Technical Specification	
Document Number	
Date	
Revision	1 (1)
State	Preliminary

Wire scanner software functionalities

Authors: B. Cheymol, H. Kocevar

This document describes the software functionalities of the Wire scanner (WS).

1. INTRODUCTION-WS SPECIFIACTIONS

Wire scanners have been deployed successfully since decade in accelerator; they represent a conservative choice for beam profile measurement. Their principle is rather simple and consists of moving a wire across the beam while monitoring a signal proportional to the number of particles interacting with the beam (see Fig. 1).

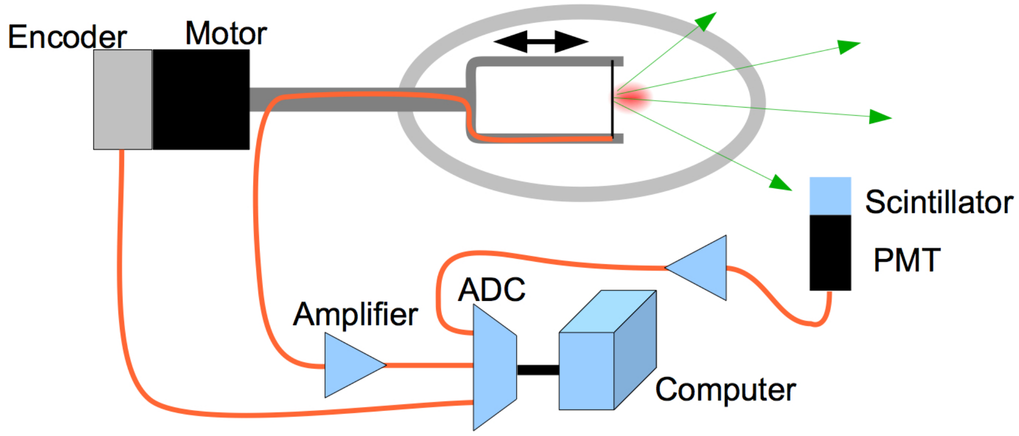

Figure 1 A thin wire is scanned through the particle beam while the secondary emission current, the signal from a calorimeter downstream, and the signal of the motor encoder are acquired simultaneously. Plotting either of the SEM or PMT signals against the encoder gives the beam profile.

The signal observed is usually either the secondary emission current (SEM) from the wire, or the flux of high-energy secondary particles downstream of the wire.

The WS will be used to measure the transverse beam profiles, the WS is designed in order to be used during the commissioning beam modes, the relevant beam parameters are:

- Beam current equal to 62.5 mA.
- Beam pulse length up to 50 μs.
- Repetition rate up to 14 Hz.

In this document, it is assumed that the timing system provided timestamps are set for all EPICS records. This document is not describing the interfaced with the MPS and with the global interlock system.

2. MOTION

The WS is actuated with stepper motor, controlled by a motion controller. Two pair of limit switches shall be installed on the WS actuator, one for the motion control system, the other one for the Beam interlock system.

The WS shall operate in two modes for motion, one call step by step mode, the other call on fly. In the first mode, the operator request a specific position of the wire, while in the second mode, the wire is moved across the beam pipe at a constant velocity, the signal from the wire as well as the wire position shall be trigger by the timing system.

The motion controller shall be compliant with the ESS standards.

3. SIGNALS ACQUISITION-DATA STORAGE

All the WS station shall be able to measure the SEM current form the wire. The signal form each wire shall be acquired separately, with two separated From End (FE) and ADCs. The operator shall be also able to delay or advance the trigger of the acquisition with respect to the timing system trigger.

Each end of the wire shall be connected to a separated acquisition channel in order to increase the measurement range. One with a high gain and low bandwidth for “halo” measurement, the second with a low gain and a high bandwidth in order to measure the beam core. In the second case, the bandwith of the FE shall be up to 1 MHz. Each channel shall be sampled with an ADC with a sampling rate up to 2 MHz.

In addition, multiple gains of the FE might be remotely controlled, the gain shall be chosen by the operator prior to the measurement.

In the elliptical section and downstream, the beam profile measurement will be preformed by measuring the signal created in scintillators positioned downstream the wire in addition of the SEM current. For each station, the signal will be acquired from 4 scintillators. The light from each scintillator will be collected with 2 fibers, one of these fibers shall be connected to a silicon photodiode, the other to an avalanche photodiode (APD). The FE of the photo-detectors shall have the same requirements as the one foreseen for the SEM current readout.

The total number of channels and the number of channels per WS station are summarized in Tab. 1.

Table 1 Number of WS channel

Location	Number of station	Actuator per station	SEM signals per station	Scintillator signals per station

MEBT	3	1	4	-
Spoke	3	2	4	-
Elliptical	4	2	4	8
A2T	1	2	4	8
Total	11	19	44	40

The digitizer card shall have a maximum sampling rate of 2 MHz, a resolution of at least 16 bits and shall be compliant with the ICS standard.

The start and the end acquisition shall be triggered; few tens of samples shall be acquired before and after the pulse to allow background subtraction in post processing. The operator shall define the time of acquisition by choosing the numbers of samples. The operator shall be also able to decimate the number of sample in order to simulate a lower sampling rate. The operator shall be also able to delay or advance the trigger of the acquisition with respect to the timing system trigger.

For each WS station channels, the raw data have to be converted from ADC counts to Volts and shall be saved (without decimation and background subtraction) after the conversion as well as the wire position and all other relevant parameters.

The position and the SEM/shower signals have to be correlated.

4. POWER SUPPLY

Each wire will be polarized to +/- 100 volts, the operator shall be able to remotely controlled the value of the bias voltage prior to the scan.

The photo detectors shall be also biased, for the APD the gain is proportional to the voltage, the operator shall be able to choose the bias voltage prior to the scan.

5. LOCAL PROTECTION

In the cold linac and downstream, each wire scanner station will equipped with 2 actuators (see Tab. 1). The local protection system of the WS system shall insure that only one actuator is inserted in the beam pipe in order to avoid collision.

If a fault is detected on the WS system, the measurement has to be stopped and the wire shall be retracted to the parking position.

If a fault on the vacuum system is detected, as well as on the electrical network, the measurement has to be stopped, the power supplies have to stopped and the beam permit has to be removed.

Note: this section is in a preliminary stage, fault modes can be added or removed.

6. ENGINEERING SCREEN-WS OPERATION

Motion controls:

The operator shall be able to choose the plane of measurement and the scan type (on fly or step by step). The scan parameters (i.e limits, number/size of the step) shall be also remotely controlled. In the on fly mode, the wire velocity shall be calculated with the knowledge of the step size requested by the operator and the repetition rate of the accelerator mode. The position of the wire shall be triggered and measured for each pulse.

In the step by step mode, multiple pulses might be acquired for each wire position the operator shall be able to choose the number of pulse to be measured.

Remote controls:

The different power supplies needed for the beam profile measurement shall be remotely controlled. For the controlled of the APD, the gain is proportional to the bias voltage applied on the detector, on the engineering screen, the operator shall be able to choose the gain, the software shall perform the conversion to voltage. The conversion curve will be provided from the APD specifications, note that this value doesn't need to be precise.

The gain of the FE electronics shall be also remotely controlled. A test of the wire integrity shall be also implemented in the software.

Raw data display:

For a single wire position, the trace of the signal as function of time shall be display at a refresh rate of 1 to 14 Hz depending on the machine mode. The trace from each measurement shall be display for 1 second at least. In the SEM mode, the date from the 2 FE shall be display on the same plot with a different trace, for the shower mode, 4 separated plot shall be implemented in the engineering screen, the data from the diode and the APD shall be display on the same screen.

The average (or the sum) signal without background subtraction and the wire position shall be used to generate the beam profile on a separated plot window during the scan (note: in the shower mode, only one scintillator signal is needed to generate this plot). On this plot, the operator shall be able to choose which wire position to calibrate the low and high gain channel. A coefficient shall be applied to one of the data in order to display a single profile trace on all the dynamic range of the WS acquisition (note: on the data point chosen by the operator, the 2 signals shall be equal after calibration)

Data analysis and display:

The operator shall be able to choose the time interval(s) needed for be background subtraction, before and after the beam pulse[1]. Another set of time interval has to be implemented in order to estimate the signal on the flat top after the transient. The background shall be estimated for each wire position and each FE channel. The same plot as the one mentioned above shall be display after background subtraction and channel calibration.

Basic data analysis might be implemented in the software, like:

- Gaussian fitting
- Bi-Gaussian fitting
- Parabolic fitting

All these parameters shall be calculated during the flat top defined by the operator and after background subtraction. The RMS value of the distribution shall be display and archive.

Flag status:

On the engineering screen, a list of flag status shall be implemented, the major ones are:

- Beam permit status
- Wire integrity status
- Motion Control status
- Power supplies status

Note that each power supply should have its one flag. For the beam permit, the engineering screen shall be locked if the beam permit is not in the right status.

Operation of the wire scanner:

This section describes as example how an automatic measurement of the beam profile with the WS system can be performed. It has to be noted that this is only an example and valid only for the on fly mode.

- *Step1*: The operator shall select the plan of measurement and the step size of the beam profile
- *Step 2*: Automatic checking of the wire integrity prior to the scan
- *Step 3*: If step 2 is ok and beam permit is allowing the insertion of the interceptive device, the scan is started, the wire will move at high-speed across the full beam pipe aperture.
- *Step 4*: The center of the beam and the RMS value of the profile will be roughly estimated from the high speed scan
- *Step 5*: The values calculated at the step 4 will be used to generate the "start/end" positions of the scan. These two limits can be defined as +/- 6 times the RMS value found in step 4 and centred on the value found for the beam center at the same step.

[1] One interval is mandatory

- *Step 6*: The WS will be retracted for the beam pipe aperture at a lower speed, in particular in the area defined at step 5, in order to perform a precise scan. The wire velocity shall be calculated form the step size defined by the operator and the machine repetition rate.
- *Step 7*: The raw data shall be display according the specifications presented in the document.
- *Step 8*: The operators might performed data analysis and/or store the data

7. SUMMARY AND ACTION LIST

Status-beam permit:

- If beam permit is removed, the wire scanner actuator shall moved automatically to its parking position
- If beam is permit is not allowing the insertion of interceptive device, the WS GUI shall be frozen.
- The WS GUI shall have:
  - ✓ Beam permit flag status
  - ✓ Wire integrity flag status
  - ✓ Motion Control flag status
  - ✓ Power supplies flag status

Scan set-up:

- The operator shall be able to choose the measurement plane (horizontal or vertical).
- The operator shall be able to define the scan parameter:
  - ✓ Start position
  - ✓ End position
  - ✓ Step size

- The operator shall be able to choose the scanning method (on fly or step by step)
  - ✓ The speed on the movement shall be automatically calculated with the step size and the machine repetition rate
  - ✓ The velocity value shall be displayed

- The operator shall be able to change the gain of the FE prior to the start of the scan (if applicable)
- The operator shall be able to define the bias voltage on the wire.
  - ✓ Out of range value shall not be allowed
  - ✓ The value shall be displayed

- The operator shall be able to define the APD/diode bias voltage
  - ✓ Out of range value shall not be allowed
  - ✓ For the APD, operator shall be able to choose the APD gain
  - ✓ The value of the bias voltage shall be identical for all the APDs (or diodes)
  - ✓ The value of the bias voltage shall be display

- In step-by-step mode the operator shall be able to define the number of consecutive pulse to be acquired at each wire positions

Timing:

- The operator shall be able to select the trigger delay with respect to the ESS master clock
- If applicable, the operator shall be able to choose the sampling rate of the ADC (for decimation purpose)
- The operator shall be able to choose the duration of the acquisition (with a post trigger or number of sample)
- Acquisition shall start a least 20 us before the pulse arrival on the wire

Data display and analysis:

- The operator shall be able to see the raw signal as function of time on dedicated plot
  - ✓ The trace of the 2 SEM FE shall be displayed on the same plot
  - ✓ The trace of the diode an APD shall be displayed on a separated plot
  - ✓ The trace shall be persistent for at least 1 second

- The operator shall be able to define 3 time windows on the raw data screen for basic data analysis (same time window for both channel):
  - ✓ A pre pulse window
  - ✓ A post pulse windows
  - ✓ A range of interested (ROI) on the signal flat top

- The software shall be able to estimate the background from the pre and post pulse window and subtract it to the data from the ROI

- The operator shall be able to see the reconstructed beam profile on dedicated plot
  - ✓ Profile shall be reconstructed by averaging (or summing) data from ROI with background subtraction

- ✓ In case of high dynamic range measurement (i.e. with 2 FE channels), the operator shall be able to choose the wire position for signal normalization. The plot shall be automatically updated.
- ✓ For shower mode, the profile estimated with scintillator shall be displayed with separated trace
- ✓ For shower mode, beam profile shall be reconstructed and displayed by summing the signal from the 4 scintillators

- The operator shall be able to make data fitting, standard fit function shall be implemented in the software like:
  - ✓ Gaussian fitting
  - ✓ Parabolic fitting
  - ✓ Bi-Gaussian fitting

- The relevant beam profile parameters shall be calculated, displayed and stored, like:
  - ✓ RMS value of the profile
  - ✓ Mean value

- The raw data and the scan parameters shall be archived

- The last known parameters and the reference value of the stepper motor shall be automatically load at start up

8. POTENTIAL UPGRADES

This section describes potential upgrades for the WS system. These functionalities will not be implemented for the commissioning of the ESS linac and therefore will not be implemented in the first version(s) of the software.

Cherenkov signal measurement:

Bremsstrahlung background from cavities might interfere with the hadronic cascade created by the wire. Monte Carlo simulations show that on the scintillator location, the background is dominated by high energy gammas, therefore a Cherenkov detector might be used to remove the contribution of the cavities.

On the detector assembly, a Cherenkov detector will be installed as well as a fiber to collect the light. The fiber will transport the light to the klystron gallery.

In an upgrade phase, the Cherenkov light will be measured with a PMT and a dedicated FE, in the elliptical section and downstream, 4 more acquisition channel will be added to each stations. The data display and analysis as well as the remote control shall be identical to the ones describes for the other system.

Halo measurement-operation at long pulse length

For high power machine like the ESS linac, the knowledge of the transverse halo is interesting in order to reduce the beam losses. The WS might be used to measure this beam parameter at longer pulse than the ones expected for the commissioning.

During halo measurement, the wire has to be positioned as close as possible to the beam core. A fast protection function must be implemented to insure the wire integrity.

Above ~2000K, the thermoionic current is dominant compare to the SEM current, the current increases exponentially with the temperature. In a first approximation, assuming a constant halo density along the pulse, the wire temperature increase linearly with the pulse length. One option to protect the wire from over heating is to detect the exponential rise of the current from the wire due to thermoionic emission.

Form the wire current, few samples can be used to estimate the average value of the signal slope, if this slope is higher than a predefined threshold, the safety system(s) shall be triggered.

At the time of this note is written it is still unknown which safety system shall be triggered. A test campaign the lab with an actuator prototype shall be performed in order to select the sequence.