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Hydrogen Fuel Cell Buses for Urban Transport in Brazil: Functional Test Results

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EPRI Project Manager

A. Rogers
M. Duvall

Cosponsors:

United Nations Development Program (UNDP)
SCN, Quadra 02, Bloco A, Ed. Corporate Financial Center, 7th floor
70712-901, Brasília DF Brazil

Project Manager
Mr. Carlos Abreu Castro
Ms. Rose Diegues

Empresa Metropolitana de Transportes Urbanos (EMTU)
Rua Joaquim Casemiro, 290 Planalto
09890-050, São Bernardo do Campo,SP Brazil

Project Manager
Mr. Carlos Zündt

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Netz Automotiva Engenheiros Associados Ltda.

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This document was prepared by

Netz Automotiva Engenheiros Associados Ltda.
R. Caucaia, 16A
04147-100, São Paulo – SP
Brazil

Principal Investigators
Luso M. Ventura
Lázaro J. P. Azêdo

Dr. Ferdinand Panik
Ohmdener Strasse 1
73271 Holzmaden
Germany

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REPORT SUMMARY

This report describes functional tests conducted on a prototype hydrogen fuel cell hybrid bus to qualify the prototype for safe operation on an urban route in Sao Paulo, Brazil. The vehicle performed at or beyond requirements in all of the tests and is fully capable of operating on the intended route. After further tests in Sao Paulo and the building of the necessary hydrogen infrastructure, the prototype and three additional buses will be operated for at least two years.

Background

The Brazilian Fuel Cell Bus Project is a new technology demonstration program for urban buses funded by the Global Environment Facility (GEF) and the Brazilian Government and implemented by the United Nations Development Program (UNDP) and the Metropolitan Urban Transit Authority (EMTU) of Sao Paulo, Brazil. The technology used in the program is an advanced concept that takes into account the lessons learned from the 30 fuel cell buses the Clean Urban Transport for Europe (CUTE) program has been operating successfully since 2003/4. The Brazilian project started in May 2006, and the test prototype bus and the hydrogen infrastructure are now in the build-up phase. The main subsystems—fuel cell systems, high voltage power electronics, hydrogen storage and fueling systems, and batteries—are well-proven and mature systems.

Objectives

- To conduct functional tests to ensure that the hydrogen fuel cell bus fulfills all legal and safety requirements necessary for operation during forthcoming verification tests in
- To confirm that the bus meets performance specifications and requirements

Approach

The project team conducted a series of tests on the prototype bus on selected road test circuits in Caxias do Sul, Brazil and in the EMTU corridor in the São Paulo metropolitan area. The functional tests covered:

- Validation of overall capability to operate on the EMTU track
- Fuel Consumption
- Noise
- Acceleration
- Speed recovery
- Maximum Speed
- Startability
- Gradability
- Hillholding
- Service Brake

- Emergency Brake
- Parking Brake
- Brake Fading
- Regenerative Brake
- Steering Force

Results

The bus has full capability to operate on the EMTU track. The vehicle performed well in all trials, generally reacting far beyond the limits required by the consortium contract. The technicians and drivers, who conducted the tests and are extremely experienced in operating diesel-powered buses, consistently expressed positive comparative impressions on the bus's reactions, especially in regards to its safety in operation and its general performance. Despite the fact that the tests were conducted on roads and bus corridors instead of a well-defined test track, the results can be taken as representative.

Due to the impossibility of running the tests exactly according the specifications, mainly due to track unavailability, some tests were given only conditional approval. However, vehicle performance in these specific tests was consistently positive.

EPRI Perspective

Currently, the prototype bus has been moved to a new location in São Paulo, Brazil. In the next phase of study, the scope of activities will change, with attention focusing on such issues as fueling, transportation, maintenance training, operators training, parking practices, and the infrastructure needed to host the bus.

Keywords

Fuel cell vehicles
Electric transportation
Buses
Hydrogen fuel cells

ABSTRACT

As part of the Brazilian Fuel Cell Bus Project, a new technology demonstration program for urban buses, functional tests on selected road circuits in Brazil were conducted to qualify a prototype hydrogen fuel cell hybrid bus for safe operation on an urban route in Sao Paulo, Brazil. The functional tests covered fuel consumption, noise, acceleration, maximum speed, and several other performance items. The vehicle performed well in all trials and is fully capable of operating on the intended route. After further tests and the building of the necessary hydrogen infrastructure, it is planned to operate the prototype and three additional buses for at least two years in Sao Paulo.

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1
INTRODUCTION

The Brazilian Fuel Cell Bus Project is a new technology demonstration program for urban buses funded by the Global Environment Facility (GEF) and the Brazilian Government, and implemented by the United Nations Development Program (UNDP) and the Metropolitan Urban Transit Authority (EMTU).

The objective of this project is to build first one Fuel Cell Hybrid Bus test prototype and the hydrogen infrastructure, and in a second phase the additional 3 buses for operation in Sao Paulo, Brazil for at least two years. An International Consortium was formed to conduct the project consisting of the following companies:

1. From Brazil: Bus companies Marcopolo and Tutto, and energy companies Petrobras and AES Eletropaulo
2. From Canada: Technology companies Ballard Power Systems and Hydrogenics
3. From Germany: Technology company Nucellsys
4. From the USA: EPRI International (EI), serving as project manager

The technology used in the program is an advanced concept that takes into account the lessons learned from the European CUTE program (30 fuel cell buses running successfully since 2003/4 in European cities), where all the technology partners were involved.

The project started in May 2006 and the test prototype bus and the hydrogen infrastructure are now in the build-up phase. The main subsystems—fuel cell systems, high voltage power electronics, hydrogen storage and fueling systems, and batteries—are well proven and mature systems with existing safety related analyses, tests and documentation.

The objectives of the functional tests are to ensure that the bus fulfills all legal and safety requirements necessary for the operation in the EMTU corridor during the phase of the verification tests and to confirm that the bus meets the performance specifications and requirements as proposed by the consortium in the contract *Project Bra/99/G32 "Hydrogen Fuel Cell Buses for Urban Transport in Brazil"*.

The following tests were conducted in the Functional Test Program:

- Validation of overall capability to operate on the EMTU track
- Fuel Consumption
- Noise
- Acceleration
- Speed recovery
- Maximum Speed

- Startability
- Gradability
- Hillholding
- Service Brake
- Emergency Brake
- Parking Brake
- Brake Fading
- Regenerative Brake
- Steering Force

The tests were partly done in Caxias do Sul, Rio Grande do Sul, Brazil, on selected road test circuits and in the EMTU corridor in ABC region in São Paulo metropolitan area.

The audience for this report includes those involved with hydrogen bus engineering and manufacturing, vehicle homologation, technical contract obligations, customer-centric bus operations, and EMTU customers themselves. This report reveals the technical approach used to approve the vehicle to those involved with product design, vehicle performance, logistics, and infrastructure for the program.

Currently, the bus that is the subject of this report has been moved to a new location—São Paulo, São Paulo, Brazil. In the next phase of study, the scope of activities will change. Infrastructure to host bus, fueling, transportation, maintenance training, operators training, and parking practices are a few of the considerations to be reviewed at a later time.

2
TEST CONDITONS

Performance Test Track

The acceleration and speed recovery measurements were done at night in an approximately 500 m long stretch at Ruben Bueno Alves Avenue in Caxias do Sul. This selected route had a slight incline with slope ranging from 0.27% in the far west and 2.9% in the far east. Due to this route slope, the measurements were done in both east and west directions.

To ensure minimum safety conditions, the measurements were performed after 10 p.m. on west direction route, which was closed by the Caxias do Sul Transit Department.

Measurements were done in dry track, with temperature between 15 and 20ºC.

Figure 2-1
Performance test track

The startability, gradeability and backward movement measurements were made on specific routes near Caxias do Sul, with route characteristics close to the specified ones.

Brake Test Track

The braking test measurements were done at night in an approximately 100 m long stretch at Rio Branco Avenue, with enough space to accelerate the vehicle to the test required speed.

In order to ensure data repeatability, all measurements were performed in the same direction, braking the vehicle always at the same point.

As with the acceleration test, the measurements were performed after 10 p.m. with support of the Caxias do Sul Transit Department.

Measurements were done in dry track and temperature between 15 and 20ºC.

Figure 2-2
Brake test track

The gradeability, fading and auxiliary brake system measurements were done in the Rota do Sol Route, in specific routes with characteristics close to the specified ones and the minimum safety conditions.

Measurements were done in dry track and temperature between 20 and 25ºC.

EMTU Track

The consumption measurement and 0%, 5% and 10% slope acceleration and gradeability test were done at EMTU route from *Santo André* to *São Mateus* terminals.

3
SANTO ANDRÉ–SÃO MATEUS ROUTE

Fading Brake Test Track

The fading and auxiliary brake system measurements were repeated at Av. Aldino Pinotti in São Bernardo do Campo.

Measurements were done in dry track and temperature between 15 and 20ºC.

Figure 3-1
Fading brake test track

Loading

The Acceleration and Speed Recovery measurements were done simulating 29 seated passengers and 37 standing ones, resulting in a 20% overload than the permitted weight (as specified by Departmento Nacional de Trânsito, or DENATRAN).

Although there are some different loading specifications for each of the different tests—that would require several vehicle loadings and unloadings, due to time, logistics and route reasons—the performance tests (acceleration, speed recovery and regenerative brake) were done at 20% overload, and the brake tests were done at the DENATRAN permissible weight (16,000 kg, or 16 t).

In the performance tests done at the EMTU track, the bus was loaded with 17 t total gross weight, 30 passengers equivalent. The consumption measurement was done with the same weight (17.7 t) at the 500 km Caxias ride test.

Table 3-1
Results of acceleration and speed recovery measurements

Weight (kg)	**Front Axle**	**Rear Axle**	**Total**
Unloaded	5.000	9.200	14.200
Axles technical limits	7.500	13.000	20.500
DENATRAN	6.000	10.000	16.000
Test weight (20% overload)	7.200	12.000	19.200

Tests Schedule and Location

Due to track and hydrogen fueling limitations, the tests were performed in Caxias and São Bernardo do Campo according to the following table.

Table 3-2
Test schedule and location

Content	**Test**	**Period**	**Location**
2	Fuel Consumption	1 Nov 2008	Caxias do Sul
		2 Apr 2009	São Paulo (EMTU track)
3	Noise	Mar 2009	Caxias do Sul
4	Acceleration	1 Mar 2009	Caxias do Sul
		2 Apr 2009	São Paulo (EMTU track)
5	Speed Recovery	Mar 2009	Caxias do Sul
6	Maximum Speed	Mar 2009	Caxias do Sul
7	Startability	Mar 2009	Caxias do Sul
8	Gradeability	1 Mar 2009	Caxias do Sul
		2 Apr 2009	São Paulo (EMTU track)
9	Backward Movement	Mar 2009	Caxias do Sul
10	Service Brake	1 Mar 2009	Caxias do Sul
		2 Apr 2009	São Bernardo do Campo

Table 3-3
Test schedule and location (Continued)

Content	Test	Period	Location
11	Emergency Brake	Mar 2009	Caxias do Sul
12	Parking Brake	Mar 2009	Caxias do Sul
13	Brake Fading	1 Mar 2009	Caxias do Sul
		2 Apr 2009	São Paulo (EMTU track)
14	Regenerative Brake	Mar 2009	Caxias do Sul
15	Steering Force	Apr 2009	São Paulo (METRA)

Data Logging

In the performance tests (acceleration, speed recovery, startability, gradeability and backward movement) the following data were logged: duration, engine power, engine rpm, speed, accelerator pedal position, and brake pedal position.

In the brake tests. the following data were also logged: brake pedal force, front axle air pressure and rear axle air pressure.

The data came from two vehicle controller-area network (CAN) lines, one operating at 29 bit, 250 kBd and the other at 11 bit, 500 kBd. The data acquisition software used was Vector CANalyzer (CANalyzer/pro, version 6.1.20) furnished by NuCellSys. The controller's software had the following versions:

- Display: Display_rev09_03_22
- VCUA: PROG1_VCUA_rev09_03_06
- VCUB1: PROG1_VCUB1_rev09_03_06
- VCUB2: PROG1_VCUB2_rev09_03_06
- DICO: UND_gw008g
- MSB: msb_STD29_250k_3Bat_V4B8_24-01-08_ExtisoOff_StdBal_5DFC

Other data necessary to perform the vehicle analysis were obtained by processing the acquired data.

Instrumentation

Figure 3-2
Brake pedal load cell

Figure 3-3
Pressure Transducer, Rear Axle Bringer BRPT 030

Figure 3-4
Pressure transducer, front axle Bringer BRPT 030

Figure 3-5
Thermometer TFA scantemp 410

Figure 3-6
Steering system load cell HBM S40
HBM S40

4
RESULTS

Validation of overall capability to operate on the EMTU track

Table 4-1
Validation of overall capability to operate on the EMTU track

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Overall operation capability check-out		
Status	Disapproved	Conditional approval	**Approved**

The vehicle has full capability to operate on the EMTU track as regards tested and analyzed items. The results of the tests carried out shows the high level of maturity of the Hydrogen Brazilian Bus project on the tested topics.

At a first 500 km Ride Test in Caxias do Sul, the vehicle showed its good potential. At that time the Netz team, supported by the partners involved in the test run, could define several adjustments and improvements (axles alignment, brake adjustment, and so on), common at this development stage. These adjustments were applied with positive results in the functional test phase. The adjustments contributed to the positive results both in functional tests and in vehicle dynamic behavior (stability, comfort, handling, and driving safety).

The vehicle responded positively in all trials, generally performin far beyond the limits established by both norms and the contract. During the tests, the Netz technicians and drivers, extremely experienced in operating diesel-powered buses, consistently expressed positive comparative impressions of the H2 Bus, especially regarding operational safety and general performance. The H2 Bus was positively evaluated in the EMTU corridor with respect to its general performance, with better performance than the conventional diesel-powered vehicle fleet.

Fuel Consumption

Table 4-2
Fuel consumption

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-3
Average fuel consumption results on a 500 km ride test on the EMTU track

	Average unloaded	**Average loaded**	
Average Consumption (kg H²/100 km)	15.76	17.37	**15.72**
Consumption with Energy Recovery System (kg H²/100 km)	13.04 (*)	14.90 (**)	

Several updates and improvements were made belatedly and, on a second phase, this functional measurement was done in the EMTU track simulating a usual bus operation: stopping in each bus stop and at a 50 km/h maximum speed limit.

500 km Ride Test: Fuel consumption measured during the first 500 km (November; 2008) and despite a very steep stretch in Caxias do Sul the result was in the range of the proposal consumption, with a 35 kW energy consumption from the auxiliaries.

Table 4-4
500 km ride test results

Date	Track	Load (passen-gers)	Distance (km)	H^2 (kg)	Con-sumption (kg / H^2/100 km)	Battery dis-charge (% SOC)	Consumption, battery corrected (kg / H^2/100 km)
18/11	1	3	20.1	2.75	13.66	1.67	13.95
18/11	2	3	29.1	4.65	15.98	– 7.67	15.04
20/11	1	3	20.75	2.90	13.99	13.67	16.34
20/11	1	3	20.6	4.01	19.46	– 14.33	16.98
21/11	2 x 2	3	68.8	12.71	18.48	– 15.33	17.68
22/11	2	3	29.4	2.92	9.92	43.33	15.19
22/11	2	3	29.4	3.55	12.06	8.67	13.11 (*)
22/11	2	3	29.4	3.81	12.97	0.00	12.97 (*)
25/11	2	3	29.3	4.69	16.00	37.50	20.57
26/11	2	40	29.2	3.95	13.52	47.00	19.27
26/11	2	40	29.0	4.77	16.43	12.33	17.95
26/11	2	40	29.1	6.04	20.77	12.67	22.33
27/11	2	40	29.2	4.43	15.17	6.67	15.98 (**)
27/11	2	40	28.9	3.94	13.63	6.00	14.37 (**)
27/11	2	40	29.6	3.92	13.26	9.00	14.34 (**)
Track 1: Overland roads: Cobblestone, gravel and paved roads					Average unloaded:		**15.76**
Track 2: Regular bus transit with stops; urban and inner city					Average loaded:		**17.37**

The test was performed with two load levels. Half of the distance only with driver and two or three technicians and the rest with 2,700 kg of additional load (equivalent to 40 passengers)

Status Report: First optimization and 500 km Reliability Test (November, 2008). The results show that when the vehicle was running with energy recovery system, even overloaded, the consumption values were around 15 kg H^2/100 km.

EMTU Track: Fuel was consumption measured on the EMTU track between Santo André and São Mateus, the most critical and inclined track. This track was chosen by the EMTU to verify bus performance. The fuel cell bus followed a common diesel bus, with a driver from the operator (Metra) to guarantee comprarable speed and stopping behavior. Due to the lack of hydrogen fuel, only two turns in each direction could be performed. See the result in the following table.

Table 4-5
EMTU track test results

Date	Track	Distance (km)	H^2 (kg)	Con-sumption (kg H^2 /100 km)	Battery Discharge (% SOC)	Consumption, Battery Corrected (kg H^2/100 km)
15/04/09	SA - SM	8.4	1.17	13.92	9	17.75
15/04/09	SM - SA	8.7	1.22	13.99	0	13.99
15/04/09	SA - SM	8.5	1.53	18.01	–2	17.17
15/04/09	SM - SA	8.7	0.95	10.93	1	11.33
					Average Consumption:	**15.06**
Load: 18.000 kg (equivalent to 40 passengers)						
In the last turn from Sao Mateus to Santo Andre (11.33 kg/100 km) the Air condition was shut off caused by a problem with the Prisma converter (24V DC/DC). Ignoring this consumption and considering the first turn of Sao Mateus to Santo Andre twice (13.99 kg/100 km), the average is corrected as follows:						
					Corrected Average Consumption:	**15.72**

Note: The test was performed at night, at 18 degree Celsius outside temperature. The average auxiliary power consumption was about 10 kW. At higher temperatures, the auxiliary power consumption might be higher because of an increased cooling fan power demand.

Acceleration and Fading Tests: During the acceleration and fading tests the fuel consumption was measured. In these conditions there was a great difference between the results, but must be considered that on the acceleration test the vehicle was always accelerated at full power and in the fading test the energy recovery system was turned off.

Table 4-6
Fuel consumption during fading and acceleration tests

Consumption	Fading Test	Acceleration Test
	Energy recovery system turned off	Energy recovery system turned on
Average Consumption (kg H^2/100 km)	20.41	17.57

Specification 1 TOR

The hydrogen gas stored in the bottles must provide minimum autonomy of 300 km to the vehicle, and the maximum expected fuel consumption is 15 kg H^2 / 100 km.
The tested vehicle, loaded in GVW, must perform city route (EMTU) in several days' cycle.
The day test temperatures must be registered as systematically as possible.

Specification 2 Consortium (According Technical Documentation October, 2006)

15 kg H^2/100 km could be reached under the conditions that the average load by the auxiliaries not exceed 35 kW.

Appendix Reference

Appendix (L) – Santo André – São Mateus route

Interior and pass-by noise

Table 4-7
Interior and passy-by noise results

Category	**Specification**	Technology	**Homologation**
Test place	Proving Ground	**Route**	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-8
Pass-by noise with auxillary engines turned off and on

Pass-by-noise – Auxiliary engines turned off			
rpm, speed		**Average Left Side** (dB(A))	**Average Right Side** (dB(A))
In: 3750rpm, 28 km/h	Out: 5000rpm, 38 km/h	70.9	71.8

Pass-by-noise – Auxiliary engines turned on			
rpm, speed		**Average Left Side** (dB(A))	**Average Right Side** (dB(A))
In: 3750rpm, 28 km/h	Out: 5000rpm, 38 km/h	77.1	78.3

Table 4-9
Interior noise with air conditioner and auxillary engines turned off and on

Interior noise – Air conditioner and Auxiliariy engines turned off				
Speed (km/h)	**Driver position** (dB(A))	**Passengers compartment**		
		Front (dB(A))	**Middle** (dB(A))	**Back** (dB(A))
40	64.8	64.8	65.3	66.8
60	69.8	67.6	68.5	69.7
70	69.8	71.3	70.2	69.2
Max. Acceleration 40-70	73.9	75.3	76.7	75.3

Interior noise – Air conditioner and Auxiliary engines turned on				
Speed (km/h)	**Driver position** (dB(A))	**Passengers compartment**		
		Front (dB(A))	**Meddle** (dB(A))	**Back** (dB(A))
40	70.5	69.9	72.6	75.3
60	72.8	71.5	72.0	78.1
70	72.4	71.7	75.9	77.8
Max. Acceleration 40-70	75.5	74.2	74.5	78.8

Interior noise – Air conditioner turned on and Auxiliary engines turned off				
Speed (km/h)	**Driver position** (dB(A))	**Passengers compartment**		
		Front (dB(A))	**Middle** (dB(A))	**Back** (dB(A))
40	70.3	70.1	70.6	75.5
60	73.1	68.6	71.4	71.3
70	71.6	70.9	71.7	72.2
Max. Acceleration 40-70	75.0	72.0	74.2	77.6

Tests done by Marcopolo. Reports 009/09 and 010/09 (03.4th.2009).

The vehicle meets the EEE 0019/4 and CONAMA 272/200 resolutions concerning interior noise.

The vehicle meets the EEE 0038/3 resolutions concerning interior noise. There was great improvement in pass-by-noise noise levels after the acoustic package improvement, mainly when the auxiliary engines are turned off.

However, as measurements were made in the Rota do Sol Route, and not in a specific track, there is a measurement reliable damage.

Specifications

Internal noise tests according to EEE 0038/3 – Marcopolo internal engineering specification.

Pass-by-noise according to EEE 0019/4 and ABNT NBR 15145/2004 to check the CONAMA 272/2000 specification.

Acceleration test

Table 4-10
Acceleration test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-11
Acceleration test results at Caxias do Sul route

Acceleration (0% slope)				
Direction		**West**	**East**	**West**
0 to 50 km/h	**Average**	**1st Measurement**	**2nd Measurement**	**3rd Measurement**
Acceleration (m/s^2)	1.15	1.27	1.06	1.22
Time (s)	12.1	11.0	13.1	11.4
Acceleration Variation Rate (0% slope)				
Direction		**West**	**East**	**West**
0 to 5 km/h	**Average**	**1st Measurement**	**2nd Measurement**	**3rd Measurement**
Average Rate (m/s^3)	1.75	3.17(*)	1.70	1.80

(*) Not considered

EMTU Route				
Acceleration (0 to 50 km/h)				
Slope	**0%**	**5%**	**10%**	**15%**
0 to 50 km/h	**0 to 50 km/h**	**0 to 40 km/h**	**0 to 30 km/h**	**0 to 20 km/h**
Acceleration (m/s^2)	1.10	1.02	1.86	-
Time (s)	12.7	10.9	6.0	-
Acceleration Variation Rate				
0 to 5 km/h	**0% slope**	**5% slope**	**10% slope**	**15% slope**
Average Rate (m/s^3)	**1.73**	**1.73**	**0.94**	**-**

The measurements were done in a 0% slope route in Caxias do Sul and in EMTU track from Santo André to São Mateus in parts with a 5% and 10% slope.

There was no other route with the specified topography available.

The final acceleration results meet the basic technical specification to a 0%, 5% and 10% slope.

In the Backward Movement Tests was recorded a 0.52 m/s^2 average acceleration at the moment of start on a 20.5% slope route, greater than a specified one to a 10% slope route (Appendix F).

Specifications

Acceleration is specified as the period (in seconds) that the vehicle takes to go from immobility to speed on a flat track. The vehicle shall be able to reach the following accelerations on slopes:

1. 1.10 m/s^2 @ 0%;
2. 1.00 m/s^2 @ 5%;
3. 0.5 m/s^2 @ 10%;
4. 0.1 m/s^2 @ 15% (at the moment of start).

The vehicle acceleration shall be limited, in whatever situation, to a maximum value of 1.3 m/s^2.

The acceleration variation rate shall be limited to a maximum value of 1.5 m/s^3, either in the moment of start of the motor or during the reapplication of the traction effort.

Procedures

From the rest position the vehicle shall be accelerated until the specified velocity. Due to the route slope the measurements were done in two directions, east and west.

The acceleration and acceleration variation rate results came from the *speed* x *time* graphics.

Appendix Reference

Appendix (A) – Acceleration test graphics

Appendix (B) – Acceleration variation rate graphics (Acceleration test)

Appendix (E) – Backward Movement test graphics

Speedy recovery test

Table 4-12
Speedy reovery test results

Category	Specification	Technology	Homologation
Test place	**Proving Ground**	**Route**	**EMTU track**
Objective	**Basic Technical Specifications check-out**		
Status	Disapproved	Conditional Approval	**Approved**

Table 4-13
Speedy reovery test results by direction

Speed Recovery					
Direction		**East**	**West**	**East**	**West**
20 to 60 km/h	**Average**	**1st Measurement**	**2nd Measurement**	**3rd Measurement**	**4th Measurement**
Acceleration (m/s²)	0.73	0.64	0.83	0.62	0.82
Time (s)	15.3	17.1	13.2	17.5	13.4

40 to 60 km/h	**Average**	**1st Measurement**	**2nd Measurement**	**3rd Measurement**	**4th Measurement**
Acceleration (m/s²)	0.54	0.44	0.63	0.43	0.65
Time (s)	9.6	11.2	8.2	11.4	7.5

The speed recovery test was done only up to 60 km/h because this is the vehicle limited speed and, due to safety issues, the vehicle powertrain is automatically turned off at 80 km/h.

The final acceleration results, numbers and driver feeling are similar to a Diesel-powered vehicle, even with the 20% overload. The test was performed at Ruben Bueno Alves Avenue in Caxias do Sul.

Specifications

Time required for recovery (vehicles with half load on a flat track): from 20 to 80 km/h; from 40 to 80 km/h; from 60 to 80 km/h.

Procedures

From the rest position the vehicle shall be accelerated from 20 km/h and 40 km/h until the specified velocity – 60 km/h

Due to the route slope the measurements were done in two directions, east and west.

The acceleration and acceleration variation rate results came from the speed x time graphics.

Appendix Reference

Appendix (C) – Speed recovery test graphics

Maximum speed test

Table 4-14
Maximum speed test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	**Conditional Approval**	Approved

Table 4-15
Maximum speed test results by direction

Maximum Speed				
Direction		**West**	**East**	**West**
	Average	**1st Measurement**	**2nd Measurement**	**3rd Measurement**
Speed (km/h)	73.04	75.15	70.81	75.87
Acceleration (m/s^2)	0.69	0.79	0.61	0.76
Time (s)	17.6	15.3	19.7	15.7

Maximum speed (average) on test conditions was 73.04 km/h. This value is compatible with a conventional diesel urban bus in this category.

The vehicle received conditional approval because it did not have a 55 km/h excess sound alert signal and a counter to record the number of times that the 60 km/h speed was reached.

These deficiencies can be easily remedied by using either the vehicle software or an easily purchased GPS navigation system.

The measurement was performed at Ruben Bueno Alves Avenue in Caxias do Sul.

Specifications

When the vehicle exceeds 55 km/h, a sound signal shall be activated.

The system shall limit the maximum speed of the vehicle at 60 km/h, and a three-digit counter shall record the number of times that that speed was reached.

Observation: Due to safety reasons, the propulsion system is turned off at 80 km/h.

Procedures

During the acceleration tests, the vehicle was made to run at its maximum speed.

Startability test

Table 4-16
Startability test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-17
Startability test results by direction

Acceleration				
Direction		west	east	west
0 to 50 km/h	Average	**1st** Measurement	**2nd** Measurement	**3rd** Measurement
Acceleration (m/s²)	1.15	1.27	1.06	1.22
Time (s)	12.1	11.0	13.1	11.4

The final acceleration results meet the basic technical specification to a 0% slope, even with a 20% overload.

Specifications

Starting from the rest position on a horizontal pavement and in an environment with a temperature between 15ºC and 25ºC, the vehicle, at 18.5 t total gross weight condition, shall reach 50 km/h at most in 15 seconds.

Procedures

From the rest position the vehicle shall be accelerated until the specified velocity. Due to the slope, the measurements were done in both track directions.

The acceleration results came from the speed x time graphics.

The measurement was performed at Ruben Bueno Alves Avenue in Caxias do Sul.

Appendix Reference

Appendix (B) – Acceleration test graphics

Gradeability test

Table 4-18
Gradeability test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional Approval	**Approved**

Table 4-19
Gradeability test results by slope

Gradeability				
Slope	**0%**	**5%**	**10%**	**15%**
Maximum speed (km/h)	73.4	61.0	38.0	–
Acceleration	0 to 50 km/h	0 to 40 km/h	0 to 30 km/h	0 to 20 km/h
Time (s)	12.7	10.9	6.0	–

The vehicle reached the bottom of a slope from 8.4% to 13.2% at 38 km/h average speed, greater than the specified to a 10% one in the test done in Caxias do Sul route. Due to the route slope variation the top speed was 47 km/h.

In the tests done in EMTU track the vehicle reached the bottom of the 5% and 10% slope at average speed greater than the specified.

Due to route availability the test was not done on a 15% slope.

Specifications

The vehicle must be able to go down a slope minimum speeds, from the rest position, on a straight line:

1. 60 km/h @ 0%
2. 40 km/h @ 5%
3. 30 km/h @ 10%
4. 20 km/h @ 15%

Procedures

Due to the unavailability of specific locations, the measurements were taken in the Rota do Sol Route in a slope from 8.4 to 13.2% and approximately 2 km long and in EMTU track from Santo André to São Mateus, in parts with a 5% and 10% slope.

The vehicle started the slope at 0 km/h and was accelerated, at full power, until the top of the route.

Appendix Reference

Appendix (D) – Gradeability test graphics

Appendix (L) – Santo André – São Mateus route

Backward movement evaluation

Table 4-20
Backward movement test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-21
Multiple measurements for backward movement test results

Backward Movement				
	Average	**1st Measurement**	**2nd Measurement**	**3rd Measurement**
Backward displacement (m)	0.055	0.039	0.100	0.026

Approved. In both conditions, the backward movement was not over 0.1 m.

Specifications

The vehicle shall be started with an automatically controlled acceleration, regardless of its load and the slope, preventing the backward movement of the vehicle, allowing the motor to be exerted in the limit conditions, without detrimental surges.

Procedures

The vehicle was positioned in two postures, facing up and down slope, using only the service brake, in a 20.5% slope route, and then started in the uphill direction.

The driver stopped the vehicle on the slope and locked the parking brake. When the parking brake was unlocked, specifications required that the vehicle remain stationary with a minimum backward movement, without any acceleration.

The measurement was performed in Caxias do Sul.

Appendix Reference

Appendix (E) – Backward Movement test graphics

The test was filmed and will be available on CD.

Service brake test

Table 4-22
Service brake test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	CONTRAN 777/93 requirements check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-23
Service brake test results by deceleration and response time

Deceleration					
60 to 0 km/h	**Average**	**1st Measurement**	**2nd Measurement**	**3rd Measurement**	**4th Measurement**
Deceleration (m/s²)	6.3	8.1	6.0	6.0	4.9
Calculated braking distance (m)	37.1	31.8	37.6	42.2	36.8

Response time					
	Average	**1st Measurement**	**2nd Measurement**	**3rd Measurement**	**4th Measurement**
FA Response Time (s)	0.25	0.20	0.25	0.35	0.20
RA Response Time (s)	0.45	0.35	0.45	0.55	0.45

FA – Front Axle RA – Rear Axle

The braking system is able to cause a deceleration greater than the specified 5 m/s² and with a response time shorter than the specified 0.6s. The vehicle is approved even considering that the measurements were not made in a specific track.

Braking distance calculated according to ABNT NBR 10967 (Based on ECE 13):

$$S = \frac{0,54 \times V}{3,6} \quad \frac{2 \times V^2}{2 \times 3,6^2 \times d}$$

where S = Braking distance (m); V = Initial speed (m/s); d = Deceleration (m/s²).

The measurements carried out on the spot, based on the braking reference point and the track tires marks, were shorter than the calculated distance ones. This difference can be attributed to the method of measuring vehicle speed, in that the speed is measured from the electrical engine rotation—during braking, the wheels are locked, reaching zero rotation before vehicle immobilization. This difference also has an effect on the deceleration variation rate calculation, turning it in a bigger value than the reality.

The dynamic behavior was the expected one: straight-line braking without any driver intervention.

As measurements of deceleration variation rate, the results were not consistent.

Specifications

Test according to CONTRAN 777/93 rules, applied to “Standard Bus”, M3 category (vehicle over eight passengers plus driver with gross total weight over 5 t).

The friction brake system shall be drum or wheel with fully pneumatic action and made up of two independent circuits, one for the front shaft and the other for the back shaft, capable to cause a 5.0 m/s^2 deceleration with the vehicle at total gross weight situation. The vehicle shall remain directionally stable, in any braking operation and under any load conditions whatsoever.

The deceleration variation rate (jolt) shall be limited to the maximum value of 1.5 m/s^3, either in application or in the reapplication of the dynamic braking.

Procedures

The vehicle was braked from 60 to 0 km/h.

The test was done in a flat and dry track, with a 70 kgf force applied to the pedal brake.

All measurements with the regenerative brake were turned off.

The measurement was performed at Rio Branco Avenue in Caxias do Sul.

Appendix Reference

Appendix (F) – Service Brake Graphics

The test was filmed and will be available on CD.

Emergency brake test

Table 4-24
Emergency brake test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	CONTRAN 777/93 requirements check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-25
Emergency brake test results from 60 to 0 km/h

Emergency Brake	
	60 to 0 km/h (*)
Deceleration (m/s²)	2.42
Calculated braking distance (m)	73.47

(*) Without energy recovery system

Due to safety reasons the vehicle as not pushed to the braking limit, however the deceleration value was very close to the specification

Braking distance calculated according to ABNT NBR 10967 (Based on ECE 13).

Specifications

Test according to CONTRAN 777/93 rules, applied to "Standard Bus," M3 category (vehicle over eight passengers plus driver with gross total weight over 5 t).

The vehicle must be braked from 60 to 0 km/h using only the parking brake, instead of the service brake.

A 2.5 m/s² average deceleration must be obtained.

Procedures

The test must be done in a flat and dry track, with a maximum 60 kgf force applied to the parking brake lever.

The measurement was performed in Caxias do Sul.

Appendix Reference

Appendix (G) – Emergency Brake Test Graphics

Parking brake test

Table 4-26
Parking brake test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	CONTRAN 777/93 requirements check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-27
Air system filling time

	0 (bar) to 65%	**0 (bar) to 100%**
Duration (s)	132	317

Parking brake

Test done on a 20.5% slope on Primo Gastaldello Street, close to Tutto Trasporti.

The parking brake was able to keep the vehicle stopped without using the service brake, even with a 20% overload.

After the eight full service brake drives, the air pressure dropped to 4.5 bar and the parking brake was driven perfectly.

Specifications

Filling Time

The pneumatic compressor must be able to fill the system, at full power, in the following times:

From 0 bar to 65% max. pressure: 3 minutes (180 seconds);

From 0 bar to 100% max. pressure: 6 minutes (360 seconds)

Parking Brake

The vehicle shall remain stationary on a 20% slope at total gross weight condition.

After eight full service brake drives, the pressure in the system must be enough to drive the parking brake once.

Procedures

The filling time test was done with the vehicle stopped in a flat surface and the air compressor rotating at 1,780 rpm.

The parking brake test was done in both directions, up hill and down hill.

The measurement was performed in Caxias do Sul.

Brake fading test

Table 4-28
Brake fading test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	CONTRAN 777/93 requirements check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-29
Brake fading Caxias test

		Cycle 1	**Cycle 2**	**Cycle 3**
Brakes by cycle		6	8	6
Average Deceleration (m/s²)		2.34	3.14	4.29
Final Temperature (ºC)	**RSFA**	180.0	164.9	213.0
	LSFA	160.0	161.0	224.3
	RSRA	51.6	61.3	63.4
	LSRA	49.2	58.4	60.1

Test done in a 2x6 and 8-times cycle instead of a 20-time due to the route characteristics and conditions. At the end of each cycle it was necessary to turn back on the road and stop to measure the brake temperature.

No efficiency loss was observed between the first and third braking cycles. The average deceleration increase is attributed to the better tires efficiency due to the temperature increasing and mainly the better precision on the way the driver carried out the braking cycle.

Table 4-30
Brake fading SP test

Brakes by cycle		20
Average Deceleration (m/s²)		3.87
Final Temperature (ºC)	**RSFA**	249
	LSFA	263
	RSRA	220
	LSRA	232

RSFA – Right Side Front Axle
LSFA – Left Side Front Axle
RSRA – Right Side Rear Axle
LSRA – Left Side Rear Axle

This test was performed at Aldino Pinotti Avenue in São Bernardo do Campo in a 20 times continuous braking cycle according to the specifications. The time between each braking was always lower than one minute.

No efficiency loss was observed between the first and last braking, and the average deceleration was greater than the specified one.

Specifications

Test according to ABNT NBR 10967 (Based on ECE 13).

The vehicle shall be subjected to a 20 times braking cycle from 60 km/h to 30 km/h. The minimum time between each braking (including speed increasing at full power) is 60 (–0 +10) seconds.

A force shall be applied to the brake pedal, enough to achieve a 3 m/s² minimum deceleration.

Procedures

The vehicle was accelerated to 60 km/h, braked until 30 km/h and than accelerated again, at full power, to 60 km/h.

The cycle was repeated as many times as that was possible on the route conditions.

The brake temperature was taken on the drum brake outside using a Laser Thermometer.

Measurements were done in dry track and temperature between 20 and 25ºC in Caxias do Sul and 15 and 20º in São Bernardo do Campo.

Appendix Reference

Appendix (H) – Caxias Fading Brake Test Graphics

Regenerative brake test

Table 4-31
Regenerative brake test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-32
Regenerative brake deceleration

20 to 0 km/h	**Average**	**1st Measurement**	**2nd Measurement**	**3rd Measurement**	**4th Measurement**
Acceleration (m/s²)	0.59	0.54	0.76	0.43	0.63
Time (s)	9.8	10.3	7.3	13.0	8.8
40 to 0 km/h	**Average**	**1st Measurement**	**2nd Measurement**	**3rd Measurement**	**4th Measurement**
Acceleration (m/s²)	0.36	0.37	0.38	0.34	0.37
Time (s)	15.3	14.9	14.7	16.5	15.0

Due to its characteristics, the regenerative brake did not operate in full power, mainly in the 20 to 0 km/h test.

The system was suitable for use and had a much better performance than a conventional engine brake from a diesel-powered vehicle in this category. However, the system could not be compared to hydraulic or electromagnetic auxiliary brake systems specifications.

Note that the vehicle was 20% overloaded.

Specifications

The control equipment shall promote a maximum deceleration (as a component of the electric braking) between 1.0 m/s² and 1.3 m/s², adjustable according to the brake pedal stroke, at total gross weight condition, starting from any speed whatsoever up to 10 km/h.

Note: These specifications are valid for hydraulic and electromagnetic auxiliary braking systems (retarder).

Procedures

The vehicle was accelerated to 20 km/h and 40 km/h, and then braked until 0 km/h using only the regenerative brake. Due to a creepage effect, the final speed was always 5 km/h.

The acceleration came from the speed x time graphics.

The measurement was performed at Ruben Bueno Alves Avenue in Caxias do Sul.

Appendix Reference

Appendix (I) – Regenerative Brake Test from 20 to 0 km/h test graphics

Appendix (J) – Regenerative Brake Test from 40 to 0 km/h test graphics

Steering system force

Table 4-33
Steering system force test results

Category	Specification	Technology	Homologation
Test place	Proving Ground	Route	EMTU track
Objective	Basic Technical Specifications check-out		
Status	Disapproved	Conditional approval	**Approved**

Table 4-34
Steering system force

	Average	**Turning to Left Side**	**Turning to Right Side**	**Wheel Turned to Left, Force to Right**	**Wheel Turned to Right, Force to Left**
With hydraulic assistance (N)	27.3	27.1	27.6	25.8	23.8
Without hydraulic assistance (N)	371.6	369.2	374.1	312.4	297.2

Specifications

The tangential effort applied by the driver, in case of a total loss of hydraulic assistance in any maneuver, shall not be higher than 500 N.

Procedures

Measurement done with the vehicle stopped (worst condition) in a dry and flat concrete surface with the tires calibrated as specified by the manufacturer and unloaded.

The force as measured with the wheels aligned and completely turned to right and left, with and without hydraulic assistance.

Measurements done with a load cell HBM S40 (Tension Load Cell Universal “S” type).

The measurement was performed at METRA in São Bernardo do Campo..

Appendix Reference

Appendix (K) – Steering System force test photos

5 CONCLUSIONS

The vehicle has full capability to operate on the EMTU track as regards tested and analyzed items.

The results of the tests carried out to verify the homologation items, performance specifications, and requirements as proposed by the Consortium in the contract Project Bra/99/G32 “Hydrogen Fuel Cell Buses for Urban Transport in Brazil” and the items concerning norms accomplishment of the vehicle, especially on brakes, noise, consumption and performance, show the high level of maturity of the Hydrogen Brazilian Bus prototype on the tested topics.

Despite the fact that the tests were not done under optimal conditions on a well defined test track but were conducted on roads and bus corridors, the results can be taken as representative. The overall validation was that the vehicle responded positively to all trials carried out, generally reacting far beyond the limits established by both norms and the contract. During the tests, the Netz technicians and drivers, extremely experienced in operating diesel-powered buses, consistenly expressed positive comparative impressions on the H2 Bus’s reactions, especially regarding safety in operation and general performance.

Due to the impossibility of running the tests exactly according the specifications, mainly due to track unavailability, some tests were given conditional approval. In each event, the vehicle performance in these specific tests was consistently positive.

Table 5-1
Test results summary

Content	Test	Specifications	Result	Validation
1	Validation of overall capability to operate on the EMTU track		Approved	The vehicle has full capability to operate on the EMTU track as regards tested and analyzed items.
2	Fuel Consumption	TOR: minimum 300 km autonomy; 15 kg H^2 / 100 km.	Approved	15.72 kg H^2/100 km average consumption on EMTU track.
3	Noise	CONAMA 272/2000	Approved	The vehicle meets the CONTRAN resolutions concerning to interior and pass-by-noise.
4	Acceleration	The vehicle shall be able to reach the following accelerations on slopes: 1.10 m/s² @ 0%; 1.00 m/s² @ 5%; 0.5 m/s² @ 10%; 0.1 m/s² @ 15%.	Approved	The final acceleration results meet the basic technical specification to a 0%, 5% and 10% slope. Due to route availability the test was not done on a 15% slope.
5	Speed Recovery	Time required for recovery: from 20 to 60 km/h; from 40 to 60 km/h.	Approved	The final acceleration results, numbers and driver feeling, are similar to a Diesel powered vehicle.
6	Maximum Speed	When the vehicle exceeds 55 km/h, a sound signal shall be activated.	Conditional approval	Vehicle does not have a 55 km/h excess sound alert signal. This item can be easily solved by either using the vehicle software or a GPS navigation system available on the market.
7	Startability	The vehicle, at 18.5 t total gross weight condition, shall reach 50 km/h at most in 15 seconds.	Approved	The final acceleration results meet the basic technical specification to a 0% slope, even with 20% overload

Table 5-2
Test results summary (Continued)

Content	Test	Specifications	Result	Validation
8	Gradeability	The vehicle must be able to go down a slope minimum speeds, from the rest position, on a straight line: 60 km/h @ 0%; 40 km/h @ 5%; 30 km/h @ 10%; 20 km/h @ 15%.	Approved	The vehicle reached a higher speed than the specified to a 0%, 5% and 10% slope. Due to route availability the test was not done on a 15% slope.
9	Backward Movement	The vehicle shall be started with an automatically controlled acceleration, regardless of its load and the slope, preventing the backward movement of the vehicle, allowing the motor to be exerted in the limit conditions, without detrimental surges.	Approved	Approved. In both conditions, upward and downward.
10	Service Brake	Test according to CONTRAN 777/93 rules, applied to “Standard Bus”, M3 category (vehicle over 8 passengers plus driver with gross total weight over 5t).	Approved	Deceleration and response time better than the specified.
11	Emergency Brake	The vehicle must be braked from 60 to 0 km/h using only the parking brake, instead of the service brake. A 2.5 m/s² average deceleration must be obtained / reached.	Approved	Due to safety reasons in the road test the vehicle as not pushed to the braking limit, however the deceleration value (2.42 m/s²) was very close to the specification

Table 5-3
Test results summary (Continued)

Content	Test	Specifications	Result	Validation
12	Parking Brake	The vehicle shall remain stationary on a 20% slope at total gross weight condition.	Approved	The parking brake was able to keep the vehicle stopped without using the service brake.
13	Brake Fading	Test according to ABNT NBR 10967 (Based on ECE 13). The vehicle shall be subjected to a 20 times braking cycle from 60 km/h to 30 km/h. The minimum time between each braking (including speed increasing at full power) is 60 (-0 +10) seconds.	Approved	No efficiency loss was observed on the braking cycle. Average deceleration, in Caxias test, greater than the specified. The test was repeated in SP with positive results.
14	Regenerative Brake	The control equipment shall promote a maximum deceleration between 1.0 m/s² and 1.3 m/s². These specifications are valid to hydraulic and electromagnetic auxiliary braking systems (retarder).	Approved	The system was suitable for use and had a much better performance than a conventional engine brake from a Diesel Powered vehicle in this category.
15	Steering Force	The tangential effort applied by the driver, in case of a total loss of hydraulic assistance in any maneuver, shall not be higher than 500 N.	Approved	The average tangential effort applied by the driver, without hydraulic assistance, was 371.6 N. The maximum value was 374.1 N.

A
ACCELERATION TEST GRAPHICS

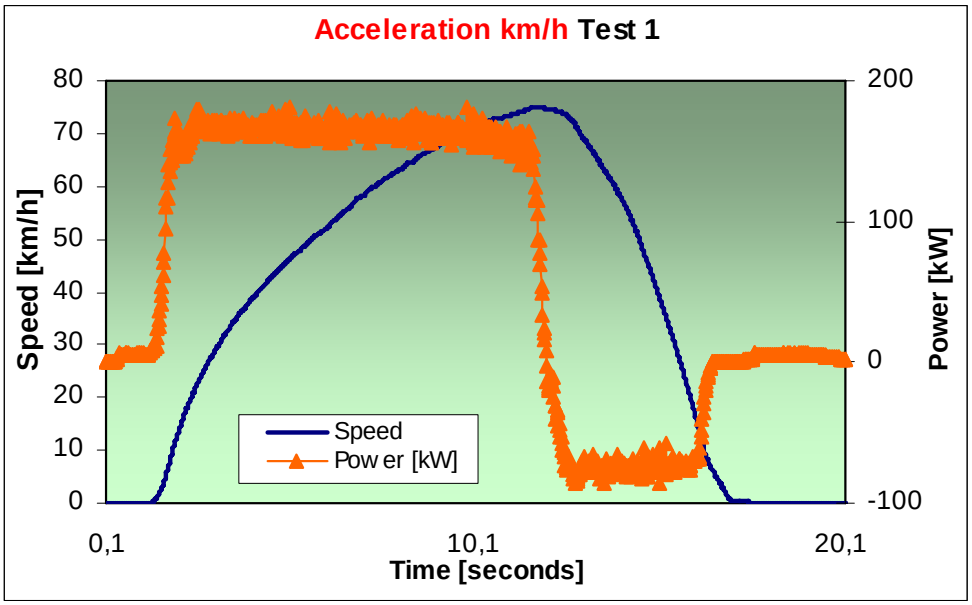


Figure A-1
Acceleration 0% Slope - Test 1 (Caxias do Sul)

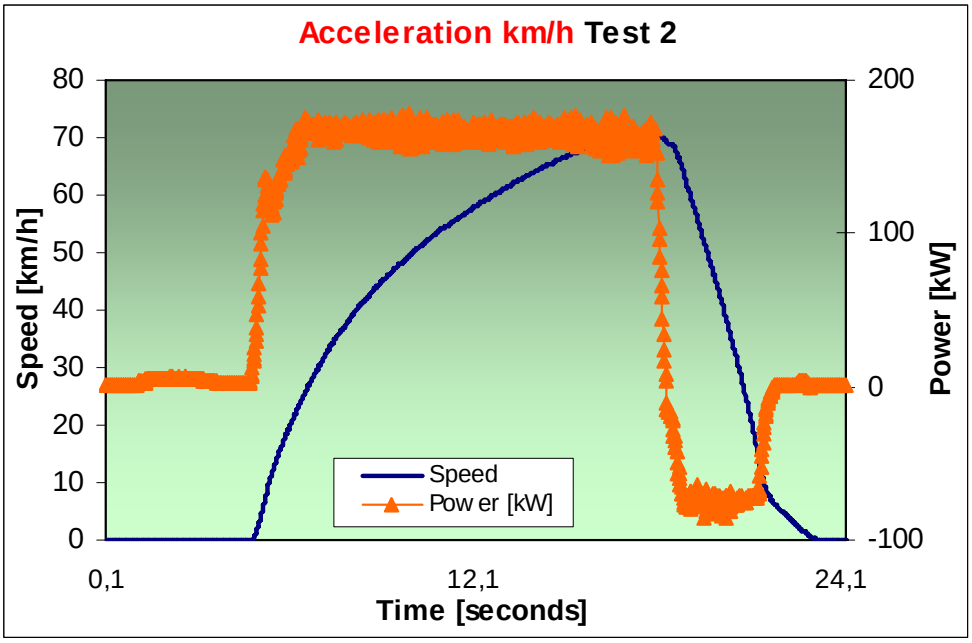


Figure A-2
Acceleration 0% Slope - Test 2 (Caxias do Sul)

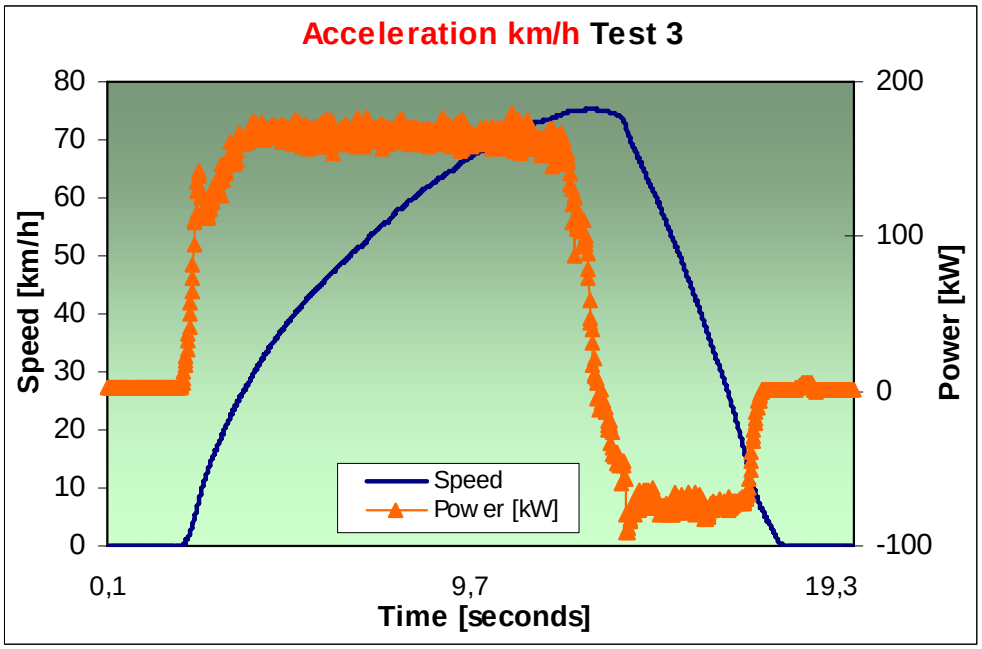


Figure A-3
Acceleration 0% Slope - Test 3 (Caxias do Sul)

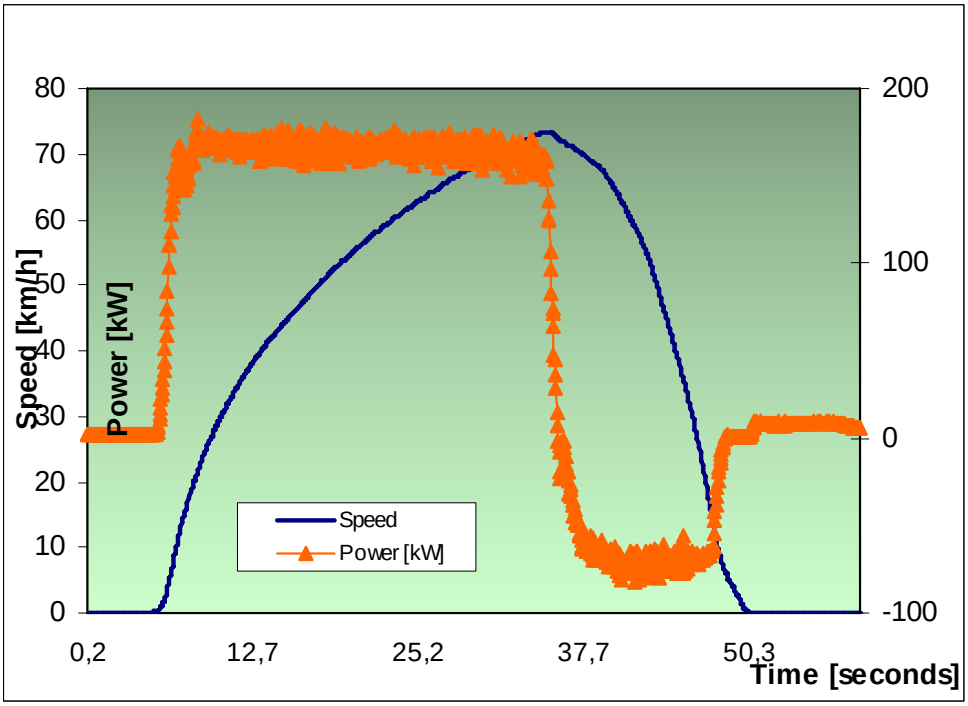


Figure A-4
Acceleration 0% Slope - Test 4 (EMTU Track)

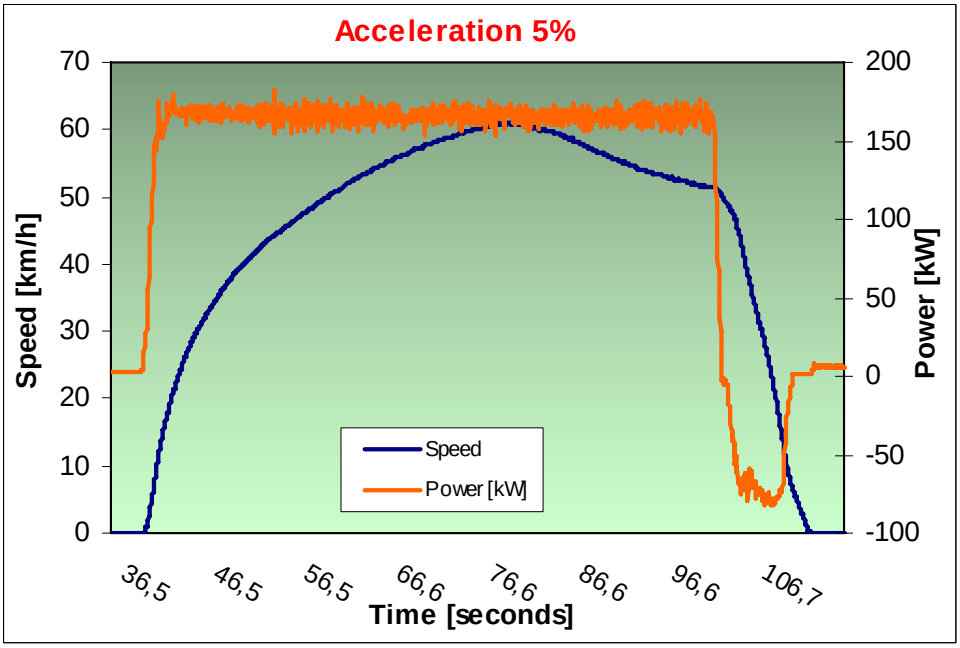


Figure A-5
Acceleration 5% Slope - Test 5 (EMTU Track)

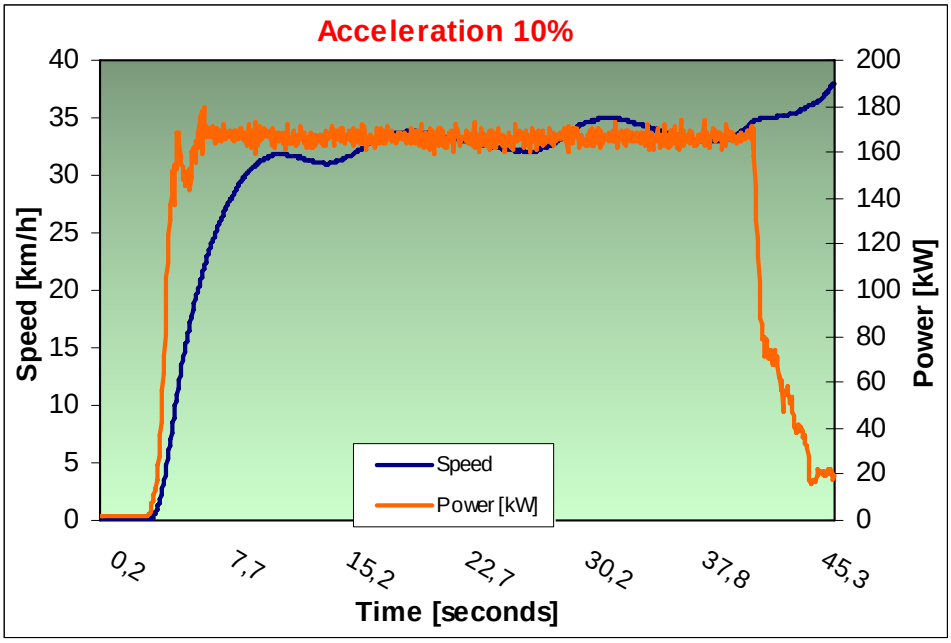


Figure A-6
Acceleration 10% Slope - Test 6 (EMTU Track)

B
ACCELERATION VARIATION RATE GRAPHICS (ACCELERATION TEST)

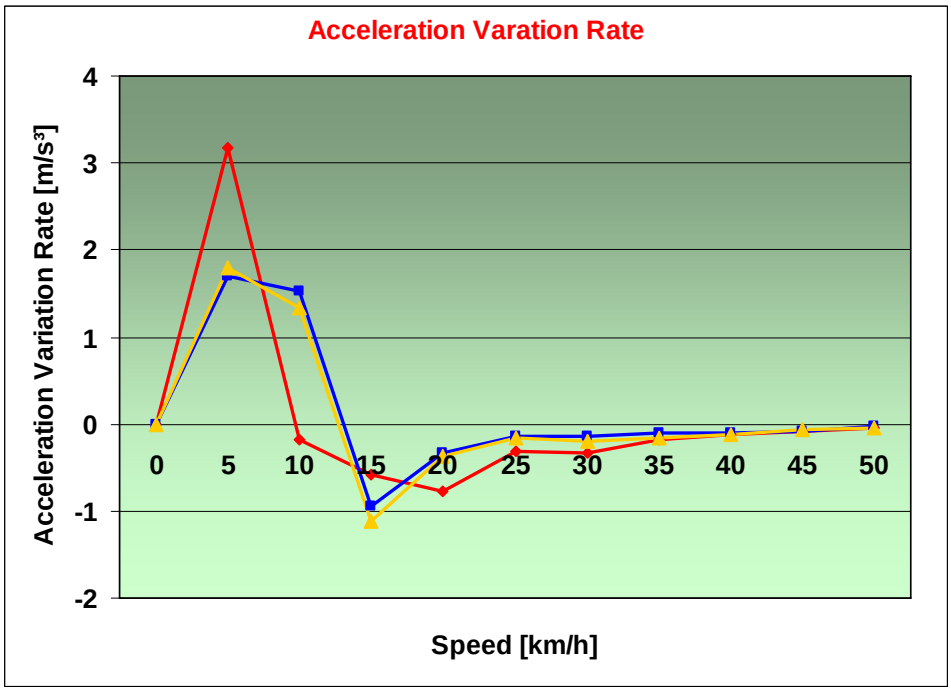


Figure B-1
Acceleration Variation Rate – Acceleration Test

C
SPEED RECOVERY GRAPHICS

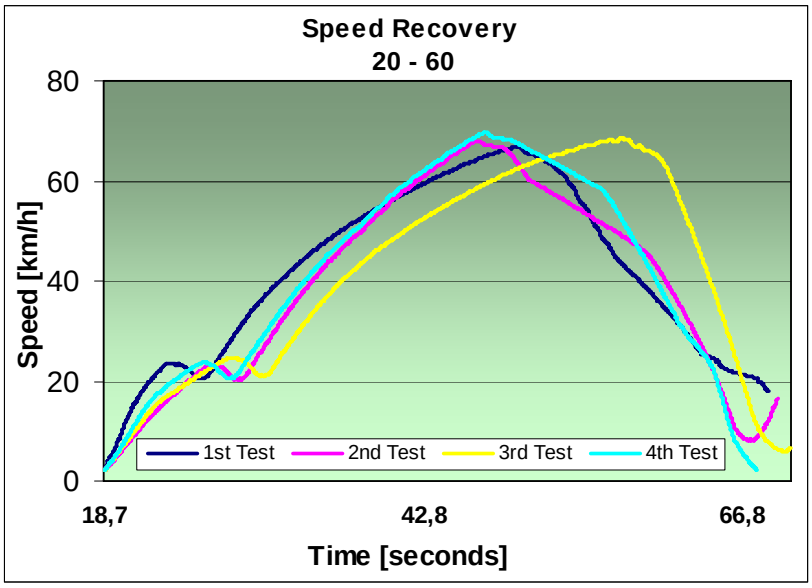


Figure C-1
Speed recovery from 20 to 60km/h

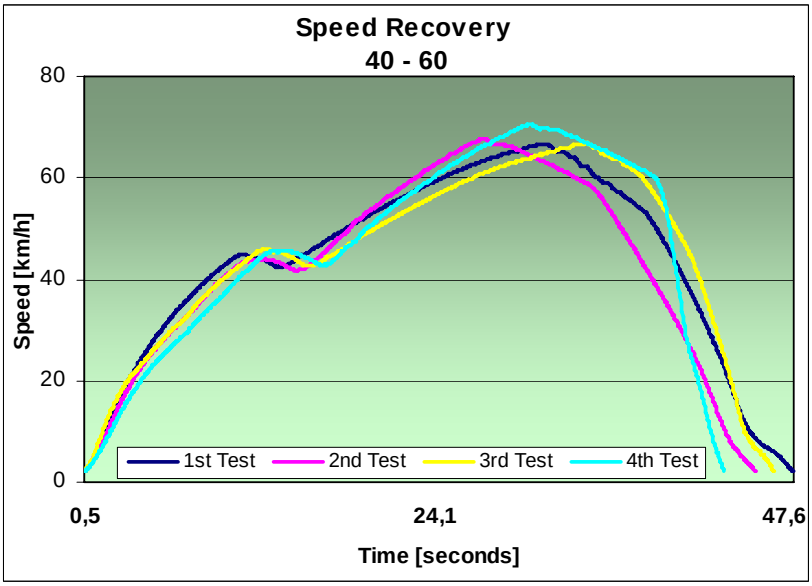


Figure C-2
Speed recovery from 40 to 60km/h

D
GRADEABILITY TEST GRAPHICS

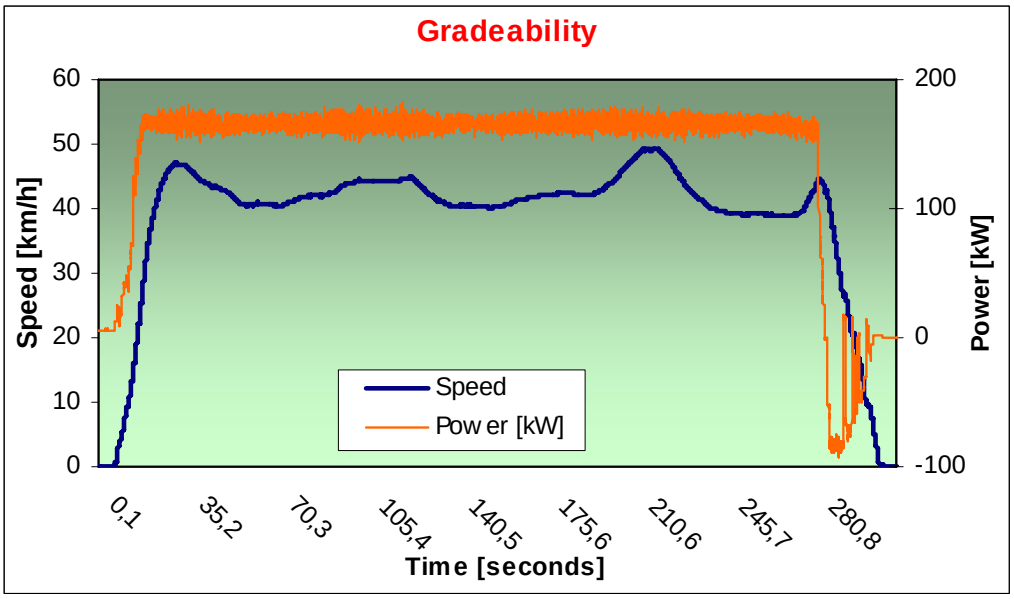


Figure D-1
Gradeability Test

E
BACKWARD MOVEMENT TEST GRAPHICS

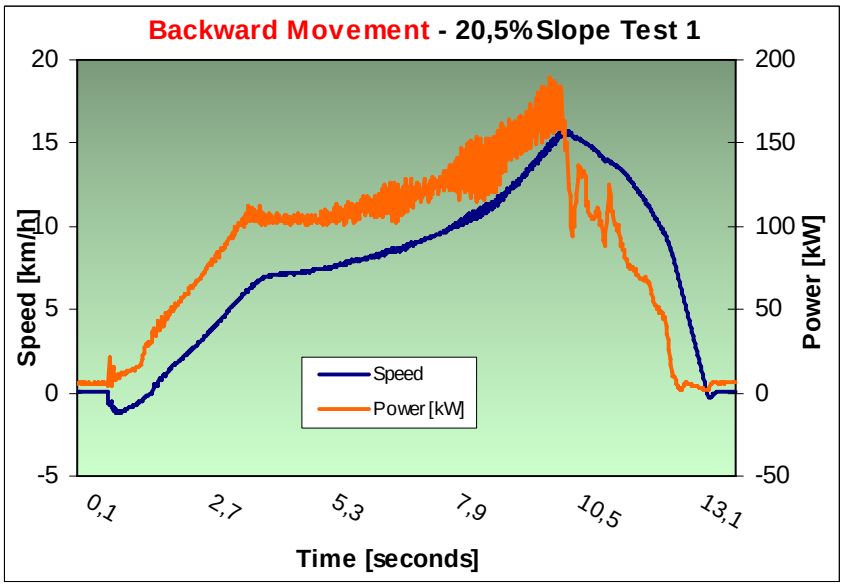


Figure E-1
Backward Movement – Test 1

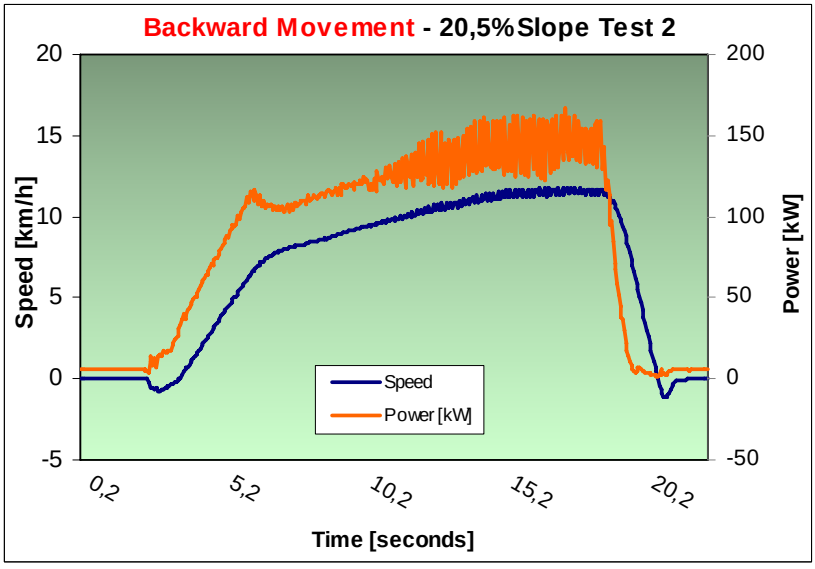


Figure E-2
Backward Movement – Test 2

F
SERVICE BRAKE TEST GRAPHICS

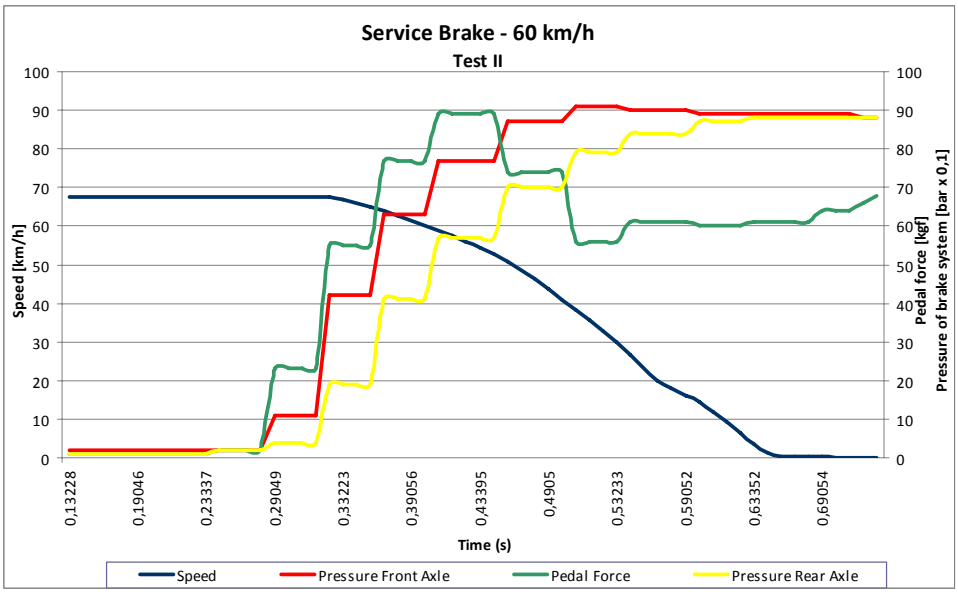


Figure F-1
Service Brake - Test 1

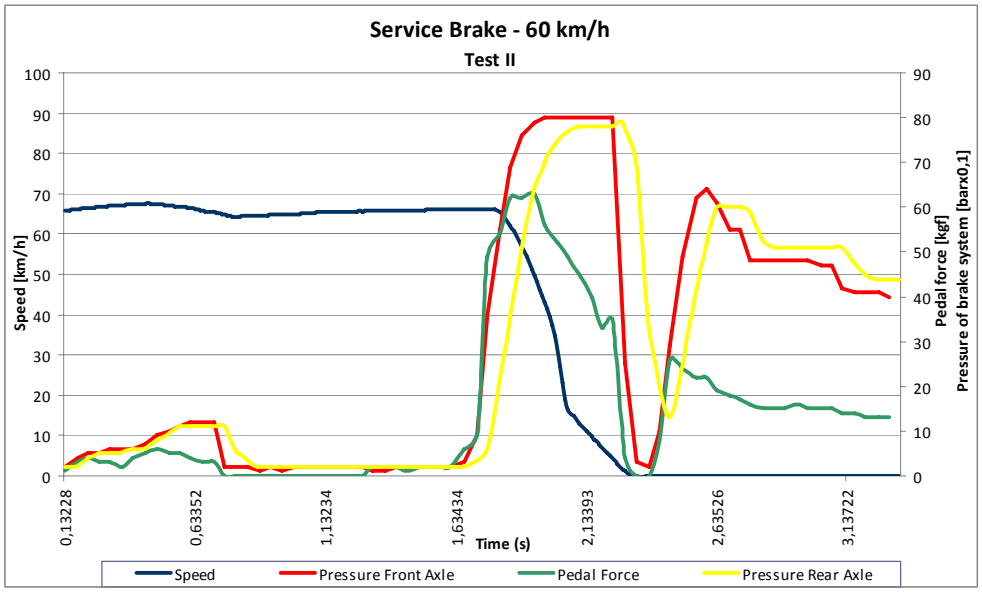


Figure F-2
Service Brake - Test 2

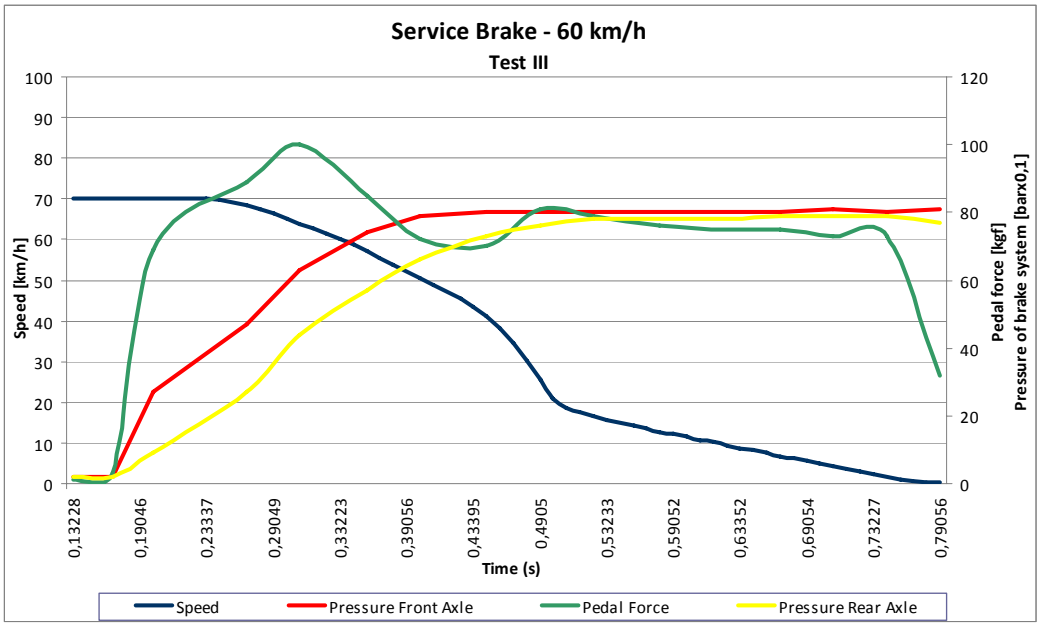


Figure F-3
Service Brake - Test 3

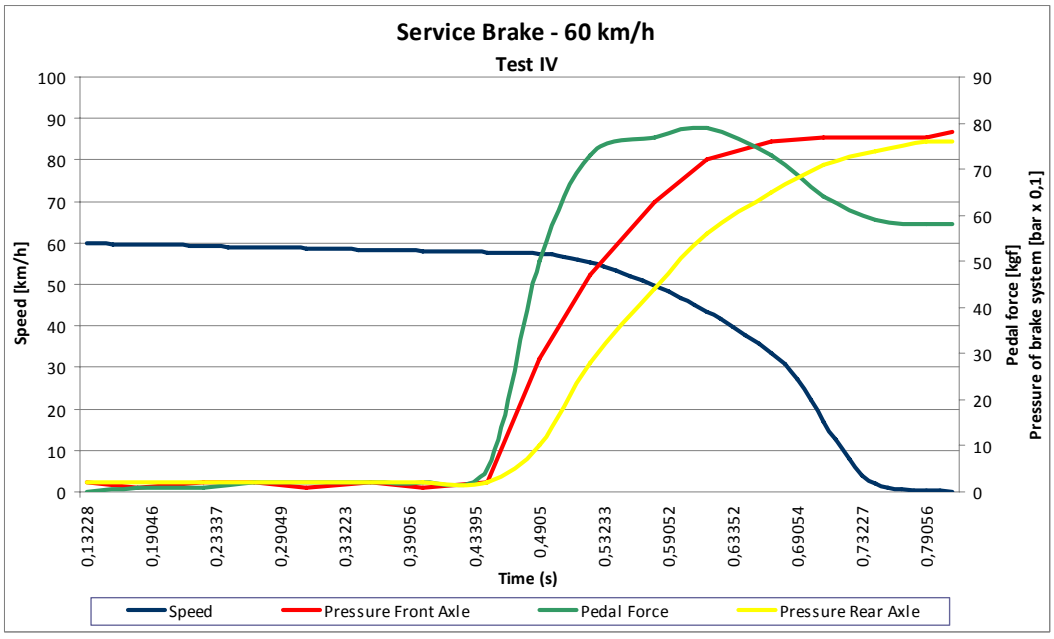


Figure F-4
Service Brake - Test 4

G
EMERGENCY BRAKE TEST GRAPHICS

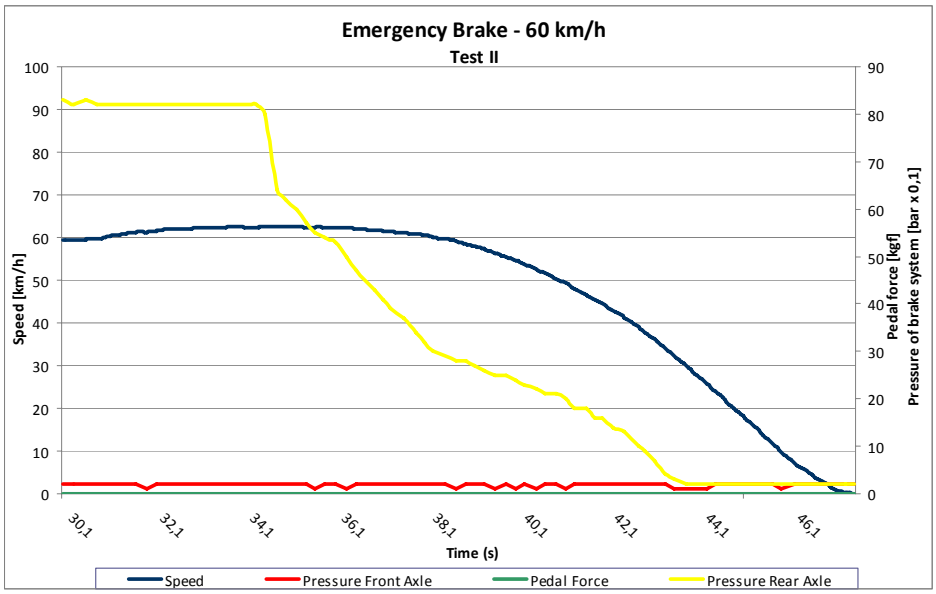


Figure G-1
Emergency Brake Test

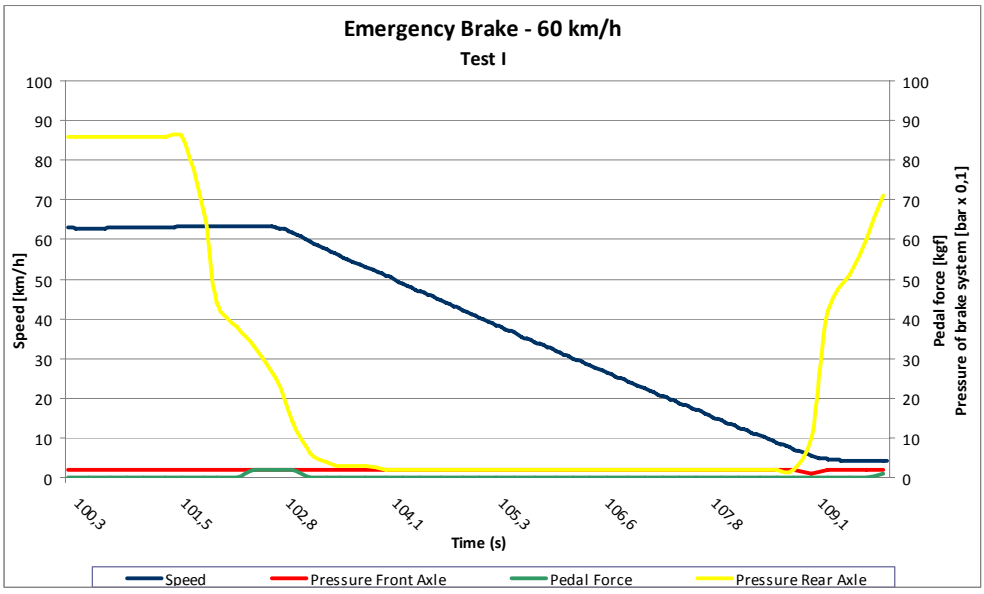


Figure G-2
Emergency Brake Test

H

FADDING BRAKE TEST GRAPHICS – TEST DONE IN CAXIAS DO SUL

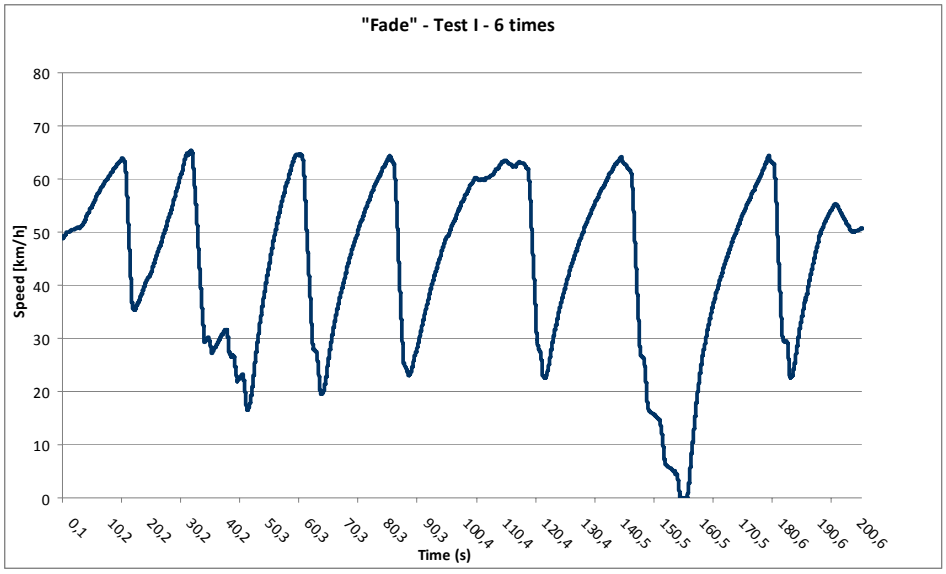


Figure H-1
Fading Brake - Test 1

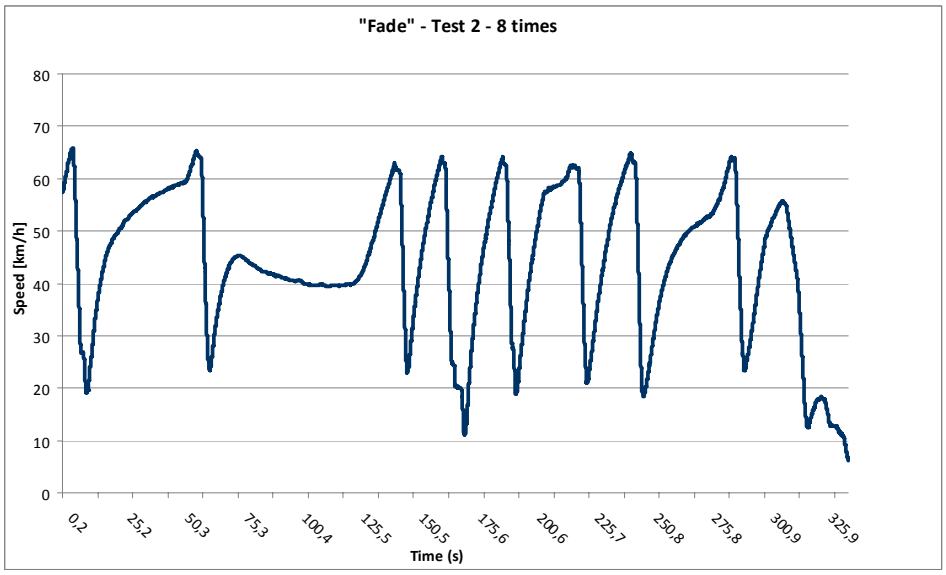


Figure H-2
Fading Brake - Test 2

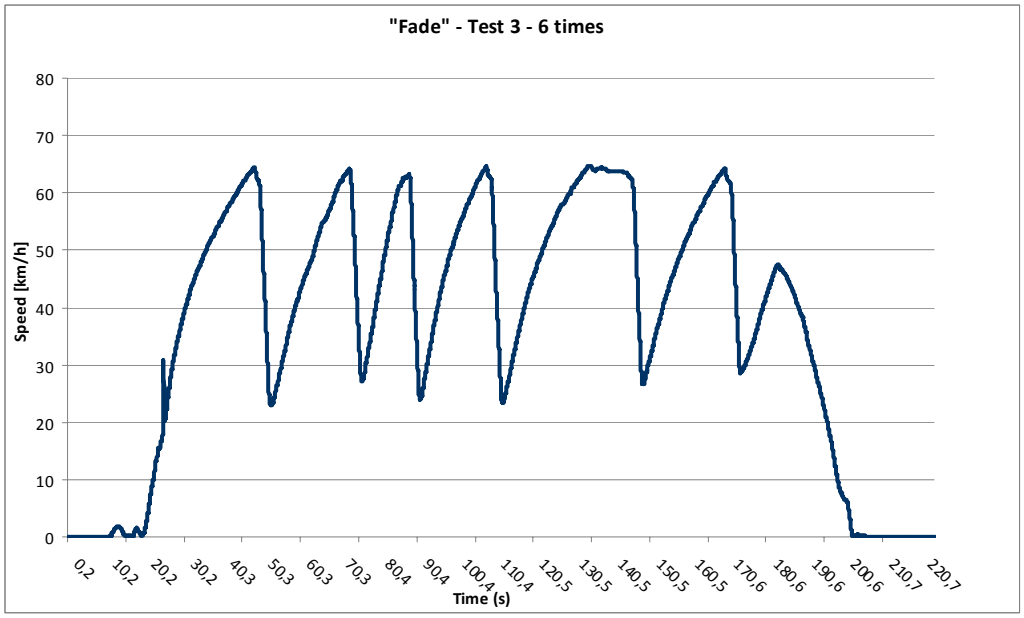


Figure H-3
Fading Brake - Test 3

I

REGENERATIVE BRAKE TEST FROM 20 TO 0KM/H GRAPHICS

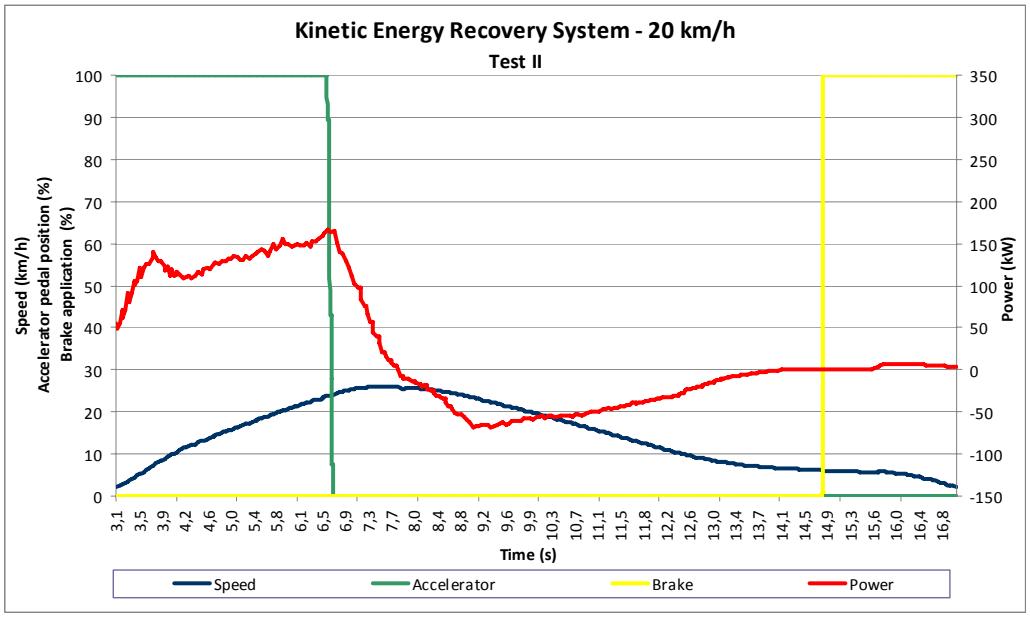


Figure I-1
Regenerative Brake from 20 to 0km/h - Test 1

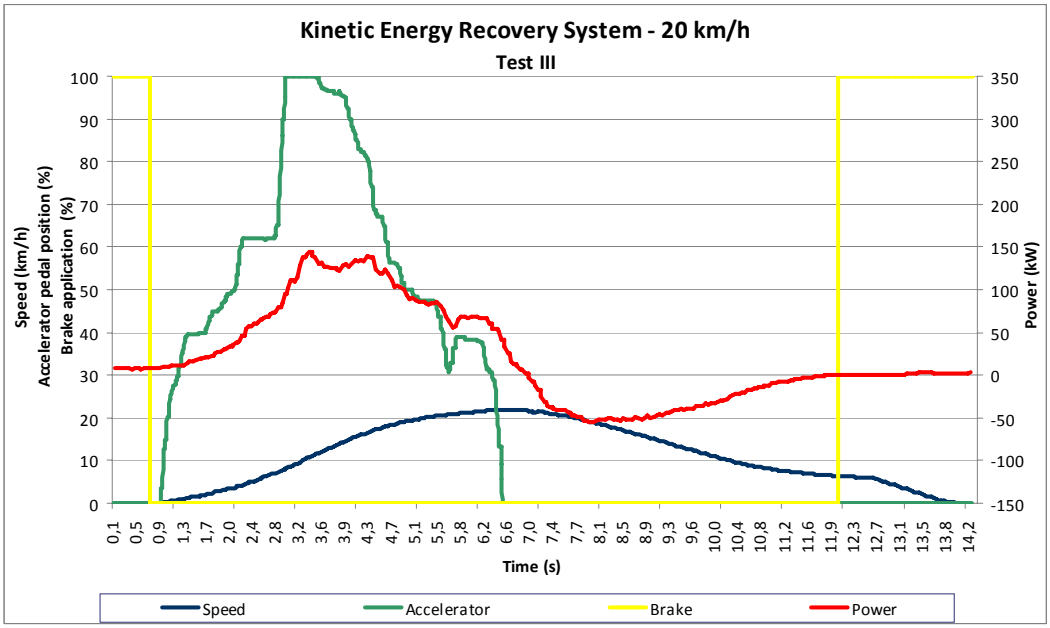


Figure I-2
Regenerative Brake from 20 to 0km/h - Test 2

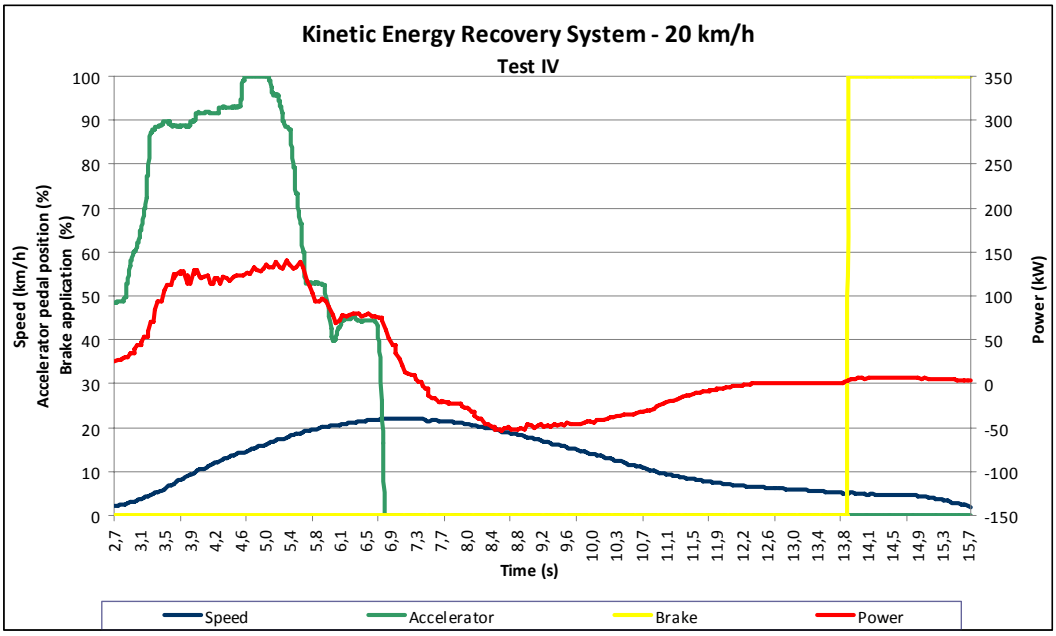


Figure I-3
Regenerative Brake from 20 to 0km/h - Test 3

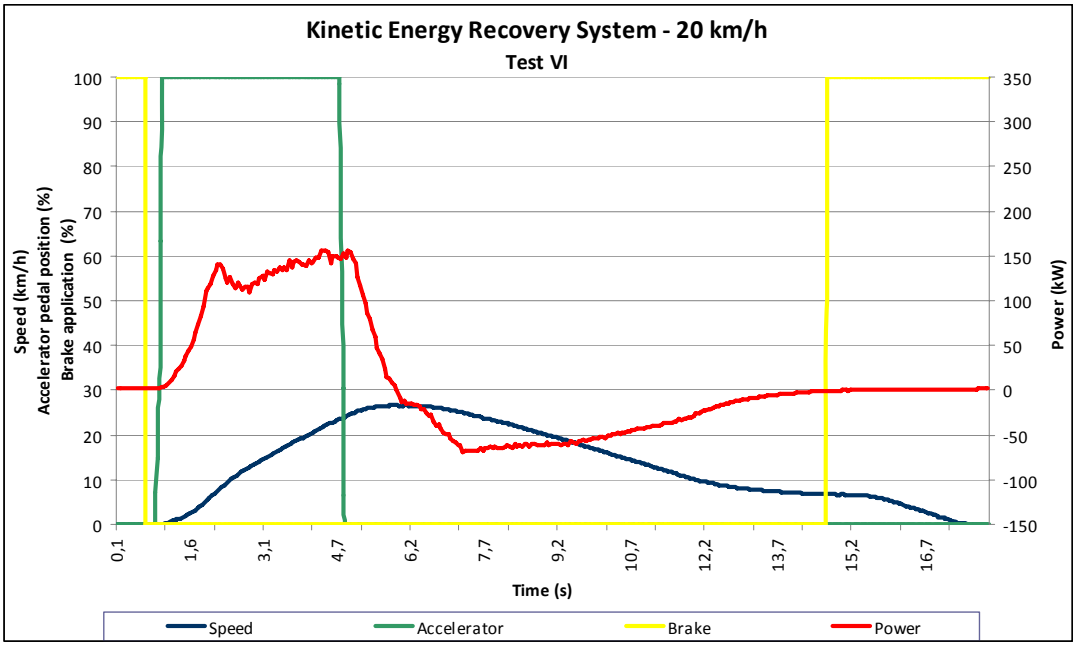


Figure I-4
Regenerative Brake from 20 to 0km/h - Test 4

J
REGENERATIVE BRAKE TEST FROM 40 TO 0KM/H GRAPHICS

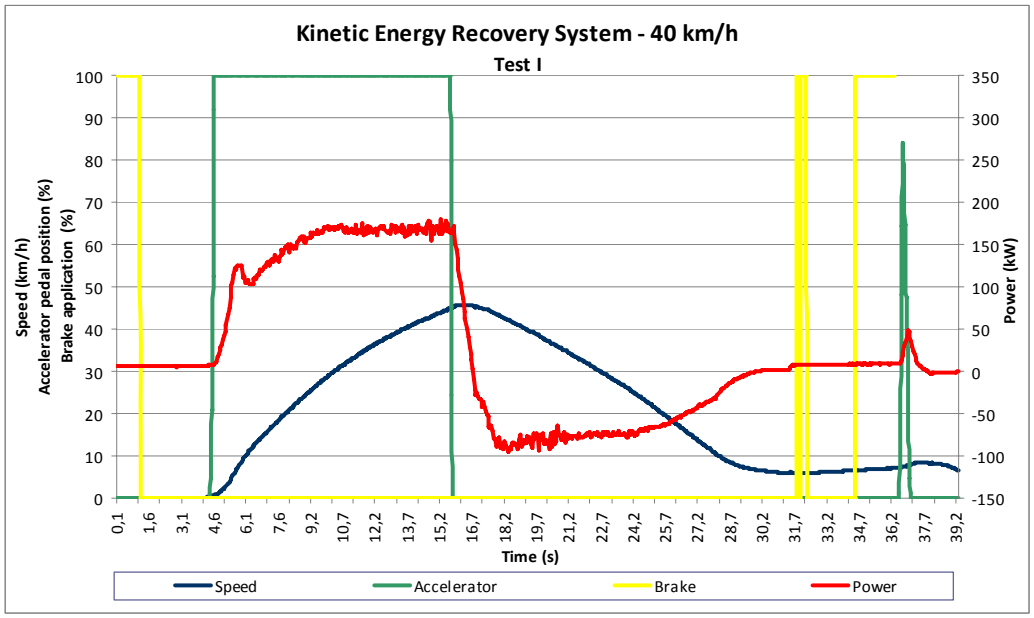


Figure J-1
Regenerative Brake from 40 to 0km/h - Test 1

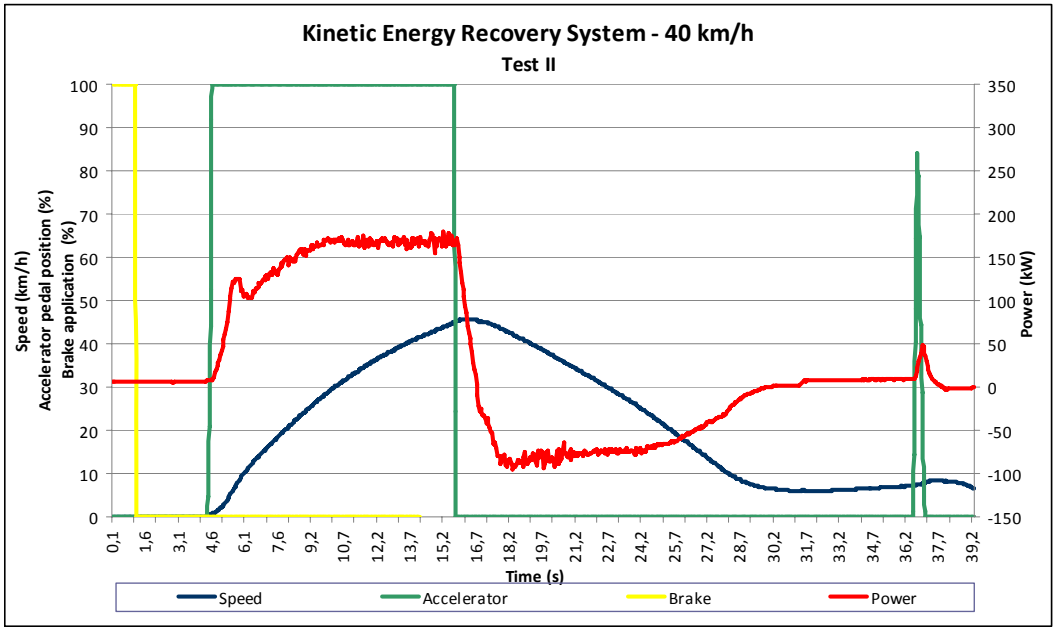


Figure J-2
Regenerative Brake from 40 to 0km/h - Test 2

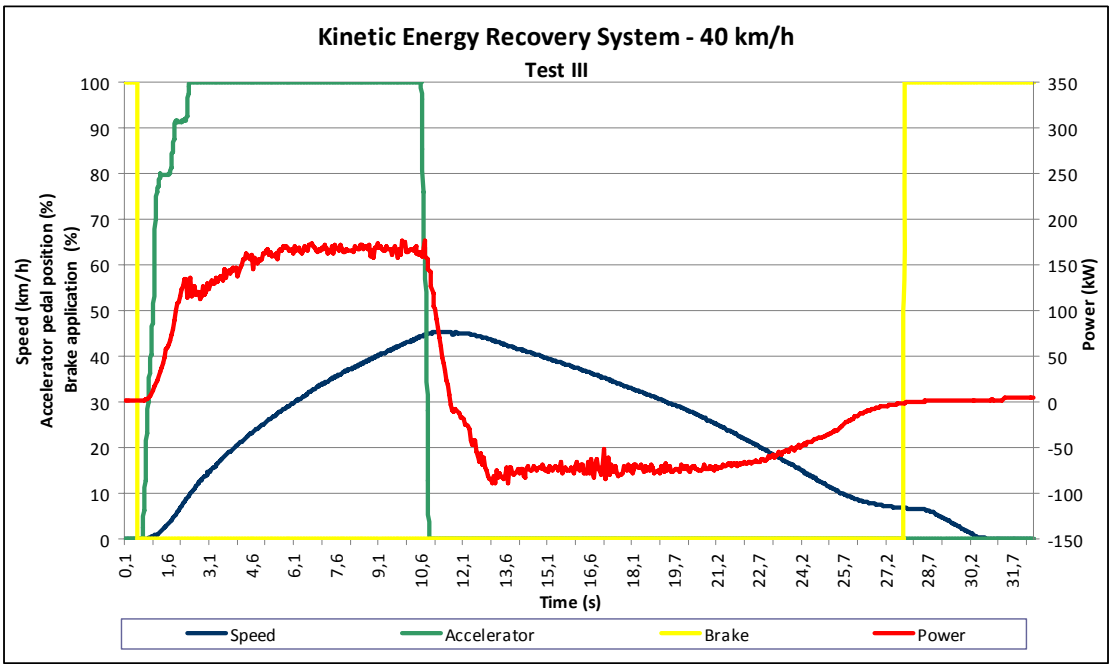


Figure J-3
Regenerative Brake from 40 to 0km/h - Test 3

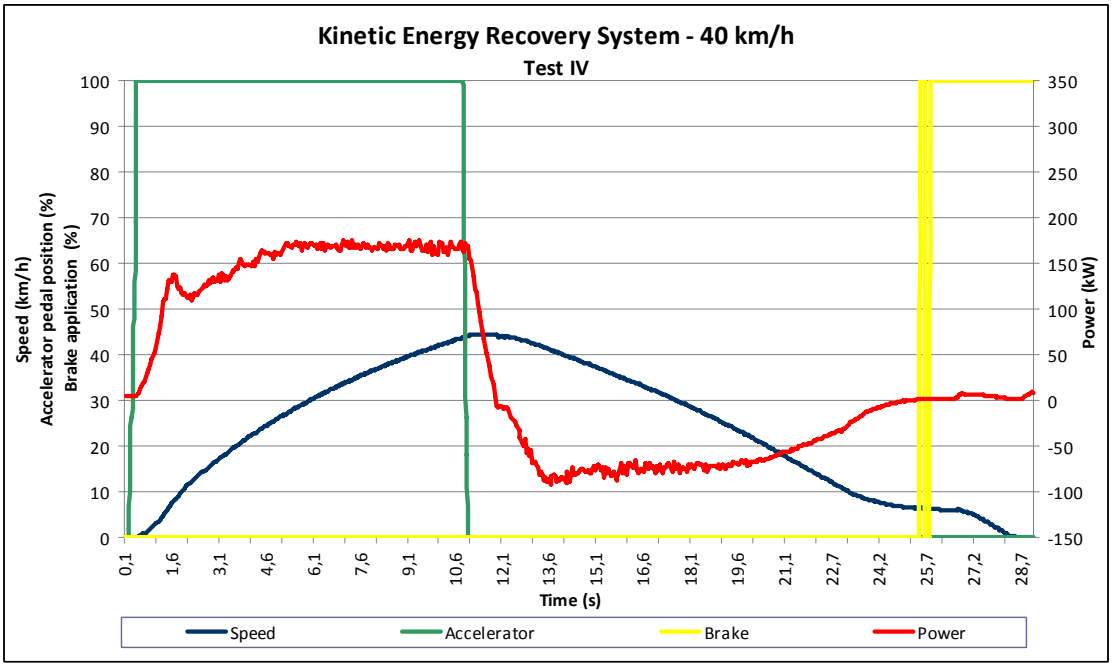
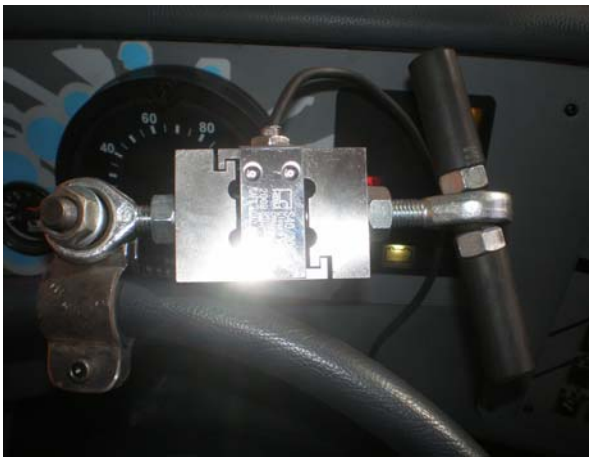


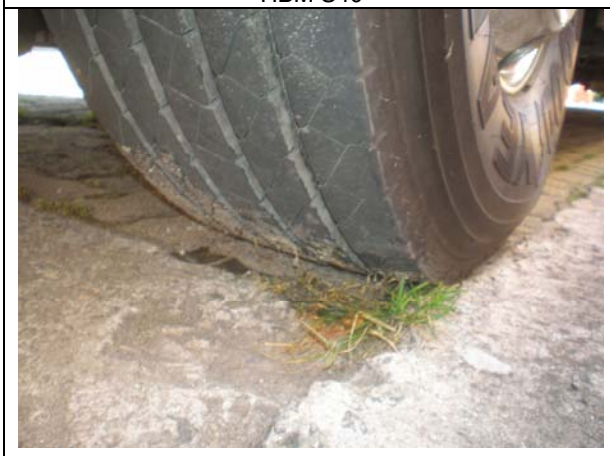
Figure J-4
Regenerative Brake from 40 to 0km/h - Test 4

K
STEERING SYSTEM FORCE

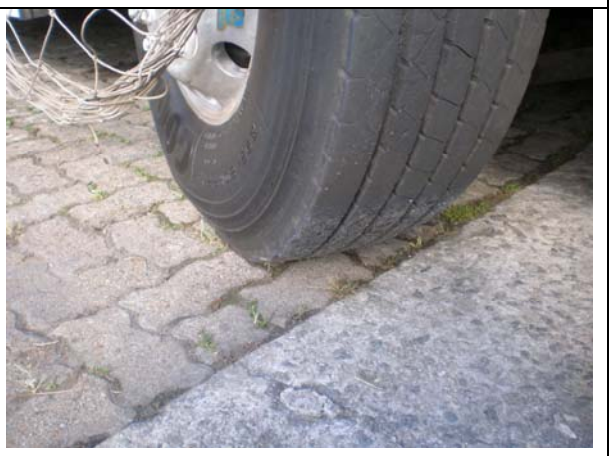


Load cell
HBM S40

Load Cell Assembling



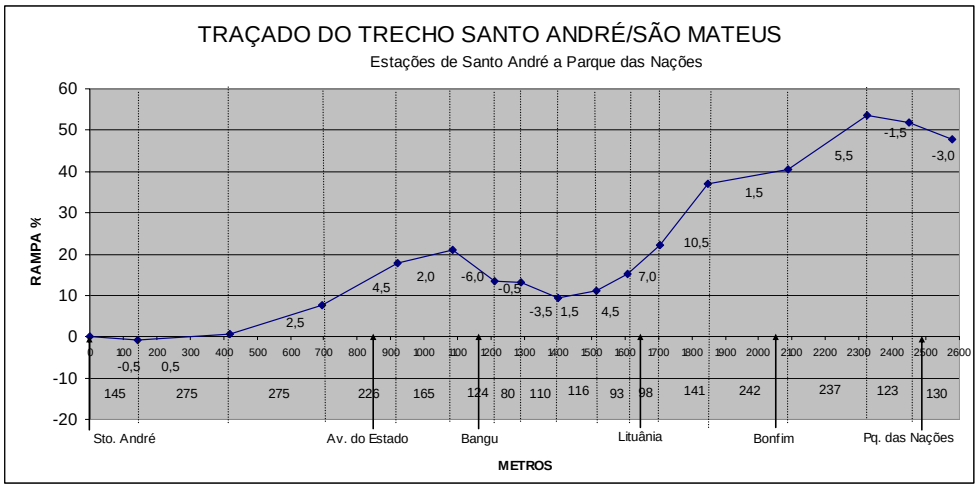
Left Side Surface

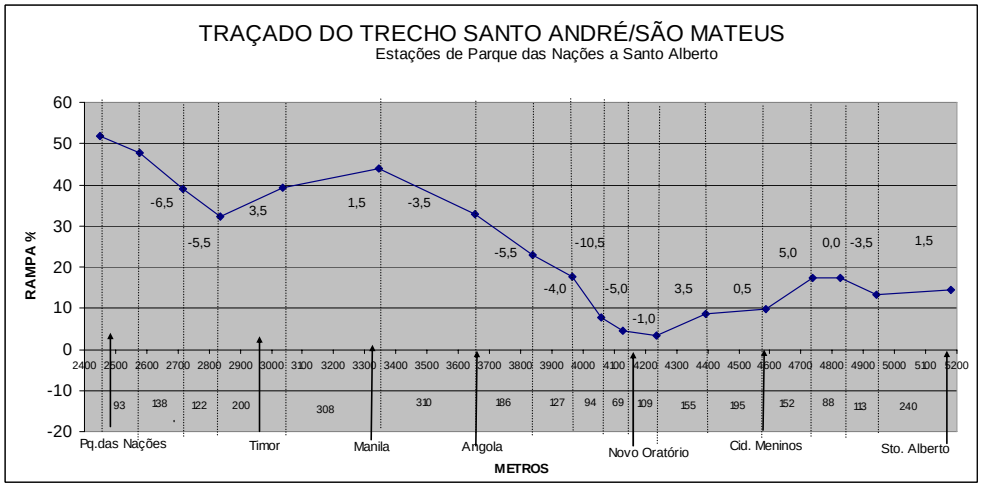


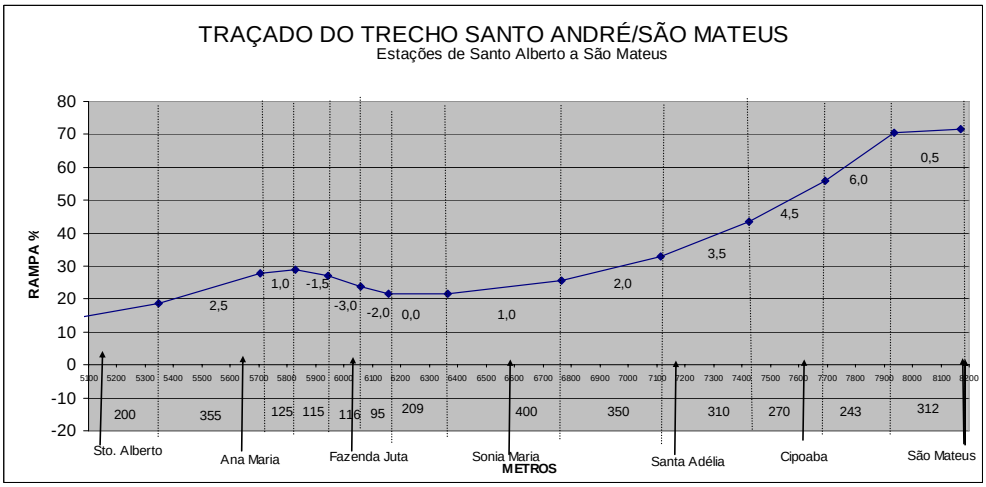
Right Side Surface

Figure K-1
Steering system force measurement

L
SANTO ANDRÉ – SÃO MATEUS ROUTE







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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
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