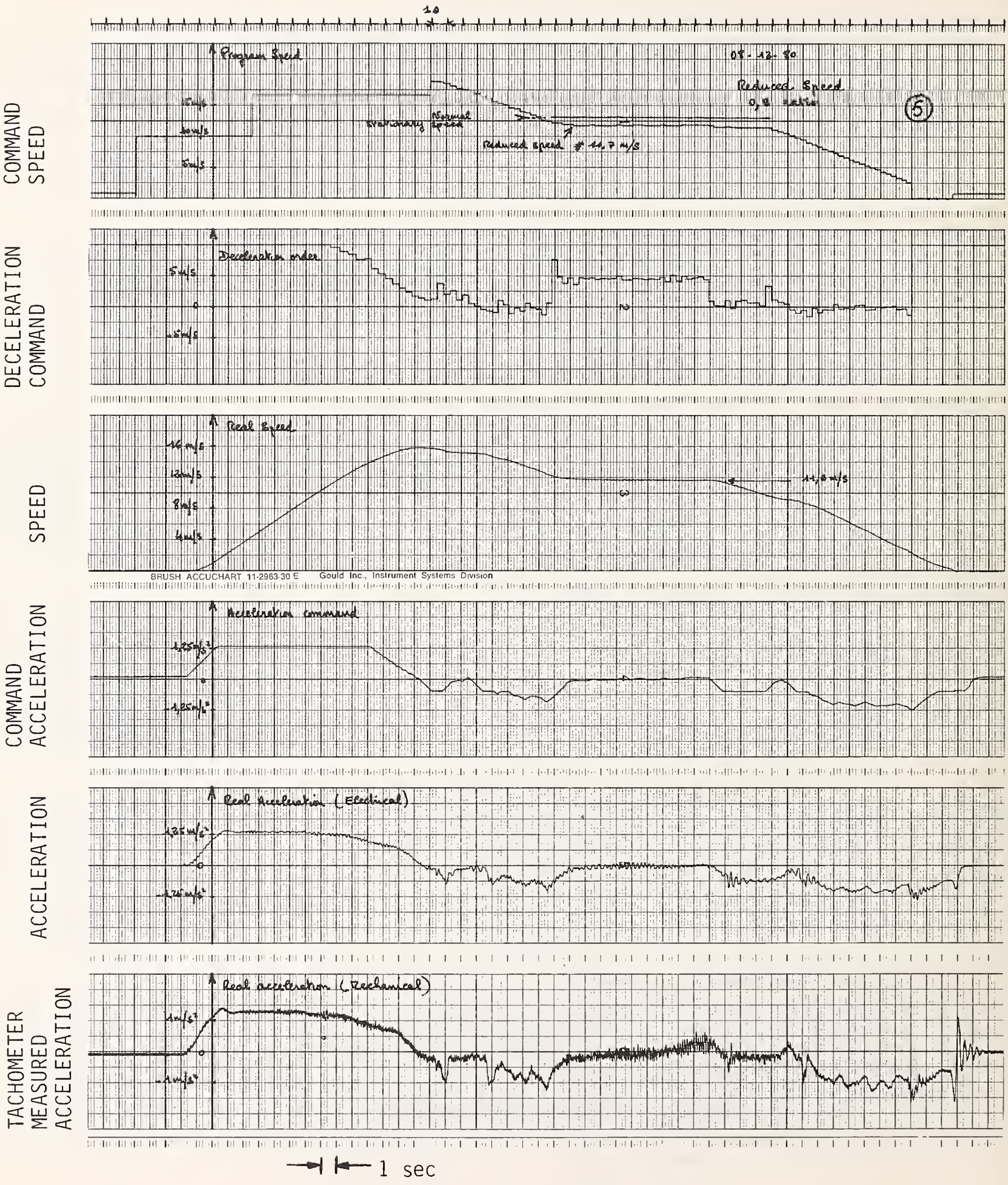


FIGURE 4-25. SPEED AND ACCELERATION PROFILES - REDUCED SPEED MODE

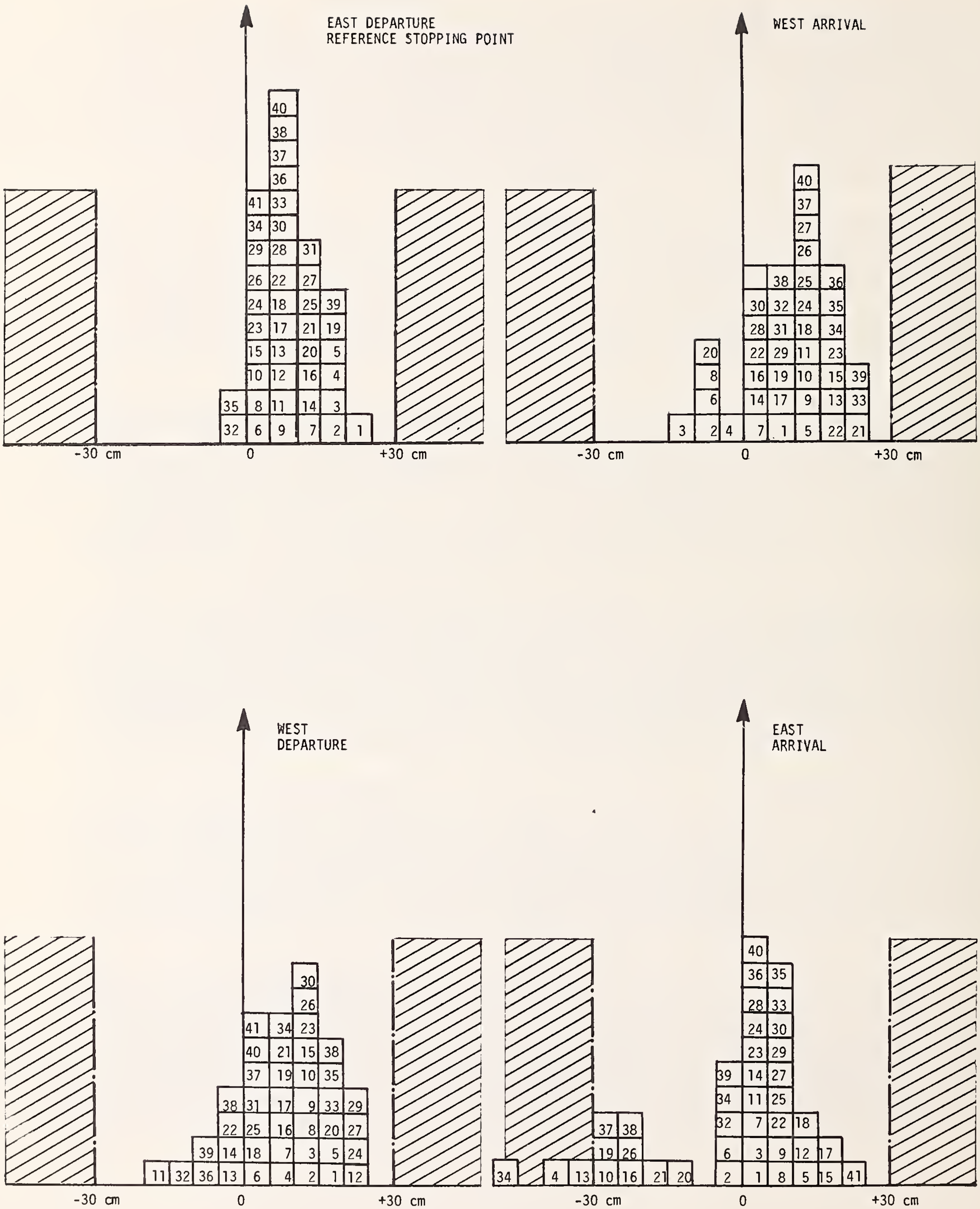
4.11 PROGRAMMED STOPS

The objective of the programmed stopping tests was to determine the accuracy of vehicle stopping at the four stations. The 02 vehicle was operated in a normal mode around the test track 40 times, stopping at each station on route. Marks were placed on the vehicle door sill in 5 cm intervals to a distance of ±30 cm. The latter represents the door opening tolerance. A mark was placed on each station platform at the theoretical or reference stopping point. The results of these trials are shown in Figure 4-26. The number inside each block indicates the trial. Its position indicates the relative distance from the reference stopping point. The results are a frequency distribution of the stopping accuracy. The bi-modal distribution at East Arrival is not understood. It is hypothesized that the upstream beacon may be improperly located and that the 4.75 percent grade just prior to the platform would cause some additional braking.

Two additional test cycles were performed in the safe stopping mode at less than or equal to 5 m/sec. At the East Departure platform +5 cm was observed on both cycles. At the West Arrival platform +0 cm and -40 cm was measured. Plus 45 cm and +40 cm was measured at West Departure. At the East Arrival -30 cm and -40 cm was observed. After a restart on block 22 after application of a safe stopping program, +5 cm and +25 cm was observed at the East Arrival platform.

A reduced speed order was given from CC at the West Arrival platform for two cycles. The deviation from the reference stopping point was +10 cm for both cases at the West Arrival, -10 cm and +25 cm at West Departure, +10 cm and -5 cm at East Arrival, and 0 cm and -25 cm at East Departure.

Two cycles were repeated at the coupling speed of 0.8 m/sec. The deviation from the reference stopping point was -35 cm and -15 cm at the West Arrival, +25 cm and +35 cm at the East Arrival, -10 cm at West Departure, and +60 cm at East Departure.



VEHICLE 02
DCA 1

FIGURE 4-26. NORMAL MODE STOPPING ACCURACY

4.12 DWELL TIME ADJUSTMENT

The objective of the dwell time adjustment test was to demonstrate the capability to remotely adjust the dwell time at each station platform. The Dwell Operational Control Unit (DOCU) was set for a dwell time of 6 seconds by a local station command of EAS. The actual dwell time was 7 seconds ± 1 second, i.e., the dwell time varied between 6 and 8 seconds. The dwell time was increased to 30 seconds in increments of 2 seconds. The actual dwell time corresponded to T = TA ÷ 1 second ± 1 second. Figures 4-27 and 4-28 show examples of these results of station and vehicle door status for TA = 8, 10, and 12 seconds.

The dwell time was set at 5 seconds from the CC and varied in 5-second increments up to 30 seconds. Results corresponding to T = TA + 1 second ± 1 second were also obtained. The dwell time command for the east dwell unit was sent to the west dwell unit and vice versa. These commands were not instituted because of improper identification.

The vehicle and station door histograms were checked over 10 trips. The accuracy remained at ±1 second. The time delay between the vehicle door opening and the station door opening was measured. Figure 4-29 shows a typical result for a dwell time of 26 seconds. The station doors opened 0.8 seconds after the vehicle doors opened and closed 1.4 seconds after the vehicle doors closed.

4.13 HEADWAY MEASUREMENT

The objective of the headway measurements was to demonstrate the minimum headway capability. Both the 01 and 02 vehicles were used in an automatic mode. The time when each vehicle left the East Departure platform was recorded. The time delay or headway was expected to be less than 60 seconds.

A dwell time of 10 seconds was remotely selected by the CC for the four platforms. The 01 vehicle was stopped at the East Departure platform. The 02 vehicle was stopped in the stub end of the East Terminal. Figure 4-30 shows three out of four headway tests. The door opening time of the first vehicle and the time until the next vehicle opened its doors was recorded. The headway was shown to vary from 56.5 to 57.5 seconds, which was below the 60-second specification.

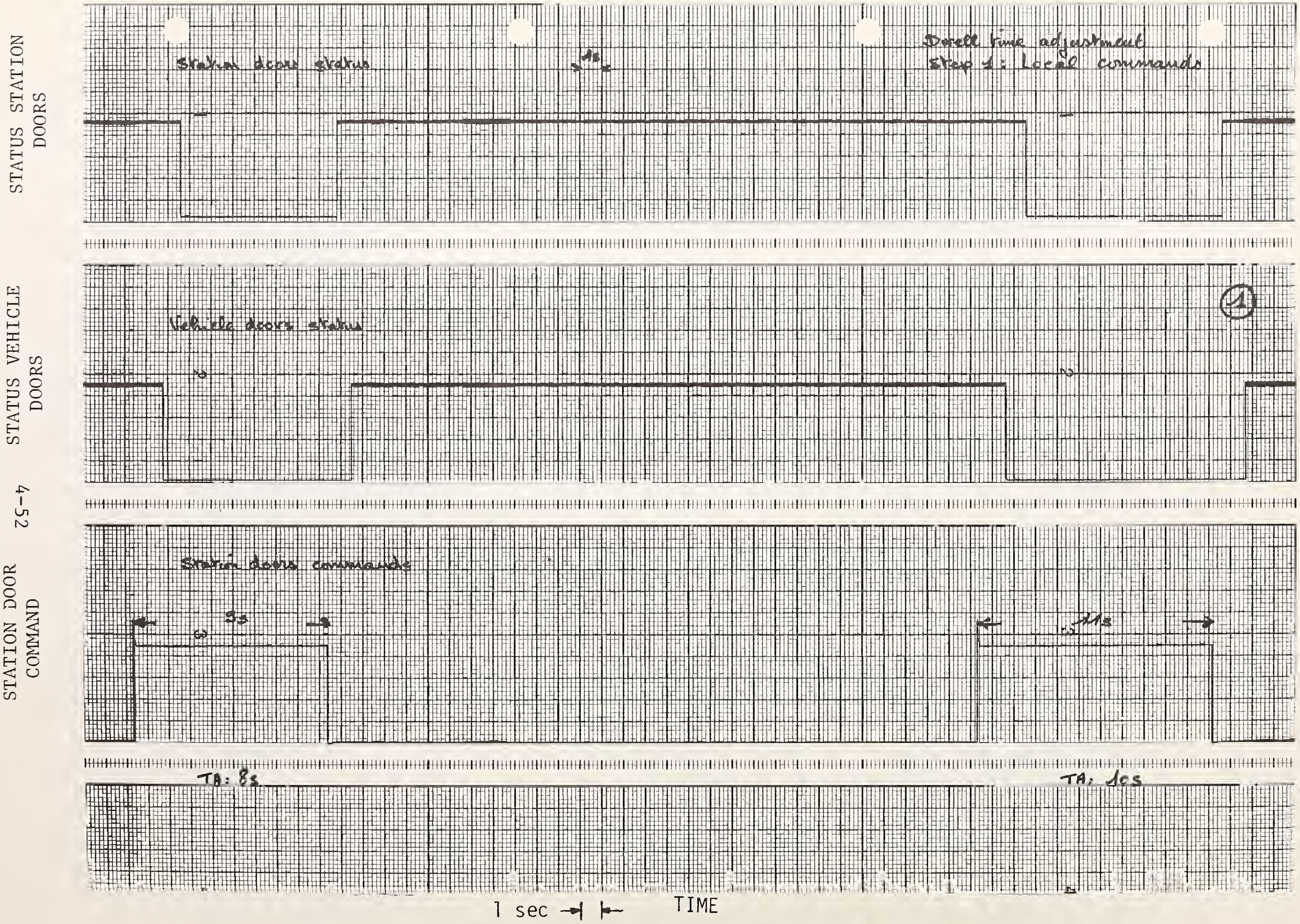


FIGURE 4-27. STATION AND VEHICLE DOOR DWELL TIME - (TA = 8 and 10 seconds)

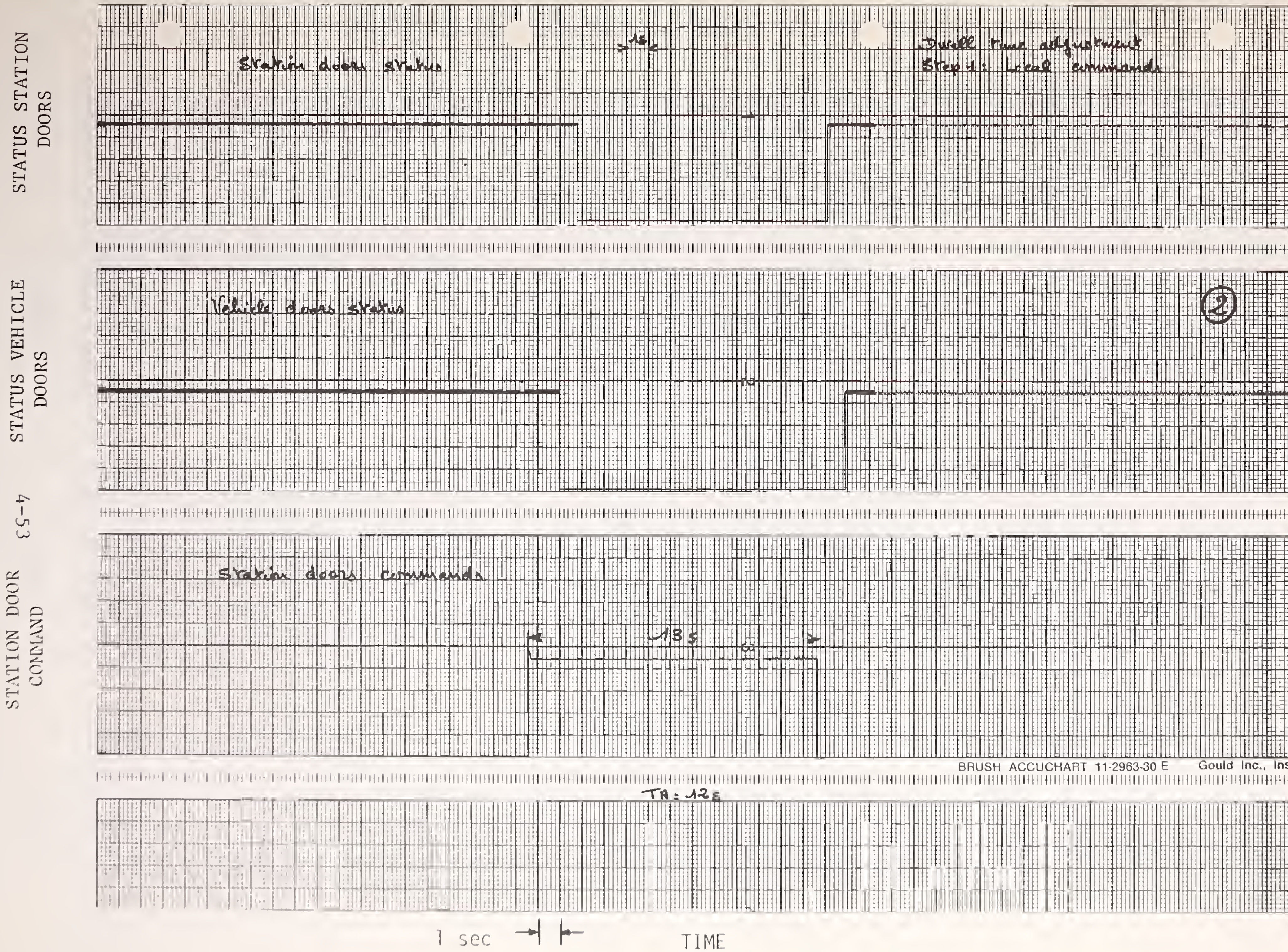


FIGURE 4-28. STATION AND VEHICLE DOOR DWELL TIME (TA = 12 seconds)

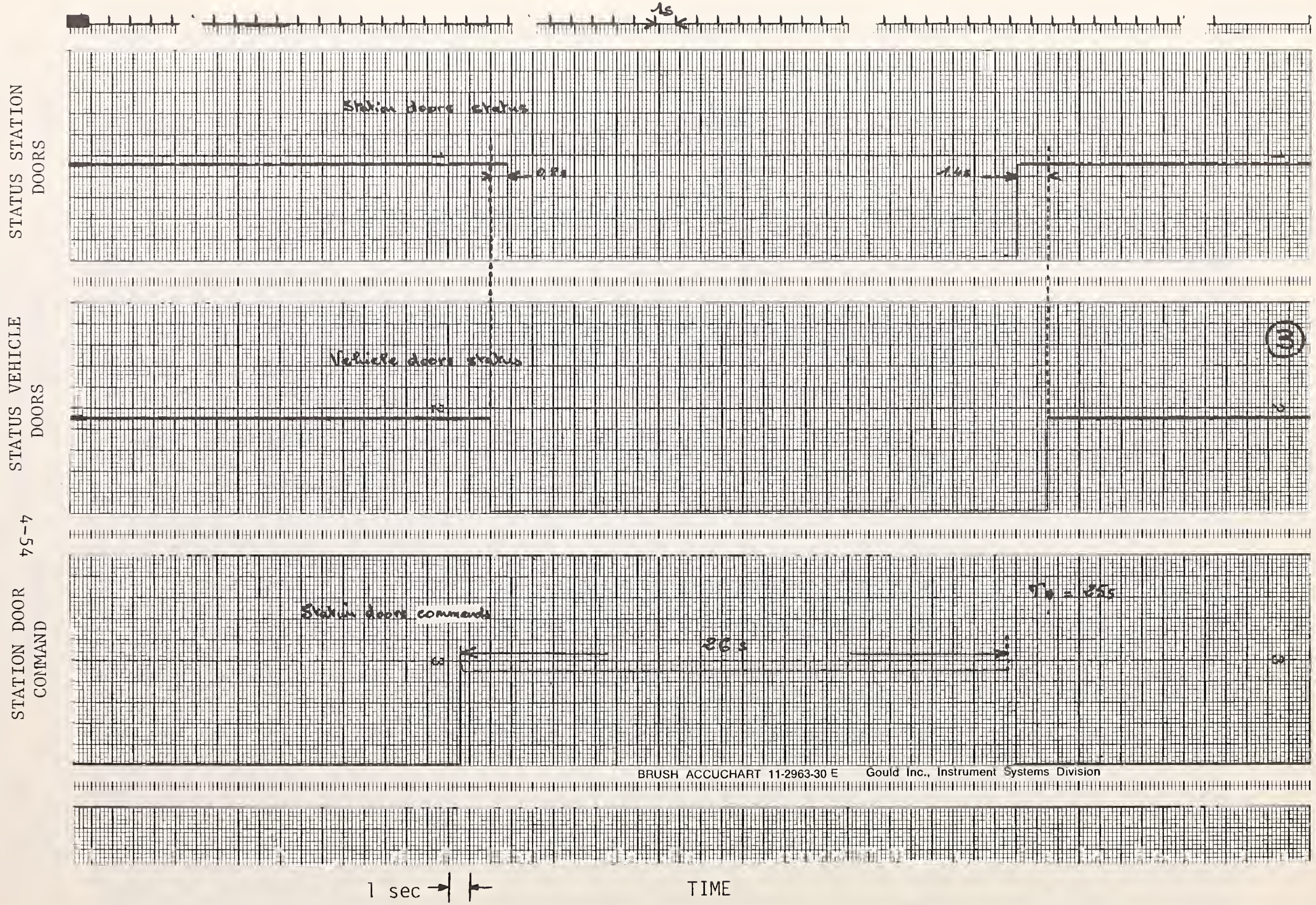


FIGURE 4-29. STATION AND VEHICLE DOOR DWELL TIME (TA = 26 seconds)

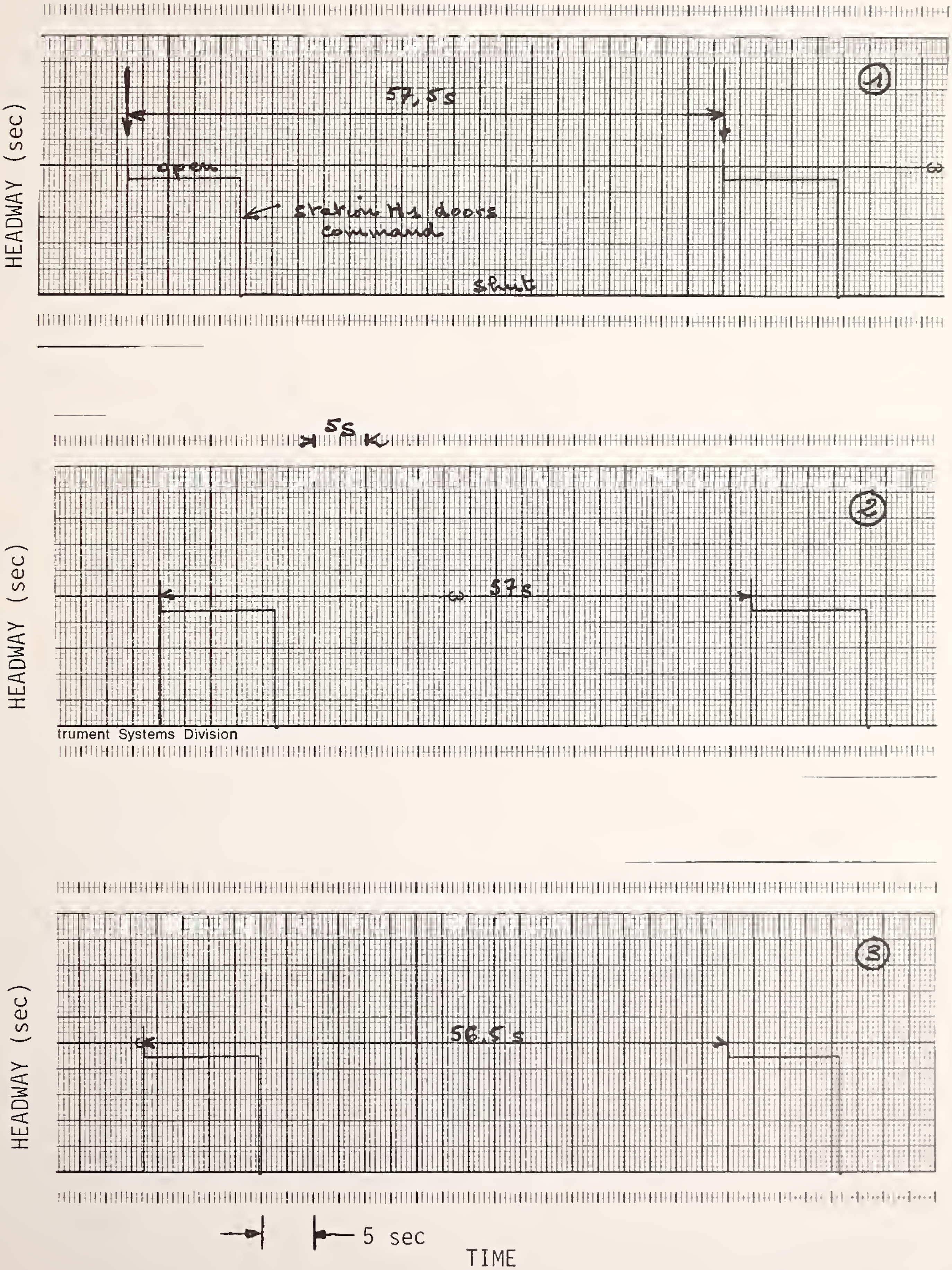


FIGURE 4-30. HEADWAY MEASUREMENT EAST DEPARTURE PLATFORM

5.0 SYSTEM ECONOMICS

The capital cost of the VAL-Lille system is presented in Section 5.1. An estimate made by MATRA for VAL operating and maintenance costs is given in Section 5.2.

5.1 CAPITAL COST

The overall capital cost of the VAL Lille system is 1650 million French francs ($387.75 million) based on January 1979 price indices and exchange rates exclusive of taxes and right-of-way acquisition costs. MATRA was awarded a fixed price contract for the system engineering, rolling stock and command and control equipment in September 1976 for 234 million French francs ($49 million). A second contract award of 272 million French francs ($55.3 million) was made to MATRA in September 1977 for the track electrification, workshop and depot, test track, and some station equipment, bringing the total MATRA contract to about 532 million French francs ($108.3 million in 1977 dollars). CUDL was given the remaining sum to provide all civil engineering and structural elements.

The capital costs of the overall system are summarized in Table 5-1. The cost of vehicles includes engineering, tooling, and on-board automatic control equipment. CE is equivalent to the basic construction costs including utility network displacement and relocation. Eqt is track equipment including layout. The 26-meter station platforms are equipped with four escalators per station and 12 platform station doors. The Gares de Lille station is equipped for interconnection between VAL and the light rail "Mongy" system, i.e., this station is considerably larger (282 meters in length). Engineering and development costs are included in the cost of command, control, and communication. The power distribution costs do not include the cost of connections between substations and the city electrical network. The cost of maintenance and parking includes all facilities and related equipment. Finally, the Engineering and Project Management cost includes both the MATRA fees for system management and the RATP SOFRETV fees for construction management fees.

5.2 OPERATING COST

Estimates of the operating cost have been prepared by MATRA and are given in Table 5-2.

TABLE 5-1. VAL CAPITAL COSTS

		Unit Costs KF	Unit Costs K$		Quantities	Total K$	% of Total
Vehicle		2,116	470		38x2 = 76	45,562	11.7
Guideway/Mile							
Elevated	CE[1]	46,587	10,948	13,751	1.480	20,351	
	Eqt[2]	11,928	2,803		(2.38 km)		
At grade	CE	55,077	12,943	15,746	0.539	8,494	
	Eqt	11,928	2,803		(0.867 km)		
Cut & Cover	CE	70,281	16,516	20,230	2.620	52,995	
	Eqt	11,928	2,803		(4.216 km)		
	Vent	3,877	911				
Bored Tunnel	CE	116,396	27,353	31,067	2.841	88,258	
	Eqt	11,928	2,803		(4.571 km)		
	Vent	3,877	911				
					7.48 miles (12.04 km)	170,098	43.9
Stations (26 m long)							
Elevated		9,861	2,317		4	9,269	
Cut & Cover		9,791	2,301		5	11,504	
Station Gare de Lille		84,370	19,827		1	19,827	
Bored Tunnel		19,417	4,563		7	31,943	
Eqt & Vent		9,821	2,308		1	2,308	
					17	74,851	19.3
Command, Control & Communication/mile		13,111	3,081		7.893 (12.7 km)	24,317	6.3
Power/Mile		6,265	1,472		7.893 (12.7 km)	11,620	3
Maintenance & Parking Area		98,706	23,196		1	23,196	6
Engineering & Project Management		162,153	38,106		1	38,106	9.8
Total						$387,750	100

NOTE: (1) CE is Civil Engineering costs.
(2) Eqt is track equipment.

TABLE 5-2. ESTIMATES OF VAL OPERATING & MAINTENANCE COSTS

Planned vehicle miles per year	3,750,000
Labor Costs associated with operations	$1,990K
Maintenance Costs (including labor, parts, & upkeep)	$3,821K
Energy:	
Traction	13.44×10^6 kw-hr
Utilities	6.6×10^6 kw-hr

6.0 ASSESSMENT SUMMARY

Overall, the VAL system has reached a high level of developmental maturity. Indicative of this level of maturity was a demonstration of automatic coupling of two vehicles (two married pairs), one of which was disabled and pushed out to the next station, thus demonstrating a fully-automated, push-recovery capability.

The Lille-VAL system is the first fully-automated, driveless, urban transportation system of the AGT (Automated Guideway Transit) type to be implemented in France. As such, the system has been extensively examined by French authorities for its safety. The French Government in conjunction with the system developer, MATRA, has adopted an overall developmental approach that has been conservative, minimizing risk; that is, the hardware selected where possible has been in use in other transportation systems, e.g., the drive motors and associated chopper controls. A fixed-block control system with a higher level of electronics to ensure control system safety of automated vehicles has been implemented. The latter is an evolutionary development of an old and proven transportation technology.

To determine the system performance capabilities of the VAL system an extensive series of tests was performed with the first 2 of 38 production vehicles scheduled for operation in Lille, France by 1982. Prototype development was completed in 1975. Three types of tests were performed: endurance, performance, and safety. The tests were performed at a point in the development cycle where all subsystem development and testing had been completed, but system integration was not completed. System integration of the traction drive and suspension systems was completed, whereas system integration of the AVP, AVO, and AVS control elements was not completed. Therefore, any malfunction of the traction drive and suspension systems was viewed and weighted differently from a malfunction of the control system elements. During the entire test program, not one malfunction was experienced with the traction drive or suspension systems.

6.1 SAFETY

A safety group (Groupe Sécurité du Métro de Lille) has been established for the purpose of ensuring a safety level for VAL that is at least equivalent to that of urban systems presently in service and whose safety is recognized as being very high by both users and the public authorities. Numerous safety studies were performed including: specification of the safety requirements and objectives; a preliminary risk analysis based on accident type; kinematic and functional safety system review of the control system; safety of the vehicle body, brakes, electrical safety connections, door safety, wiring, and materials; safety of the traction and emergency brake command, i.e., absence of traction in emergency braking; safety of station platform doors and emergency doors; safety of lateral guidance, switching, running track, detection of under-inflation, grounding circuits, emergency lighting, and fire detection; safety during a variety of weather conditions; operational safety; and test verification. Although the safety systems have been reviewed and tested, these extensive studies and reports have not been translated and thoroughly examined. Overall, the VAL system has been designed to be safe and appears to meet all safety standards with the exception of the door closing force which exceeds the U.S. maximum.

Numerous safety tests were performed for verification. The safety systems in all instances of the test program performed successfully. No mishap or incident was recorded or observed. Specifically, the collision avoidance, overspeed protection, direction control, switch interlocking, and station safety were extensively tested. These were discussed in Sections 4.5 through 4.9. Each of these safety subsystems performed in accordance with their intended function in the presence of simulated malfuctions.

Evacuation of VAL is through the normal side exit doors onto a platform level with the floor. Thus, evacuation of a fully-loaded vehicle is possible within 20 second, providing an adequate and reasonable margin of time in the event of fire. Moreover, level evacuation to a platform on the side of the vehicle makes it easy for elderly to use and possible for handicapped in a wheelchair (60-centimeter width).

Fire retardant materials have been used throughout the vehicle. Differences between French and American material standards have not been examined in detail. On the whole, they appear to be similar.

The door closing force was found to be about 980 newtons. This is approximately seven times greater than the U.S. maximum of 133.4 newtons (30 pounds) allowable on elevators.[1] A small child could be injured by such a door closing force. A

[1]ANSI A17.1-1971 American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks.

safety edge on the door was not used. Rather, a hydraulic system is used to close the door that will reverse direction if the door is not allowed to close. However, reversal of the door will not be effected if the door is less than 5 centimeters from the closed position. Redesign of the door closing mechanism is necessary to meet U.S. standards. This may involve only an adjustment to a pressure regulation device.

6.2 VEHICLE

All system functions and operations including individual vehicle control were accomplished satisfactorily and without major problems. A comparison of the test results with the VAL published operational capacity and technical specifications indicated good agreement. Section 4.0 contains a detailed discussion of the test results.

The interior of the vehicle is 1.96 meters (6.43 feet) in width. The narrow width approach was taken to decrease civil engineering costs and to increase the number of seated passengers. This vehicle width does not allow easy movement up and down the aisles and likely provides a small degree of inconvenience for a seated passenger in the middle to access the numerous doors. Some inconvenience would also be experienced by other seated passengers. Standees would occupy the door area. They would have easy access to the large doors. Because of smaller numbers of people a passenger would encounter, in the seated and standing areas, entry and egress are more rapid. Although the layout of the narrow vehicle presents some minor inconvenience, it appears functional, aesthetically pleasing, and provides rapid entry and egress. The latter is important in minimizing dwell time during peak period operation and the concomitant effect on wait time. This trade off has placed higher importance on waiting time than on convenience of sitting, which is a sound consideration.

Access and egress to the vehicle interior was tested with a handicapped person in a wheelchair having a width of 60 centimeters. Little difficulty was presented to a handicapped person in a wheelchair; entry and egress presented no problem. Even with the auxiliary seat down there was no problem. Moreover, movement in a 60-centimeter-wide aisle was possible despite a near interference fit (see Figures 6-1, 6-2, and 6-3.) A specific area was not

FIGURE 6-1. WHEELCHAIR EGRESS THROUGH DOORS

FIGURE 6-2. WHEELCHAIR POSITIONED IN VEHICLE

FIGURE 6-3. WHEELCHAIR POSITIONED IN AISLE

available for a wheelchair, which necessitated the use of the doorway area. Evacuation in an emergency is through the normal side exit doors onto a 70-centimeter-wide guideway platform, level with the floor. A simulated test of an evacuation onto such a platform was performed demonstrating that a handicapped person in a wheelchair could evacuate the vehicle.

The location of the emergency stop handle above the doors would not permit a handicapped person in a wheelchair to reach the handle in the event of an emergency. Rather, such a handicapped person would have to use the voice communications system and request Central Control to stop the vehicle. However, it is not clear whether this handicapped person could access the voice communications system.

A handicapped person evaluated the comfort of lateral and longitudinal positions during the course of several trips around the test guideway. The brakes on the wheelchair were not functioning necessitating his holding on to the center or seat stanchions. The wheelchair in the longitudinal direction presented the greatest effort. This was tested facing forward and backward to the direction operation. The lateral position was considerably preferred in spite of a small radius turn (30 meters). The VAL vehicle interior did not present any problem to a handicapped person in a wheelchair, even though a specific area was not designed into the vehicle.

A 20-hour per day, 100-hour dependability test described in section 4.1 was conducted entirely in an automated mode with a single vehicle simulating revenue operation. The objective of these tests was to obtain preliminary dependability data on the VAL system. These tests were performed on the 02 production vehicle before integration testing of the control system was completed and prior to any endurance testing of the system.

The system availability for a single vehicle operation was determined not as a definitive system availability but as an indication of the potential performance of the system. The average availability for the 100-hour test was 0.959. On the final day of testing the total down time was 4 minutes out of 20 hours of continuous operation for an availability of 0.997 (see Table 4-1).

The principal cause of malfunctions was attributable to poor communications between the vehicle and station. In all instances the condition was cleared by Central Control through restart, retransmission of commands, and reinitiation of procedures. This demonstrated the flexibility of the software and the flexibility given to the Central Control operator to remotely circumvent problems or anomalous conditions in real time. If it is assumed that the majority of malfunctions experienced can be corrected during system integration of the command and control system, then a system availability of 0.98 appears achievable with four vehicles at the Lille Metro test track.

No failure occurred in the vehicle rolling stock equipment (i.e., propulsion brakes and suspension) which had completed system integration testing. Furthermore, throughout the entire period of testing not one malfunction was experienced with the running gear.

A series of emergency braking and propulsion and service braking tests were performed to determine their performance characteristics. Their performance was found to be in accordance with their technical specifications. The results of these tests are given in Sections 4.2 and 4.3.

Tests were performed to demonstrate that the vehicle speed and the commanded speed are in agreement and to demonstrate that longitudinal ride-comfort requirements were not exceeded. The vehicle speed, acceleration, and deceleration profiles were measured and compared to the speed command, acceleration command, and deceleration order under a variety of speed and braking conditions. In most instances the vehicle performance was within limits of the technical specification. These test results are presented in Section 4.0.

The stopping accuracy of vehicle in stations and the dwell-time adjustment for each platform of each station was measured. The ability to adjust the dwell time by both Central Control and by local station commands was measured. Satisfactory performance was achieved in each of these areas. A detailed discussion if given in Section 4.9.

Minimum headway measurements were made with two vehicles operating around the test track. Headways of 56.5 to 57.5 seconds were measured(see Section 4.13). This demonstrated the published capacity capability of VAL (7440 passengers/hr-lane).

The maximum vehicle interior noise level of 75 dbA at 60 km/hr was considerably higher than desirable (70 dbA). This noise level is primarily attributable to universal joints in the drive line. A change to a drive shaft system with three constant velocity joints has been designed and parts were on order. This is expected to greatly minimize the noise to an acceptable level.

Braking in the final station stopping loop was found to be somewhat erratic (see Figure 4-21). A redesign of this brake loop has been completed, but was not implemented at the time of test. It essentially involves a change to several values of gain within the loop to smooth the brake response. This is not a problem, but simply a part of the normal development cycle which must be completed.

Automatic coupling of vehicles was demonstrated with the coupling vehicle under manual control on a straight section, a 40-meter radius curve, and an "S" section. Lights, air, brake operation, and door operation in all instances were successfully restored to the failed vehicle. Failure recovery was demonstrated by successfully pushing the failed vehicle in an automatic mode.

Automatic coupling of two vehicles in an entirely automatic mode was also successfully demonstrated. Section 4.4 contains a detailed discussion of these tests. Vehicle 01 was disabled on a straight section of track with a 5 percent grade. Vehicle 02 was brought around the loop under automatic control. When it encountered an occupied block the vehicle stopped. A remote command was given from Central Control for the vehicle to proceed and couple automatically with the vehicle ahead. After successful coupling, power, air, brake operation, and door operation were restored to the failed vehicle. Push out of the failed vehicle up the 5 percent grade was then accomplished. A stop was made at the next station. The vehicles (married pairs) were automatically uncoupled in a terminal. This capability will permit failure recovery by pushing without the need to send maintenance personnel to the vehicle. Hence, the availability will be enhanced by significantly decreasing down time.

6.3 GUIDEWAY AND STATIONS

The guideway construction in Lille was subdivided into the basic structure (the responsibility of CUDL), and the running and guidance surfaces and the power distribution and control (the responsibility of MATRA). Four types of concrete guideway have been employed: elevated, at grade, cut and cover, and tunnels. Aesthetically, the elevated guideway appears more massive than necessary. This is due to the high concrete parapet walls. These were used in Lyon and Marseilles. Their acceptability in these locations was a prime determinant for their use in Lille despite the questions raised over aesthetics. The high parapet wall provides a handrail 1 meter above the emergency egress platform which is level with the vehicle floor.

The Berlin and modified Berlin methods have been employed for cut and cover. In essence, this approach maintains a ramp in the excavation area that is used for access by construction vehicles. The ramp is continuously excavated. This technique has resulted in rapid construction of 250 meters per month, a minimum of disruption, and low cost.

The biggest problem associated with tunneling in Lille is to insure that the waterproofing impregnation material for the limerock structure is uniformly applied. The tunnel structures were designed with a minimum cross section.

Each station was designed by a different architect, thereby retaining a unique character. This facilitates identification of stations. It also had the effect of spreading the work among many architects.

The switches operated quite satisfactorily. During the course of the test program each switch functioned approximately 5000 times. It is fast acting; the switch functions within 3 seconds.

6.4 POWER DISTRIBUTION

The power distribution system is a conventional 750 volt dc system. It employs hardware that has been used in other systems. The lateral guidance beams double as power and ground rails. Measurements for ground faults were not made. The performance of the power distribution system was without fault; however, a number of power outages were experienced. This was determined to be a problem residing with the French power company. Overloads in the immediate region caused circuit breakers to trip, cutting out power to the test track. This was not a fault of the system.

6.5 COMMAND AND CONTROL

The development and testing of the command and control subsystem and the AVP, AVO, and AVS were completed. However, system integration and system level tests were not completed. Because of this, a number of minor problems were experienced, primarily of a communication nature. In one case a simple repositioning of an antenna loop to increase the gain eliminated the majority of problems.

The safety system was extensively tested. Collision avoidance, switch interlocking, station safety, direction control were tested for safety. Their design and performance were satisfactory. Headway control with two vehicles was also tested. Its performance was in accordance with the design requirements; that is, headways of less than 60 seconds were satisfactorily demonstrated. Moreover, a successful demonstration of push recovery was performed; automatic coupling of two passenger units, one of which was disabled, and push-out to the next station were demonstrated. This capability provides significant potential for a system with high availability.

6.6 CONCLUSIONS

The VAL system has reached an advanced state of development and is presently being developed as a 12-kilometer, fully-automated urban transportation system in Lille. The technology employed is essentially state-of-the-art. It represents an evolutionary step beyond rapid rail automatic vehicles with manual override. A more extensive Automatic Vehicle Protection (AVP) system has been developed to take the place of the manual override.

During the course of the demonstration test program, VAL demonstrated that it could achieve high levels of dependability and availability. On its best day the system with a single vehicle operating accumulated 4 minutes of downtime over a 20-hour test period. This is considerably higher than the system availability requirement of 0.98 which is to be achieved 1 year after qualification testing with four vehicles operating simultaneously. Moreover, VAL has demonstrated the advanced capability of automatic coupling and push out. This will enhance operational availability.

The safety of the system was tested extensively. Numerous faults were artificially created. In all these cases the safety system responded to these faults safely. VAL has been designed to operated safely under all perceivable conditions.

VAL is currently completing the development engineering phase. When it is completed in mid-1981, it is expected that all engineering development problems, which are only of a minor nature, will be corrected.

220 copies

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981 500-856/238

...artment
...portation
...rch and
...l Programs
...istration
...uare
..., Massachusetts 02142

Postage and Fees Paid
Research and Special
Programs Administration
DOT 513

U.S. MAIL

Official Business
Penalty for Private Use $300