Title: Sources of Temperature Variance in Dispenser Cathodes

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ABSTRACT

Typical temperature specifications for dispenser cathodes range from 950Cb to 1100Cb with 1 to 2 percent tolerance. With current techniques tolerance and repeatability of measurements are impacted by variables in construction materials, material surface conditions, test equipment and arrangements, and temperature measurement when dispenser cathodes are vacuum thermal tested. Dispenser cathodes are constructed from various refractory metals and oxide materials which present certain unique properties and associated unique uncertainties. This paper discusses the manufacturing processes and materials contributing to these temperature variables, including emitter surface conditions, surface finish variability on the cathode body and heat shields, heater wire resistance, potting density, and temperature measurement deviation.

The data includes sample sets of cathode test data demonstrating the cumulative effects of the variables, error factors, and specific parameters evaluated in the paper.

HEATER

The major component of determining the temperature of a dispenser cathode is the heater. Tungsten-3% rhenium wire is the material most prevalent in the industry, and the amount of rhenium content is typically held to 3.1 to 3.4 % tolerance. The alloy will perform differently among suppliers, with heaters manufactured having somewhat different wire cold resistance. For example, Nippon wire has approximately 3% lower resistance than Osram wire, requiring an increase in heater length to compensate. This is generally not a problem, since the heater cavity can usually accommodate this adjustment to meet the cold resistance specification. The resistance measurement is made at room temperature with a 4-wire technique to within 5% tolerance of specification[1]. For accurate correlation to cathode test conditions, the cold resistance measurement is taken at the same length and leg locations as the hot test will be performed. Other materials used to manufacture heaters include pure tungsten, tungsten-25%rhenium, and pure molybdenum.

Consistent wire resistance and dimensions are critical parameters to heater performance. Recent improvements[2] in supplier processes by eddy current testing the wire have reduced the opportunity for splits, inclusions, and other mechanical defects in the final product.

POTTING

During cathode operation the energy supplied by the heater conducts throughout the potted heater cavity and into the cathode body and emitter. Aluminum oxide is the primary material used in potting the heater into the cathode body and various formula mixes of grit size are used, depending upon the application. The potting compound may also be doped with other oxides to reduce shrinkage and potential crack formations.

Temperature differences due to variances in the potting density effect the thermal energy conduction from the heater to the cathode body. A tightly packed heater with dense potting offers more conduction to the cathode surface. A less dense arrangement will conduct less heat, operate at a higher wire temperature, and perform with less efficiency. The potting density is manually controlled by the assembler during manufacturing, and a rigid qualification matrix must be completed and maintained to address consistency. In Table 1 data samples gathered over a period of one year demonstrate from 1.2% to 2.4% temperature capability, based on a simple six sigma calculation. The data are cumulative of the variances discussed and represent the sum of all the error factors in a practical end result. The cold resistance ranges from 1.8% to 2.8% which is a factor in contributing to the temperature variance. The largest cold resistance capability in data set D of 2.78% does not correspond to the largest Tk3 capability of data set A. The smallest cold resistance capability of 1.85% in data set B also does not correspond to the smallest temperature capability of 1.23% in data set D. Additional sources of variance are involved other than cold resistance. The average capability across all data sets is 1.67% for temperature, which represents the final average variance, and 2.29% for Rc.

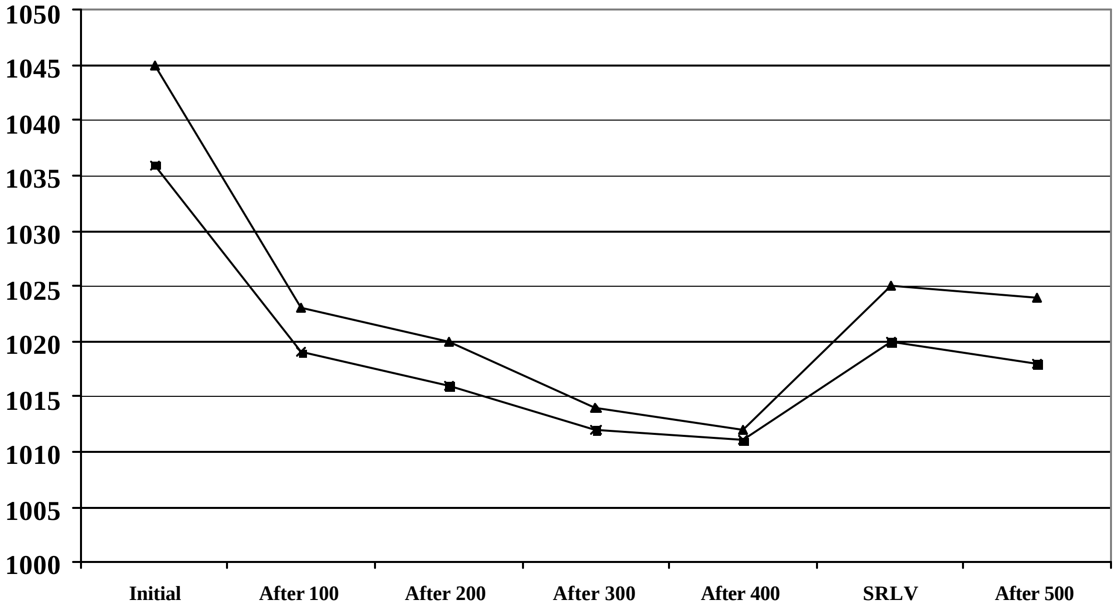
Table 1 - Cathode Data Sample Set

Dataset:	A	B	C	D	E	F
Tk3 mean, ºCb	1083	1086	1084	1087	1089	1083
Tk3 stdev	8.686	5.109	6.376	4.442	5.228	6.333
Tk3 stdev X 3	26.06	15.33	19.13	13.33	15.68	19
capability (3s/mean)X100	2.405	1.411	1.765	1.226	1.44	1.755
est. variance	75.45	26.1	40.66	19.73	27.33	40.1
Rc mean, ohms	0.313	0.31	0.308	0.305	0.307	0.305
Rc stdev	0.002	0.002	0.003	0.003	0.002	0.002
Rc stdev X 3	0.006	0.006	0.008	0.008	0.007	0.006
capability (3s/mean)X100	2.075	1.851	2.724	2.779	2.19	2.095
est. variance	5E-06	4E-06	8E-06	8E-06	5E-06	5E-06

COMPONENTS

The cathode emitter surface and body components will radiate the energy provided by the heater. Sources of variance include the emitter surface condition, coatings, radiation effectiveness of the body and shielding, and changing conditions of emissivity on all surfaces. During operation the barium compounds will migrate to the emission surface. This will cause a change in the surface emissivity and corresponding change in the temperature measurement. In Figure 1 tests have shown after 500 hours of cycling operation, the temperature measurement may drop 20Cb to 30Cb. To confirm this effect, SRLV cleaning and re-testing the cathodes was performed, resulting in the rise of 10Cb to 15Cb toward the original temperatures. The remaining percentage is due to the normal drop in initial temperature, where the cathode potting structure will have an initial burn-in phase that establishes stable heat conduction and then performs with minimal change over the design life of the part. Estimated variance due to surface emissivity is 1%.

Fig. 1-Sample data for two cathodes showing temperatue effects of tungsten surface conditions.



An emitter surface coating of osmium-ruthenium alloy is typically applied to lower surface work function. This can also cause a temperature measurement shift of 30Cb lower than a non-coated surface.

The radiation losses from the cathode body surface can dramatically affect the energy intended for the cathode emitter. In Figure 2 temperature data from a surface study shows the machining finish and the overall “shiny-ness” or “dull-ness” conditions will radiate with different efficiencies. A polished molybdenum body may cause the emitter surface to run 10Cb to 15Cb hotter than normal, with similar results from a lightly grit blasted surface on the cathode radius. Drastic effects are demonstrated when the molybdenum body is grit blasted, with 100Cb lower temperature at the cathode surface. The change in emissivity of the body causes more energy to be radiated from the body and less energy from the cathode emissive surface. In Figure 3 data shows the corresponding effects of current during the same test. The higher current demonstrates that more power is required for the grit blasted surface. Total estimated variance could be up to 10%, but typically around 1%.

Surface conditions and thickness of any shields and their ability to re-radiate or insulate can also have an effect on the temperature measurement. Thicker shields tend to run cooler, but also they conduct more heat from their braze joints. The quality and consistency of shield attachment methods are crucial to stable temperature performance.

Fig. 2 - Effects of Modified Surface Conditions on Temperature

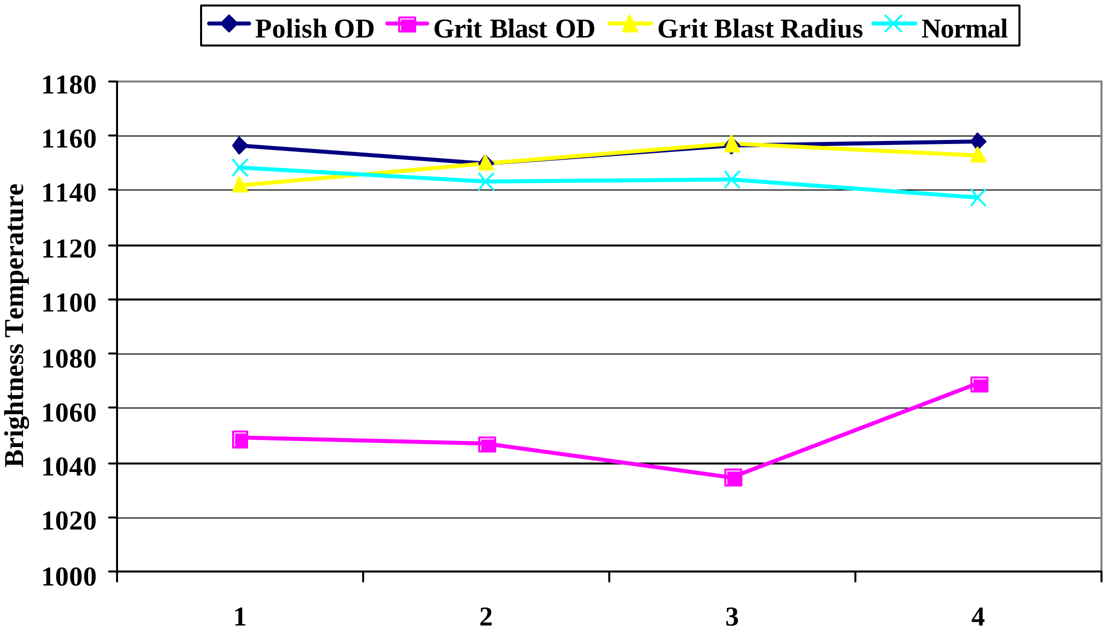
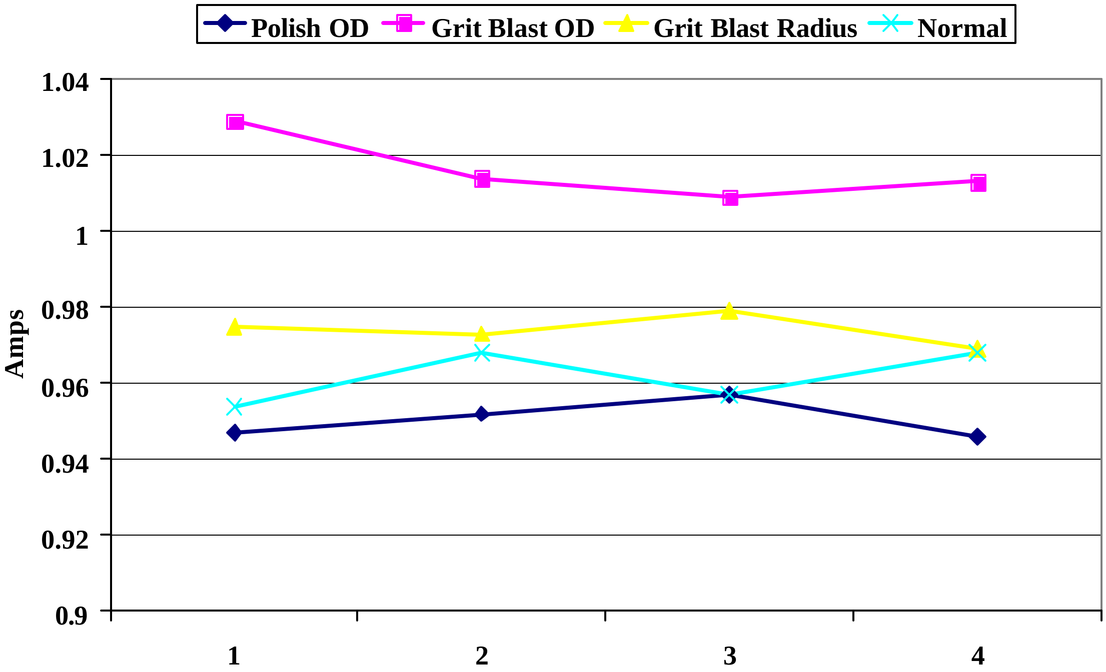


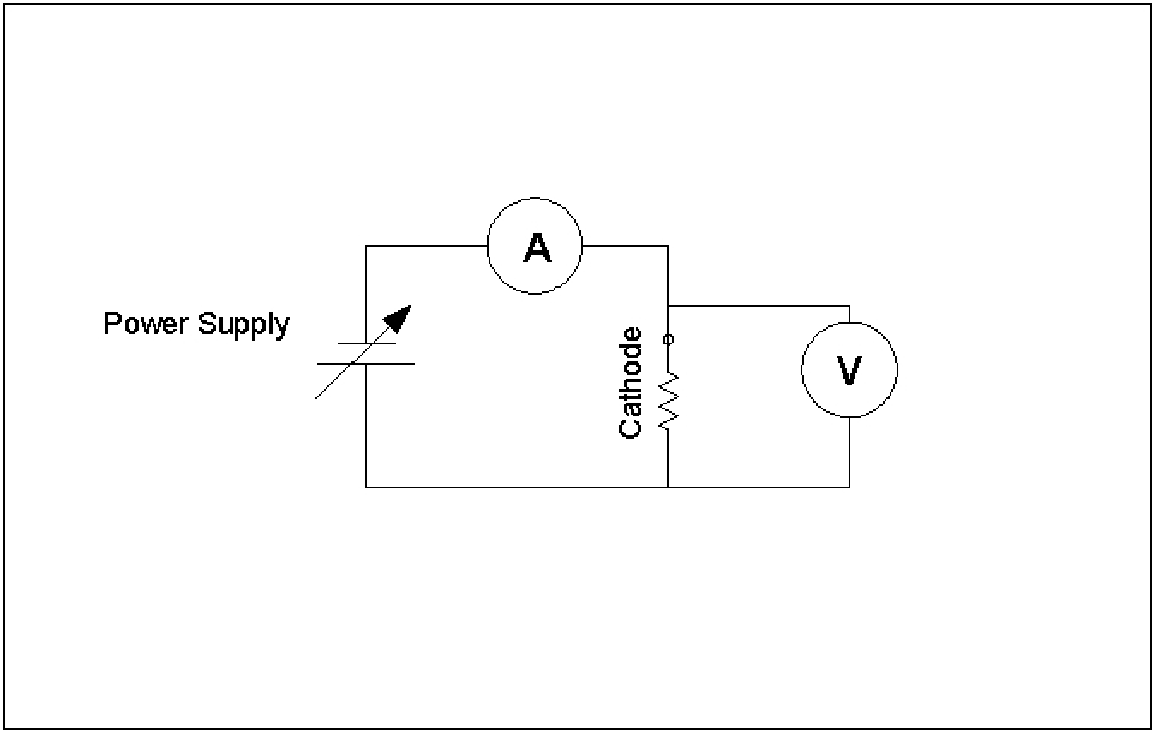
Fig. 3 - Effects of Modified Surface Conditions on Current



TEST CONDITIONS

The typical manufacturing test environment for dispenser cathodes is in a vacuum bell jar (<2X10-6 Torr) and performed with a power supply and instrumentation in a 3-wire or 4-wire configuration mode (see Fig. 4). Voltage and current measurements are typically 4 significant digits and are taken at the heater connection points. Sources of variance include the current meter shunt resisters (1% tolerance, typical) and the cathode connections. Resistance loss in poor connections will dramatically affect the data and must be avoided. A standard test setup is used for repeatability and accuracy of the measurements across multiple test positions. Tolerance is typically maintained within 2%. For example, a 2 ohm 1% tolerance calibration resistor is measured for cold resistance. The resistor is then tested at 5 volts and the current recorded. The theoretical current value is calculated based on the cold resistance measurement, and then compared to the actual current measurement. Across all test positions the data is held within .050 amps of the theoretical value for this test setup. This may have up to 1.5% effect on the wire temperature of a cathode with similar characteristics and correspondingly affect the surface temperature of the cathode.

Fig. 4 – Schematic of Test Setup



Most cathodes are designed non-inductive with bifilar or toroid configurations, allowing AC or DC operation. Proper polarity must be considered for DC testing, to avoid electro-chemical effects of the heater to potting interface. History has shown unstable performance when the heater is made positive and the body is negative. All cathodes with grounded heater leads are tested with the heater negative and the body positive, or tested in AC mode.

Additional precautions are taken when testing large cathodes. A proper warm up schedule must be followed to avoid excessive heating of the internal potted heater. Wire temperature calculations are used to avoid separating the heater from the potting and causing unstable performance or damage.

TEMPERATURE MEASUREMENT

The temperature measurements are generally measured with optical pyrometers. Testing conditions are not 100% accurate, since black body conditions do not exist on the emitter surface. The temperature measured is called the "brightness" temperature, usually designated Tb by the industry. The accuracy of an L&N Optical Pyrometer is plus or minus 4ºC in the range of cathode operation[3]. This is equivalent to ±.4% uncertainty of a cathode at 1000Cb temperature.

The operator's ability to use the instrument is also a source of variance. Correlation of temperature tests between Semicon and two customers are shown in Tables 2 and 3. In Table 2 the worst case of 4ºC std. dev X 3=±12ºC capability. Therefore measurement is about 1% uncertainty. Table 3 shows correlation between operators using the same pyrometer with about 2ºC std. dev.

Table 2 – Correlation of Test Data Semicon vs. Customer A

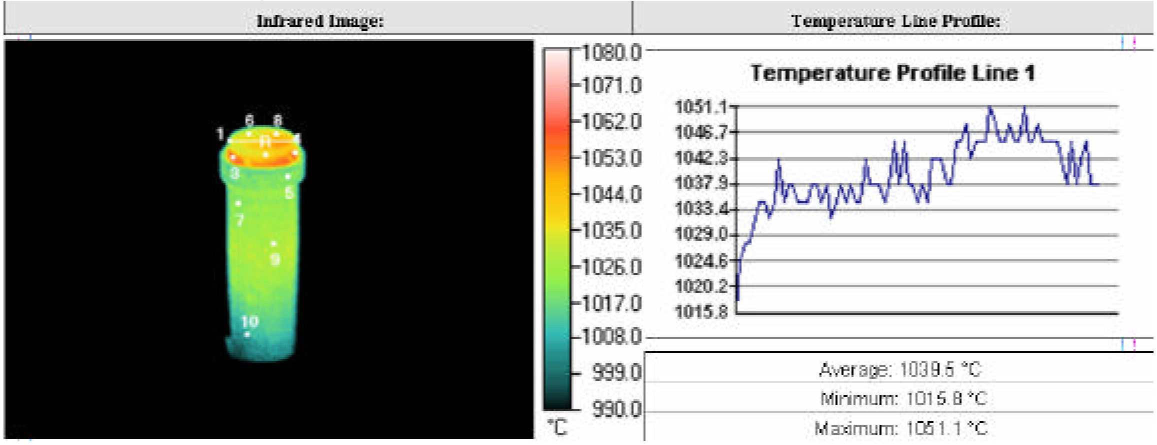
Part #	Semicon Pyro - Operator A	Customer A Pyro - Operator B	Semicon Pyro - Operator B	Customer B Pyro - Operator A	std. Dev
1	1082	1082	1078	1082	2.00
2	1083	1089	1084	1086	2.65
3	1083	1088	1085	1082	2.65
4	1085	1089	1088	1088	1.73
5	1084	1089	1087	1086	2.08
6	1075	1078	1073	1076	2.08
7	1079	1086	1077	1082	3.92
11	1080	1080	1080	1082	1.00
12	1065	1069	1060	1068	4.04
13	1072	1080	1074	1072	3.79
14	1085	1082	1088	1079	3.87
15	1086	1090	1084	1086	2.52
16	1084	1080	1081	1082	1.71
17	1086	1085	1082	1085	1.73

Table 3 – Correlation of Test Data Semicon vs. Customer B

Part #	Semicon Pyro - Operator A	Semicon Pyro - Operator B	Semicon Pyro - Operator C	std_dev
1	1120	1124	1120	2.309
2	1119	1123	1120	2.082
3	1112	1111	1115	2.082
4	1123	1121	1124	1.528
5	1119	1118	1118	0.577
6	1125	1123	1126	1.528
7	1125	1126	1124	1.000
8	1124	1123	1121	1.528
9	1126	1123	1124	1.528
10	1124	1121	1125	2.082
11	1126	1124	1127	1.528
12	1115	1119	1118	2.082
13	1131	1128	1126	2.517
14	1120	1125	1124	2.646
15	1110	1109	1112	1.528
16	1104	1105	1106	1.000
17	1116	1116	1116	0.000
18	1125	1126	1124	1.000

Uniformity of the cathode surface can also be affected by the thickness of the cathode pellet. In Figure 5, the line profile of a cathode surface shows the pellet is approximately 10ºC hotter in the center than on the edge. This is about 1% of temperature uncertainty.

Fig. 5 – Line profile of cathode surface temperature



Average: 1039.5 °C
Minimum: 1015.8 °C
Maximum: 1051.1 °C

CONCLUSION

For a simple calculation of the total percentage uncertainty from sources discussed the following method was used:

% heater wire variance =5%
+ % potting density variance (operator controlled) =2.4%
+ % surface conditions variance(emissivity error) =1%
+ % test equipment error =.4%
+ % temperature measurement error (gage rr) =1%
= total % of uncertainty 9.8%

The actual temperature results from Table 1 of 1.67% average variance demonstrate on this specific cathode the target temperature is achieved well beyond worst case. However, typical target specifications are ±25ºC or more and many cathode designs cannot achieve this. Further investigations are necessary to explain the convergence of variance from sources identified. Additional mathematical treatment is necessary to arrive at a proper statistical model.

References

1. EIA-940 Engineering Specification for Cathode Heaters,para.7.4.2
2. Title III of the Defense Production Act (50 U.S.C. App. 2061)
3. Leeds and Northrup Directions for 8634 Optical Pyrometer, #177483, Issue 2

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