THERMAL LOAD AND SIGNAL LEVEL OF THE ESS WIRE SCANNER

B. Cheymol*, European Spallation Source, Lund, Sweden

INTRODUCTION

In the ESS linac [1] and in the transfer line to the target, a number of wire scanners will be installed. Due to the high power of the beam, the measurement can not be done during the production mode (2.86 ms, 62.5 mA, 14 Hz), the beam power has to reduced in order to preserve the wire integrity. Two modes will be dedicated to commissioning and specific beam studies where the insertion of interceptive devices are allowed, a slow tuning mode (*i.e.* 100 μs, up to 62.5 mA, 1 Hz) and a fast tuning mode (*i.e.* 10 μs, up to 62.5 mA, 14 Hz).

The ESS linac consists in two section, one equipped with normal conduction cavities and the second with superconduncting cavities, the current layout of the ESS linac is shown in Fig. 1.

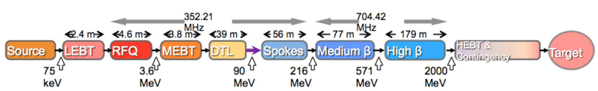

Figure 1: Current ESS accelerator baseline (2014).

In the warm linac, 4 wire scanner are foreseen to be installed in the MEBT, 4 more will be installed between the DTL tanks and one in the transition between the cold and the warm linac (LEDP).

Ideally, 4 wire scanner will be installed at the beginning of each cold section and of the HEBT in order to preform emittance measurement with the 3 gradient method.

THERMAL LOAD

Two types of wires have been considered a 33 μm carbon wire for the warm linac and a 40 μm tungsten wire for the cold linac.

Warm Linac

MEBT The maximum temperature reached by each wire scanner during a scan at 1 Hz are summarized in Tab. 1 as well as the expected beam sizes at the wire location.

Table 1: Maximum temperature with a scan at 1 Hz.

Beam sizes [mm]		T_{max} [K]	T_{max} [K]
σ_x	σ_y	50 μs	100 μs
1.85	1.45	1900	–
3	1.5	1430	2110
2.5	2.4	1240	1780
3.2	3.2	975	1350

Due to the low beam energy, the MEBT represents the worst case for the wire scanner, in addition beam density is relatively high. As shown in Tab. 1 the temperature increase for the first wire scanner is above the mechanical limit of the wire even with a reduced beam power, the wire will survive only if the pulse length is reduced to 50 μs. In this case, the maximum temperature is around 1900 K, below threshold of thermoionic emission and the limit of a carbon wire. In fast mode, the temperature is below 1400 K.

DTL The relevant beam parameters at each wire scanner location are summarized in Tab. 2. The stopping power is lower than the MEBT case and the wire can withstand a 100 μs pulse.

Table 2: Beam parameters at the DTL wire scanner location,

Position	σ_x [mm]	σ_y [mm]	Energy [MeV]
DTL1	1.7	1.2	21.29
DTL2	1.3	2	39.11
DTL3	1.8	1.6	56.81
DTL4	1.6	1.9	73.83
LEDP	2.6	1.8	89.91

WS are named according to their position.

After DTL tank 1, the expected temperature on the wire is ≈ 1400 K during the slow tuning mode, the temperature is decreasing with the energy and is around 700 K in the LEDP. The evolution of temperature for these two cases is shown in Fig. 2.

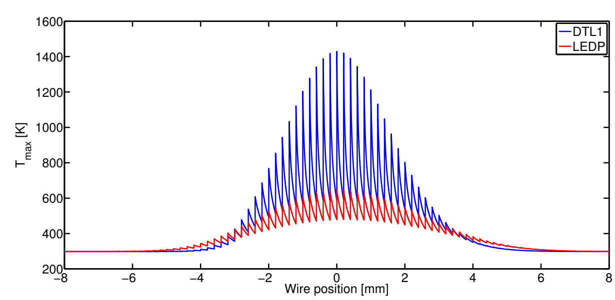

Figure 2: Maximum temperature on the wire during a scan as function of the wire position for a 21 MeV beam (blue line) and 90 MeV beam (red line).

At 90 MeV, the expected signal in case of carbon wire is weak and a tungsten wire might be considered to improve the signal level.

An estimation of the temperature has been performed for the wire scanner positioned in the LEDP in order to check the possibility of replacing the carbon wire by a 40 μm tungsten wire. During the slow tuning mode, the temperature will reach 1860 K, while during the fast tuning mode the peak temperature will be less than 1500 K. In both case, signal will not be perturbed by the thermoionic emission. Tungsten wire

* benjamin.cheymol@esss.se

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can be used in this case, and is probably a better choice than carbon due to the proximity of the first spoke cryomodule.

With beam parameter used during the fast mode, the temperature is below 1000 K for a carbon wire.

Cold Linac

In the superconduncting linac, thermal analysis has to been done carefully to avoid any possible risk on the wire which can lead to damages on the superconducting cavities. In the spoke section a wire scanner will be installed after the first 4 cryomodules, the beam sizes at the wire scanner location and the maximum temperature reached during the scan are summarized in Tab. 3.

Table 3: Beam parameters at the Spoke wire scanner location, WS are named according to their position in the lattice.

Beam sizes [mm]		T_{max} [K]	T_{max} [K]
σ_x	σ_y	slow mode	fast mode
2.5	1.9	1790	1325
2.9	1.6	1730	1260
2.6	2.1	1610	1240
2.8	2.2	1500	1170

In the elliptical section, the exact position of the wire scanner is not know at the time this note is written, average beam sizes (σ_x =σ_y=2 mm) have been considered for a beam energy of 200 MeV, 500 MeV, 1000 MeV and 2000 MeV, the maximum temperature on the wire are shown in Tab. 4.

Table 4: Maximum temperature on a tungsten wire in the elliptical section.

	$T_{max}[K]$	
Energy [MeV]	slow mode	fast mode
200	1590	1215
500	1340	978
1000	1250	890
2000	1210	860

In the spoke section, the temperature might be to high during the slow tuning mode, a smaller wire diameter (20 μm) can be used. In this case the temperature will drop by almost 200 K after spoke 1 during the slow tuning mode and 100 K during the fast tuning mode after spoke 4.

In the elliptical section, The temperature is below 1600 K for all the cases and should not be an issue for the wire integrity. New estimations with accurate beam sizes will be performed in the future to confirm these results.

SIGNAL ESTIMATION

Up to the spoke section the beam profile will be reconstructed by measuring the SEM current generated in the wire [2]. Above 200 MeV, the secondary emission might be too weak to reconstruct the beam profile, the reconstruction can be done by measuring the shower created in the wire.

Secondary Emission Mode

In the MEBT and at full current (62.5 mA) the maximum peak signal expected is around 400 μA for the more focused beam and 180 μA for the less focused one.

In the DTL, after the first tank, the peak signal is around 120 μA. For a beam energy of 90 MeV, after the last tank, the peak signal will drop to 16 μA and might be too weak after the DTL tank 5, a tungsten wire can be considered. With a 40 μm diameter tungsten wire, the signal will increase to 90 μA.

In the spoke section, the maximum expected signal will be 120 μA after the first spoke cryomodule and 60 μA after the fourth cryomodule.

The wire scanner shall be also able to measure the beam profile with the lowest current foreseen in the linac (i.e. 6.5 mA). The level of signal increase linearly with the beam current at constant beam sizes, in first approximation, we can assume a signal divided by a factor 10 compare to our previous estimation for the lowest current. This means that the peak signal will be around 40 μA in the MEBT and will drop to 6 μA in the spoke section.

Detection of the Hadronic Cascade

In the cold linac, the beam instrumentation will be positioned in warm section, between quadrupoles doublet. Due to the low energy of the beam, the shower created in the wire will be stopped in the quadrupole, in order to keep a sufficient signal, both wire scanner actuator and scintillator shall be positioned between the magnetic elements, in consequence the full system has to fit in less than 45 cm. The Monte Carlo code FLUKA [3] has been used to measure the detector homogeneity and estimate the signal.

Detector homogeneity The signal produced by the detector shall be independent on the beam position, the geometry of the detector is done in order to minimize this effect. The detector consists in 4 scintillators positioned around the beam pipe, the size of each active element is $5 \times 5 \times 25$ cm, arrange in order to have a square with a dimension equal to 30×30 cm, each scintillator is surrounding by a 1 mm thick aluminum foil.

The homogeneity of the detector has been checked at different beam energies by moving a a 1D gaussian beam ($\sigma = 2$ mm) across the beam pipe aperture. for each energy, 49 points have been simulated to cover an square aperture from -30 to 30 mm in step of 10 mm in both transverse direction.

The signal on each scintillator shows a strong dependency on the wire position, in the worst case a variation about a factor 2 can be measured along the full beam pipe aperture . By summing the signal from the 4 scintillators, the variation on the deposited energy can be decreased to few %.

At low energy, the detector is less homogenous, for the 220 MeV case, the error compare to the reference is less than 10 % if the beam is kept in a square of 40×40 mm and less than 5 % for a square of 10x10mm (see Fig. 3). At

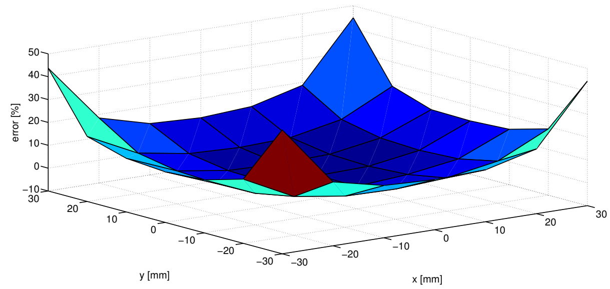

Figure 3: Error map for a 220 MeV beam.

2 GeV, the error compare to reference is less than 5 % over the range considered in the simulations. From these results, and assuming a beam sizes less than 3 mm (1 rms) along the cold linac, it can be concluded that the homogeneity of the detector is sufficient for transverse profile measurement.

Signal estimation A plastic scintillator might not be suitable for the ESS linac in term of radiation hardness and light production. Other type of scintillators have been studied. The evolution of the signal as function of the beam energy has been estimated for 3 commons scintillators type [4]:

- BC 412 plastic scintillator (λ_{peak} = 434 nm)
- NaI crystal (λ_{peak} = 410 nm)
- BGO (Bismuth germinate) (λ_{peak} = 480 nm)

The photon yield are respectively 9.6 γ per keV, 40 γ per keV and 8 γ per keV.

Beam energies from 200 MeV to 2100 MeV have been considered with step of 100 MeV, assuming the beam in the center of the beam pipe, the geometry is the same geometry as presented in the previous section. The number of photons produced per primary crossing the wire in each scintillator has been calculated from the average energy deposition in the 4 scintillators and the photon yield. The results of the simulations are presented in Fig. 4.

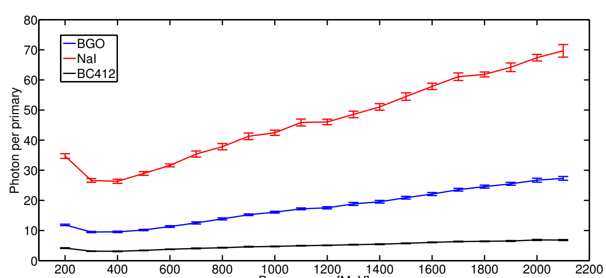

Figure 4: Production of scintillation photon per primary particles as function of beam energy for 3 types of scintillator.

These values have been used to estimated the light power generated in each scintillator for typical beam sizes in the superconducting linac and for the nominal beam current. For these estimations, the scintillation photons have been considered as mono energetic, with an energy equal to the luminescence peak. In this case, the minimum power is about 3.5 mW at 300 MeV for a plastic scintillator and up to almost 50 mW at 2 GeV for a NaI crystal.

At these levels of power, a photodiode can be used a light detector. Assuming a light collection and transmission from the scintillator to a photodiode of 20 % and a typical spectra response of 0.2 $A.W^{-1}$ for the NaI and plastic scintillator and 0.3 $A.W^{-1}$ for the BGO scintillator, the signal level at the output of the photodiode is in the mA range for the inorganic scintillators [5]. If the light transmission and collection is good enough , an optical fiber can transport the scintillation light from the scintillator to the klystron gallery and reduce the risk of failure of the electronic due to radiation. Other type of detector might be considerer to increase the sensitivity (like avalanche photodiode, PMT....).

NaI crystal might not be a good option due to its sensitivity to water, BGO seems a good compromise.

CONCLUSION AND OUTLOOK

Thermal load in the warm linac is critical, the pulse length has to be reduced to 50 μs in the MEBT to preserve the wire integrity. The reduction will also be beneficial for the other diagnostic installed in the MEBT and will increase the safety margin in the cold linac.

In SEM mode, the acquisition electronic shall be sensitive for a range from 10 nA to 1 mA in order to reconstruct the beam profile for all beam intensity, these electronic shall be installed on all the wire scanner.

The light collection efficiency and the transmission through an optical fiber has to be estimated in order to provide more accurate value of the signal, a prototype of the detector will be assembled and test in the lab in 2015. The choice of photon detector will be done after the test results. This setup can be reused in RF bunker to study the effect of the gamma background due to the cavity on the profile measurement.

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