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FLUTE DIAGNOSTICS INTEGRATION

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Abstract

FLUTE (Ferninfrarot Linac- Und Test-Experiment) will be a new compact versatile linear accelerator at KIT. Its primary goal is to serve as a platform for a variety of accelerator studies as well as to generate strong ultra-short THz pulses for photon science [1]. The machine consists of an RF gun, a travelling wave linac and a D-shaped bunch compressor chicane with corresponding diagnostic sections. In this contribution we report on the latest developments of the diagnostic components. An overview of the readout and control system integration will be given.

OVERVIEW OF DIAGNOSTICS

At FLUTE, various transverse beam diagnostics and charge diagnostics (see Fig. 1) have been installed for the measurement of the transverse beam position, transverse beam profile and bunch charge. Furthermore, these tools are complemented by longitudinal diagnostics, such as Electro-Optical (EO) setup and THz streaking [2]. In this contribution we present the status, and the expected performance, of the transverse and charge diagnostic devices which are now being used for the commissioning of the FLUTE injector section up to the linac entrance.

SCREEN MONITOR

At the FLUTE injector section, two screen monitors similar to those previously used at the SwissFEL Injector Test Facility [3] have been installed. Figure 2 shows the screen holder mounted with an aluminum-coated silicon mirror to generate optical transition radiation (OTR) and a cerium doped yttrium aluminum garnet (YAG) crystal to generate scintillation light. Both screens have a size of 30 mm × 30 mm × 200 µm (width, height and thickness) and are mounted at an angle of 45° to the beam axis. Furthermore, a calibration target with grid spacing of 500 µm has been installed for determining the magnification of the imaging system.

The imaging system, which consists of an objective with a focal length of 85 mm and a CMOS camera (Basler acA1300-60gm), is mounted at an angle of 90° to the beam axis. The objective is slightly tilted away from its optical axis to have the whole screen in focus according to the Scheimpflug principle. Figure 3 shows a zoomed in area of the camera image taken with the installed calibration target. The measured spatial resolution of the screen monitor amounts to 28.3 µm/pixel in both the horizontal and vertical planes.

The control system of FLUTE is developed based on EPICS base version 3.15 [4] in an Ubuntu environment, which is supported by the Basler camera's own software package Pylon 5. This eases the IOC development for the cameras. The camera communication is kept in a separated VLAN, as it is recommended to the GigE Vision (a layer 2 protocol) interface of the Basler cameras.

For the IOC we made a fork for a linux version from the Windows-based camera IOC of the PSI diagnostics group. With the cameras in triggered mode at the maximum repetition rate of FLUTE, i.e. 10 Hz, the data stream requires ~ 150 MBit/camera in full resolution (1280 × 1024 pixels with 12 bit). In order to have a stable camera communication, we use a separated POE CISCO switch type WS-C3850 with a 10 GBit uplink to the camera server, where the IOC and MATLAB have been installed to process the beam images in real-time, avoiding network traffic outside the camera server. For the uplink of the control system server to the control room, a GigE connection is sufficient to transport a single camera stream, e.g. the X-Window of the MATLAB tool to display the preprocessed beam image and parameters (see Fig. 4).

BEAM POSITION MONITOR

FLUTE demands high beam position accuracy in the order of micrometres. This is hard to achieve for the single shot measurements where the pulse lengths are in the order of fs and no averaging is possible. These challenges can be overcome by the use of cavities built with the exact ge-

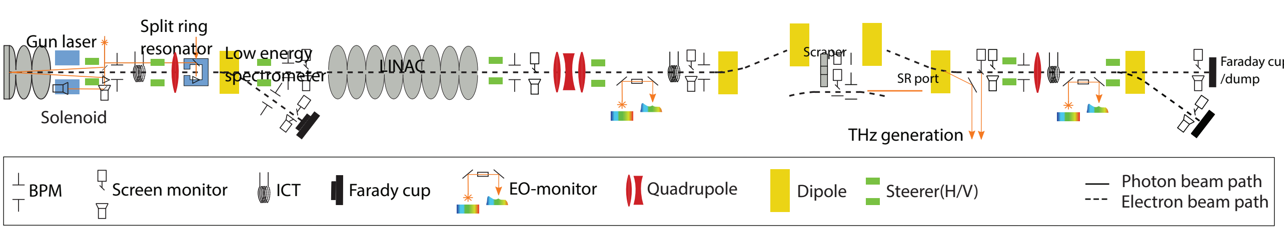

Figure 1: Scheme of the FLUTE accelerator with all installed and planned components.

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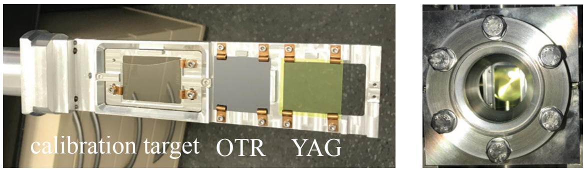

Figure 2: (Left) Screen holder mounted with the three screens. (Right) View through the vacuum window onto the mounted YAG screen.

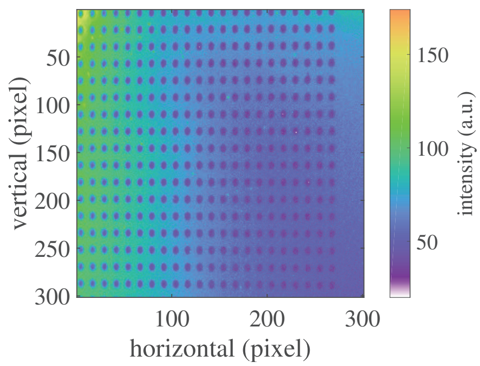

Figure 3: Camera image of the calibration target.

ometries such that the passing pulse can excite resonating modes.

For the FLUTE injector section, three cavity Beam Position Monitors (BPMs) are installed. The cavities and the Modular BPM Unit (MBU), a unit that houses the RF front end (RFFE) readout electronics, were designed and supplied by PSI [5]. Detailed description of the BPM is given in [5]. The so-called BPM38 (Fig. 5) has two cavities, one at each end. The up-stream one has four pick-ups for readout while the down-stream one has only two. The up-stream cavity provides the horizontal (x) and vertical (y) coordinates using a TM110 (dipole) mode, and the product of bunch charge with the TM010 (monopole) mode. For increased sensitivity the two x, and two y ports can be summed. The down-stream cavity is used as the reference resonator with a TM010 (monopole) mode giving the total bunch charge. Again, the two ports can be summed for increased sensitivity.

The RFFE filters the pickup signals, adjusts the signal level via amplifiers and variable attenuators, and performs IQ down-conversion to baseband using a locally generated LO frequency locked to an external machine reference clock. After mixing, the signals go through another lowpass/bandpass filter. The resulting RFFE output signals are connected via differential signalling to a digitizer board with 16-bit 160 MSample/s ADCs and FPGAs for digital signal processing and interfacing to control, timing and feedback systems.

The standalone MBU unit provides SFP(+) interfaces, supporting Ethernet, PCIe, or custom protocols for control, timing and feedback system interfaces. With the help and collaboration of both PSI and DESY, the system was extended with a controller based on the Micro Telecommunications Computing Architecture (MicroTCA) standard, which pro-

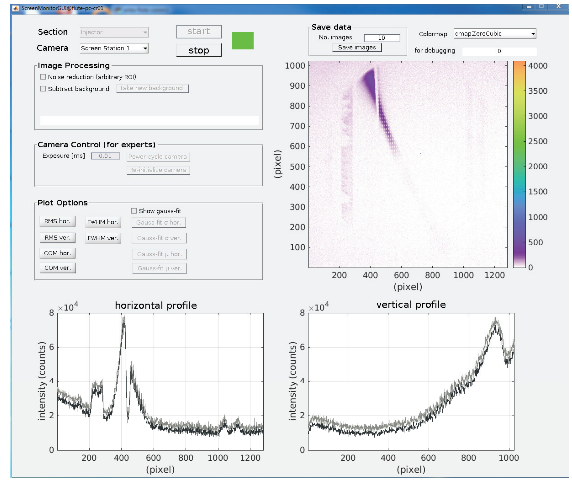

Figure 4: Screenshot of the MATLAB-based screen monitor GUI which displays the processed image (upper right), the horizontal (lower left) and the vertical profile (lower right).

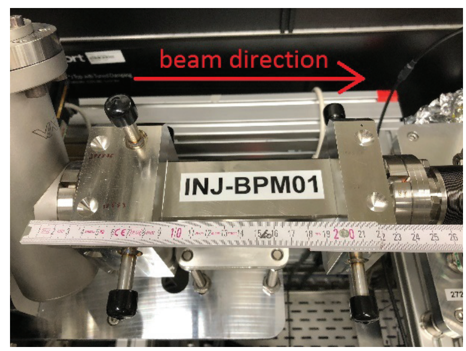

Figure 5: BPM cavity installed at FLUTE injector section.

vides the interface between the MBU and the FLUTE control system. The MicroTCA controller consists of a processor unit, MCH, and DAMC2 (provided by DESY) [6]. The DAMC2 handles the optical data connection to the MBU and gives the control system access to the data via ChimeraTK interface [7] and DAMC2 kernel drivers, also provided by DESY.

INTEGRATING CHARGE TRANSFORMER

We use the Turbo Integrating Charge Transformer (Turbo-ICT) from Bergoz Instrumentation for sensitive charge measurements. A normal ICT integrates the beam charge and delivers a long output pulse. Thus when a strong noise pulse like a laser electromagnetic pulse (EMP) coincides in time with the beam charge, the EMP is integrated as well. Since FLUTE will be operated with a bunch charge down to 1 pC, charge diagnostics providing sub-pC resolution is required. The Turbo-ICT was developed by Bergoz Instrumentation to avoid the EMP noise by operating at a fixed frequency. The bunch pulse modulates the amplitude of the fixed-frequency carrier. Then, the carrier is demodulated by an RF receiver to extract the signal modulation. Turbo-ICT therefore oper-

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ates in frequency domain and ignores signals which have a different frequency.

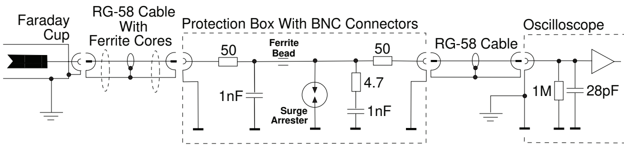

Figure 6: Schematic of the protection box.

At the FLUTE injector section, one Turbo-ICT with resolution of 10 fC rms is installed. The ICT signal is read out by a LabVIEW program delivered by Bergoz Instrumentation. As the next step, an IOC will be developed for the readout, allowing a full control system integration.

FARADAY CUP

One Faraday cup of the model FARC-04 from RadiaBeam Technologies is installed at the end of the FLUTE injector section, working as a charge diagnostics and local low-energy (7 MeV) electron beam dump. The impedance of the Faraday cup is matched to 50 Ω. Although both, the expected dark current and the individual bunch charge, are small (max. 30 nA and 3 nC, respectively), some protection is required when connecting sensitive measuring equipment to the Faraday cup. This is due to the very short bunch length that transfers the bunch charge to the Faraday cup and into the connected coaxial signal cable. Feeding a charge of 3 nC within 1 ps into the 50 Ω characteristic impedance of a transmission line would result in a 1 ps pulse with a current of 3 kA and a voltage of 150 kV.

Of course this is a rough estimation since the Faraday cup, due to its mechanical dimensions, is no longer a coaxial cable with the rated characteristic impedance of 50 Ω. There are some mechanisms to smoothen the sharp pulse, which however are difficult to be assessed quantitatively: i) most of the energy will be irradiated back into the beam tube as the used Faraday cup starts to be confined to the TEM propagation mode only below ~ 6 GHz whereas most of the incident energy is in the 0.5 THz ($\lambda = 0.2$ mm) spectral range, ii) there is some attenuation and dispersion in the RG-58 coaxial signal cable.

For initial rough charge and dark current measurements with this Faraday cup, a simple charge integration and protection box was designed and built in-house. The following basic requirements have to be fulfilled: i) measurement of bunch charges from 50 fC to 3 nC at a repetition rate of max. 10 Hz, ii) provide spatial separation of several metres between the Faraday cup and the measuring equipment to reduce X-ray exposure. Figure 6 shows the schematic of the box and its connections to the Faraday cup as well as to an oscilloscope.

After the arrival of an electron bunch at the Faraday cup, the oscilloscope shows a negative voltage step given by the bunch charge divided by the total capacitance to ground. This capacitance is formed by the cables, the capacitors in the protection box and the input capacitance of the oscilloscope.

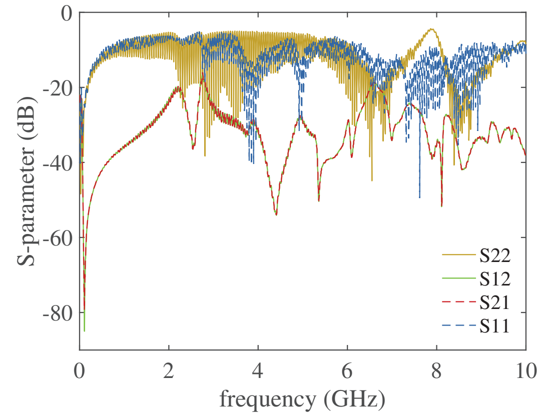

Figure 7: Scattering parameters of the protection box.

Here, this sum amounts to 2.3 nF which results in a charge-to-voltage conversion factor of 0.43 V/nC. Static dark currents are taken up by the oscilloscope input resistance of typically 1 MΩ and will result in a corresponding voltage drop of 1 V/μA.

The purpose of the protection box is to provide additional wide-band attenuation while passing through bunch charge and dark current information. For frequencies > 1.5 MHz, the 1 nF capacitors to ground will form a short circuit and the 50 Ω resistors will absorb most of the incoming RF power. The ferrite bead and the 4.7 Ω resistor provide attenuation of parasitic resonances. The ferrite cores on the input cable will attenuate sheath waves generated by high frequency components leaking through the coaxial cable shielding braid. Figure 7 shows the scattering parameters of the box with the planned cables, measured between 100 MHz and 10 GHz. Both reflected and transmitted energy are attenuated effectively in both directions, which means that sharp voltage pulses are effectively kept away from the oscilloscope input.

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