Performance of a Tungsten-Wire Profile Scanner in the SNS Superconducting Linac

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Introduction

Although a carbon or silicon carbide wire would be more suitable for use as a profile monitor in the superconducting cavity linac, concern about sublimation or ablation of these materials may preclude their use due to possible contamination of the superconducting cavities.

Tungsten wires have been used extensively in stepping wire scanners for many years. Tungsten has a very high melting point, 3370°C, which partially compensates for the very high density and the relatively low specific heat, which together contribute to a very high temperature rise in pulsed particle beams.

Specific properties of the tungsten wire used in this note are:

Density	19.3 grams/cm^3
Specific heat	0.150 Joules/gram-°K
Emissivity	0.11 at 1000°C to 0.33 at 3000°C
Diameter	100 μm

The beam properties used in this note are

Beam energies	185 and 1000 MeV, H^-
Peak beam current	56 mA
Beam pulse length	50 μsec
Pulse repetition rate	1 Hz
dE/dx	3 x 3.31 and 3 x 1.56 MeV-cm^2/gram (see note below)

Note: The thermal heating is expected to be about 3 times that for protons, because the two valence electrons on H^- very quickly separate from the proton in the wire, and produce additional dE/dx heating.

A plot of the peak wire temperature vs. time is shown in Figure 1. Only thermal radiation heat loss (σT^4) is included. At very high temperatures, thermionic-emission electrons will carry away some thermal energy, resulting in additional heat loss.

Table 1 compares the peak temperature rise using the parameters above and used in Figure 1 with different operating conditions.

Table 1. Effect of changing parameters on peak temperature.

Effect	185 MeV	1000 MeV
Baseline parameters (above)	2142° C	1343° C
2 Hz rep rate (vs. 1 Hz)	2315°	1506°
100 μsec pulse length (vs. 50 μsec)	3615°	2054°
50 μm diameter wire (vs. 100 μm)	1994°	1203°

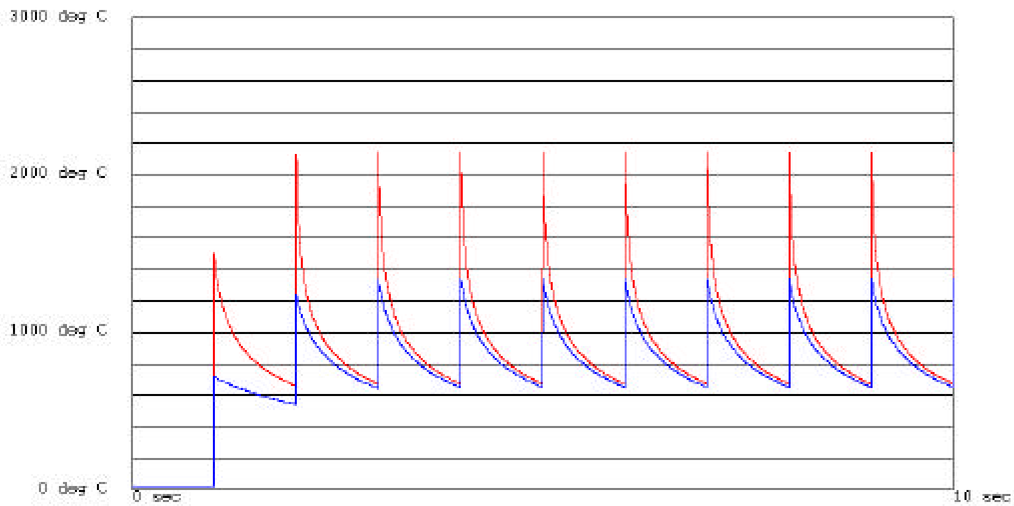

Figure 1. Wire temperature vs. time for 185 MeV H^- (red, upper) and 1000 MeV (blue, lower).

It is clear from the table above that the 100 µm diameter tungsten wire will work at both 185 and 1000 MeV with the baseline parameters shown above. Because of the lower dE/dx at 1000 MeV, there is more leeway in changing the operating parameters for the wire at 1000 MeV. Tungsten wires will not survive for even a single full 1000-µsec beam pulse at full beam current.

Discussion

Secondary-emission electron signal

During the baseline pulse discussed above, about 60 nC of H^- will hit the wire. The secondary-electron-emission (SEM) signal is then about 0.5 to 1 nC in 50 µsec, corresponding to a signal current of 10 to 20 µA.

Thermionic emission

Thermionic emission for a 2-mm length of 0.1-mm dia. tungsten wire is about

Temperature	Current
1500	0.2 µA
1600	1
1700	4
1800	17
1900	60
2000	190

It is clear that at wire temperatures above about 1600° C, the thermionic emission current is significant. Reducing the wire diameter to 25 mm (1 mil) reduces the peak temperature to 1870° C at 185 MeV, and the thermionic emission current to about 10 µA. It may be preferable to detect the radiation from beam loss than to measure the SEM current.

Emittance mismatch and deceleration

Because the H^- is being converted to protons in the wire, there will be a significant transverse focusing mismatch. If the RF cavities are on, the protons will also be decelerated.

Multiple scattering

The rms multiple scattering angle in 100 μm of tungsten at 185 MeV is about 6 milliradians. This is 10 to 20 times larger than the beam divergence.

Nuclear scattering

The nuclear scattering probability in the wire is about 0.001. Thus about $3x10^8$ protons will be nuclear scattered per beam pulse.

Activation and power loss

The maximum number of H^- hitting the wire per second is about 100 nC, which at 1 Hz represents 18 watts of beam loss at 185 MeV, and 100 watts at 1000 MeV. This beam loss might create significant activation at 1000 MeV if the wire scanner is used continuously. It also represents an additional heat load on the cryomodules.

There should be a significant beam loss (ionizing radiation) signal from the beam hitting the wire. This would be the preferred method for measuring the beam profile, in part because of the thermionic emission current background in the wire current signal.

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