Reducing Boron Embrittlement of Tungsten Cathodes By Timed Filament Power Reduction

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The Problem

Life-limiting Boron embrittlement of tungsten filaments heating LaB_6 cathodes has been observed[2]. Therefore it is important to prevent boron from condensing on the tungsten surface and subsequently diffusing into the tungsten volume.

The Cause

Boron embrittlement is thought to be due to the difference in thermal expansion of tungsten (~ 3 ppm/°C) and of boron (~ 8 ppm/°C) that has diffused into the tungsten. Boron evaporating from LaB_6 cathodes condenses on cooler surfaces. During normal operation, the tungsten filament heating the cathode to electron emission temperatures typically operates several hundred degrees hotter than the cathode. Under these conditions, the probability of boron condensing on the tungsten filament and subsequently diffusing into its volume is quite low. However, if the filament power is turned off rapidly, the filament can cool quicker than the cathode due to its lower mass and conduction cooling along its leads. When this happens, the filament presents a cooler surface for boron condensation.

A Solution

One way to prevent the diffusion of boron condensate is to reduce the sticking probability of evaporated boron arriving at the tungsten surface. This can be done by gradually reducing the filament power so that the filament temperature is always a few hundred degrees hotter than the cathode as the cathode cools to ambient temperature by thermal radiation.

Theoretical Calculations

The results of calculations for the conditions necessary to meet this requirement for a small e-gun cathode and filament are shown in Figure 1. Plotted as a function of the thermal radiation cathode cool-down time, the upper curve is the cathode temperature normalized with respect to the cathode operating temperature. The lower curve is the filament power required to maintain the filament temperature 250 °C hotter than the cathode temperature normalized with respect to the maximum operating filament power. The straight line is the ambient temperature normalized with respect to the cathode operating temperature. Figure 1 shows that the thermal radiation cool-down time to reach ambient temperature is in excess of one hour.

Practical Implementation

The practical filament power-down procedure suggested by these results is as follows: Initially reduce the filament power to 60% of its normal operating power, then gradually reduce this power according to the normalized filament power curve of Figure 1 until a filament power of 5% is reached in approximately 300 seconds (5 minutes). At 600 seconds, the cathode temperature is below 300 °C it should be safe to turn the filament completely off. This procedure is summarized in the Table 1.

[1] http://www.asaellc.com

[2] Dan Goebel, Ph.D., Principle Scientist Jet propulsion Laboratory, Pasadena, CA, Private communication, 2008

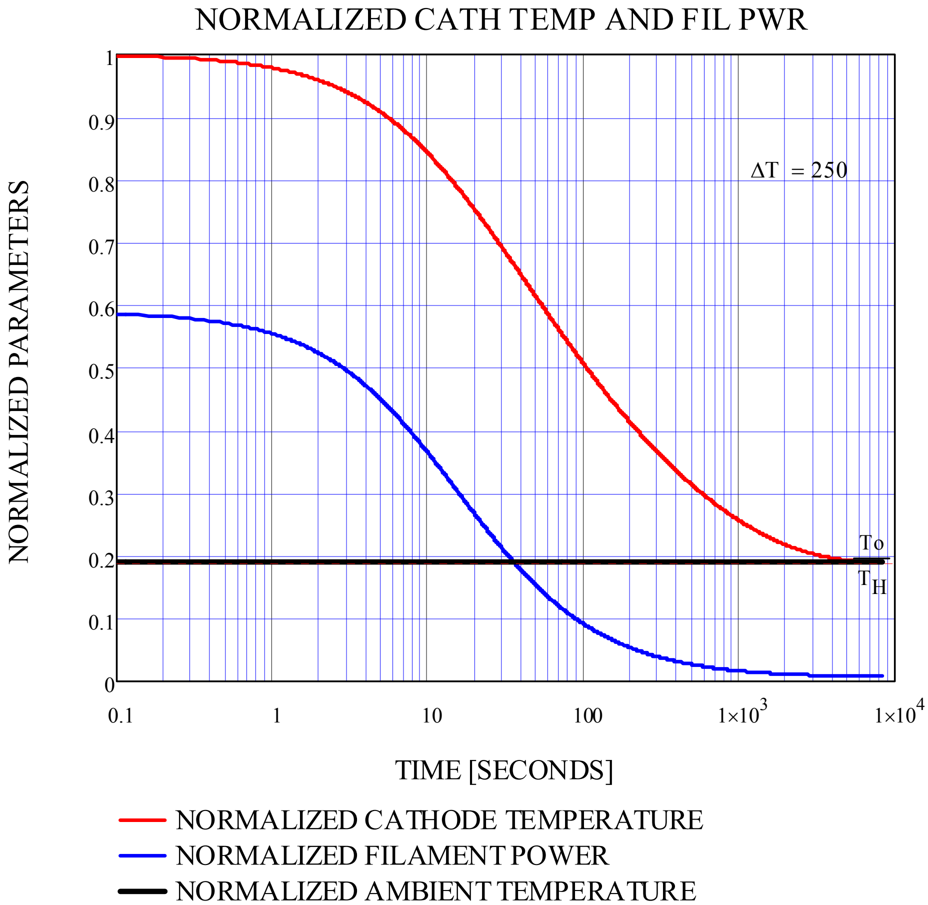

Figure 1 Normalized filament power-down rate required to maintain filament temperature greater than the cathode temperature during cathode cool-down by thermal radiation to the ambient environment.

Table 1 Practical Filament Power-Down Schedule

TIME AFTER INITIATION OF FILAMENT SHUT-DOWN [SECONDS]	NORMALIZED FILAMENT POWER [PERCENT OF FULL POWER]
0	100
1	60
3	50
8	40
15	30
35	20
90	10
300 (5 minutes)	5
600 (10 minutes)	OFF