DESIGN AND SIMULATION OF THE WIRE SCANNER FOR HALO FORMATION MEASUREMENTS IN AN INTENSE BEAM RFQ LINAC*

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Abstract

A high current proton RFQ accelerator has been constructed in China for the basic study of Accelerator Driven Subcritical System. A new beam line will be set up for the 3.54MeV, 50mA proton beam from the RFQ in order to study beam halo phenomenon. Therefore, 18 wire scanners consist of a thin carbon wire and two scrapers will be installed on the beam line to traverse the entire beam cross-section. So we can experimentally study the beam loss and beam halo. Some simulations results of the heat on the devices by using finite element method software—ANSYS are presented. The electronics interface will also be discussed.

INTRODUCTION

Intense beam proton accelerator is interested in China for its applications in China Spallation Neutron Source project (CSNS) [1] and Accelerator Driven Subcritical System (ADS) study program. Beam loss control is recognized as the key issue in the accelerator design. Space-charge induced beam halo and emittance growth is a major source of the beam loss. For a better understanding of the beam halo formation and development of the beam halo diagnostics technology, we plan to build a beam line following the intense-beam RFQ accelerator at IHEP, Beijing [2]. It is consists a periodical focusing channel with some inserted diagnostic instruments, as shown in Figure 1. A special demand for the instruments is to detect particle density distribution in a dynamic range greater than 105:1. Based on the experience of the Low Energy Demonstration Accelerator (LEDA) [3], the traditional wire scanners are used to measure the core of the distributions and the scraping devices with cooling water are used to detect the tails of the distribution. The mechanical model of the wire scanner and halo scrapers (WS/HS) is shown in Figure 2.

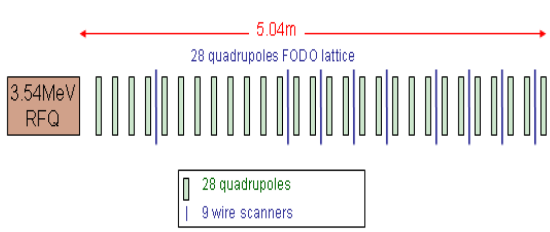

Figure 1: Layout of the WS/HS.

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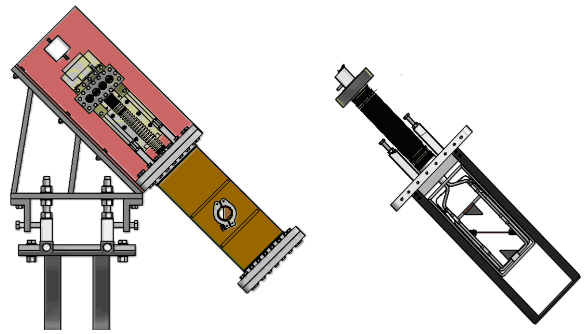

Figure 2: the mechanical model of the WS/HS.

THE WIRE SCANNER

The kinetic energy at the RFQ exit is 3.54MeV so the choice of wire for the wire scanners deserves careful consideration. Based on the experience of SNS [4], LEDA and J-PARC [5], two material options for the wire are considered: tungsten and carbon. The 32 micron diameter carbon wire is selected to use. For the tungsten wire we investigate 25 micron diameter wire.

The goals of designing the wire are determining the maximal temperature of the wire during the scan and the beam parameter range safe for operation of the wire scanner. The temperature increasing for a wire is decided by the heating of the wire by the beam and three cooling mechanism: radiant cooling, heat conduction along the wire and thermionic cooling. Since the heat conduction and thermionic cooling are small compared with the radiant cooling, the value of the wire temperature can be mainly deduced by the heating of the wire by the beam and radiant cooling.

The software ANSYS is used to simulate the peak temperatures of the wire for the various cases. The most challenging wire parts locate where the beam current is the smallest and the greatest. The minimum beam size and the maximum beam current are 0.5 mm RMS and 50 mA, respectively. ANSYS simulations give the maximum wire temperatures vs. beam RMS sizes, as shown in Figure 3.

For the beam parameters of a 0.5-mm RMS size, 50-mA current, a 20-μs pulse length and a beam repetition rate of 1Hz, the predicted pseudo-steady-state peak temperature for the carbon and tungsten wires are greater than the allowable temperature of 1800K where the onset of thermionic emission is believed to occur. Since the carbon wire can survive in more operating conditions, the 32-μm carbon wire will be used to measure the beam profiles.

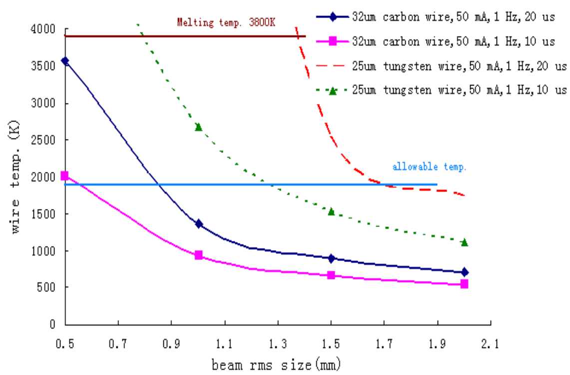

Figure 3: Max. wire temperatures vs. beam RMS sizes.

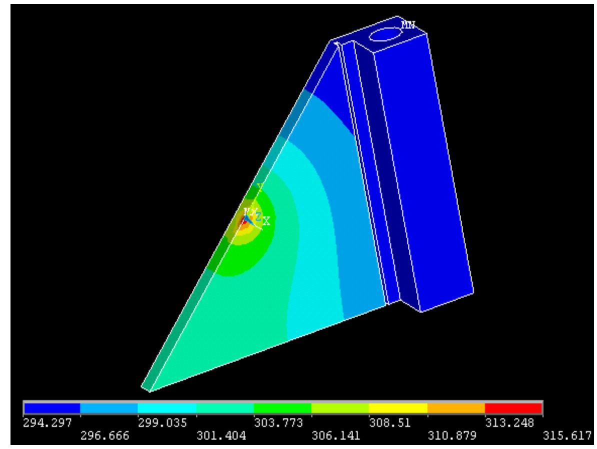

Figure 4: Isothermal map of the halo scraper.

THE HALO SCRAPER

The scraper consists of a copper base with a water cooling channel on one side, and an aluminium surface. The machining of aluminium electroplating on copper is easy to implement, and the aluminium can protect the copper from activation by decreasing the beam energy for the copper base. The scraper is 40mm on side, and is 3.0mm thick. For our beam condition, the 3.54MeV protons are stopped in the first 0.1mm of the aluminium thickness, so the 1.5mm thickness of the aluminium surface is chosen. To ensure the mechanical strength and heat conduction, the thickness of the copper base is chosen to be 1.5mm.

The finite-element model was used to analyze the thermal profile of the scraper. To make a good margin, it is assumed that the peak heat flux that the scraper is exposed is twice than the nominal heat flux. The peak heat flux that the scraper is exposed is 22.6MW/cm^2 (3.54 MeV, 50mA, σ = 0.5mm), the convective film coefficient of the cooling water is 5400W/m^2/K and the initial temperature of the scraper is 293K. The thermal results of the scraper for various cases are listed in Table 1.

Table 1: Max. Temp. of the Scraper vs. Beam Conditions

Repetition rate (Hz)	Pulse length (μs)	Duty factor (%)	Aluminium surface peak. temp. (K)	Copper base peak. temp. (K)
1	50	0.005	313	294
20	50	0.1	320	295
10	100	0.1	339	296
5	500	0.25	493	300

It is clear from the table 1 that the results of the scraper predicted that the intercepting aluminium surface in most operation beam mode can be kept well below the melting temperature of aluminium. Since the wire and the halo scrapers are under the same operating condition, the heat for the scrapers is not an issue. The cooling water flow doesn't affect the temperature of the aluminium strongly, as shown in Figure 4.

SIGNAL LEVELS OF THE WS/HS

There are three sources of the signal generated in a wire by collision of proton beam: protons secondary electron emission and thermal electron emission. The protons penetrate the wire for 32-μm carbon wire and 25-μm tungsten wire, and thus there is no measurable signal. The rest two sources are analysed as follows.

Secondary Electron Emission (SEM)

A well-known theory from Sternglass describes the secondary emission yield [6]. For 32-μm carbon wire, SEM yield Y ~ 0.36. When σ = 2mm, I=50mA, the SEM current is about 0.11 mA. For 25-μm tungsten wire, Y ~ 1.35 and the SEM current is about 0.34 mA.

Thermal Electron Emission

The current density emitted from the wire is described by Richardson Dushman [7]. A plot of the thermionic current vs. the wire temperature is shown in Figure 5. It is clear that at wire temperatures above about 1800K, the thermionic emission current is significant.

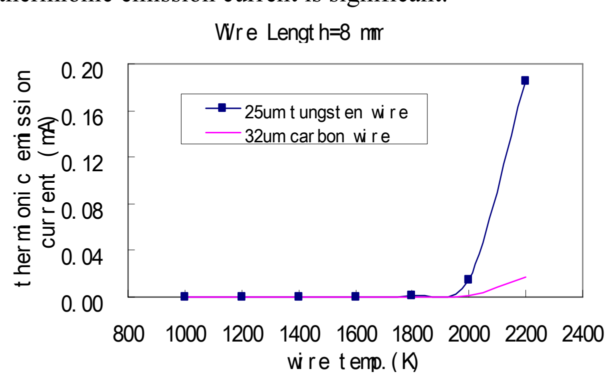

Figure 5: Thermionic currents vs. wire temperatures.

Since the SEM current is used to measure the profile, the wire must stay cool enough to keep the thermionic electron emission currents less than 1% of the SEM current. The limiting temperature for both wires is 1800K , at which the onset of thermionic emission occurs.

With carbon work function φ=5eV, the thermionic current density at 1800K is about 40.7mA/m^2. For 8mm length of 32-μm diameter carbon wire, this is equivalent to 32.7 nA that is less than 1% or so of the SEM current. The work function of 25-μm tungsten is 4.5eV and the thermionic current at 1800K is about 0.64 μA that is also less than 1% of the SEM current.

The resulted total wire current is a sum of the SEM current and the thermionic current. The total currents at the center of beam for the two kinds of wire vs. the beam RMS sizes are plotted in Figure 6.

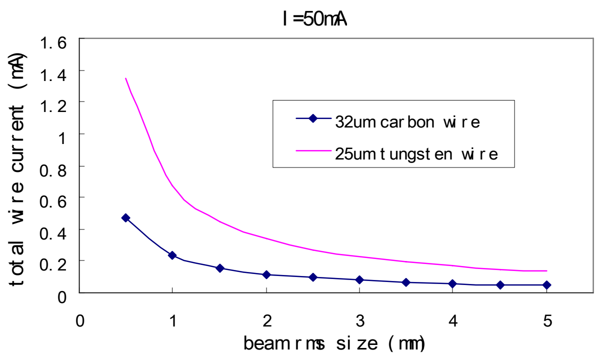

Figure 6: Max. total wire currents vs. beam RMS sizes.

Although the total signal of tungsten wire is greater than that of carbon wire, the 32-μm diameter carbon wire is selected due to its low energy deposition.

For the integral current of the halo scraper, the dynamic range of the integral current is greater than 10^5:1 since the scrapers are used to probe the beam to the approximate 2-RMS-width location.

For our beam conditions, the current range of the halo scraper is 6.4 nA to 1.6 mA. And the current of the 32-μm carbon wire ranges from 0.1 μA to 0.24 mA. Therefore, the total current range is 6.4 nA to 1.6 mA.

ELECTRONIC INTERFACE

The design difficulties of the WS/HS are high measurement accuracy and large dynamic range of current. The WS/HS read-out system consists of analog-front-end electronics (AFE) and data acquisition (DAQ).

Integration circuit which has discharge reset loop will be used as AFE circuit that can measure a dynamic range over 10^6 for the system. By using the guarding ring technology, the measured signal will get a safe shield. Therefore, it will be used to detect the current of the WS/HS.

As showed in the Figure 7, SYNTRON 56 series stepper motor with 2.5 N·m holding torque is selected, and the minimal step angle of the motor is 0.9 degree. The motor driver is SYNTRON SH-20806N, which fits the stepper motor very well. The power supply of the motor driver is 24V-70V DC and the max output current is 6 A. Because the data communication is based on VME bus, the Oregon Micro Systems VX2 family motor controller is chosen.

For the part of DAQ, AVME9668 and IP330A of the Acromag company will be selected, the former one is an IP Carrier Cards, and the latter one is a 16-Bit A/D Converter. The reason for choosing the hardware is the EPICS (Experimental Physics and Industrial Control System) has the drivers for the hardware. And the other reason is that many laboratories have used them a lot, so it is quite easy to handle.

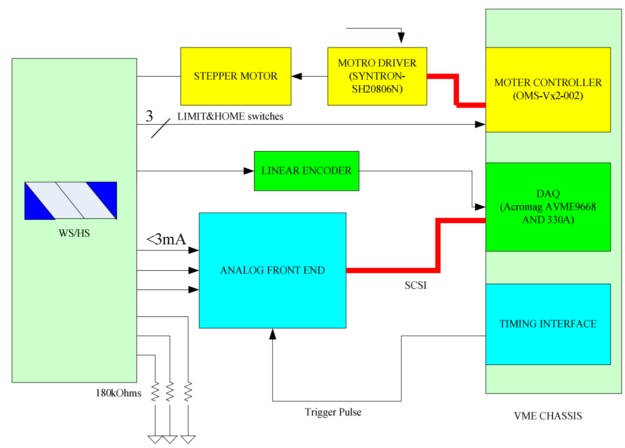

Figure 7: Block diagram of the electronic system for WS/HS.

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