STUDY OF SINGLE WIRE SCANNER MONITOR FOR FETS-FFA TEST RING

E. Yamakawa*, D. W. Posthuma de Boer, S. Machida, A. Pertica, A. Letchford, RAL STFC, Didcot, United Kingdom
Y. Ishi, T. Uesugi, Kyoto University Institute for Integrated Radiation and Nuclear Science, Osaka, Japan

Science and Technology Facilities Council

Abstract: To confirm the use of Fixed Field Alternating gradient accelerator (FFA) as a high power pulsed neutron spallation source, a prototype called FETS-FFA is studied at Rutherford Laboratory (RAL). A single Wire Scanner Monitor (WSM) is planned to be used to measure beam position and beam profile in the ring. One of the concerns of this monitor is the thermal damage on the Carbon Nano Tube (CNT) wire due to high energy deposition of low energy proton beam in FETS-FFA (3 - 12 MeV). Furthermore, to measure a beam profile during beam acceleration in the ring, a diameter of CNT wire needs to be smaller than the orbit displacements in turns. To confirm whether a single WSM is suitable for FETS-FFA ring, two different beam tests were performed at RAL and at the Institute for Integrated Radiation and Nuclear Science, Kyoto University (KURNS). Both measurements demonstrated that the single WSM is applicable for FETS- FFA ring if the diameter of CNT is smaller than the orbit separation between two consecutive turns. In this paper, the detail of the design study of single WSM as well as the performance tests are presented.

Introduction

A **stationary, single Wire Scanner Monitor (WSM)** with a **CNT wire** will be used in the FETS-FFA test ring (Tab.1) as a beam profile/position monitor.

How to measure beam profile in FETS-FFA ring:
Injection/Extraction beam: wire position is moved over the beam size.
Multi-turn accelerating beam: wire position is fixed, and measures the profile by intercepting the beam over multiple turns during an acceleration cycle (Fig.1).

Constraint:
- Heat damage of the wire due to low energy proton beam.
- Emittance growth due to scattering, resulting in beam loss when measuring the profile of the multi-turn accelerating beam.

Aim of the study: Investigate whether the monitor can measure the beam profile in the FETS-FFA ring.

Table 1: Parameters of 4-fold symmetry FD-spiral FETS-FFA ring in 2023

Beam energy range	3-12 MeV
Bunch intensity	3E11 ppp
Repetition rate	100 Hz (50 pps)
Injection rate	50 Hz
RF frequency bandwidth	2-4 MHz
Harmonic number	2
Normalised Beam Core	10 π mm mrad
Beam Size	±20 mm
Orbit Excursion	600 mm
Vertical Physical Acceptance	±32 mm

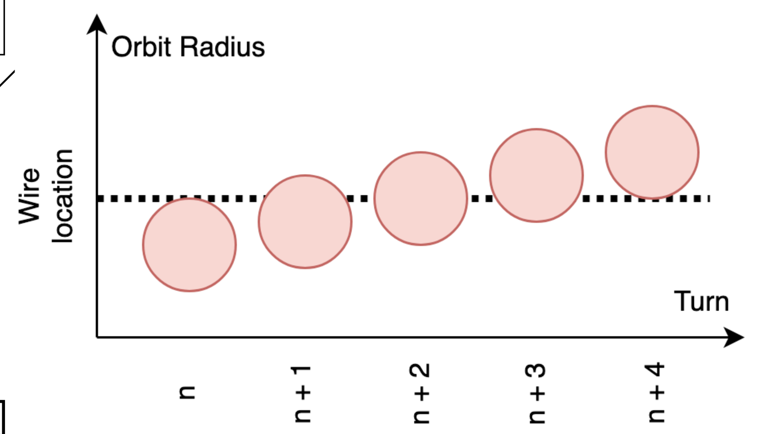


Figure 1: Schematic drawing of the profile measurement of an accelerating beam over several turns (red circles) in the FETS-FFA ring.

Feasibility Studies

Wire Thickness:

To investigate the impact of wire thickness on the measured beam profile, a computer simulation was performed (Fig.2).

Expected:
- Accurate profile: given by the wire thickness less than the turn separation by limiting the number of consecutive scattering events.
- Signal strength: proportional to the cross-section of the wire.

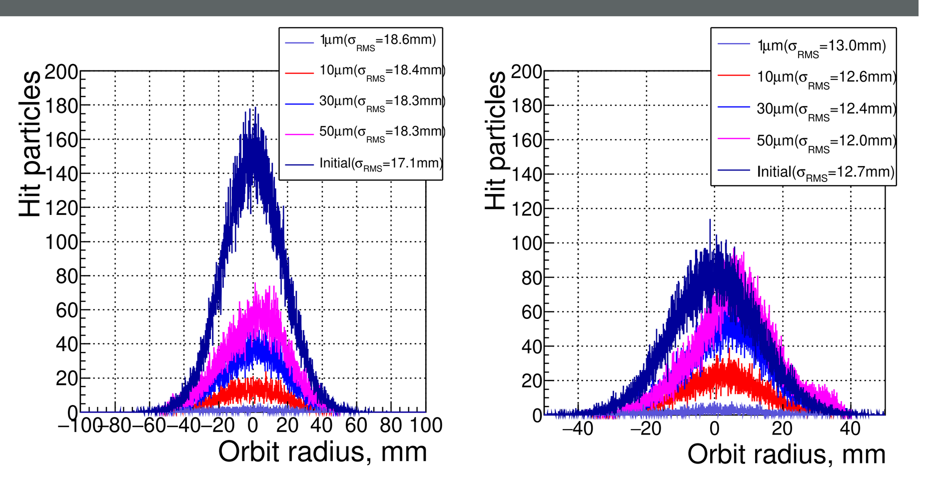


Figure 2: Computed beam profile with several thicknesses of CNTs at around 3 MeV (left) and 12 MeV (right).

Wire size should be chosen with a reasonable balance between the SNR and the accuracy of profile.

Heat Analysis

Temperature rise in the wire when measuring the beam profile over multiple turns is estimated based on the FETS-FFA ring (Fig.3), corresponding to 0.143 mA of 3E11 ppp, at injection beam energy of 3 MeV. <u>The steady temperature on each wire is below the melting temperature of CNT.</u>

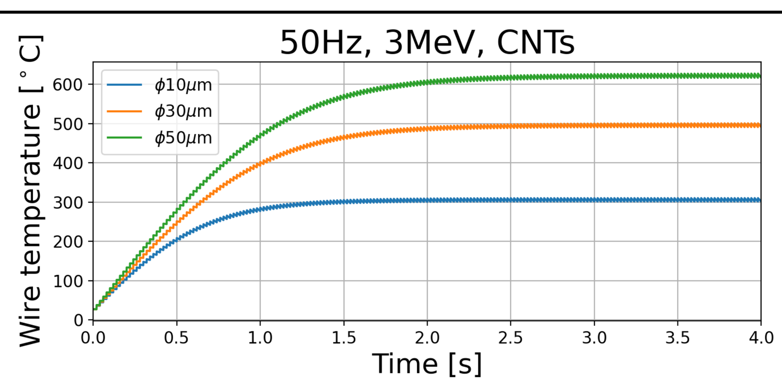


Figure 3: Transient temperature in each CNT wire. A thermal emissivity of CNT in vacuum is estimated to be 0.2 in this simulation.

Heat Tests on FETS

Beam tests were performed with a 3 MeV H- beam on the FETS [2] (Fig.4).

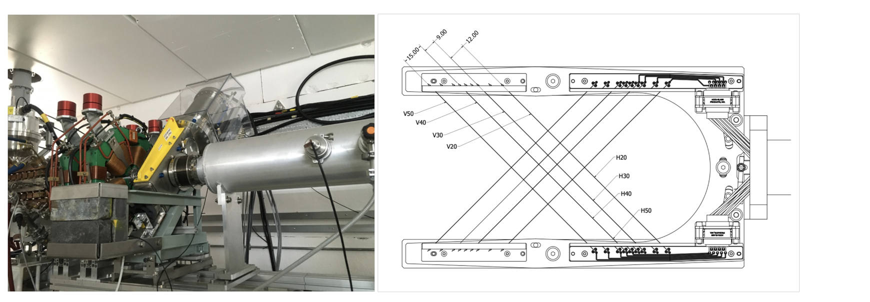


Figure 4: Left: The single WSM on FETS beam line. Right: The monitor head with CNTs. The horizontal wires are upstream of the vertical wires, which are 3 mm apart in the beam direction. The ϕ10 μm CNT was too thin to be mounted on the monitor head.

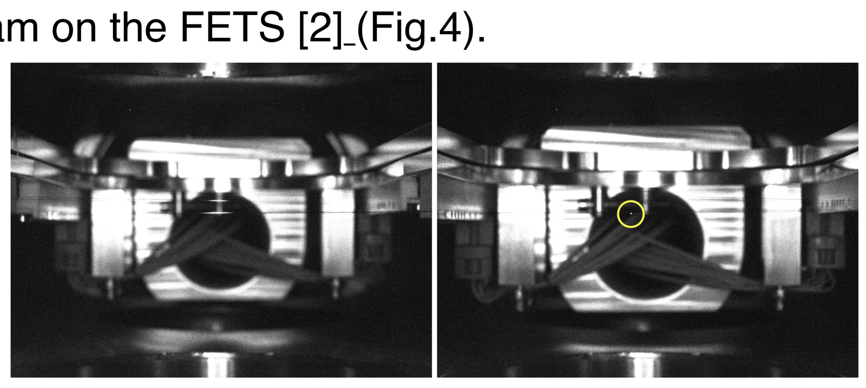


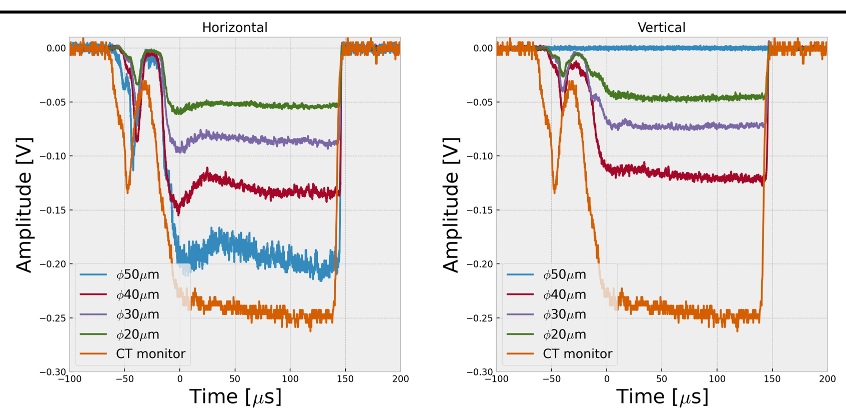
Figure 5: Light emission from the ϕ50 μm (left) and the ϕ20 μm (right, in the circle) CNTs with the 3 MeV FETS H- beam. The wire was aligned at the centre of the beam pipe when the photo was taken.

- No broken wires (>400°C expected) were found after at least 10 minutes with 28 mA FETS peak current, that is factor of 100 larger than the pulse current of FFA multi-turn beam.
- <u>The considered thickness of CNTs will not be damaged rapidly by the injection beam in the FETS-FFA ring.</u>

Pulse Width Measurement on FETS

Pulse width: the time window which is above 2 times of standard deviation of the noise level.

Integrated signal: integration within the pulse width.



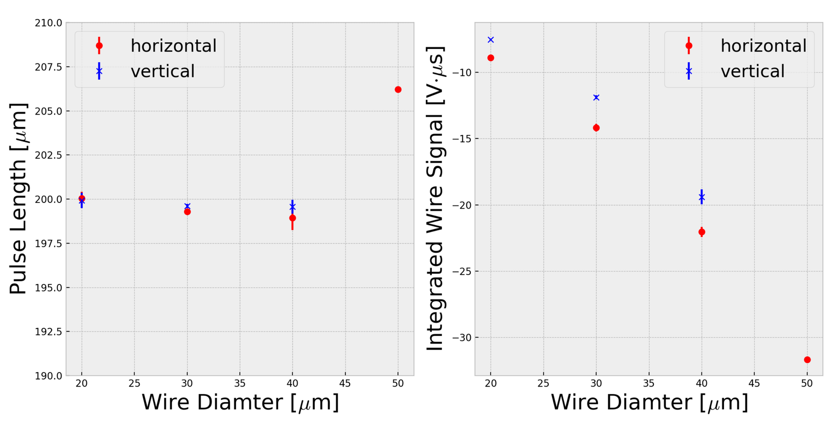


Figure 6: The measured pulse length (left) and the integrated pulse signal (right) of the FETS beam. The error bar is the RMS pulse length and the RMS integrated wire signal over 5 pulses.

- Pulse width : ~ 5% different from the one measured by the CT monitor (210 μm), located at about 535 mm upstream of the WSM.
- Integrated signal : not proportional to the cross-section of the wires, but these data will be useful to predict the signal strength when the required diameter of wire is used in the FETS-FFA ring.

Profile Measurements

Profile Measurement on FETS

- The measurement was done by scanning the wire positions over the beam size.
- The control units set the wire positions with a stepper motor and acquire the signal at every trigger timing. The control units have a signal amplifier with a gain of 4.7E3 V/A at bandwidth of 50 kHz after low pass filtering.
- At each monitor step, 10 samples were acquired over 100 ms following a trigger, and averaged before being saved to disk.

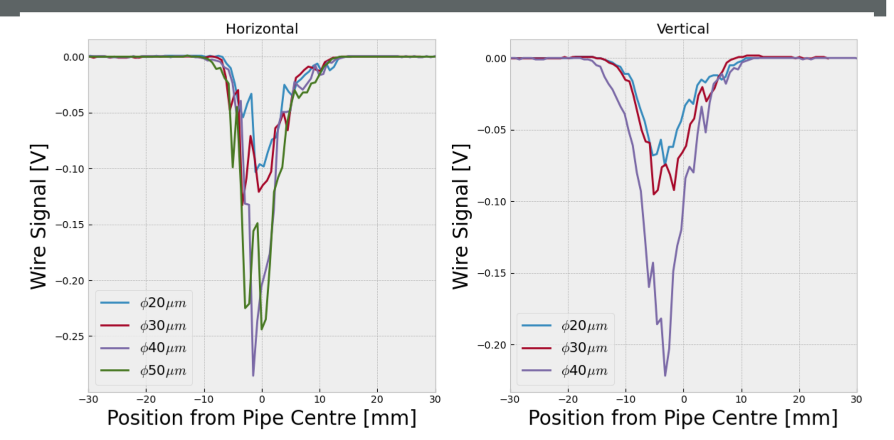


Figure 7: Beam profiles measured by each CNT wire. The scan range was 148.5 mm with a step size of 1 mm. The peak pulse intensity measured by the CT monitor was about 13 mA in this measurement.

- Beam profiles were measured by all CNT wires.
- Horizontal beam sizes are consistent. But vertical beam sizes are not, which could be due to scattering from the up-stream horizontal profile wires.

Table 2: The measured RMS beam size with design values. The errors are RMS of three different beam sizes

CNT	RMS Beam Size Horizontal [mm]	RMS Beam Size Vertical [mm]
ϕ20 μs	3.5±0.28	4.2±0.04
ϕ30 μs	3.4±0.35	3.8±0.27
ϕ40 μs	3.8±0.77	4.6±0.27
ϕ50 μs	3.8±0.25	N.A
Design	4-5	4-5

Profile Measurement on hFFA

- Beam experiment with the single WSM was performed in the hFFA ring at KURNS [3].
- Wire position was fixed at the orbit of about 13.5 MeV where the turn separation is about 29 μm.
- Wire diameter of ϕ10 μm CNT was mounted on the frame (Fig.8).
- Secondary electron emissions were read by the signal amplifier with a gain of 1E7 V/A and a cutoff frequency of 4.8 kHz that was wide enough to detect the ≈300 μs beam signal.

Figure 8: The radial probe (left) and the monitor head of the single WSM with ϕ10 μm CNT wire (right). The monitor head was attached on the radial probe controlled by the motion control driver.

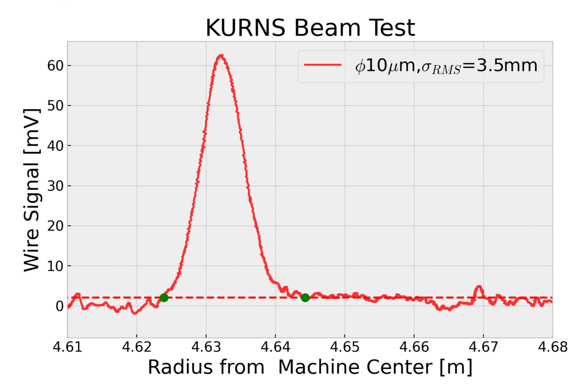


Figure 9: The accelerating multi-turn beam profile measured by ϕ10 μm CNT wire. The dashed line is the 2 times of standard deviation of the noise level, computed by the RMS within a time window at the end of the data when there is no beam.

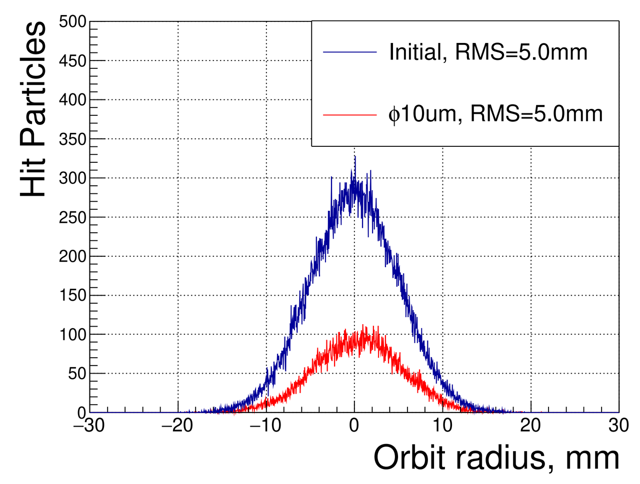


Figure 10: The computed beam profile measured by ϕ10 μm wire. The initial beam is a Gaussian distribution with the design value of beam size (σ=5 mm). The scattering angle and energy loss at the wire are computed by PHITS, which are taken into account in this simulation.

The multi-turn beam profile was successfully measured by the single WSM in hFFA, but the beam size is smaller than that of design value.

- Differences between the actual and design beam emittance due to recommissioning of the ion source as well as Linac at the tests.
- Some of secondary electrons will be confined by the magnetic stray fields (~0.05T) and eventually return to the wire, decreasing the signal and resulting in a smaller measured beam size.

Further tests and analysis with bias voltages will be required in future.

Conclusion

The WSM with a single, stationary CNT wire has been developed as a beam profile monitor for the FETS-FFA test ring. Tracking simulations have motivated the study of wires with a small diameter, to minimise scattering over many turns. <u>The durability of these wires has been demonstrated by exposing them to the 3 MeV H- beam of the FETS Linac.</u> Whilst it has been demonstrated with simulations and measurements that heating of these wires is not expected to produce short-term effects, heat damage over a longer time periods should be also observed in future. <u>It has also been demonstrated with simulations and experimentally, that the single WSM will be able to measure the pulse length and profile of low energy mono-energetic beams as well as the accelerating beam over multiple turns in the FETS-FFA ring.</u> A beam scraper will also be installed in the FETS-FFA ring, and offers an alternative method to measure the beam size of accelerating beams over multiple turns. However, there are challenges in using such monitors when distributions such as hollow beams are possible. As the single WSM will be able to identify the beam profile and the beam size even for a hollow beam, the single WSM will be an invaluable diagnostic for commissioning the FETS-FFA test ring.

References

[1] J.-B.Lagrangeetal.,Proc.IPAC'19,pp.2075–2078(2019).
[2] A. Letchford, 31st Int. Linear Accel. Conf, MO1AA01 (2022).
[3] YMorietal.,Proc.IPAC'11,WEPS077(2011).

*emi.yamakawa@stfc.ac.uk