Calibration and Accuracy Report

ECE 492 - Spring 2016

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Introduction

This document serves to estimate any uncertainties which will be associated with all measurements required for ATP. It includes some analysis of measurement uncertainty as well justification for ATP test design to ensure that uncertainty can be suitably determined. This document is closely linked to from ATP to serve as the pass/fail criteria for some tests which require measurements to fall within a confidence interval in order to be deemed acceptable.

In the statement of work for this project, it is stated that “Numerical specifications shall be considered “passed” if the measured value is demonstrated by empirical statistical trials to meet the specification at a 90% confidence interval.”Confidence interval is calculated by a straightforward formula from statistics:

confidence interval bounds = x ± t * sm

Where x is the sample mean, sm is the standard error, and t is a value which represents the allowable number of standard deviations for a given sample size. In our system, all measurements will be sampled with only one set of measurements, **meaning that the t value for each measurement will be 6.314.** Therefore, in order to find the confidence interval for each measurement, only the standard error will need to be calculated.

This document will serve to find those confidence intervals, and be used in conjunction with the ATP document for this project to determine if measurements are suitably accurate.

Motor RPM

Motor RPM is measured in the current setup by an optical encoder, which should be very accurate and require little calibration. Nevertheless, some tests in ATP depend on this measurement to pass, so it must be ensured that the measurement is accurate. In order to determine if the voltage readout from the currently installed encoder is accurate to the actual speed of the motor, a test has been performed which uses a handheld tachometer as a calibration standard. The protocol for this primary calibration test is as follows:

RPM Data Collection

(1) Obtain a handheld tachometer and affix a piece of reflective tape to the larger load gear in the dynamometer setup.
(2) Connect to the AEC401 lab computer using teamviewer from an outside location with view of the motor. Open the curtis 1314 data monitoring software. Open VirtualBox and the OpenSuse machine, and then the Dyno.exe software.
(3) Power on the huff box and controller cooling, and flip the switch to turn on high voltage.

(4) Station a trained team member of professor to stand behind the caution tape in AEC 401 with the tachometer trained on the reflective tape on the large gear. Safety goggles are required.
(5) Starting at 10% throttle and remaining below 25%, spin the motor at ten known throttle positions (allowing 30 seconds to settle) and record the RPM monitored by the 1314 software and the RPM given by the tachometer. For purposes of safety, maintain an RPM measurement below 3000.
(6) For each set of measurements at a given RPM, divide the RPM measurement from the tachometer by the measurement from software. Expect a value of 2.5, representative of the gear ratio in the current dynamometer setup.
(7) If the average of all sets of measurements provide a gear ratio within one standard deviation of 2.5, then no further calibration is required. Otherwise, plot the difference between expected and and recorded values and use the slope and offset of this graph for calibration purposes.

The results of this test can be seen below:

Recorded RPM (tachometer, large Gear)	1314 Software RPM (small gear)	1314 RPM(w/ 2.5 gear ratio)	pct diff	Calc Gear Ratio	
138	348	139.2	0.8695652174	2.52173913	
227	575	230	1.321585903	2.533039648	avg error
321	805	322	0.3115264798	2.507788162	1.18
638	1585	634	-0.6269592476	2.484326019	stdev error
733	1830	732	-0.136425648	2.496589359	6.368987361
821	2020	808	-1.583434836	2.460414129	**Standard error**
901	2257	902.8	0.1997780244	2.504994451	**2.014050645**
1005	2527	1010.8	0.5771144279	2.514427861	**Confidence**
1075	2708	1083.2	0.7627906977	2.519069767	**12.71671577**
1140	2872	1148.8	0.7719298246	2.519298246	

As can be seen above, the values output by the tachometer into the 1314 software provide a standard deviation of measurement of 6.37 RPM. This provides for a standard error of 2.014. Multiplied by the above-mentioned t-value of 6.314, a confidence interval of +/- 12.72 RPM is found. For purposes of determining if relevant ATP tests pass, **expected values will need to fall within an adjusted confidence interval of +/- 15 RPM of any measurement.**

Relevant ATP Items

ATP Items 01 and 06 involve measurement of motor RPM, so this confidence interval is relevant to those items.

Torque

Torque is currently measured by a load cell connected to the bar in dynamometer system. Calibration of the voltage output from this cell into the Huff box as compared to the actual torque on the bar has been performed using a test involving masses of known weight being hung off of the bar. The protocol for this primary calibration test is as follows:

Huff Box Setup (Box on the wall)

(1) Make sure there are no fuses blown and that the power supply is putting out voltage to the board.
(2) You must first install InstaCal (a copy may be downloaded from mccdaq.com) then install the USB-7204 board(it should show up in instaCal)
(3) Open the InstaCal program and change the board from Board 0 to Board 1
(4) Change the properties of the board to : 8 single ended.

Torque Data Collection

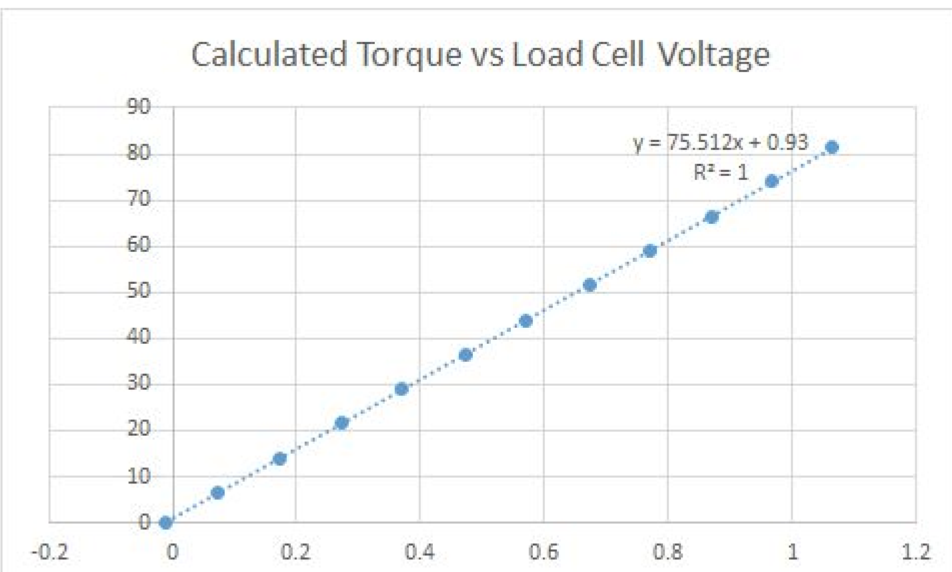
(1) Obtain a mass hanger and a minimum of 10 known masses to hang from the torque bar in the dynamometer system.
(2) Before hanging the mass from the torque bar tap the bar with your hand or another tool to remove any stiction.
(3) Hang the mass, recording the actual value of the mass and the voltage value displayed on the InstaCal software for the torque channel (with slope 1 and 0 offset).
(4) Repeat steps 2 and 3 for each weight chosen
(5) Calculate the theoretical torque values for each mass by multiplying the weights in lbs by 1.5 (for 18inches)
(6) Plot torque vs voltage as a result and use the equation for a trendline that matches this graph to obtain the slope and offset for a calibration curve.

Data from this test can be seen below:

	WinDyno-800 (measured in Volts)	Multimeter (Volts)	Torque(lb-ft)

Weight (lbs)	1 up	2 down	3 up	4 down	Vout Direct	Theoretical	VSCADA
0	-0.015	-0.01	-0.01	-0.01	-0.01		-0.12
4.34	0.068	0.078	0.073	0.073	0.074	6.51	2.366
9.34	0.166	0.176	0.171	0.171	0.173	14.01	5.44
14.34	0.269	0.273	0.273	0.273	0.271	21.51	8.368
19.34	0.366	0.371	0.371	0.371	0.372	29.01	11.3
24.34	0.469	0.479	0.474	0.474	0.471	36.51	14.37
29.34	0.566	0.576	0.571	0.571	0.572	44.01	17.3
34.34	0.669	0.674	0.674	0.674	0.671	51.51	20.23
39.34	0.771	0.771	0.771	0.771	0.77	59.01	23.3
44.34	0.869	0.869	0.869	0.869	0.869	66.51	26.23
49.34	0.967	0.967	0.967	0.967	0.969	74.01	29.06
54.34	1.064	1.064	1.064	1.064	1.067	81.51	32.23

A plot of theoretical torque vs measured load cell voltage reveals the following slope and offset values to be used for calibration of this measurand:



The calibration factor determined for this data has been incorporated into the proejct's legacy VSCADA software for purposes of data logging, and therefore measurements for the purposes of ATP items should be accurate to the standard set by a voltmeter.

Calculations performed on the test data listed above using operational calibration from the slope and offset listed above provide a standard deviation of .0728 ft-lb. This corresponds with a standard error of .021, and with the t value of 6.314, a confidence value of +/- .133 ft-lb is calculated. **To ensure that ATP tests pass, expected values of torque should be within an adjusted +/- 0.2 ft-lb confidence interval as compared to measurements of the system.** The torque calculations from the mathematical model developed for requirement R006 are subject to this confidence interval.

Relevant ATP Items

ATP Items 01 and 06 involve measurement of torque, so this confidence interval is relevant to those items.

Power Delivered to the Load (including current and voltage)

The power which has been delivered to the load can be calculated by multiplying the above-mentioned torque and RPM values, but it is also important to know the power supply current and voltage values for several purposes; one notable calculation which is made in ATP item 03 is system efficiency by comparing these two power calculations. It has been determined that the current and voltage readouts from the power supply can be accepted as accurate, so determining the accuracy of measurements elsewhere in our system is trivial. Using the calculated confidence intervals of **0.2 ft-lb of torque and 15 RPM,** a confidence interval of 0.00057 horsepower or 0.43 Watts is calculated for power. As long as expected values of power fall **within a confidence interval +/- 0.43 Watts** of the measurements for current and voltage, then the measurements are acceptable.

For purposes of measuring current output from the high voltage power supply used in the dynamometer test setup, the current and voltage readouts on the power supply display are being read through legacy SCADA software.

The Hantek CC-650 current sensor has been chosen as the calibration standard for measuring current in this case, and proper calibration of the power supply readout has been determined through measurement of several data points and comparison between the Hantek sensor and the power supply readout. Additionally, the current output by the Magna Power Supply is specified to be within +/- .075% of full scale current, meaning that the calibration procedure above should be redundant.

Relevant ATP Items

ATP Items 01, 03, and 06 involve measurements of current and voltage supplied to the load, so this confidence interval is relevant to those items.

Cell, Pack, and total TSV Voltages

Cell Voltage Calibration

(1) Obtain a multimeter for use as a calibration standard.
(2) Connect the banana jacks on the first AMS board to be tested to the 0-6VDC output of the lab supply using test leads.
(3) Attach jacks from the meter to the studs on the first AMS board to be tested
(4) Ensure that the AMS board being tested is in communication with PackMan software via I2C, with voltage measurements able to be read onscreen.
(5) Use the lab power supply to input 2.7 and 3.7 Volts and record the multimeter and PackMan readings for each of these values.
(6) Repeat steps 2-5 for all AMS boards being calibrated.
(7) Use the two points to find a slope and offset

In carrying out the steps specified above, the following table was populated for each AMS board. The data in these tables was used to generate slope and offset values which will configure operational calibration for each AMS board.

	Cal standard (V)	AMS board (V)	With operational cal	Primary cal m	Primary cal b
Cell V 0	2.705	2.724	2.705	0.99503968	-0.0054881
	3.708	3.732	3.708		
1	2.701	2.718	2.701	0.99603175	-0.00621429
	3.705	3.726	3.705		
2	2.699	2.724	2.699	0.99603175	-0.01419048
	3.703	3.732	3.703		
3	2.699	2.712	2.699	1.00199601	-0.01841317
	3.703	3.714	3.703		

4	2.698	2.7	2.698	0.99603175	0.00871429
	3.702	3.708	3.702		
5	2.696	2.718	2.696	0.99112426	0.00212426
	3.701	3.732	3.701		
6	2.695	2.694	2.695	0.99801587	0.00634524
	3.701	3.702	3.701		

The standard deviation from this operationally calibrated data was determined to be 0.003 volts for the 2.7V measurements and 0.002 volts for the 3.7V measurements. This corresponds with a standard error value of 0.007. Multiplied by the above-used t value of 6.314 **a confidence interval of 7.3 mV is found for measurements of cell voltage.**

Pack Voltage Calibration

(1) Obtain a multimeter for use as a calibration standard.
(2) Transmit power to PackMan using the lab test stand setup
(3) Attach jacks from the meter to the battery + and pack - terminals on the PackMan board, which are directly wired to the cells through fuses.
(4) Use the lab power supply to input 18 and 25 Volts and record the multimeter and PackMan readings for each of these values.
(5) Use the two points to find a slope and offset

In carrying out the steps specified above, the following table was populated for a pack. The data in this table was used to generate slope and offset values which will configure operational calibration for pack voltage.

	Actual (V)	Measured (V)	Calc (using m and b)	m	b
pack V	17.993	17.9	17.993	0.98690141	0.32746479
	25	25	25		

For purposes of determining if all relevant ATP items regarding measurement of pack voltage pass, a confidence interval of +/- 0.2V will be used between measured and expected voltage values. This is based on a standard error calculation from the above data of 0.033V.

Relevant ATP Items

ATP Items 01 and 02 involve measurement of cell, pack, and TSV voltages, so this confidence interval is relevant to those items.

Tractive System DC Current

DC Current from the accumulator will be measured using a current sensor which will be embedded inside the pack. This sensor has been deemed accurate for use in comparison purposes.

Two current sensors are in use in the tractive system: shunt on the PackMan charge current and low current output, and an Ametes BBM-01 attached to aluminum bar senses all current discharged through AIRS.

Current Sensor Primary Calibration (1mOhm shunt resistor, PackMan charge current and low current output)

(1) Ensure that the mOHM shunt resistor is connected in order to measure PackMan charge and low current.
(2) Ensure that the pack being tested is at a 0% state of charge.
(3) Put the pack through one charge and one discharge cycle, obtaining a minimum of 15 data points for current through the sensor (lab power supply current draw used as calibration standard).
(4) Using recorded data, plot a graph of the difference in recorded current from the Ametes sensor and shunt current sensor. The slope and offset of this graph will be configured into PackMan to be used for calibration of current reading.

Performing this protocol has generated the following results:

	Actual (mA)	Measured (mA)	Calc (using m and b)	m	b
shunt(mA)	61	72.5	61	0.96363636	-8.86363636
	114	127.5	114		

Operational calibration factors from this data are shown above. These data points correspond with a standard error of 0.707 mA, so with the t value of 6.314, **operationally calibrated data for PackMan charge current and low current output is subject to a confidence interval of 4.5mA.**

Current Sensor Primary Calibration (through AIRS)

(1) Acquire the Ametes BBM-01 current sensor and ensure that it is electrically connected in order to sense all current discharged through AIRS.
(2) Ensure that the pack being tested is at a 0% state of charge.
(3) Put the pack through one charge and one discharge cycle, obtaining a minimum of 15 data points across the range of 0-20A through the sensor (lab power supply current draw used as calibration standard).
(4) Combine the data collected in the 0-20A test with that collected from the 20-250A test (results below)
(5) Fit the data points from these two tests to a power series to account for the nonlinearity below 20A and linearity up to 250A.

The power series result from the above described calibration protocol will be configured into the PackMan software in order to display calibrated current measurements. The high range of the current sensor (>20A) data has already been collected, and will be used to fit the power series. This data is shown below:

PS Current (A)	**C.S. Voltage (A)**	**A calc (9mV/A)**	**m**
0	-0.009	0.989701	107.811
20.4	0.171	20.395681	**b**
40.1	0.351	39.801661	1.96
60.2	0.538	59.962318	
80.5	0.726	80.230786	**STDEV (excluding 0A point)**
99.4	0.902	99.205522	0.209123034
120.2	1.096	120.120856	**STDERROR (excluding 0A point)**
140.2	1.285	140.497135	0.058000294
160.7	1.474	160.873414	**Confidence Interval**
179.9	1.653	180.171583	0.366213856
200.3	1.842	200.547862	
220	2.024	220.169464	
240.7	2.216	240.869176	

250.9	2.309	250.895599	

With the operational calibration described above in place, the measurement of DC current form the accumulator should be trusted as accurate. For purposes of passing ATP tests, **a confidence interval of +/- 0.366A** should be met between the measured and expected values of current during a test.

Relevant ATP Items

ATP Items 01, 03, and 06 involve measurement of these currents, so this confidence interval is relevant to those items.

Rate of Charge/Discharge and SOC of Accumulator

State of charge will be determined by integration of the tractive system DC current listed above, so its accuracy is linked with the accuracy of the current measurement. Once operational calibration has been performed on the DC current being delivered to and from the accumulator, only calibration verification needs to take place to ensure that the state of charge reading is accurate.

Assuming the slowest possible discharge current for an accumulator at 20A, the actual current is expected to be within the range of 20.366 and 19.634A. Given an accumulator capacity of 60 A-h, the capacity in Coulombs is equal to 216000. At 20 Coulombs per second, the pack will discharge in 10800 seconds, meaning a discharge rate of 1% every 108 seconds. For 20.366 and 19.634 A, the pack discharges 1.018% or 0.982% every 108 seconds respectively. .018 multiplied by 100 to account for the possible accumulation of error gives **a confidence interval of +/- 1.8%** between the measured and expected values for state of charge.

To verify calibration cell voltage will be monitored. As it peaks or rolls off to indicate a 100% or 0% state of charge, the algorithm will be account for these voltage changes and accurate values for state of charge will be displayed.

Relevant ATP Items

ATP Items 01 and 05 involve measurement of ROC and SOC, so this confidence interval is relevant to those items.

Temperatures of cells and other subsystems

For purposes of calibration and determining the accuracy of our temperature measurement, a thermocouple meter will be used as the standard measurement.

Cell Temperature Primary Calibration

(1) Obtain a thermocouple meter to be used as a calibration standard.
(2) Ensure that all AMS boards are currently at room temperature (ambient air temperature and board temperatures are identical to within +/- 5%)
(3) Ensure that all AMS boards being tested are in communication with PackMan software via I2C, with temperature measurements able to be read onscreen.
(4) Record the temperature with a thermocouple and readout on PackMan for each board and fill a table with the results (see example table below).
(5) Place one AMS board in bypass in order to raise its temperature (one at a time to ensure that current limit is not exceeded)
(6) Once the thermocouple reads 60C, record the temperature of the board and temperature displayed by PackMan (see example table below).
(7) Repeat steps 5 and 6 for all other boards being calibrated.
(8) Use the two points to find a slope and offset for each board.

	Actual (deg C)	Measured (deg C)	Calc (using m and b)	m	b
Cell deg C 0	23.3	22.6	23.3	0.80054645	5.20765027
	52.6	59.2	52.6		
1	24	23.6	24	0.76536313	5.93743017
	51.4	59.4	51.4		
2	23	24	23	0.80769231	3.61538462
	52.4	60.4	52.4		
3	22.6	23	22.6	0.69459459	6.62432432
	48.3	60	48.3		
4	22.8	22.8	22.8	0.81283422	4.26737968
	53.2	60.2	53.2		
5	22.5	22.2	22.5	0.7421875	6.0234375

	51	60.6	51		
6	22.6	23.2	22.6	0.78074866	4.48663102
	51.8	60.6	51.8		

The standard deviation from this operationally calibrated data was determined to be 0.49 degrees for the ambient temperature measurements and 1.49 degrees for the 60C measurements. This corresponds with a standard error value of 0.562. These values multiplied by a t value of 1.895 corresponding to seven samples gives **a confidence interval of 1.1 degrees C for measurements of cell voltage.**

Relevant ATP Items

ATP Items 01, 03, and 05 involve measurements of voltage, so this confidence interval is relevant to those items.

Coolant flow rate

In the current dynamometer test setup, there is no simple way to perform primary calibration on the coolant flow rate which is displayed on the Koolance CTR-CD1224 box mounted on the tower in the lab. For purposes of determining if the coolant rate measured by SCADA software is accurate, **a confidence interval of +/- 10%** will be used between the displayed value and value output on the Koolance box.

Relevant ATP Items

ATP Item 01 involves measurement of coolant flow rate, so this confidence interval is relevant to that item.