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**Laboratory Tests Evaluating the
University of South Florida
Mobile Data Acquisition System
Type 1**

D. M. Kiser

Lockheed
Idaho Technologies Company

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INEL-95/0060

Laboratory Tests Evaluating the University of South Florida Mobile Data Acquisition System, Type 1

**Dennis M. Kiser
Idaho National Engineering Laboratory**

March 1995

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ABSTRACT

The University of South Florida Mobile Data Acquisition System, Version 1, was evaluated in battery laboratory bench tests and in conjunction with laboratory dynamometer tests, for accuracy, ease of operation, and performance. Two tests in each of the two environments are reported. The collected data were also used to evaluate the MDAS data conversion software package XRD10.EXE. Test results show only slightly lower accuracy than results from standard laboratory equipment and data reduction procedures. Additional environmental tests were deferred pending receipt of an improved version of the system.

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INTRODUCTION

The Electric Vehicle (EV) Site Operator Program, sponsored by the Department of Energy (DOE) and managed at the Idaho National Engineering Laboratory (INEL), is currently composed of twelve Site Operators. In addition to operating electric vehicles for demonstration of the technology, the Site Operators also perform operational field testing. Data collected by the programs are input to the Site Operator Database at each site and transmitted, periodically, to the database at the INEL. As the program has expanded, some Site Operators have begun operating vehicles at sites remote from their offices. Other Site Operators are planning to expand their engineering and vehicle performance test programs. With the advent of these expanded test programs, 40 new electric vehicles have been purchased, 30 of which will be equipped with Mobile Data Acquisition Systems (MDAS) in order to provide automated data acquisition capability. In order to assure that the MDAS units will perform as required by the Site Operator Program, the MDAS units have been tested, as described herein, by the Idaho National Engineering Laboratory (INEL) Electric and Hybrid Vehicle (EHV) Program Battery and Vehicle Test Laboratories.

The tests were conducted in two phases. During the first phase the MDAS was tested in the INEL Battery Laboratory by measuring battery voltage and current concurrently with the laboratory test equipment during battery tests utilizing a nine module battery pack composed of Dynasty GC12V100 modules. The tests were then conducted as described in the Test Plan of Reference 1. During the second phase of the evaluation, a Solectria Force electric vehicle, furnished by Virginia Power, and equipped with a MDAS unit, was tested by acquiring data concurrently with the vehicle test equipment in the INEL Dynamometer Laboratory. This vehicle test was conducted during the conduct of the California Air Resources Board (CARB) tests as described in the Test Plan of Reference 1.

It should be pointed out that during the testing of the MDAS unit described herein, a second, improved design of the MDAS was made available by Sigma TecSystems, Inc. Thus, the test program for the unit described in this report was cut short and Battery Laboratory SFUDS tests and other tests utilizing (a) the laboratory vibration table; and (b) the laboratory

environmental chamber were not performed. In addition, two problems were encountered with the MDAS units tested in the INEL Vehicle Test Laboratory. First, a malfunctioning speed sensor for the MDAS unit was not repaired during testing of the vehicle. Second, the MDAS unit that was installed in the vehicle failed for an unknown reason. In order to continue testing the vehicle and provide MDAS data for the tests, testing of the Battery Laboratory MDAS unit was stopped and the unit was installed in the Solectria vehicle. Thus, only three tests were completed in the Battery Laboratory, and three were completed in the Vehicle Test Laboratory. A complete series of tests will be performed on the new improved MDAS version.

This report covers the tests performed, at the INEL EHV Battery and Vehicle Test Laboratories, on the first version of the MDAS, herein designated as MDAS-1. The two test phases permitted the evaluation of both the MDAS hardware and software by comparing the MDAS results with the laboratory results obtained using the standard laboratory equipment and data reduction procedures. These tests evaluated the MDAS accuracy, ease of operation, and performance in both a battery test laboratory and a vehicle test laboratory environment. Using data collected during the various tests, the MDAS data conversion software package, XRD10.EXE, was also utilized.

PURPOSE

The purpose of these tests is a laboratory evaluation of the University of South Florida's (USF) Mobile Data Acquisition System (MDAS) designed for use in electric vehicles.

The USF MDAS was developed for use as an automatic data acquisition system for electric vehicles. A preliminary evaluation (Reference 2), comparing the MDAS to the INEL Versatile Data Acquisition System (VDAS), and to the Instrumental Solutions Autologger, recommended that a number of vehicles in the Site Operator Program be equipped with MDAS units. However, nearly all the testing of the MDAS, to date, has been done at USF. Thus, a need was identified to independently verify that the system operates as designed. This document describes the MDAS tests that were conducted and presents the test results obtained from such an independent evaluation.

By combining the MDAS evaluation with on-going battery and vehicle tests, data was acquired by the MDAS concurrently with that acquired by the laboratory data acquisition system (LDAS) at little additional cost. During all the tests described, data were collected with both the MDAS and the LDAS, and both systems were set to acquire data at the same sample rate in order to provide a direct comparison.

DEVICE DESCRIPTION

The MDAS is a data acquisition system designed specifically for use in electric vehicles. It is a versatile, compact, self-contained unit that requires very little interaction from the user once it is installed. The device requires 12 Vdc for operation. The MDAS is actually a computer with a central processor unit (CPU), a floppy disk drive, (drive A:), and several data acquisition channels that are set up to monitor and record battery pack voltage, battery pack current, vehicle speed, battery temperature, cab temperature, and ambient temperature by utilizing its 8-bit analog-to-digital (A/D) converter. Once placed in an EV, the MDAS monitors the vehicle ignition switch and battery charger door position to determine when to begin or end acquiring data.

When the MDAS receives a signal from the ignition switch, by turning the switch to the ON position, or the battery charger door of the vehicle, by opening the door and plugging in the battery charger, its CPU is turned on and it goes through a "boot" sequence. The boot sequence tests memory and input, output (I/O) channels. After the completion of the boot tests, the MDAS reads the system disk in drive A, thus invoking the Config.sys and Autoexec.bat files, which, in turn, invokes the operation software. The operation software determines which data channels will be utilized in collecting data. The MDAS then begins collecting data. The data were written to extended memory during the data collection cycle. When the ignition switch is turned off, or the battery charger door is closed, the data collection cycle is completed, and the MDAS then transfers the data file to the floppy disk in drive A. The MDAS then turns itself off in order to conserve the vehicle battery power.

The vehicle data stored on the disk can be transferred to another location for permanent storage and analysis. The number of tests that can be stored on the 3.5" disk is determined by the sampling rates used and the number of channels recorded.

Voltage, current, and temperature sensors included in the MDAS package; these are calibrated before shipping and are ready to interface the MDAS to the vehicle under test. Besides monitoring the variables mentioned above, the MDAS is equipped to monitor the

on/off switches of the vehicle's air conditioning and heating units to indicate when these devices are in operation.

When ordering an MDAS unit, Sigma TecSystems personnel configure the system software to meet the requirements of the specific vehicle to be tested. The MDAS is then completely ready to acquire data, once its sensor leads are in place and the device is installed in the vehicle and powered up. For a more detailed description of the MDAS specifications and operation, refer to Appendix B (Reference 3).

TEST PROGRAM AND SETUP

Tests Performed

Battery Laboratory Tests

The tests performed at the INEL EHV Battery Laboratory were:

1. Manual test varying between a discharge and a recharge state
2. Constant-power test
3. Manual charge test at 10 amperes to 129.6 volts.

During all the tests described, data was collected with both the MDAS and the laboratory data acquisition system (LDAS) and both systems are set to acquire data at the same sample rate in order to provide a direct comparison. A brief description of each test follows.

Manual Discharge/Recharge Test

This test involved acquiring data with both the MDAS and the LDAS during a manual test varying between a discharge and a recharge state of the battery pack. The sample rate for the test was set at 2 Hz. The purpose of this test was to determine the stability and accuracy of the MDAS while the variables being monitored are changing slowly between the discharge state and the charge state.

Constant-Power test

This test involved connecting both the MDAS and the LDAS to a battery pack in the Battery Laboratory and acquiring data during a constant-power discharge of 1.5 kW and at a sampling rate of 2.0 Hz. The purpose of the constant-power tests was to verify the over-all stability and accuracy of the MDAS while the voltage and current change slowly.

Manual Charge Test

This test involved acquiring data with both the MDAS and the LDAS during a manual charge of the battery pack. The sample rate for the test was set at 0.1 Hz. The purpose of this test was both to determine the stability and accuracy of the MDAS during a constant-current battery charge, and to observe the MDAS temperature-sensing capability.

Dynamometer Laboratory Tests

A Solectria Force electric vehicle, furnished by Virginia Power and equipped with a MDAS unit, was tested by acquiring data concurrently with, and at the same sampling rate as, the vehicle test equipment in the INEL Dynamometer Laboratory, during the conduct of the California Air Resources Board (CARB) tests as described in the Test Plan, (Reference 1).

The tests performed at the INEL EHV Vehicle Test Laboratory were:

1. An All-Electric Cycle Test
2. A FUDS Test
3. An LA-92 Driving Cycle Test

During all the tests described, data were collected with both the MDAS and the LDAS, and both systems were set to acquire data at the same sample rate in order to provide a direct comparison. A brief summary of each test follows.

SUMMARY OF MDAS PERFORMANCE RESULTS

Battery Laboratory Tests

Table 1 summarizes the types of tests run on the MDAS at the Battery Laboratory. For the tests conducted in the Battery Laboratory, Test 1 represents a test cycle, varying slowly between both a discharge and a charge of the battery pack. This test was performed in order to verify that the MDAS calibration scale factors were correct. The voltage and current offsets were accounted for in the spreadsheet analysis of the results. Test 2, is a typical 1.5 kW constant-power discharge. Test 3 represents a short manual battery charge at the MDAS default sample rate of 0.1 Hz. This charge test was performed to verify the correct operation of the MDAS after recharging its 12 V battery power supply. Room temperature in the Battery Lab was about 20°C.

Table 1. Summary of MDAS Tests conducted in the INEL Battery Test Laboratory

Test Number	Discharge/Charge Profile	Sample Rate (Hz)	Test Temperature
1	Manual Discharge/Charge	2.0	Room
2	1.5 kW constant-power	2.0	Room
3	Manual Charge	0.1	Room

Graphs of test data for each MDAS test are also presented in Appendix A as Figures A-1 through A-7. A discussion of the results pertinent to each plot is given below.

The various plots were generated by importing data files, from both the MDAS and the LDAS, into a spreadsheet and plotting the measured quantities (voltage, current and temperature) versus time. However, because the MDAS raw data files are in binary form, these files were first converted into ASCII form by running the computer program XRD10.EXE, which was supplied with the MDAS. Once the data were in the spreadsheet, both the MDAS and the LDAS data were aligned on the time axis by shifting the data in time so that the first current measurement significantly greater than zero, for each of the two

systems, overlaid the other. Given that the MDAS and LDAS were programmed to measure the same parameters, and to sample at the same rate, during each test, this ideally *should* have resulted in the two sets of data matching sample-for-sample in each plot. Using this method to align the data, the time difference between any of the aligned samples can be no more than one sample period.

Dynamometer Laboratory Tests

Table 2 summarizes the types of tests run in the Vehicle Test Laboratory to evaluate the MDAS. The electric vehicle tested was a Solectria Force electric vehicle, furnished by Virginia Power, and equipped with an MDAS unit. Of the tests conducted, two were All-Electric Cycle tests (Tests 4, 5); three were FUDS Cycle tests (Tests 6, 7, 8); and one was a LA-92 Driving Cycle test (Test 9). Ambient temperature in the Vehicle Lab was about 20°C.

Table 2. Summary of in-vehicle MDAS tests conducted in the INEL vehicle test laboratory in a Solectria Force vehicle, supplied by Virginia Power.

Test Number	Discharge/Charge Profile	Sample Rate (Hz)	Test Temperature
4	All-Electric Cycle	1.0	Room
5	All-Electric Cycle	1.0	Room
6	FUDS Cycle	1.0	Room
7	FUDS Cycle	1.0	Room
8	FUDS Cycle	1.0	Room
9	LA-92 Driving Cycle	1.0	Room

Graphs of LDAS and MDAS test data, typical of each test, are presented in Appendix A as Figures A-8 through A-16. However, because of the similarity of the results, data from all of the tests conducted were not plotted. Instead, the plots present data from one of the tests that is considered typical. A discussion of the results pertinent to each of the plots is given in the following section.

As with the plots generated for the Battery Laboratory results, the various plots of Vehicle Test Laboratory results were generated by importing data files, from both the MDAS and the LDAS, into a spreadsheet and plotting the measured quantities (voltage, current and vehicle speed) versus time. However, because the MDAS raw data files are in binary form, these files were first converted into ASCII form by running the computer program XRD10.EXE, which was supplied with the MDAS. Once the data were in the spreadsheet, both the MDAS and the LDAS data were aligned, on the time axis, by shifting the data, in

time, so that the first current measurement that was significantly greater than zero, for each of the two systems, overlaid the other. Given that the MDAS and LDAS were programmed to measure the same parameters, and to sample at the same rate, during each test, this ideally *should* have resulted in the two sets of data matching sample-for-sample in each plot. Using this method to align the data, the time difference between any of the aligned samples can be no more than one sample period.

DISCUSSION OF RESULTS

Battery Laboratory Tests

Manual Test Varying Between a Discharge and a Recharge State

The results of Test 1, the manual test varying between a discharge and a recharge state, are shown in Figures A-1 and A-2. The sample rate for the test was set at 2 Hz.

Some differences between the MDAS and LDAS data are to be expected because of the difference in the resolution of the MDAS compared to the LDAS. Since the MDAS utilizes an 8-bit A/D converter, its resolution is 1 part in 256. Thus, the MDAS 300 V range, divided into 256 parts, gives a resolution of 1.17 V/bit. Similarly, the MDAS 600 A current range yields a resolution of 2.34 A/bit. The LDAS utilizes a 16-bit A/D converter so that its resolution is 1 part in 65536. Thus, the LDAS 300 V range, divided into 65,536 parts, gives a resolution of 5 mV/bit. Similarly, the LDAS 1000 A current range, utilizing an internal discharge shunt, yields a resolution of 16 mA/bit. Thus measurements taken by the MDAS should agree with those taken by the LDAS within 2.27 V and 4.54 A with 95% confidence.

The data for the voltage plots of both the MDAS and LDAS data, in Figure A-1, indicate that the MDAS voltage measurement is approximately 0.119 V higher than the corresponding LDAS measurement. Since the MDAS has a 300 V range, this difference represents an uncertainty of less than 0.1% of the MDAS voltage range, which is insignificant.

Similarly, the data for the current plots of both the MDAS and LDAS data, in Figure A-2, show that the MDAS current measurement is approximately 1.482 A higher than the LDAS's current measurement. The MDAS has a current range of -300 A to 300 A, and therefore this 1.482 A discrepancy results in an uncertainty of less than 0.5% of the device's full range, which is insignificant.

Constant-Power Test

The results of Test 2, the constant-power test, are shown in Figures A-3 and A-4. The sample rate for the test was set at 2 Hz.

The voltage plots of both the MDAS and LDAS data, in Figure A-3, indicate that the MDAS voltage measurement is approximately 0.274 V lower than the corresponding LDAS measurement. As discussed for Test 1, this 0.274 V difference represents an uncertainty of less than 0.1% of the MDAS voltage range. The voltage difference is well within the uncertainty limit discussed for Test 1.

The data illustrated in Figure A-4 show that the MDAS current measurement is approximately 2.128 A higher than the LDAS's current measurement. As discussed for Test 1, this 2.128 A difference results in an uncertainty of less than 0.5% of the device's full range. The voltage difference is well within the uncertainty limit discussed for Test 1.

The interesting result of this test is that even though the data sets are aligned, in time, at the beginning of the plots, they drift apart as the number of samples increases. This phenomena is easily seen in Figures A-3 and A-4. At first thought, this would seem to indicate that the MDAS and the LDAS were not sampling at precisely the same rate, although they were programmed to do so. This phenomena is also seen in the in-vehicle tests conducted at the INEL Vehicle Test Laboratory and is discussed more fully at the end of this section.

Manual Charge Test

Figures A-5 and A-6 illustrate the voltage, current, and temperature results, respectively, for Test 3, a manual charge of the test batteries, for which the MDAS unit was set to a sampling rate of 0.1 Hz. This test was performed to verify that the MDAS can record data at its default sampling rate.

Figures A-5 and A-6 show that the voltage and current accuracy of the device during this dynamic profile are as good as those displayed during the constant-power tests. In particular, the voltage difference between the LDAS and MDAS measurements was +0.609 V, and the current difference between the LDAS and MDAS was +0.961 A. There is, however, approximately a 2 A difference between the MDAS and LDAS measurements at the initiation of the charge. The shape of the MDAS current graph suggests that this discrepancy is due to an amplifier warm-up or perhaps the Hall Effect transducer warm-up effect. Differences in both voltage and current measurements are well within the uncertainty limits discussed for the Manual Discharge/Charge test discussed above. The magnitudes of voltage and current measured can be corrected by increasing the offsets as recommended.

Figure 7 shows the battery temperature measured during charging. The data plotted with short dashes show the LDAS thermocouple temperature, which is seen to fluctuate often $\pm \approx 0.5^{\circ}\text{C}$. This is typical of a thermocouple measurement, which also has a typical uncertainty of $\pm 2^{\circ}\text{C}$, with 95% confidence. The two MDAS temperature measurements are shown as a long dashed line and as a chain dashed line. These temperature devices are thermistors, which respond more slowly than thermocouples, and therefore do not fluctuate as much nor as rapidly as does the LDAS thermocouple. The plot shows good agreement between the LDAS and the MDAS systems, and the temperature differences were -0.999°C for the Number 1 thermistor, and -1.086°C for the Number 2 thermistor. Both temperature differences are well within the uncertainty limits of temperature measurements.

The battery laboratory tests were terminated at this point because of the sudden failure of the MDAS unit in the Solectria vehicle being tested in the INEL Vehicle Test Lab. In order to expedite the vehicle tests, the Battery Laboratory unit was used to replace the defective MDAS unit in the Solectria vehicle. After the vehicle tests were completed, further testing of the MDAS unit was dropped and a second-generation MDAS was purchased for further testing.

Dynamometer Laboratory Tests

All-Electric Cycle Tests

Two All-Electric Cycle tests were conducted at INEL. The All-Electric Cycle test consists of consecutive FUDS and HWFET cycles with a ten-minute break after each set of cycles. Typical plots of battery voltage, current and vehicle speed vs time are shown in Figures A-8, A-9, and A-10, respectively, which are the results for Test 4 (All-Electric Cycle 1). The MDAS unit utilized in the Battery Laboratory tests was used to perform this test because of the sudden failure of the MDAS unit in the test vehicle. The sample rate for the test was set at 1 Hz.

Figures A-8, A-9, and A-10 show MDAS data, compared to LDAS data for Cycle 1 (a FUDS and a HWFET) of the All-Electric Driving Cycle. The vehicle finished three full cycles (FUDS and HWFET) for this first test. Also, during this first test, the vehicle completed a range of 84.5 km (52.5 miles) with a net energy out of the battery for the complete test of 10.95 kW·h. The average energy consumption for the completed three cycles was 9.605 kW·h which yields an energy consumption rate of 113.6 W·h/km.

Figures A-8 and A-9 show that the voltage and current accuracy of the MDAS device, during this dynamic profile, are as good as those displayed during the Battery Laboratory tests. In particular, the voltage difference between the LDAS and MDAS measurements was +0.0859 V, and the current difference between the LDAS and MDAS was -2.1651 A. Differences in both voltage and current measurements are well within the uncertainty limits discussed for the Manual Discharge/Charge Test described in the Battery Laboratory test discussions, and, the magnitudes of voltage and current, measured, can be corrected by changing the offsets as recommended. The close agreement of battery voltage and current is to be expected, because the MDAS unit utilized for this test was that utilized in the Battery Laboratory tests described above, for which the voltage and current calibration and offset was carefully set by comparison of results to a laboratory LDAS.

Figure A-10 shows that the vehicle speed measured by the MDAS agrees with that measured by the LDAS within a small difference. In particular, the difference between the LDAS and MDAS measurements was +2.3406 km/h. Since the MDAS speed sensor has an uncertainty of $\pm 1\%$ of full range, which is about 100 km/h, then the sensor accuracy is about ± 1 km/h. The difference between the MDAS and the LDAS speed measurements was +2.3406 km/h, or somewhat greater than twice the expected uncertainty. The graph of the speed measured by the MDAS speed sensor also shows spikes in the speed as the speed during each cycle drops to zero. After several attempts to re-adjust and re-calibrate the instrument it was concluded that the speed sensor was defective and that an accuracy within ± 3 km/h was acceptable. Because the sensor failed later in the test series, after the MDAS measurements were concluded, this conclusion was vindicated.

The most interesting result of this test is that even though the data sets are aligned, in time, at the beginning of the plots, they drift apart as the number of samples increases. This phenomena is easily seen in Figures A-3 and A-4. At first thought, this would seem to indicate that the MDAS and the LDAS were not sampling at precisely the same rate, although they were programmed to do so.

To investigate this timing difference further, consider Figure A-10. The number of samples recorded by each data acquisition system were tabulated between the beginning of the first discharge step of the SFUDS, and the end of the last HWFET step. The MDAS recorded 2,108 samples during this period while the LDAS recorded 2,123. For a sampling rate of 1 Hz (1 s), the MDAS data indicates that this sequence of events took 2,108 s, and the LDAS data indicates that it took 2,123 s. Assuming that the LDAS system is the standard of accuracy, correcting the MDAS sample frequency by taking the time measured by the LDAS, 2,123 s and dividing by the MDAS's 2,108 samples gives a corrected MDAS sample period of 1.00712 s, a 0.712% difference (or a factor of 1.00712) from the expected sampling period of 1.000 s.

The results of this test indicates that the accuracy of the sampling rate at which the MDAS records data is not controlled by a separate counter/timer as is typical of laboratory data systems, and is probably controlled by the DOS clock counter, which ticks 18.2065 times per second. This counter requires a correction of 1 tick every 5 seconds to keep time within ± 0.0065 s/s. Thus, if the MDAS sample period is in error by 0.0065 s/s for 2108 sample periods, a net error of 13.702 s results. Adding the net error to the MDAS sample time of 2108 s gives a corrected sample time of 2122 s, which is close to the LDAS sample time. This discrepancy in time keeping will cause problems if exact time measurements are required, and will introduce error into calculations utilizing time-based data, such as ampere-hour or kilowatt-hour calculations.

FUDS Tests

Three Federal Urban Driving Cycle (FUDS) tests were performed at the INEL, and regenerative braking was enabled for all three tests. Typical plots of battery voltage, current, and vehicle speed versus time are shown in Figures A-11, A-12, and A-13, respectively, which are the results for Test 8 (FUDS Cycle 3). The vehicle-equipped MDAS unit was utilized for testing at the INEL. The sample rate for the test was set at 1 Hz.

The average energy consumption per kilometer for the three FUDS tests was 108.9 W·h/km. The average energy consumption for each complete FUDS cycle was 1.306 kW·h.

Figures A-11 and A-12 show that the differences between the voltage and current measurements of the MDAS unit utilized during this dynamic profile and the LDAS are somewhat greater than those displayed during the Battery Laboratory tests and the All-Electric Cycle described above. In particular, the voltage difference between the LDAS and MDAS measurements was +1.0118 volts, and the current difference between the LDAS and MDAS was -2.1908 amperes. This difference was due to the fact that the unit and sensors could not be as precisely adjusted in place, in the vehicle, as in the battery laboratory. However, differences in both voltage and current measurements are well within the uncertainty limits

discussed for the Manual Discharge/Charge Test described in the Battery Laboratory test discussions, and, the magnitudes of voltage and current, measured, can be corrected by changing the offsets as recommended.

Figure A-13 shows that the vehicle speed measured by the MDAS agrees with that measured by the LDAS within a small difference. In particular, the difference between the LDAS and MDAS measurements was +1.50172 km/h, or about 50% greater than the expected uncertainty. As described in the discussion of results for the All-Electric Cycle test, the graph of the speed measured by the MDAS speed sensor also shows spikes in the speed as the speed during each cycle drops to zero, indicating possible problems with the sensor.

A timing difference similar to that described for the All-Electric test is also shown in Figures A-11 through A-13 which indicates that the problem exists for all MDAS units.

LA-92 Driving Cycle Tests

One LA-92 Driving Cycle test was also performed at INEL. Regenerative braking was enabled during the test. Typical plots of battery voltage, current, and vehicle speed vs time are shown in Figures A-14, A-15, and A-16, respectively, which are the results for Test 9. The MDAS unit utilized was that with which the vehicle was equipped, upon delivery of the vehicle at the INEL. The sample rate for the test was set at 1 Hz.

The average energy consumption per kilometer for the LA-92 Test was 137.4 W·h/km. The average net energy for the test conducted was 9.008 kW·h and the gross energy used for the driving cycle was 11.156 kW·h.

Figures A-14, A-15, and A-16 are plots showing the MDAS and LDAS results for battery voltage, current, and vehicle speed, respectively. The plots show that the differences between the voltage and current measurements of the MDAS unit utilized during this dynamic profile and the LDAS are somewhat greater than those displayed during the Battery Laboratory tests and the All-Electric Cycle described above. In particular, the voltage

difference between the LDAS and MDAS was -1.62717 amperes, and the speed difference between the LDAS and MDAS was +1.72167 km/h. The results support the discussions and conclusions presented for the All-Electric and FUDS Tests described above.

CONCLUSIONS

The tests reported herein show that the signals measured by the MDAS are within the accuracy and precision specified by Sigma TecSystems as in Appendix B, and within the measurement uncertainty in comparison to the INEL laboratory LDAS units. However, comparing the MDAS sampling time increment to that of the LDAS indicates that the accuracy of the sampling rate at which the MDAS records data is not controlled by a separate counter/timer as is typical of laboratory data systems, and is probably controlled by the DOS clock counter, which ticks 18.2065 times per second. This discrepancy in time keeping will cause problems if exact time measurements are required, and will introduce error into calculations utilizing time-based data, such as ampere-hour or kilowatt-hour calculations. In particular:

- The short analysis presented in the Discussion of Results, for the Battery Laboratory, Manual Test Varying Between a Discharge and A Recharge State, shows that voltage and current measurements taken by the MDAS should agree with those taken by the LDAS within 2.27 V and 4.54 A, respectively, with 95% confidence. In all of the test results presented herein, the voltage and current measurements agree well within these uncertainty limits.
- No conclusions can be reached concerning the accuracy of the speed measurements, because the speed sensor failed shortly after the tests reported were complete. Because the MDAS speed results differed from the LDAS measurements by an amount greater than the expected uncertainty, and efforts to re-adjust the sensor were not fruitful, then the data is suspect.
- An analysis of the results of the All-Electric driving cycle test, conducted in the INEL Vehicle Test Laboratory, indicates that the accuracy of the sampling rate at which the MDAS records data is not controlled by a separate counter/timer

as is typical of laboratory data systems. The analysis showed that in order to keep sample interval time within ± 0.0065 s/s a net error of 13.702 s resulted. This net error corrected the MDAS test sample rate to approximately agree with that for the LDAS unit.

RECOMMENDATIONS

Based on the tests conducted at the INEL, the second generation MDAS unit, manufactured by Sigma Tec., at the University of South Florida, is recommended as a field test data acquisition unit, of reasonable capability, for use in the DOE Site Operator Program. The system can be significantly improved if the following two recommendations are implemented:

- If the MDAS scale factors are calculated for instrumentation that is calibrated utilizing a calibrated shunt, as is the INEL LDAS, then differences in measurements taken by the MDAS and LDAS types of systems will be negligible.
- Either the calculations of the sample period and sample frequency must be reformulated, or a separate counter/timer must be implemented, in order to provide sample intervals that are accurate in time. The results of these tests indicate that the accuracy of the sampling rate at which the MDAS records data is governed by the MDAS DOS clock counter, which ticks 18.2065 times per second. Timing also appears to be corrected by the typical means of adding one tick every five seconds to keep sample interval time within ± 0.0065 s/s. This discrepancy in time keeping will cause problems if exact time measurements are required, and will introduce error into calculations utilizing time-based data, such as ampere hour or kilowatt hour calculations. At low sampling rates of 1 or 2 Hz, these errors would be less significant.

REFERENCES

1. EHV-TP-22 (Revision 1), February 17, 1994, "Electric and Hybrid Vehicle Program Test Plan for the Laboratory Evaluation of the University of South Florida Mobile Data Acquisition System", Idaho National Engineering Laboratory.
2. EGG-EP-10948, September, 1993, "Preliminary Evaluation of the University of South Florida Mobile Data Acquisition System, The Idaho National Engineering Laboratory Versatile Data Acquisition System, And The Autologger Vehicle User Survey System, Produced by Instrumental Solutions of Ottawa, CN, For The Site Operator Program Field Data Collection".
3. Operating Manual for the University of South Florida Mobile Data Acquisition System (provided in Appendix B).

APPENDIX A

Test Data Graphs for Each MDAS Test

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Figure A-1. Battery test laboratory Test 1 (voltage) manual discharge/charge test, at 2.0 Hz sample rate.

Figure A-2. MDAS battery test laboratory Test 1 (current) manual discharge/charge test, at 2.0 Hz sample rate.

Figure A-3. MDAS battery test laboratory Test 2 (voltage) 1.5 kW constant power discharge test at 2.0 Hz sample rate.

Figure A-4. MDAS battery test laboratory Test 2 (current) 1.5 kW constant power discharge test at 2.0 hz sample rate.

Figure A-5. MDAS battery test laboratory Test 3 (voltage) manual charge test at 0.1 Hz sample rate.

Figure A-6. MDAS battery test laboratory Test 3 (current) manual charge test at 0.1 Hz sample rate.

Figure A-7. MDAS battery test laboratory Test 3 (battery temperature) manual charge test at 0.1 Hz sample rate.

Figure A-8. MDAS vehicle test laboratory Test 4 (battery voltage) all-electric cycle test at 1.0 Hz sample rate.

Figure A-9. MDAS vehicle test laboratory Test 4 (battery current) all-electric cycle test, at 1.0 Hz sample rate.

Figure A-10. MDAS vehicle test laboratory Test 4 (vehicle speed) all-electric cycle test at 1.0 Hz sample rate.

Figure A-11. MDAS vehicle test laboratory Test 8 (battery voltage) FUDS cycle test at 1.0 Hz sample rate.

Figure A-12. MDAS vehicle test laboratory Test 8 (battery current) FUDS cycle test at 1.0 Hz sample rate.

Figure A-13. MDAS vehicle test laboratory Test 8 (vehicle speed) FUDS cycle test at 1.0 Hz sample rate.

Figure A-14. MDAS vehicle test laboratory Test 9 (battery voltage) LA-92 driving cycle test at 1.0 Hz sample rate.

Figure A-15. MDAS vehicle test laboratory Test 9 (battery current) LA-92 driving cycle test at 1.0 Hz sample rate.

Figure A-16. MDAS vehicle test laboratory Test 9 (vehicle speed) LA-92 driving cycle test at 1.0 Hz sample rate.

APPENDIX B

Detailed Description of the MDAS Specifications and Operation

Sigma TecSystems, Inc.

Tel/Fax 813-948-2372

**MOBILE
DATA
ACQUISITION
SYSTEM**

A complete system for the automatic collection, transmission, analysis and presentation of performance data for electric and alternative fuel vehicles.

FEATURES

- Instant setup
- User friendly
- Battery Operated.
10 to 12 VDC
- Auto ON/OFF
- Watchdog alarm
- Power Failure Detector
- 16 Analog input channels
- Built-in Anti-Aliasing Circuitry
- 8 Digital Input Ports
- 8 Digital Output Ports
- Sensor Input ready
- 2 Serial Ports
- Secure Disk Data Storage
- Up to 4 MBytes of RAM
- Compressed Binary Data
- 100% IBM compatible

ADVANTAGES

- Preconfigured, calibrated and tested.
- No special training or maintenance required.
- 30mA standby, 1.2A normal operation.
2A maximum current draw during disk I/O.
- Self turn-on if 5V to 12V pulse sensed from any of 3 inputs or from telephone ring.
Software power-down after task completion.
- Audible alert on hardware or software error.
- Automatic reset of CPU if power falls outside proper operational window.
- Accepts any -10V to +10V transducer input.
- Eliminates measurement errors due to noise on any analog input channel.
- Monitor the state of 8 separate devices.
- Control 8 separate devices via SCRs or relays.
- Built in F/V converter to measure speed.
Precision voltage reference for thermistors.
- Serial interface for optional concurrent processors or I/O devices.
- Reliable 1.44M floppy disk for portability.
- All data written to RAM until system is at rest.
- Secure encrypted data, compressed up to 90% from ASCII to minimize telemetry and media time and expense.
- Vast selection of IBM compatible software and hardware for custom applications and expansion.

OPTIONS

ADVANTAGES

• Cellular Link• Telephone Ring Detection• Mini Console• Data Presentation Software	• Cellular phone software and hardware interface for automatic remote data retrieval.• Use standard telephone lines, if convenient, for data communications.• Realtime feedback or instructions for operator or monitor, with keypad entry for special tasks.• On-site analysis, graphics and hardcopy of user selected parameters.

Sigma TecSystems, Inc.

P. O. Box 271646, Tampa, Florida 33688-1646 Tel/Fax: 813-948-2372

THE SIGMA TECSYSTEMS MDAS: NOT JUST A DATA LOGGER!

The Sigma Tecsystems Mobile Data Acquisition System (MDAS) was specifically designed for applications in electric (EV) and alternative fuel vehicles. Generic data loggers (GDLs) are not particularly suited for use in EVs but are best used for slowly occurring events or short time spans. The following will explain some of the differences and show why the MDAS out performs GDLs in electric and alternative fuel vehicle installations.

PERFORMANCE

Sampling rates of up to 5000 Hz can be implemented with MDAS. Although a sampling rate of 64 per second will exceed any present measurement requirements in an EV, the capability to switch to a high sampling rate under software control is sometimes used to more closely examine specific EV phenomena.

SIZE

Overall outside dimensions of 3.25" x 6" x 12" make the MDAS convenient to install in an EV and yet house a complete IBM compatible CPU, modem, power supply, A/D card, Signal Conditioning card, and 1.44 Meg. floppy disk drive. The MDAS designers have sacrificed a little extra size over the typical GDL for the unlimited compatibility and expandability of the IBM platform.

POWER CONSUMPTION

No separate batteries are required by the MDAS since it derives power from the existing vehicle auxiliary battery. To conserve power the MDAS shuts itself off when the EV is idle, then automatically powers up on several stimuli indicating EV activity or incoming telephone call.

SENSITIVITY

With 12 bit resolution on 16 A/D channels the MDAS is capable of accuracy of .005 volts per input for a 20 volt input range. This accuracy exceeds that of any transducers currently used in EVs but ensures that the A/D conversion process has the precision required for scientific research.

SIGNAL CONDITIONING

All inputs to the MDAS A/D channels are fully conditioned by double pole active filters providing a 60dB per decade attenuation of noise.

SPEEDOMETER INPUT

On board circuitry allows the direct input of an EV speedometer signal for speed, acceleration and distance measurements. The typical GDL requires additional circuitry to accomplish these measurements.

THERMISTOR INPUTS

Four channels are provided for the direct connection of external thermistors. An on board precision voltage reference allows accurate temperature measurements of EV cab, battery and ambient temperatures. A GDL would require additional circuitry for these measurements, while the MDAS comes with easy to install thermistors.

STORAGE MEDIA

It has been determined that daily measurements on EVs may require the storage of up to 200 Kbytes of information. The MDAS can typically retain up to a full week of vehicle performance data, while the typical GDL cannot even hold one day's requirements! The MDAS saves considerable time and expense in data transferal and operator intervention.