# WIRE SCANNER DESIGN FOR THE EUROPEAN SPALLATION SOURCE

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*Abstract*

The European Spallation Source (ESS) [1] , to be built in the south of Sweden, will use a 2 GeV superconducting linac to produce the worlds most powerful neutron source with a beam power of 5 MW. The beam power is a challenge for interceptive beam diagnostics like wire scanner, the thermal load on intercepting devices implies to reduce the beam power in order to preserve the device integrity. For nominal operation, non-disturbing technics for profile measurements are planned, while for commissioning phase, accurate measurements and cross checking, wire scanners will be used. This paper describes the preliminary design of the wire scanner system in the normal conducing linac as well as in the superconducting linac.

## INTRODUCTION

Wire scanners have been deployed successfully since decade in accelerator, they represent a conservative choice for beam profile measurement. However, in high power hadron machine like ESS, these type of diagnostic can not be used with full beam power (2.86 $ms$, 14 $Hz$, 62.5 $mA$). In order to preserve the wire integrity the beam duty cycle has to be reduced. In consequence, the wire scanners will be used only during commissioning and dedicated beam studies periods when high resolution beam profile measurements are requested, while at full duty cycle, non invasive methods are the primary choice. The wire scanners and the interceptive diagnostics will be used with 2 beam modes:

- A slow tuning mode ($i.e.$100 $\mu s$, 62.5 $mA$, 1 $Hz$) (slow).
- A fast tuning mode ($i.e.$10 $\mu s$, 62.5 $mA$, 14 $Hz$) (fast).

27 wire scanner will be installed in the linac. The number of wire scanner per section is presented in Table .

Table 1: Number of Wire Scanner in each ESS Linac Section

| Section | Energy range $[MeV]$ | number of wire scanner |
|---|---|---|
| LEBT | 0.075 | 0 |
| MEBT | 3.6 | 4 |
| DTL | 3.6 to 90 | 5 |
| Spoke | 90 to 220 | 4 |
| Medium $\beta$ | 220 to 520 | 4 |
| high $\beta$ | 520 to 2000 | 4 |
| HEBT | 2000 | 7 |

In the DTL, a wire scanner will be positioned after each tank, in the superconducting linac, the wire scanners will be positioned at the beginning of each section in the same location as the non invasive beam profile.

## THERMAL LOAD

Two wire materials have been considered for the wire scanner tungsten and carbon due to their high melting/sublimation point. For carbon wires, a diameter of 33 $\mu m$ had been choose, while for tungsten wires the diameter is 20 $\mu m$.

### *Warm Linac*

Carbon wire is the best choice for the wire scanner at low energy [2], the energy deposition in the carbon wire is less and the specific heat capacity of carbon much higher than the tungsten, the estimation of the temperature increase for the different location are presented in Table .

Table 2: Maximum Temperature on a Carbon Wire at Different Position in the Warm Linac

| Section | Energy [Mev] | beam sizes $[mm]$ $\sigma_x$ | $\sigma_y$ | T$_{max}$ [K] slow | fast |
|---|---|---|---|---|---|
| MEBT | 3.6 | 2 | 1 | 3760 | 1620 |
| MEBT | 3.6 | 3 | 2 | 1900 | 1160 |
| DTL1 | 21 | 1.5 | 1.5 | 1360 | 980 |
| DTL2 | 40 | 1.5 | 1.5 | 1110 | 870 |
| DTL3 | 61 | 1.5 | 1.5 | 970 | 790 |
| DTL4 | 75 | 1.5 | 1.5 | 880 | 750 |
| DTL5 | 90 | 1.5 | 1.5 | 820 | 710 |

In term of thermal load, the critical location is the MEBT, the stopping power of 3.6 MeV proton is larger than any other location in the ESS linac. Even with a beam pulse reduced to 100 $\mu s$, the wire will not survive in the MEBT, if the profile monitor is positioned at the location of the smallest expected beam sizes. By reducing the beam pulse by a factor 2, the temperature decreases to 2400 K, sufficient to preserve the wire integrity, but the thermoionic emission will perturb the measurement. According to the results, the wire scanner shall not be installed where the expected beam sizes are small. For the other cases, the wire will survive both modes without problem of thermoionic emission.

The slow tuning mode is the most critical, the evolution of the maximum temperature on the wire along several beam pulse for the DTL section is shown in Fig. 1, equilibrium is reached after 3 pulses.



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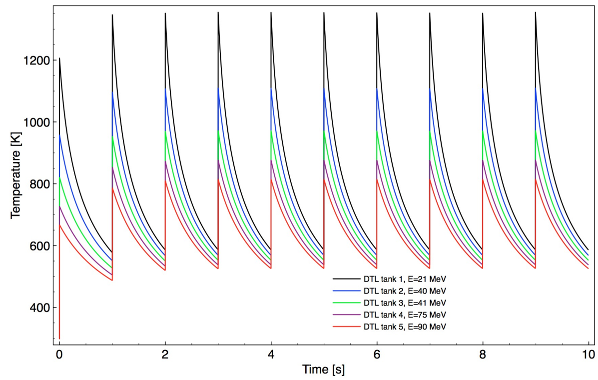


Figure 1: Maximum temperature on a carbon wire after each DTL tank (beam sizes are 1.5 mm in both planes).

### *Cold Linac*

Transverse profile measurement poses a challenge, particularly in the cold linac. There are concerns that fragments from physical wires, if broken, could contaminate he superconducting cavities. Carbon wires are contra-indicated by a test made at GANIL, where the effect of sublimating different wire materials near superconducting cavities was studied. Tungsten, seems to be an acceptable material.

Table 3: Maximum Temperature on a Tungsten Wire at Different Location in the Superconducting Linac (Beam Sizes are in mm)

| Section | Energy [Mev] | beam sizes $\sigma_x$ | $\sigma_y$ | $T_{max}$ [K] slow | fast |
|---|---|---|---|---|---|
| Spoke | 90 | 2 | 1.6 | 1970 | 1490 |
| Medium $\beta$ | 220 | 2 | 1.4 | 1640 | 1340 |
| High $\beta$ | 520 | 1.6 | 1.8 | 1330 | 1160 |
| HEBT | 200 | 2 | 2 | 1080 | 950 |

The lowest energy is the worst case, nevertheless, the wire will survive and the themoionic emission is negligible, as the energy increases, the energy deposition in the wire decreases and in consequence the temperature. At the minimum of ionization (i.e. $\approx 2GeV$) the temperature are respectively 950 K and 1080 K for the fast and slow tuning mode.

## SIGNAL ESTIMATION

### *Measurement of the Secondary Emission*

The signal generated on the wire can be divided in two main components:

- The emission of secondary electron emitted when the protons are crossing the boundary between vacuum and the wire
- The charge deposition due to proton stopped in the wire.

The Secondary Emission Yield (SEY) can estimate with the Sternglass theory [3]. The expected current on carbon and tungsten wire as function of the beam energy is shown in Fig. 2.

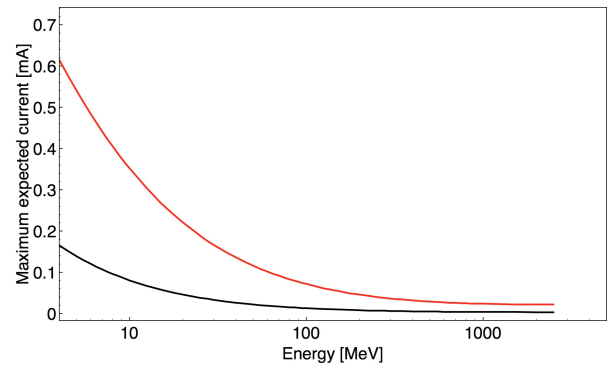


Figure 2: Maximum expected current on the wire in function of the beam energy, in red for a tungsten wire and in black for a carbon wire assuming $\sigma_x = \sigma_y = 2\ mm$.

For a tungsten wire, with the beam sizes presented in Table the intensity of the signal varies from 52 $\mu A$ for a beam energy of 90 MeV to 30 $\mu A$ at 220 MeV. For a carbon wire the maximum signal is expected in the MEBT with 0.85 $mA$, at the end of the $5^{th}$ DTL tank, the signal decreases to 16 $\mu A$.

At high energy, where the SEY is low, the effect of $\delta - rays$ emission is significant and is in the order of magnitude of the secondary emission signal.

Above few hundreds of MeV, the secondary emission signal becomes small, a better way to measure the profile is to measure the shower created in the wire.

### *Measurement of the Shower Produced by the Wire*

In the cold linac, the beam instrumentation will be positioned in the warm section, between the quadrupoles, the space available in this area is 46 cm (see Fig. 3).

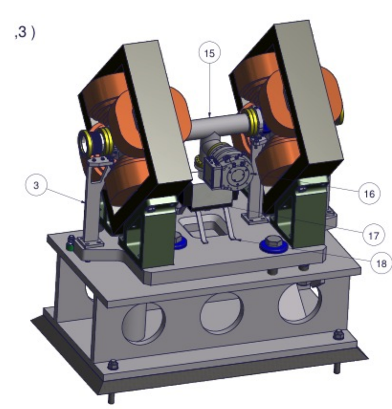


Figure 3: Warm Section Layout (courtesy of Aarhus University).

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Due to the low energy of the beam, the shower created in the wire will be stopped on the quadrupole, in order to keep a sufficient signal, both wire scanner actuator and scintillator shall be positioned between the magnetic elements. A distance of 35 cm between the two components has been chosen to keep enough space for mechanical integration of the wire actuator and the non invasive profile.

The signal produced by the detector shall be independent on the beam position, the ideal geometry is a cylinder with a large diameter around the beam pipe (in the Medium and High $\beta$ section, the aperture is 10 cm). Due to mechanical constraints, a different geometry has to be used, the geometry has been determined with the Monte Carlo code FLUKA, by scanning the wire across the beam pipe aperture. For each position, a 1D gaussian beam ($\sigma = 2\ mm$) interacting with a thin tungsten foil has been simulated. Different beam energies, form 200 $MeV$ to 2 $GeV$, and detector geometries have been simulated. The geometry with less dependency on the position is shown in Fig. 4.

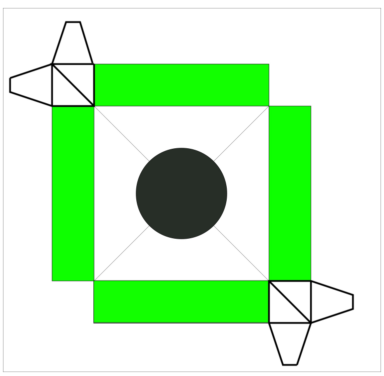

Figure 4: Scintillator geometry, in green the scintillator with the light guide (black line) and in grey the beam pipe.

The detector consists in 4 scintillators positioned around the beam pipe, the size of each active element is $5 \times 3 \times 20\ cm$, while considering only 1 of the 4 detectors parallel to the wire axis, the variation of the deposited energy is 50 %. By summing the signal from the 4 scintillators, the variation is less than 2 % along the beam pipe aperture.The choice of the scintillator will depend of light production yield and the time response needed for the measurement.

3 scintillators type will be investigated:

- BGO (Bismuth germinate $Bi_4Ge_3O_{12}$), medium light production yield, slow decay time.
- $LuYSiO_2$, high light production yield, medium decay time.
- Lead Tungstate ($PbWO_4$), low light production yield, fast decay time.

Each scintillator will be connected to a PMT with a light guide and the sum of the 4 signal will be done in an FPGA. Optical grey filters shall be inserted between the light guide and the PMT in order to modulate the light input on the photocathode.

## FUTURE DEVELOPMENT

At 2 GeV, the stopping power of protons is low, and downstream the last cavity in the HEBT, carbon wires can be used for profile measurement. Preliminary estimation shows that a 7 $\mu m$ or a 33 $\mu m$ carbon wire will survive during production mode, the temperatures reached are 1800 K and 2300 K respectively, assuming beam sizes equal to 2 mm in both planes.

With fast movement the measurement can be done in one pulse, assuming a speed of 20 $m.s^{-1}$ the wire interacts with the beam during 500 $\mu s$. The temperature increase during this time, assuming a wire in the center of the beam without movement, is 1260 K for the thicker wire far below the sublimation point of carbon. More accurate thermal load simulation and signal estimation will be perform in the next months.

Flying wires mechanisms have been developed with speed up to 20 $m.s^{-1}$ at CERN [4] and KEK [5] or are under development and can be used as a baseline for a future development at ESS.

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