PREDICTED FOIL TEMPERATURES IN THE BROOKHAVEN ACCUMULATOR RING FOR THE NSNS[*]

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Abstract

An investigation has been carried out into the peak equilibrium stripping foil temperatures that could be expected in the 1 GeV NSNS Accumulator Ring proposed by Brookhaven National Laboratory.

A carbon foil is assumed. Computed foil temperature distributions on the foil's surface are presented, as well as the predicted relationships between foil temperature and quantities such as the average number of recirculated proton hits, linac intensity, and foil mass per unit area used.

1 INTRODUCTION

The 1 GeV NSNS accumulator ring has been designed to use H^- injection. In order to ascertain whether the stripping foil would survive under the injection conditions present in the NSNS a computer simulation has been carried out. This is described below.

The foil simulation is based on a rectangular carbon foil , 8 mm wide and 4 mm high. This is a very small foil, and the injected beam spot touches both edges. The foil is modelled as supported only on the top edge. The temperature of the frame is fixed at 295 K . A foil mass per unit area of 400 μgcm^{-2} is chosen, corresponding to a thickness of approximately 2.6 μm for carbon. The H^- beam is centred in the foil, and is modelled with a Gaussian elliptical transverse profile with standard deviations of 1.7548mm in the horizontal direction and 0.8544mm in the vertical direction. Other relevant input parameters are a 1280 turn injection at a repetition frequency of 60 Hz and with a macro-pulse duration of 1.076864 ms. The original planned beam intensity of 1.04×10^{14} ppp would give a target power of 1 MW, but present project philosophy is to do all calculations for the 2 MW case, ie 2.08×10^{14} ppp. Both intensities are simulated.

Injected H^- ions, stripped electrons and recirculating protons scatter in the foil and large temperature rises result from atomic excitations. The initial rate of temperature rise is inversely dependent on the foil specific heat. The temperature reaches a maximum at the end of each injection and the temperature rise in the 60 Hz cycling is limited mainly by radiation, with a small additional contribution from conduction within the foil. Energy losses due to radiation and conduction scale as the fourth and first power of the temperature difference from the surroundings, and are proportional to the foil emissivity and thermal conductivity respectively. Specific heat, emissivity and thermal conductivity are all material and temperature dependent.[1],[2].

With the parameter range covered by this study, a constant peak temperature is reached after a time which varies between three and fourteen beam pulses, this number being inversely related to the energy deposited in the foil.

2 SIMULATION

Heating and cooling of the NSNS foil are simulated in a program based on finite elements, both for time passage and transverse position co-ordinates. A fifty by fifty array of elements is used. Each element is rectangular and the same shape as the foil as a whole. The distribution of recirculating protons on the foil is modelled as uniform. A real distribution from tracking codes will be used in the near future. Since the energy density at the peak of the Gaussian distribution is 3.78 times that at the edge of the foil, (for 400 μgcm^{-2} and 2.5 foil hits) the recirculated distribution has a much smaller effect on the peak temperature than the H^- beam spot. The time distribution of recirculated proton hits is approximated as linearly increasing during each accumulation, in proportion to the size of the accumulated beam. In reality the recirculating proton hits do not have a simple time distribution, but the use of an approximation is justified because a previous study [8] had shown the time distribution chosen to be unimportant. Energy deposited in the foil is calculated using charged particle energy loss data, (both for protons and stripped electrons) and mean H^- and H^O lifetimes [3],[4],[5]. High temperature estimates for specific heat have been made by scaling normalised Debye curves [6] in both dimensions to give a best fit for published data. The asymptote used for the specific heat at high temperatures is 2125 $Jkg^{-1}K^{-1}$ .The emissivity is assumed constant at 0.80 and the thermal conductivity is approximated by:

$15 + 305958\, T^{-1.3091}$ for $T > 573$ K and
$217.9653 - 0.2233\, T$ for $T < 573$ K.

The effects of different numbers of foil hits and of using a foil of a different thickness are also investigated. By altering independently input parameters such as emissivity, heat capacity, and the energy deposited in the foil by one H^- ion, the variations in foil temperature

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[*] The U.S. National Spallation Neutron Source

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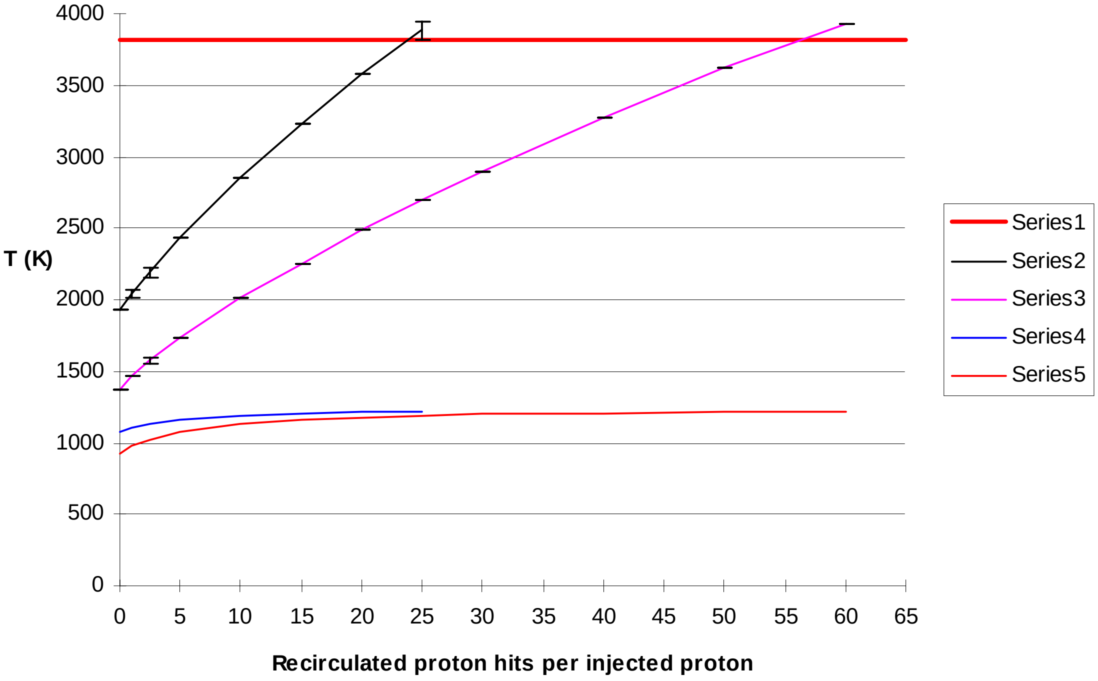

Figure 1. A plot of 400 µgcm^{-2} stripping foil temperatures versus recirculated proton hits.
KEY: Series 1 = Melting point of Carbon
Series 2 = Peak equilibrium temperatures at 2 MW
Series 3 = Peak equilibrium temperatures at 1 MW
Series 4 = Minimum equilibrium temperatures at 2 MW
Series 5 = Minimum equilibrium temperatures at 1 MW

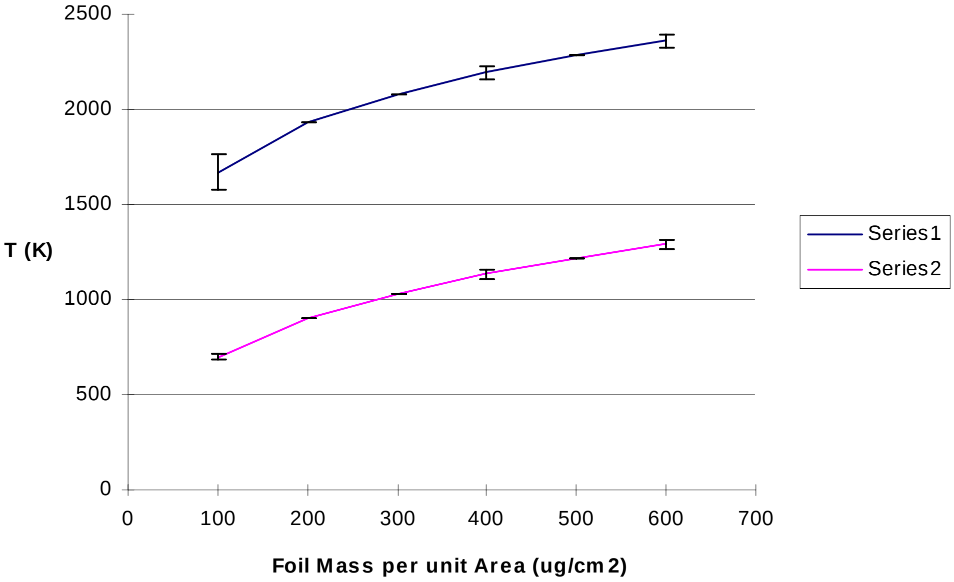

Figure 2. A plot of Carbon stripping foil temperatures versus foil mass per unit area
KEY: Series 1 = Peak equilibrium temperature with 2.5 foil hits per injected proton, at 2 MW
Series 2 = Minimum equilibrium temperature with 2.5 foil hits per injected proton, at 2 MW

caused by the uncertainties in the input conditions are explored For thinner foils, eg 100 μgcm^{-2}, variations in specific heat and deposited energy dominate the total uncertainty , but for thicker foils, eg 400 μgcm^{-2} and above, the variation in emissivity dominates. For 2.5 foil hits, the summed estimated uncertainties in temperatures at the peak of the temperature cycle are:
1 MW: 1.5% 2 MW : 1.6%
Uncertainties in minimum temperatures are:
1 MW: 2.0%. 2 MW : 2.2%

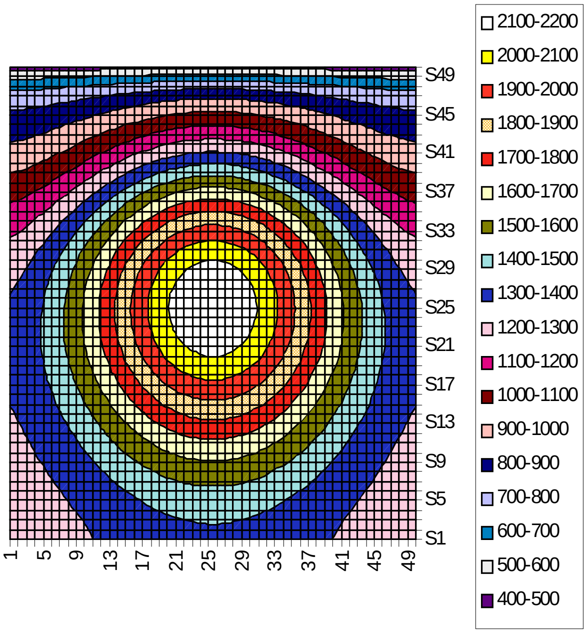

Figure 3. Peak Equilibrium temperature distribution after eight pulses for a 400μg cm^{-2} foil with 2.5 foil hits per injected proton. (Please note, the foil is actually twice as wide as it is high).

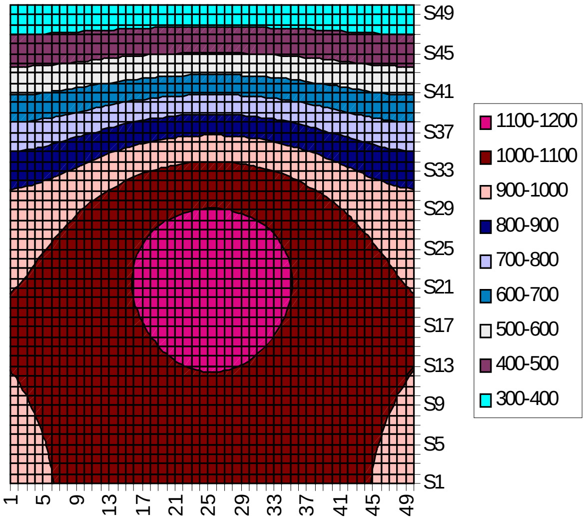

Figure 4. Minimum Equilibrium temperature distribution an instant before the eighth pulse, for the same parameters as in Figure 3

3 CONCLUSION

The peak temperature in the carbon foil, assuming a value of 2.5 recirculated proton hits per injected proton, is 1575 K for 1 MW and 2195 K for 2 MW. These should be compared to the melting point of carbon of 3823 K. Therefore the foil as presently proposed by Brookhaven would be below its melting point, but no account has yet been taken of the stresses caused by the temperature gradients or by constant proton impact.

4 ACKNOWLEDGEMENTS

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