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ADDITIONAL DYNAMOMETER TESTS OF THE FORD ECOSTAR VEHICLE #41

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**Additional Dynamometer Tests
of the
Ford Ecostar Electric Vehicle #41**

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ABSTRACT

A Ford Ecostar vehicle was tested in the Idaho National Engineering Laboratory (INEL) Hybrid Electric Vehicle (HEV) Laboratory over two standard driving regimes, coastdown testing, and typical charge testing. The test vehicle was delivered to the INEL in February 19, 1995 under the DOE sponsored Modular Electric Vehicle Program. This report presents the results of dynamometer driving cycle tests, charge data, and coastdown testing for California Air Resources Board (CARB) under a CRADA with the Department Of Energy (DOE).

EXECUTIVE SUMMARY

A Ford Ecostar electric vehicle powered by a sodium-sulfur battery was tested in the INEL HEV Laboratory over two standard driving regimes. The test vehicle was delivered to the INEL on February 19, 1995 under the DOE sponsored Modular Electric Vehicle Program (MEVP). Tests sponsored by the DOE were concluded in June 1995 and reported in "Dynamometer Testing of the Ford Ecostar Electric Vehicle #41" DOE/ID-10518, September 1995. Subsequently, additional testing was requested by the California Air Resources Board (CARB) to obtain test data which could not be gathered under the DOE-sponsored testing because of funding constraints. Specifically, CARB was interested in obtaining the actual road coastdown parameters and traction battery charge data for this vehicle. A series of on-road vehicle coastdown tests and dynamometer test using the Federal Urban Dynamometer Driving Schedule (UDDS), and Highway Fuel Economy Test driving schedule (HWFET) were conducted under the Cooperative Research and Development Agreement between Lockheed-Martin Idaho Technologies Company and CARB. Time based traction battery charge data was recorded after the dynamometer driving schedule tests. The equipment and methods required to obtain the charge data was difficult to design and required a very elaborate instrumentation test setup.

Vehicle coastdown tests were performed on a smooth level roadway located at the INEL. Differences between the calculated speed dependent vehicle road load measured by Ford and derived from these tests were noted. INEL calculated the Ecostar road load as a result of the coastdown tests as being approximately 7% higher than that previously determined from the Ford coastdown data.

Energy consumption over two different dynamometer driving schedules were measured using the force-speed relationships derived from the coastdown tests performed by INEL. The energy consumptions measured on the Urban Dynamometer Driving Schedule (UDS) and the Highway Fuel Economy Test (HWFET) driving schedule were 204 and 188 W-h/km, respectively. The distance driven on these two driving regimes was 120 and 199 km, respectively. An anomaly in the vehicle caused the system to shut off during a rest period near the end of the tests. Therefore, these distances do not represent the full driving range of the vehicle.

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ADDITIONAL DYNAMOMETER TESTS OF THE FORD ECOSTAR ELECTRIC VEHICLE #41

INTRODUCTION

The subject test vehicle is a Ford Ecostar electric vehicle which was delivered to the Department of Energy (DOE) under the cost shared Modular Electric Vehicle Program contract with Ford Motor Company. This vehicle was extensively in June through September, 1995. The results of these tests are documented in "Dynamometer Tests of the Ford Ecostar Electric Vehicle #41", DOE/ID-10518, September, 1995.

This report presents the results of additional road and dynamometer tests performed on this vehicle at the request of the California Air Resources Board. The intent of these tests was to provide additional information and data which was not obtained during the DOE-sponsored test program. The additional information provided in this report includes the results of coastdown tests, Urban Dynamometer Driving Schedule (UDDS) tests, Highway Fuel Economy Test (HWFET) tests, and traction battery recharge data. The UDDS and HWFET driving schedule test results differ from the previously reported results primarily because the dynamometer load was derived from INEL coastdown tests while the previously reported results used dynamometer loads derived from coastdown data supplied by Ford and corrected for axle losses measured independently on the INEL dynamometer. Traction battery recharge data was not reported previously.

TEST PROGRAM AND RESULTS

Measurements and Data Acquisition

Speed-time data during the on-road coastdown tests was recorded with the INEL Versatile Data Acquisition System (VDAS). Vehicle speed was measured using a fifth wheel.

During dynamometer tests 35 channels of actual and calculated parameters were recorded using the INEL Laboratory Data Acquisition System (LDAS). All data channels were recorded at 1 second intervals. A list of these parameters is given in Table 1. The schematic diagram of Figure 1 shows the location of the current and electrical power instrumentation placed on the vehicle for all dynamometer testing.

Data acquired during traction battery recharge was recorded using a special purpose-built data acquisition setup. The main component of this setup was an Amklay PC which was programmed to interrogate the measurement instrumentation at regular intervals and record these replies on its hard drive. Figure 2 shows the location of the additional current and electrical power measurements made during recharge. Data fields recorded during traction battery charging are presented in Table 2.

Table 1. List of measurements recorded during recharge.

ELAP_TIME	SEC	Elapsed time from beginning of charge
CHGIN_VOLT	DC_VOLTS	Voltage at charge station/vehicle interface
CHGIN_CURR	DC_AMPS	Current at charge station/vehicle interface
CHGIN_PWR	DC_WATTS	Power delivered by charge station
CHGIN_KWH	DC_KWH	Cumulative energy delivered by charge station
CHGIN_AH	DC_AH	Cumulative ampere-hours delivered by charge station
AUX_CURR	DC_AMPS	Auxiliary systems current
AUX_PWR	DC_WATTS	Auxiliary systems power
AUX_KWH	DC_KWH	Cumulative auxiliary systems energy
AUX_AH	DC_AH	Cumulative auxiliary systems ampere-hours
HTR_CURR	DC_AMPS	Current to battery heaters
HTR_PWR	DC_WATTS	Power delivered to battery heaters
HTR_KWH	DC_KWH	Cumulative energy consumed by battery heaters
HTR_AH	DC_AH	Cumulative ampere-hours to battery heaters
WALL_VOLT	AC_VOLTS	AC voltage into charge station
WALL_CURR	AC_AMPS	AC current into charge station
WALL_PWR	AC_WATTS	Power into charge station
WALL_KWH	AC_KWH	Cumulatiave energy into charge station

Figure 1. Schematic diagram of instrumentation placed on the vehicle.

Figure 2. Data acquisition setup for obtaining data during recharge.

Table 2. List of measurements recorded on the Laboratory Data Acquisition System.

<u>Measurement</u>	<u>Units</u>	<u>Explanation</u>
ELAP_TIME	SEC	Elapsed time from beginning of test.
SPEED	KMH	Dynamometer roll speed
DYNO_RPM	RPM	Dynamometer roll speed
DYNO_FORCE	NEWT	Force at roll surface
AMB_TEMP	DEGC	Ambient temperature
SPEED_MPH	MPH	Dynamometer roll speed
NOM_SPEED	KMH	Target driving cycle speed
AH/KM	AH/KM	Cumulative ampere hours per kilometer
WH/KM	WH/KM	Cumulative Watt hours per kilometer
BAT_VOLT	VOLT	Traction battery voltage
BAT_CURR	AMPS	Traction battery current
BAT_PWR	KW	Traction battery power
BAT_ENR_O	KWH	Cumulative gross vehicle DC energy
BAT_ENR_I	KWH	Cumulative regen DC energy
BAT_ENR_N	KWH	Cumulative net DC energy
BAT_AH_O	AH	Cumulative gross ampere hours
BAT_AH_I	AH	Cumulative regen ampere hours
BAT_AH_N	AH	Cumulative net ampere hours
MAIN_CURR	AMPS	Current to traction motor
MAIN_PWR	KW	Power to traction motor
AUX_CURR	AMPS	Auxiliary systems current
AUX_PWR	KW	Auxiliary systems power
CYCLE_NO	#	Driving cycle count
DISTANCE	KM	Cumulative distance
DYNO_HP	KW	Dynamometer power
DYNO_TRQ	NM	Dynamometer torque
TB_BAK_PWR	KW	Traction battery backup power measurement
XBAT_VOLT	VOLT	SLI (12 v) battery voltage
XBAT_CURR	AMPS	SLI (12 v) battery current
XBAT_PWR	KW	SLI (12 v) battery power
DCO_CURR	AMPS	DC/DC converter output current
DCO_PWR	KW	DC/DC converter output power
HTR_CURR	AMPS	Current through battery heaters
HTR_PWR	KW	Power through battery heaters
TEMP_1_REF	DEGC	Thermocouple reference temperature

Test Set-up

The road loads programmed into the dynamometer were determined from the on-road coastdown trials. These loads were determined according SAE J1263 "Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques" May 1984. The resultant speed dependent road load is given by the equation :

$$\text{Road Load Force} = 116.1 + 0.0487 v^2$$

where road load force is in newtons and velocity (v) is in km/h.

The road loads programmed into the dynamometer for the previous tests (reported in "Dynamometer Tests of the Ford Ecostar Electric Vehicle #41", DOE/ID-10518, September, 1995) were determined from coastdown data supplied by Ford corrected for driveline losses measured on the dynamometer. For the series of tests reported in this document, dynamometer loads were independently determined from coastdowns performed by INEL at the proper test weight and drive axles installed on the vehicle. Figure 3 compares the derived dynamometer coastdown speed-time curve and speed dependent road load force derived from our coastdown tests and those derived using Ford's coastdown data. The road load horsepower determined from the INEL coastdown tests is slightly higher (7.7% higher at 96 km/h and 4.6% higher at 16 km/h) than the road load determined from Ford's coastdown tests.

Figure 3. Comparison of coastdown results.

Test Termination Criterion

Under normal conditions, the dynamometer driving cycle tests are terminated according to the criteria specified by SAE J1634, "Electric Vehicle Energy Consumption and Range Test Procedure", which is generally defined as the inability of the vehicle to attain some minimum level of performance, or some alternative point which may be specified by the manufacturer. During each of these tests, the vehicle monitoring system detected an abnormal rise in battery temperature, resulting in the inability to restart the vehicle after the 10 minute rest period between cycles. This, in effect, became the de facto "alternative" criteria specified by the manufacturer and the tests were terminated. This phenomenon was not experienced during previous tests of this type. Subsequently during routine maintenance by Ford personnel, it was discovered that the battery coolant level was below normal due to improper filling of the coolant made by Ford personnel during a previous maintenance operation. Ford representatives had drained the traction battery coolant preparatory to repairing fittings on the coolant system and did not adequately refill the system with coolant. This condition caused a temperature gradient in the battery greater than predefined limits and the vehicle shut down.

Federal Urban Driving Schedule (FUDS)

One Federal Urban Driving Schedule (UDS) test was performed (test number LECOFN16). This test involved driving the vehicle on the dynamometer while following the UDS speed-time profile until any of the test termination criteria were met. A graph of the recorded data showing vehicle speed, traction battery power and auxiliary battery power is shown in Figures 4 and 5 . The auxiliary power increases for a period of time in response to the battery heating on discharge. The test was terminated when the vehicle traction battery over-temperature indications caused the vehicle to automatically shut down. A total distance of 120.6 km and 10 UDDS cycles were completed before this occurred.

Summary results of each two cycles is shown in Table 3. Energy consumption values reported in this table include the energy required for traction battery heating and cooling.

Figure 4. Speed, traction battery power and auxiliary power during UDDS tests cycles 1 through 6.

Figure 5. Speed, traction battery power and auxiliary power during UDDS test cycles 7 through 10.

Table 3. Results of UDDS driving cycle tests.

	Cycle Number					
	1-2	3-4	5-6	7-8	9-10	Total
General:						
Distance (km)	24.2	24.2	24.2	23.9	24.2	120.6
Vehicle DC Energy Consumption (Wh/km)	208.6	202.6	203.0	202.4	202.8	203.9
Gross Ampere-hours (Ah)	18.2	18.2	18.3	18.1	18.5	91.2
Regen Ampere-hours (Ah)	0.8	1.1	1.2	1.2	1.3	5.5
Net Ampere-hours (Ah)	17.5	17.1	17.1	16.9	17.2	85.7
Gross DC Energy (kWh)	5.3	5.3	5.3	5.2	5.3	26.3
Regen DC Energy (kWh)	0.2	0.4	0.4	0.4	0.4	1.7
Net DC Energy (kWh)	5.0	4.9	4.9	4.8	4.9	24.6
Driving Cycle Discharge Information:						
Minimum Battery Voltage (V)	242.2	244.7	248.9	242.6	240.4	240.4
Maximum Battery Current (A)	187.8	187.4	176.8	198.8	204.7	204.7
Maximum Battery Power (kW)	45.9	45.8	42.1	48.2	49.4	49.4
Driving Cycle Regen Information:						
Maximum Battery Voltage (V)	319.6	319.0	320.5	320.9	318.1	320.9
Maximum Battery Current (A)	29.3	30.1	36.3	33.4	36.2	36.3
Maximum Battery Power (kW)	9.4	9.6	11.6	10.7	11.5	11.6

Highway Fuel Economy Driving Schedule

One Highway Fuel Economy Test driving profile test was performed (test number LECOHN22). This profile was driven repeatedly without rest periods until the test termination criteria was met. Figure 6 shows the vehicle speed, traction battery power and auxiliary power during this test. The increase in the auxiliary power (AUX_PWR) over the apparent baseline at the beginning of the test is due to the battery heaters being energized. Results of measurements for every two HWFET cycles are given in Table 4. The test was terminated when the vehicle traction battery over-temperature indications caused the vehicle to automatically shut down. A total distance of 199.1 km and 12 HWFET cycles were completed before this occurred. Energy consumption values reported in this table are not adjusted for the energy required for traction battery heating and cooling.

Figure 6. Speed, traction battery power and auxiliary power during HFEDS tests.

Table 4. Results of HFEDS driving cycle tests.

	Cycle Number						
	1-2	3-4	5-6	7-8	9-10	10-12	Total
General:							
Distance (km)	33.2	33.2	33.2	33.1	33.2	33.2	199.1
Vehicle DC Energy Consumption (Wh/km)	188.8	186.6	188.9	187.0	189.1	186.4	187.8
Gross Ampere-hours (Ah)	22.5	22.5	22.9	22.9	23.7	24.0	138.4
Regen Ampere-hours (Ah)	0.4	0.5	0.6	0.6	0.5	0.4	31.0
Net Ampere-hours (Ah)	22.0	21.9	22.3	22.4	23.1	23.6	135.3
Gross DC Energy (kWh)	6.4	6.4	6.4	6.4	6.4	6.3	38.3
Regen DC Energy (kWh)	0.1	0.2	0.2	0.2	0.2	0.1	1.0
Net DC Energy (kWh)	6.3	6.2	6.3	6.2	6.3	6.2	37.4
Driving Cycle Discharge Information:							
Minimum Battery Voltage (V)	258.5	238.9	254.2	248.2	236.7	237.8	236.7
Maximum Battery Current (A)	145.1	150.5	162.7	156.7	163.7	161.3	163.7
Maximum Battery Power (kW)	37.7	38.3	41.3	38.9	39.2	38.4	41.3
Driving Cycle Regen Information:							
Maximum Battery Voltage (V)	324.5	320.3	317.9	315.6	313.0	301.6	324.5
Maximum Battery Current (A)	43.6	43.8	42.1	45.8	50.4	27.4	50.4
Maximum Battery Power (kW)	14.4	14.1	13.4	14.3	15.6	7.9	15.6

Charge Test Setup And Data

During the instrumentation of the vehicle and traction battery charging system, it was discovered that vehicle's ground fault detection scheme causes the traction battery voltage to be applied through a high impedance to the vehicle chassis, periodically connecting the positive and negative terminals of the traction battery to the vehicle chassis. This safety feature is intended to assure that the traction battery is electrically isolated from vehicle chassis, thus preventing a shock hazard. However, this feature also caused unwanted ground loops through the laboratory instrumentation and data acquisition system which can severely damage instruments and other components of these systems.

Several methods of instrumenting and collecting the charge data were attempted without success. The final method used to capture the charge data was to use a separate (and therefore isolated) battery to power the Xitron power measurement devices and a computer to interrogate the Xitron instruments and record the returned power, voltage, and current..

Figure 7 shows a block diagram of the recharge data acquisition setup. All electronic components for measuring and recording data during recharge are isolated from both the vehicle chassis ground and earth ground.

Data from the recharge immediately following the HWFET driving cycle test is shown in Figure 8. This recharge is also representative of the recharge immediately following the UDDS driving cycle. The overall efficiency of the vehicle charging electronics calculated (i.e. wall plug to battery terminals) from this data is 89% and the efficiency of the charging station alone is 93%. The energy values from which these efficiencies are calculated is shown in Table 5.

Using this data, the energy utilization during traction battery recharge can be determined. The overall recharge efficiency (the quotient of energy obtained from the wall and the energy returned to the battery) is 82% during recharge.

Figure 7. Data acquisition setup for obtaining data during recharge.

Figure 8. Ecostar recharge data.

Table 5. Charge half-cycle energy measurements.

Wall energy, kWh	41.82
Energy from charging station, kWh	40.93
Auxiliary Energy (used to charge battery), kWh	34.24
Heater Energy, kWh	1.40

OBSERVATIONS

Several observations are made relative to the Ecostar vehicle as a result to performing the tests:

- This Ecostar vehicle exhibits consistent performance over the entire driving range tested, with respect to energy consumption measurements between successive driving cycles and driver-observable acceleration performance. During the driving cycle tests, no observable acceleration degradation was noted as the battery state-of-charge decreased.
- Instrumenting the vehicle proved difficult in several respects:
 1. The electric noise generated by the vehicle subsystems made it difficult to obtain "clean" measurement signals,
 2. In some instances, the instrumentation interfered with the vehicle control systems and much care was needed to avoid damage to both the vehicle and the data acquisition system, and
 3. The vehicle's built-in ground fault protection causes the traction battery voltage to periodically be applied through a high impedance to the vehicle chassis. This is a safety feature to assure isolation of the traction battery, but causes unpredictable ground loops through the laboratory instrumentation and data acquisition system their were several associated problems. Any attempt to gather data without completely isolating the entire data acquisition system including the test measurement equipment will result in damage to the vehicle and damage to the test equipment.