The Hex Mod Performance Test

10/22/2014

Abstract:

The Hex Mod is tested precisely to characterize the voltage drop, resistance and power loss. The test differentiates voltage drop measurements across all of the various components in a vaporizer. This includes the mod, battery, atomizer and coil. Measurements are made with various coil resistances to positively ensure consistent results across coil resistances from 0.167 to 1.5Ω, the results consistently show that the largest and most dominating contribution of voltage drop is due to the battery's internal resistance at 0.0386Ω on average. On average, the atomizer used measures 0.004Ω and the Hex mod measures at 0.0026Ω. While the mod resistance is the lowest of all, both the mod and atomizer contribute negligible effects to power loss.

Test Result Summary:

	Average Resistance Summary	
Component	Value	Units
R_{mod}	0.0026	Ω
$R_{atomizer}$	0.0040	Ω
$R_{battery}$	0.0386	Ω

	Mod Voltage Drop Summary	
Configuration	Voltage Drop	Units
1.5Ω	0.0092	V
1Ω	0.0088	V
0.75Ω	0.0086	V
0.5Ω	0.0177	V
0.25Ω	0.0371	V
0.167Ω	0.0652	V

Introduction:

The test will precisely measure the current and voltage drop across various components in a personal vaporizer. From the measurements, precise resistances can be calculated, including the mod, atomizer, coil and the battery internal resistance. From the results, power loss will be characterized on each component. The results will determine each components contribution to voltage drop and power loss in a personal vaporizer.

Theory:

Personal vaporizers operate from a battery source that energizes a heating coil, which produces the vapor. Ideally, all of power from the battery should go to the coil; however, power is lost in transmission through the mod, the atomizer body and the battery itself. The performance of a vaporizer is characterized by the amount of power realized at the coil as opposed to power lost in the other components.

The circuit of a vaporizer is depicted in Fig. 1. It is a single loop, where current flows from the battery, through the atomizer center pin, coil, atomizer base, and returns through the mod body. As such, the current is equal in all points in the loop and only needs to be measured at one point. The voltage from the battery drops across each component of the vaporizer and needs to be measured at each component. This is a rather difficult task as measurement points are difficult to access. Using fine gauge wire, voltage measurement points are brought out such that these measurements are possible. Only one voltage measurement point is not measured, which is across the mod center pin. It is assumed that the voltage drop across the pin in negligible since it is short and made from highly conductive material.

Formulas:

$V = I * R$: Ohm's Law equation

$P = I * V$: Electrical power equation

$V_{battery} = V_{atomizer} + V_{coil} + V_{mod}$: Voltage drop across components equal the battery voltage

Note: $V_{atomizer+coil} = V_{atomizer} + V_{coil}$

$V_{error} = (V_{battery} – (V_{coil} + V_{atomizer} + V_{mod})) / V_{battery} * 100\%$: Voltage measurement error

$I_{battery} = I_{atomizer} = I_{coil} = I_{mod}$: Current through all components are equal

$P_{battery} = P_{battery\_loss} + P_{atomizer} + P_{coil} + P_{mod}$: Power supplied by the battery equals the sum of power lost on each component

$R_{battery} = (V_{battery\_open} – V_{battery\_closed}) / I_{battery}$: Battery internal resistance

$R_{coil} = V_{coil} / I_{battery}$: Coil resistance

$R_{atomizer} = V_{atomizer+coil} / I_{battery} – R_{coil}$: Atomizer resistance

Note: $R_{atomizer} = R_{atomizer\_center} + R_{atomizer\_base}$

$R_{mod} = V_{mod} / I_{battery}$: Mod Resistance

$P_{battery} = V_{battery\_closed} * I_{battery}$: Power supplied by the battery with its internal resistance

$P_{battery\_loss} = (V_{battery\_open} – V_{battery\_closed}) * I_{battery}$: Internal batter power loss

$P_{coil} = V_{coil} * I_{battery}$: Power delivered to the coil

$P_{atomizer} = V_{atomizer+coil} * I_{battery} - P_{coil}$: Power lost in the atomizer

$P_{mod} = V_{mod} * I_{battery}$: Power lost in the mod

$P_{error} = (P_{battery} - (P_{battery\_loss} + P_{coil} + P_{atomizer} + P_{mod})) / P_{battery} * 100\%$: Power calculation error

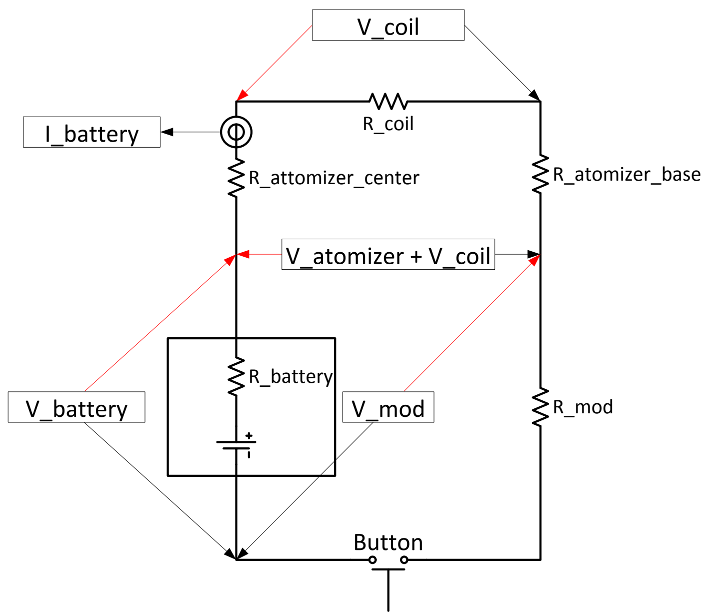

Fig. 1: Vaporizer Schematic

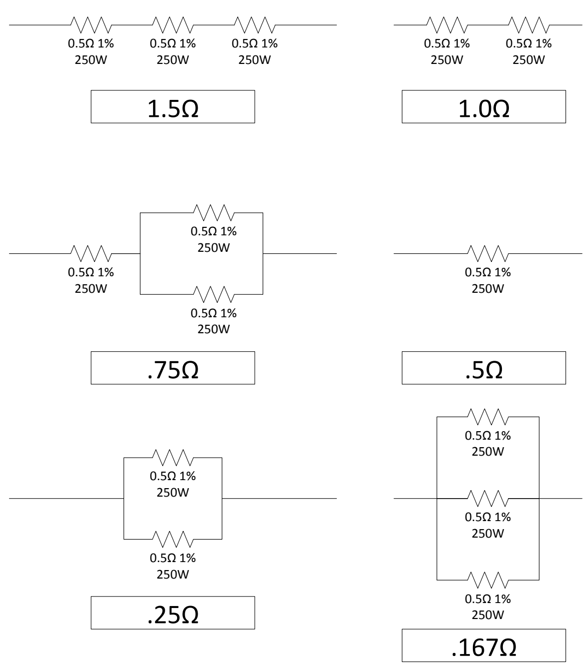

Fig. 2: Resistor Configurations

Process and Procedure:

When using a traditional coil, inconsistent results have been observed due to varying amounts of juice. If the wick is removed for a bare coil, elevated temperature cause erratic voltage measurements and damage to the atomizer and measuring equipment. The coil will be substituted with high power resistors to minimize the effect of heating for more consistent results and a safer test. Three 250W 0.5 ohm resistors will be used in series/parallel combinations according to Fig. 2 to create 1.5, 1, 0.75, 0.5, 0.25 and 0.167 ohms. Precise and accurate resistances will be calculated after measurements are made to account for resistance in the leads and resistor tolerances.

Voltages measurements are also a difficult measurement to attain accurately since the battery voltage drops with use and voltage changes with temperature as components warm up. As such, ten voltage measurements will be made for each resistance configuration. Data will be taken for ten seconds at one second intervals for a total of ten measurements at each resistance. Voltages will be measure across the following components for each coil resistance mentioned above:

1. Battery open (one measurement)
   a. Battery
2. Battery closed (ten measurements at one second intervals)
   a. Battery
   b. Atomizer, which includes the coil voltage
   c. Coil
   d. Mod

Current will be measured with a current clamp on the lead from the atomizer center pin to the resistor load, which is equal on every component in vaporizer. This measurement is taken in conjunction with the voltage measurements.

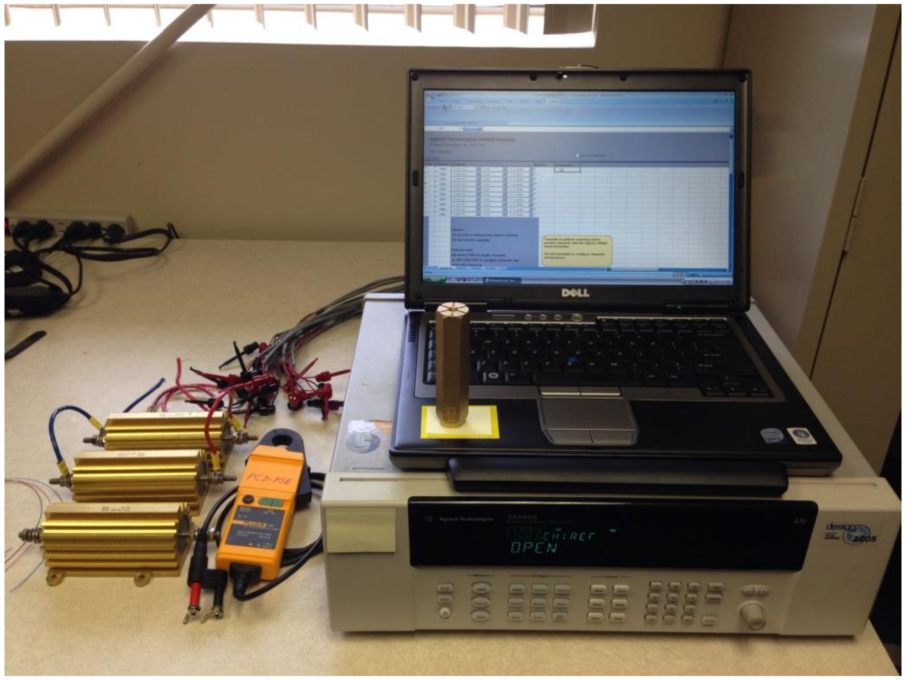

Fig. 3: Test Equipment

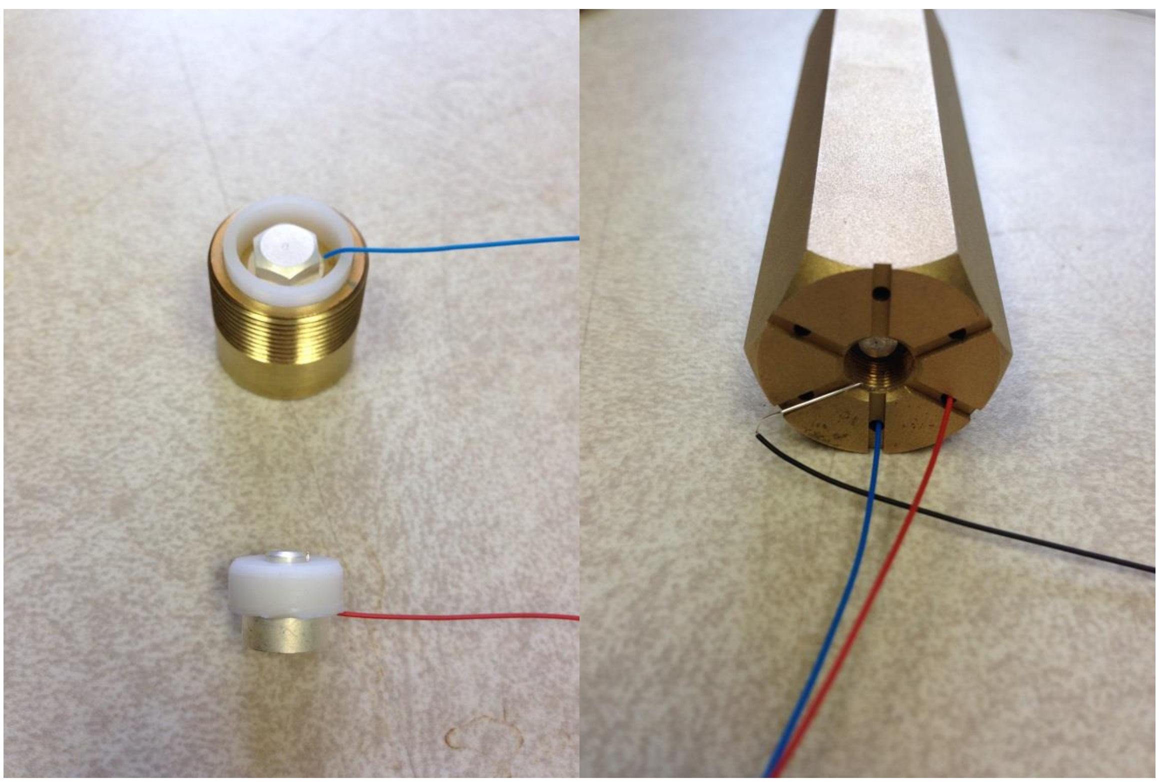

Fig. 4 Voltage Measurement points

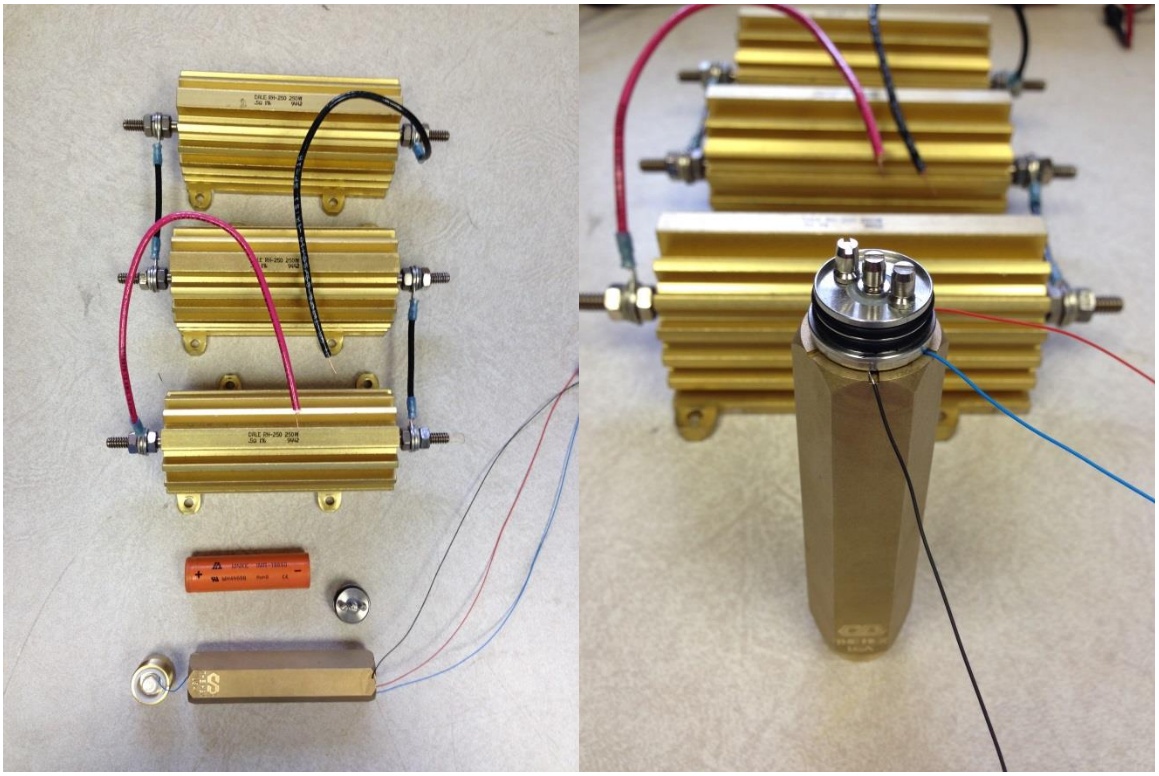

Fig. 5: Test Devices and Load

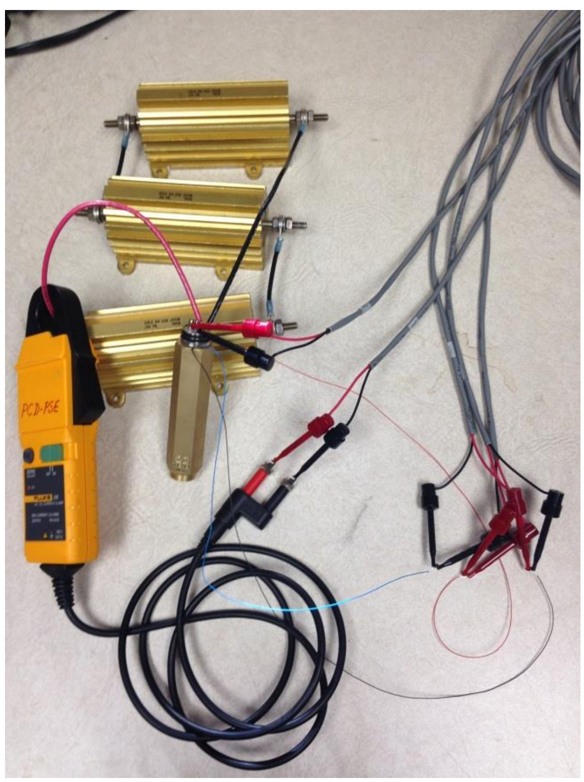

Fig. 6: Test Devices and Measurement Connections

Equipment:

The Hex Mod, 464 Naval brass, silver-plated contacts

MNKE 18650 battery, charged to 4.2V

Trident atomizer base

Three Dale 250W 0.5 ohm resistors

Agilent 34980A Mulitfunction Switch/Measurement Unit, set to 4.5 digits, 1 second sampling

Fluke i30 AC/DC current clamp

PC with Agilent's Excel plug-in to capture data

Raw Data:

	Battery Voltage	Atty + Coil	Mod	Coil	Current 100mV/A
	VOLT	VOLT	VOLT	VOLT	VOLT
	1001	1002	1003	1004	1005
16:21:48	4.1517	4.1517	0.000005	4.1511	-0.0016
Pause Data Log					
16:22:12	4.0558	4.0493	0.001729	4.0358	0.2688
16:22:13	4.0482	4.0412	0.002226	4.0278	0.2688
16:22:14	4.0396	4.0331	0.005538	4.0213	0.2678
16:22:15	4.0248	4.0252	0.00510	4.0047	0.264
16:22:16	4.0294	4.0092	0.018945	4.0073	0.2656
16:22:17	4.024	4.0063	0.018258	3.9939	0.2651
16:22:18	4.0186	4.0019	0.017185	3.99	0.2661
16:22:19	4.0143	4.0024	0.011351	3.9906	0.2661
16:22:20	4.01	4.004	0.006131	3.9906	0.2661
16:22:21	4.0078	4.0024	0.005295	3.9895	0.2656
Pause Data Log					
16:22:52	4.1237	4.1237	0.000011	4.1237	-0.0011
Pause Data Log					
16:23:10	4.0057	4.0024	0.003257	3.983	0.3976
16:23:11	3.99	3.9868	0.002712	3.9685	0.3965
16:23:12	3.9787	3.9766	0.002896	3.9566	0.3944
16:23:13	3.9739	3.9706	0.003904	3.9518	0.396
16:23:14	3.968	3.9523	0.015513	3.9335	0.3944
16:23:15	3.9599	3.9464	0.013863	3.9281	0.3922
16:23:16	3.955	3.9329	0.020959	3.9157	0.3906
16:23:17	3.9502	3.9335	0.016441	3.9157	0.3911
16:23:18	3.9453	3.941	0.004211	3.9238	0.3917
16:23:19	3.9405	3.9362	0.004012	3.9211	0.3917
Pause Data Log					
16:24:25	4.1167	4.1172	0.000011	4.1167	-0.0011
Pause Data Log					
16:24:44	3.9588	3.9534	0.005306	3.9286	0.5221
16:24:45	3.9416	3.9028	0.02674	3.8941	0.5194
16:24:46	3.9292	3.9168	0.010687	3.8958	0.5188

16:24:47	3.9238	3.9098	0.013621	3.8888	0.5172
16:24:48	3.9146	3.9076	0.007797	3.8866	0.5172
16:24:49	3.9071	3.9022	0.00509	3.8818	0.5167
16:24:50	3.9017	3.8963	0.005268	3.8764	0.5156
16:24:51	3.8952	3.8909	0.004659	3.8704	0.5151
16:24:52	3.8909	3.8866	0.003359	3.8661	0.5151
16:24:53	3.8855	3.8812	0.003295	3.8607	0.5134
Pause Data Log					
16:25:45	4.0946	4.0956	0.000005	4.0956	0
Pause Data Log					
16:26:23	3.8731	3.8381	0.032197	3.8069	0.7548
16:26:24	3.8661	3.8494	0.016371	3.8155	0.758
16:26:25	3.8489	3.8343	0.013286	3.8036	0.7543
16:26:26	3.8349	3.8187	0.016727	3.7875	0.7516
16:26:27	3.823	3.8036	0.019547	3.7751	0.7494
16:26:28	3.8176	3.7999	0.017557	3.7713	0.7489
16:26:29	3.8101	3.7923	0.018484	3.7643	0.7478
16:26:30	3.8015	3.788	0.01457	3.7589	0.7467
16:26:31	3.7939	3.7794	0.014553	3.753	0.7456
16:26:32	3.7864	3.7735	0.013319	3.7465	0.7435
Pause Data Log					
16:27:48	4.0832	4.0827	0.000011	4.0832	-0.0005
Pause Data Log					
16:28:20	3.6668	3.6463	0.019865	3.5924	1.4159
16:28:21	3.642	3.5989	0.040625	3.5472	1.3992
16:28:22	3.6258	3.5596	0.064987	3.5084	1.3825
16:28:23	3.6043	3.5827	0.020307	3.5326	1.3927
16:28:24	3.5876	3.565	0.020981	3.5154	1.3857
16:28:25	3.572	3.5326	0.037238	3.4863	1.3738
16:28:26	3.5574	3.5095	0.047759	3.4604	1.3625
16:28:27	3.5553	3.5095	0.043612	3.461	1.3652
16:28:28	3.5353	3.4998	0.035378	3.4518	1.3609
16:28:29	3.5262	3.4879	0.039961	3.4378	1.355
Pause Data Log					
16:29:18	4.0396	4.0396	0.000005	4.0396	-0.0005
Pause Data Log					
16:29:42	3.4944	3.4314	0.062247	3.3554	1.9686
16:29:43	3.4707	3.3904	0.078618	3.3241	1.9519
16:29:44	3.44	3.3656	0.070357	3.3037	1.9406
16:29:45	3.4173	3.3473	0.064097	3.288	1.9336
16:29:46	3.3947	3.329	0.063525	3.2633	1.9174
16:29:47	3.3699	3.2961	0.071808	3.2347	1.9013
16:29:48	3.3435	3.2837	0.059497	3.2207	1.8905
16:29:49	3.3171	3.2595	0.062485	3.1948	1.877
16:29:50	3.2945	3.2218	0.0836	3.148	1.8512
16:29:51	3.2724	3.2347	0.035815	3.1749	1.8652
Pause Data Log					

Raw Voltage Data (average of 10 measurements over 10 seconds):

	Averaged Raw Voltage Data					
Configuration	Battery	Atty + Coil	Mod	Coil	Current 100mV/A	Verror (%)
Open	4.1517	4.1517	0.000005	4.1511	-0.0016	0.00
1.5Ω	4.0273	4.0175	0.009176	4.0052	0.2664	0.01
Open	4.1237	4.1237	0.000011	4.1237	-0.0011	0.00
1Ω	3.9667	3.9579	0.008777	3.9398	0.3936	0.00
Open	4.1167	4.1172	0.000011	4.1167	-0.0011	-0.01
0.75Ω	3.9148	3.9048	0.008582	3.8850	0.5171	0.04
Open	4.0946	4.0956	0.000005	4.0956	0.0000	-0.02
0.5Ω	3.8256	3.8077	0.017661	3.7783	0.7501	0.00
Open	4.0832	4.0827	0.000011	4.0832	-0.0005	0.01
0.25Ω	3.5873	3.5492	0.037071	3.4993	1.3793	0.03
Open	4.0396	4.0396	0.000005	4.0396	-0.0005	0.00
0.167Ω	3.3815	3.3160	0.065205	3.2508	1.9097	0.01

Calculated Voltage Drops and Current (from averaged data):

	Averaged Voltage and Current Data					
Configuration	$V_{battery\_drop}$ (V)	$V_{atomizer+coil}$ (V)	V_{mod} (V)	V_{coil} (V)	$V_{atomizer}$ (V)	$I_{battery}$ (A)
1.5Ω	0.124	4.018	0.00918	4.005	0.012	2.664
1Ω	0.157	3.958	0.00878	3.940	0.018	3.936
0.75Ω	0.202	3.905	0.00858	3.885	0.020	5.171
0.5Ω	0.269	3.808	0.01766	3.778	0.029	7.501
0.25Ω	0.496	3.549	0.03707	3.499	0.050	13.793
0.167Ω	0.658	3.316	0.06520	3.251	0.065	19.097

Calculated Resistance:

	Resistance			
Configuration	$R_{battery}$ (Ω)	R_{coil} (Ω)	$R_{atomizer}$ (Ω)	R_{mod} (Ω)
1.5Ω	0.047	1.503	0.00464	0.00344
1Ω	0.040	1.001	0.00460	0.00223
0.75Ω	0.039	0.751	0.00384	0.00166
0.5Ω	0.036	0.504	0.00393	0.00235
0.25Ω	0.036	0.254	0.00361	0.00269
0.167Ω	0.034	0.170	0.00341	0.00341
Average	0.039		0.0040	0.0026

Calculated Power:

	Power					
Configuration	$P_{battery}$ (W)	$P_{battery\_loss}$ (W)	P_{coil} (W)	$P_{atomizer}$ (W)	P_{mod} (W)	P_{error} (%)
1.5Ω	11.06	0.33	10.67	0.03	0.02	0.01
1Ω	16.23	0.62	15.51	0.07	0.03	0.00
0.75Ω	21.29	1.04	20.09	0.10	0.04	0.04
0.5Ω	30.71	2.02	28.34	0.22	0.13	0.00
0.25Ω	56.32	6.84	48.27	0.69	0.51	0.02
0.167Ω	77.15	12.57	62.08	1.24	1.25	0.01

Calculated Power in percentage:

	Power			
Configuration	$P_{battery\_loss}$ (%)	P_{coil} (%)	$P_{atomizer}$ (%)	P_{mod} (%)
1.5Ω	3.00	96.47	0.30	0.22
1Ω	3.81	95.54	0.44	0.21
0.75Ω	4.90	94.37	0.48	0.21
0.5Ω	6.57	92.27	0.72	0.43
0.25Ω	12.15	85.70	1.22	0.91
0.167Ω	16.29	80.47	1.61	1.61

Summary:

The test yielded consistent results overall and voltage measurement errors were minimal since multiple measurements were made and averaged. Resistances do vary across different coil configurations since the measured voltages are at very low levels, especially when the coil resistance is high and dominates the voltage drop. Lower coil resistances accentuate other component resistances. Overall the average calculated battery, atomizer and mod resistances stayed relatively constant as expected. The calculated coil resistance matched its theoretical configuration.

The test showed the dominating resistance in a vaporizer is the battery resistance which averaged 0.039Ω. This value is not attainable with traditional “inline” voltage measurements since it cannot differentiate the battery voltage and mod voltage under load. The atomizer resistance averaged very low at 0.004Ω and the mod resistance averaged the lowest of all at 0.0026Ω. The atomizer and mod resistances are low enough to cause negligible effects to the vaporizers overall resistance and performance.

As coil resistance drops, more power is lost in peripheral components and less power is applied to the coil. The reasoning for this is more difficult to conceptualize. Since $P = V^2 / R$, more power is lost as the resistance is lowered. As the coil resistance is lowered, power increases, thus creating more vapor. At the same time, power lost in peripheral components also increases because $P = I^2 * R$, R being relatively constant on the battery, atomizer and mod. Even at very low coil resistance of 0.167Ω, the power loss in either the atomizer or mod was less than 2%, which is minimal compared to the 16% lost at the battery.