ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-TUPP014

NEW COMBINED FUNCTION WIRE SCANNER-SCREEN STATION FOR THE HIGH RESOLUTION TRANSVERSE PROFILE MEASUREMENTS AT FERMI

M. Veronese*, A. Abrami, M. Bossi, S. Grulja, G. Penco, M. Tudor, M. Ferianis
Elettra-Sincrotrone Trieste S.C.p.A., Trieste, Italy

Abstract

We present the upgrade of the transverse profile diagnostics at the end of the FERMI Linac with a new high resolution instrumentation with the aim of improving the accuracy of the measurement of the twiss parameters and of the emittance. A scintillating screen, has been adopted instead of OTR screen due to known COTR issues. We used the same COTR suppression geometry that we had already implemented on our intra undulator screens and YAG:Ce as scintillating material. Screen based transverse profile diagnostics provide single shot measurements with a typical resolution of the order of tens of microns mainly due to refraction effects, geometry and other physical material properties. To extend the resolution to the micron level needed in case of low charge operation, we have equipped the same vacuum chamber with a wire scanner housing 10 µm tungsten wires. This paper describes the design and the first operational experience with the new device and discusses advantages as well as limitations.

INTRODUCTION

In a Free Electron Laser (FEL) it is of critical importance to have accurate knowledge of the optics along the machine to ensure stable operation of the machine. This translates in a significant effort from the electron beam instrumentation point of view in providing beam transverse profile measurement all along the FEL. For this reason modern FELs are equipped with instrumentation for transverse profile measurements all along the accalarator spanning from the injector to the very end of the accelerator. The two main types are wire scanners and view screens. Wire scanners have better resolution but can provide only 1D projection of the electron beam in a multi shot acquisition and thus are quite slow. View screens offer complete 2D distribution reconstruction in a single shot but have less resolution and may suffer from coherent optical transition radiation (COTR) or scintillator related limitations. At Fermi the initial design choice [1] for the linac was to have only views screens equipped with both YAG:Ce and OTR screens and no wire scanners. The screens have tilted at 45° screen with respect to the electron beam and with the imaging optics axis at 90° with respect to the electron beam. During operational experience at FERMI it became clear that COTR contamination was present on OTR screen making the unusable downstream the first bunch compressor (BC1) and also that it may also be present on YAG:Ce screen even with the laser heater. At the end of the linac (1.5 GeV) where one of the key optics measurement is performed, it has become evident that the resolution of such view screen was not enough. To overcome such limitations in the undulator region the view screens where designed with a COTR suppressing geometry and better resolution [2]. A a first experience with wire scanners was achieved with the tests of the PSI wire scanner prototype [3]. We recently decided to build an hybrid instrumentation hosting in a single vacuum chamber a wire scanner and a view screen. This paper describes its design and performances. The view screen which is used more often has a variable magnification to allow for high resolution for optics measurements and moderate resolution (but larger field of view) for longitudinal profile measurements when used in conjunction with the high energy RF deflector. Wire scanner can provide profile measurement with resolution of the order of few microns and is mandatory to be used for measurement at low charge (where the emittance drops and the screen resolution is insufficient) and is used for comparison with view screen in normal operation.

FERMI LAYOUT

FERMI is a seeded FEL based on the high gain harmonic generation (HGHG) scheme [4]. Two FEL lines, FEL-1 and FEL-2, are presently installed at the facility. FEL-1 is a single stage seeded FEL generating coherent light in the 65–20 nm wavelength range. FEL-2 is a double stage seeded FEL based on the fresh bunch injection technique [5,6], where the additional stage extends the spectral range to 20–4 nm. At FERMI the electron bunch is generated at 10 Hz by a photo-injector GUN with energy of 5 MeV [7]. The electrons are accelerated by an S-band linac. The bunch length can be manipulated by means of a magnetic bunch compressor chicane (BC1). The microbunching present in the bunch can be mitigated before BC1 by a laser heater (LH) system. The final energy is up to 1.5 GeV in FEL operative conditions. After the acceleration, the electrons are injected into one of the two FEL lines (either FEL-1 or FEL-2). A layout of the FERMI FEL is shown in Fig. 1. The new combined function wire scanner plus screen station (MSCR-WS) is installed at the end of the linac before entering the Undulator Hall.

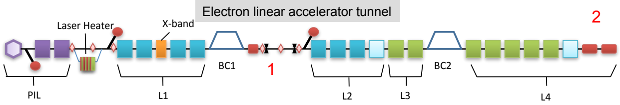

Figure 1: Layout of FERMI linac.

---

[*] marco.veronese@elettra.eu

ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-TUPP014

DESIGN CONCEPTS

The view screen is based an the COTR suppressing geometry developed for the intra undulator view screens [2]. This geometry is conceptually very similar to the one used at SWISSFEL [8] and XFEL [9] as it collects the radiation emitted by the scintillation as a consequence of beam energy deposition with an off axis mirror without collecting COTR. Using the analytical description in [8] our system has a screen incidence angle α of 15° and a collection angle β angle of 0°. In this configuration the β angle does not minimize the refraction effects but allows for the optical axis of the imaging system to be orthogonal to the scintillator plane so that no Scheimpflug arrangement of the detector is needed. This has been particularly beneficial when coming to a variable magnification imaging system. The addition of wire scanner function is mandatory in case of low charge operation since the beam size drops below the resolution limits of scintillation based screens as a consequence of a smaller emittance. Moreover the wire scanner provides a reference measurement to establish, on the exact same beam, the resolution limits of the view screen. As recently shown at XFEL view screens may suffer from important effects that may harm their performances. For example in the case of LYSO a quenching of the optical yield at high electron densities of primary electrons takes place, corrupting the measurement [10]. This effect was not predictable and was unexpected as it did not appear in the measurement campaign done in the previous years [11].

ENGINEERING

The vacuum chamber houses two vacuum motorized translators one at 90° with respect to the electron beam axis for the view screen and one at 45° for the wire scanner. The imaging system is located below the vacuum chamber see Fig. 2. To have more compact and stable vacuum translation, vacuum slits are installed in the chamber equipped with platforms to house the screen and wire scanner assemblies. The platforms are moved back and forth by a small rod. The two systems have a single contact point that allows a minimum of joint flexibility. Motorized actuators are Heidon Kerk (E28M47) and the encoders are Tonic by Renishaw Tonic series with 0.1 mm accuracy. The mechanical accuracy and stability has been verified at the manufacturer by means of a CMM machine. The views screen platform is designed to house two COTR suppressing screen assemblies. The wires scanner platform is equipped with a detachable frame on which the wires are installed, whose design is inspired to the SWISSFEL prototype tested at Fermi. The frame is equipped with two pairs of tungsten wires (Goodfellow Corp.) for each direction, set at a distance of 10 mm from each other. The wires diameter is 10 µm. A parking position is devised within the frame aperture and guarantees a stay clear diameter of 22 mm. The view screen assembly shown in Fig. 3 is an evolution of the FERMI intra undulator screens. The scintillator is a Baikowski optical ceramic YAG with a Ce doping of 0.5% and a thickness of 100 µm. The vacuum mirror is custom made UV fused silica Al coated mirror. The assembly does not have an in vacuum calibration target since it will not work for the whole magnification range (0.35 to 2.2). All calibrations have been done in the laboratory before the final installation. The vacuum window for imaging is a UV fused silica with a special design that allowed it to be installed it in vacuum. This was needed to reduce the working distance to the minimum possible. The view screen imaging optics is based on a Navitar motorized zoom 6000 objective lens. The design allows for two possible configurations: horizontal and vertical. The horizontal configuration has a nominal working distance of 175 mm and a resolving power of 9.5 µm. The vertical has a 113 mm working distance and a nominal resolving power of 6.3 µm. In this paper we only report data concerning the horizontal configuration. The detector is a Basler acA1300-75gm CMOS camera with 4.8 µm pixels and a maximum full frame acquisition rate of 75 frames per second. As shown in Fig. 4, in front of the motorized lens we installed a custom made filter wheel equipped with neutral density filters based on a Renishaw

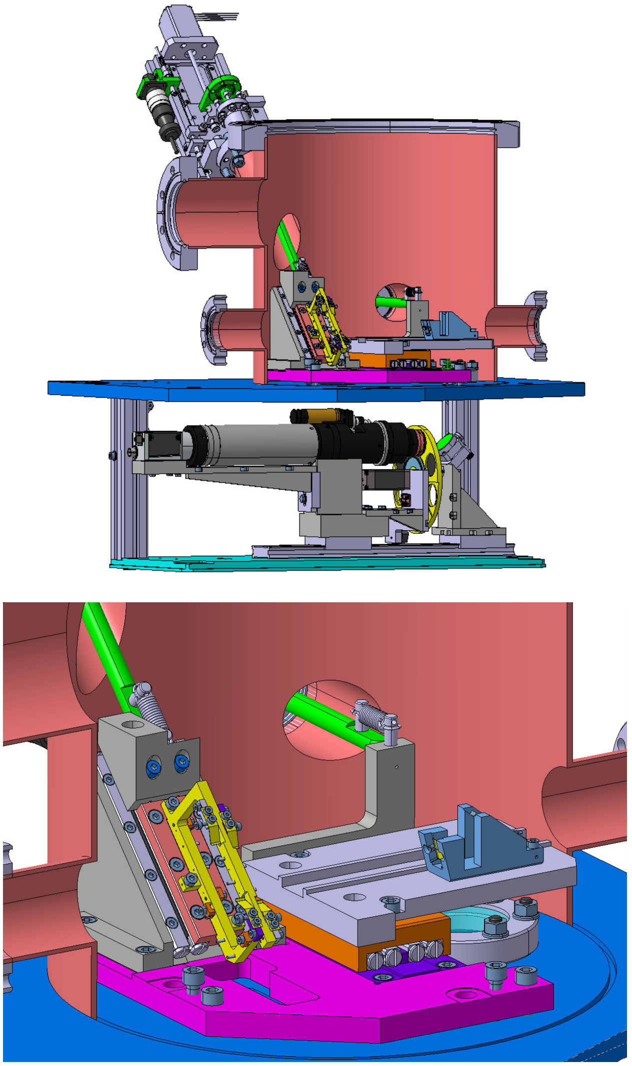

Figure 2: Pictorial representation of the vacuum chamber.

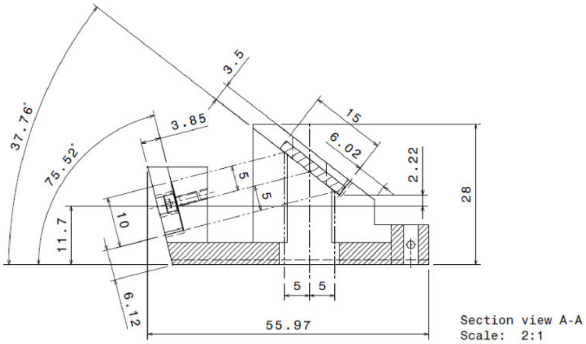

Figure 3: Mechanical drawing of the view screen vacuum assembly that hosts the YAG:Ce scintillator and the vacuum mirror.

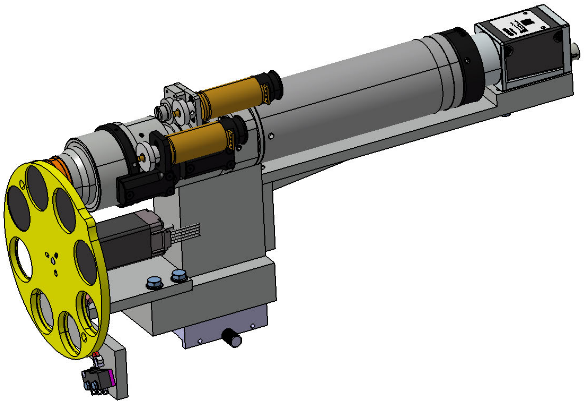

Figure 4: Imaging optics assembly.

Atom rotary encoder plus a RCDM glass disk. The filter wheel is actuated by a Nema 8 Stepper Nanotech stepper motor. All the 5 motorized axes are controlled by a in house developed YAMS controller [12].

The controller has a special software operation mode that is used for wire scanner scans which allows reading shot by shot the encoder position and tagging it with a bunch number to better correlate the position with the loss detector data data. The loss detection system for the operation of the wire scanner is the one used for the SWISSFEL prototype tests. Light from Cherenkov and scintillating fibers due to radiative losses induced by the electron hitting the wires, is transported out of the tunnel to the klystron gallery where are converted to electrical signal and acquired by a CAEN VX1720 12bit, 250Ms/s digitizer.

COMMISSIONING

The electron beam optics has a waist at the MSCR-WS position which determines very small beams. The measurement were performed at a charge of 700 pC, and with an electron beam energy of 1.5 GeV. A typical beam image is shown in Fig. 5. The horizontal beam size is 32 µm while the vertical beam size is 34 µm. The charge density is then 0.64 pC/µm^2 which may potentially lead to saturation effects. However the YAG:Ce has a 0.5% doping and the ratio of electron-hole pair per primary electron can be calculated to be less than unity consistent with no saturation. This means according to [13] that saturation is not taking place. For comparison the reported XFEL [10] quenching effects for LYSO were reported at 0.2 pC/µm^2 (for a 1 nC beam width beam sizes (100 µm × 50 µm) as measured by a YAG:Ce). Since the charge densintyin our case is even higher this seems to confirm that YAG:Ce is less prone to quenching at this level of charge density than LSYO. In the attempt to verify the resolution limit of the view screen we purposely stretched the electron beam vertically to squeeze it as much as possible horizontally. We made a slice analysis of the image by creating multiple profiles by averaging few slices and fitting them with a Gaussian function. In this way we obtained the results shown in Fig. 6: a beam that has a large beam size at the center and smaller at the bottom. The sigma is plotted as a function of the slice number. The thinnest slices at the bottom of the image show a consistent sigma of about 18 µm. As a final step in our characterization we compared wire scanner measurement data with views screen, see Fig. 7. The wire scanner geometrical resolution is the wire diameter divided by 4 [3]. In our case this means

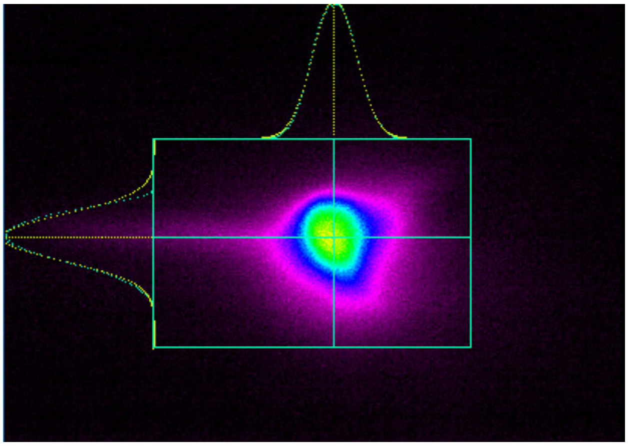

Figure 5: Typical image transverse distribution acquire for matched beam.

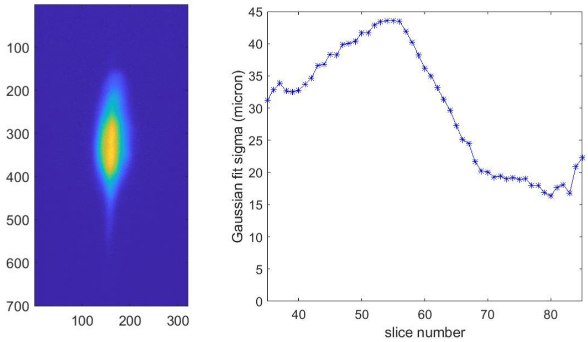

Figure 6: Stretched beam and slice beam size (Gaussian fit) vs slice number.

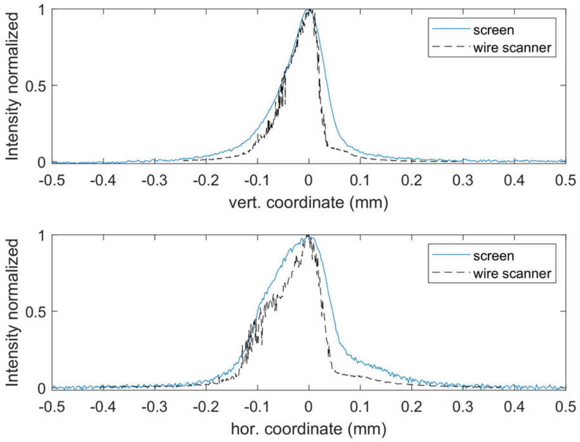

Figure 7: Transverse profile comparison view screen vs wire scanner. Top plot vertical profiles, bottom plot horizontal profiles.

2.5 µm which for all electron beam sizes considered in this paper is negligible and thus the wire scanner measurement can be taken as the reference. The top plot shows a comparison between the vertical profile obtained with the view screen and with the wire scanner. The wire scanner beam size is 32 µm, while the view screen beam size is 43 µm. The bottom plot shows a comparison between the horizontal profile obtained from the views screen and from the wire scanner. The wire scanner beam size is 51 µm, while the view screen beam size is 62 µm.

CONCLUSION

We have described the requirement, the design and commissioning results of the new instrumentation for high resolution transverse beam profile measurement at FERMI. The combined function of view screen and wire scanner is beneficial because it provides the flexibility of using the best tool depending on the application. The view screen is more suitable for fast measurements of the beam spot size, for instance during a quadrupole scan, while the wire scanner can provide a very high resolution measurement. It extends the range of measurable electron beam size from a few microns to a few millimeters. It potentially extends the range of bunch charge from a few pC to few nC. Moreover, it allows a benchmarking of view screen measurement and a direct evaluation of views screen total resolution. This last point is of increasing importance in the light of the ongoing effort in the instrumentation community to provide view screen based on scintillators with the highest possible resolution.

ACKNOWLEDGEMENTS

The authors would like to thank colleagues from the FERMI machine physics and instrumentation groups for fruitful discussions. Moreover we would like to thank G. L. Orlandi and C. Ozkan for sharing their knowledge about wire scanner design and operation.

REFERENCES

[1] C. J. Bocchetta *et al.*, “Conceptual Design Report for the FERMI@Elettra project”, Elettra-Sincrotrone Trieste, Trieste, Italy, Rep. *ST/F-TN-07/12*, 2007.

[2] M. Veronese *et al.*, “Intra Undulator Screen Diagnostics for the FERMI@Elettra FEL”, in *Proc. IBIC’12*, Tsukuba, Japan, Oct. 2012, paper TUPB76, pp. 519–523.

[3] G. L. Orlandi *et al.*, “Design and experimental tests of free electron laser wire scanners”, *Phys. Rev. Accel. Beams*, vol. 19, p. 092802, 2016. `doi:10.1103/physrevaccelbeams.19.092802`

[4] L. H. Yu, “Generation of intense uv radiation by subharmonically seeded single-pass free-electron lasers”, *Phys. Rev. A*, vol. 44, pp. 5178–5193, 1991. `doi:10.1103/physreva.44.5178`

[5] E. Allaria *et al.*, “Highly coherent and stable pulses from the FERMI seeded free-electron laser in the extreme ultraviolet”, *Nat. Phot.*, vol. 6, p. 233, 2012. `10.1038/nphoton.2012.233`

[6] E. Allaria *et al.*, “Tunability experiments at the FERMI@Elettra free-electron laser”, *New J. Phys.*, vol. 14, p. 113009, 2012. `doi:10.1088/1367-2630/14/11/113009`

[7] G. Penco *et al.*, “Optimization of a high brightness photoinjector for a seeded FEL facility ”, *JINST*, vol. 8, p. P05015, 2013. `doi:10.1088/1748-0221/8/05/p05015`

[8] R. Ischebeck, E. Prat, V. Thominet, and C. Ozkan Loch, “Transverse profile imager for ultrabright electron beams”, *Phys. Rev. Accel. Beams*, vol. 18, p. 082802, 2015. `doi:10.1103/physrevstab.18.082802`

[9] Ch. Wiebers *et al.*, “Scintillating Screen Monitors for Transverse Electron Beam Profile Diagnostics at the European XFEL”, in *Proc. IBIC’13*, Oxford, UK, Sep. 2013, paper WEPF03, pp. 807–810.

[10] G. Kube, S. Liu, A. I. Novokshonov, and M. Scholz, “A Simple Model to Describe Smoke Ring Shaped Beam Profile Measurements With Scintillating Screens at the European XFEL”, in *Proc. IBIC’18*, Shanghai, China, Sep. 2018, pp. 366–370. `doi:10.18429/JACoW-IBIC2018-WEOC03`

[11] G. Kube, C. Behrens, C. Gerth, B. Schmidt, W. Lauth, and M. Yan, “Inorganic Scintillators for Particle Beam Profile Diagnostics of Highly Brilliant and Highly Energetic Electron Beams”, in *Proc. IPAC’12*, New Orleans, LA, USA, May 2012, paper WEOAA02, pp. 2119–2121.

[12] A. Abrami, M. De Marco, M. Lonza, and D. Vittor, “YAMS: a Stepper Motor Controller for the FERMI@Elettra Free Electron Laser”, in *Proc. ICALEPCS’11*, Grenoble, France, Oct. 2011, paper WEPMN034, pp. 958–960.

[13] A. Murokh, I. Ben-Zvi, J. B. Rosenzweig, X. J. Wang, and V. Yakimenko, “Limitations on Measuring a Transverse Profile of Ultra-Dense Electron Beams with Scintillators”, in *Proc. PAC’01*, Chicago, IL, USA, Jun. 2001, paper TPAH049, pp. 1333–1335.