X-BAND TDS PROJECT

B. Marchetti*, R. Assmann, B. Beutner, J. Branlard, F. Christie, R. D‘ Arcy, W. Decking, U. Dorda, J. Herrmann, M. Hoffmann, M. Huening, O. Krebs, G. Kube, S. Lederer, F. Ludwig, F. Marutzky, D. Marx, J. Osterhoff, I. Peperkorn, S. Pfeiffer, F. Poblotzki, J. Roensch-Schulenburg, J. Rothenburg, H. Schlarb, M. Scholz, S. Schreiber, M. Vogt, A. de Z. Wagner, T. Wilksen, K. Wittenburg
DESY, 22607 Hamburg, Germany
A. Grudiev, N. Catalan Lasheras, G. Mcmonagle, W. Wuensch
CERN, 1211 Geneva 23, Switzerland
P. Craievich , M. Bopp, H.-H. Braun, M. Pedrozzi, E. Prat, S. Reiche, K. Rolli, R. Zennaro
PSI, 5232 Villigen PSI, Switzerland

Abstract

Based on the success of the X-band Transverse Deflecting Structure (TDS) diagnostic at LCLS [1], a collaboration between DESY, PSI and CERN has formed with the aim of developing and building an advanced modular X-band TDS system. The designed TDS has the new feature of providing variable polarization of the deflecting field [2]. The possibility of changing the orientation of the streaking field of the TDS to an arbitrary azimuthal angle allows for 3D characterization of the phase space using tomographic methods [3]. Moreover the complete 6D characterization of the beam phase space is possible by combining this technique with quadrupole scans and a dipole spectrometer. As this new cavity design requires very high manufacturing precision to guarantee highest azimuthal symmetry of the structure to avoid the deterioration of the polarization of the streaking field, the high precision tuning-free assembly procedures developed at PSI for the SwissFEL C-band accelerating structures will be used for the manufacturing process [4]. The high-power rf system is based on the hardware developed for the CERN X-band test stands. We summarize in this work the status of the project and its main technical parameters.

INTRODUCTION

Transverse Deflecting Structures (TDS) are well known diagnostics devices for the characterization of the longitudinal properties of electron bunches in a linear accelerator. The resolution of such devices depends, among other parameters, on the RF frequency [5].

In 2014 the first X-band TDS system has been commissioned at LCLS [6]. This system proved to be capable of reaching sub-fs resolution in longitudinal phase space measurements and constitutes the state of the art of such technology [1].

By using a conventional TDS system it is possible to characterize the slice properties of an electron beam in the transverse direction perpendicular to the time-dependent streaking. Therefore typically only either the horizontal or the vertical slice envelopes can be measured.

* barbara.marchetti@desy.de

Recently, an innovative design for a TDS structure has been proposed at CERN [2], which would give full control of the angle of the transverse streaking field inside a TDS structure, in order to characterize the projections of the beam distribution on different transverse axes, as illustrated in Fig. 1.

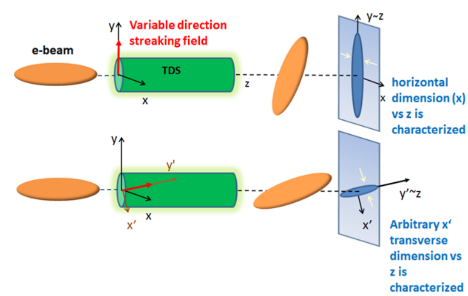

Figure 1: Use of Variable Polarization TDS for beam diagnostics.

The possibility of changing the orientation of the streaking field of the TDS to an arbitrary azimuthal angle allows for exciting new opportunities for the characterization of the electron bunch. By collecting measurements of the bunches streaked at different angles and combining those using tomographic techniques, it is possible to retrieve 3D distributions of the bunch properties, such as the charge. Moreover the complete 6D characterization of the beam phase space is possible by combining this technique with quadrupole scans and a dipole spectrometer.

This new RF-cavity design requires very high manufacturing precision to guarantee highest azimuthal symmetry of the structure to avoid the deterioration of the polarization of the streaking field. At PSI a high precision tuning-free assembly procedure has been developed for the SwissFEL C-band accelerating structures [4]. This procedure has been used to fabricate 104 cavities for the SwissFEL linac and it is currently being used for the realization of the tuning free X-band structure prototypes for CLIC.

In this paper we present a common RF design of a variable polarization X-band TDS which allows for fs or sub-fs beam characterization in four experiments taking place at

DESY and PSI. We comment on the feasibility of the production of a prototype of such a device based on tolerances evaluations. Finally we introduce novel applications of the variable polarization TDS for e-beam diagnostics.

E-BEAM PARAMETERS

Several experiments at DESY (FLASH2, FLASHForward, SINBAD) and PSI (ATHOS at SwissFEL) are interested in the utilization of high gradient X-band TDS systems for high resolution longitudinal diagnostics. In this section we will briefly introduce the different experiments and highlight their needs.

FLASHForward

The FLASHForward project [7] is an innovative plasma-wakefield acceleration experiment, aiming to accelerate electron beams to GeV energies over a few centimeters of ionized gas. These accelerated beams must be of sufficient quality to demonstrate free-electron laser gain; achievable only through rigorous analysis of both the drive- and accelerated-beam's longitudinal phase space. The pulse duration of these accelerated beams is typically in the few femtosecond range, and thus difficult to resolve with traditional diagnostic methods. In order to longitudinally resolve these extremely short bunch lengths it is necessary to utilize the properties of such an X-band transverse RF deflector with high frequency and power, mapping longitudinal onto transverse coordinates.

FLASH2

At FLASH1 [8], the direct measurement of the longitudinal phase space with a deflecting RF structure has been proven to be of uttermost importance to establish femtosecond scale photon pulses [9, 10]. The installation of such a transverse deflecting cavity is planned also at FLASH2 [11]. Its combination with an existing dipole as a spectrometer will allow exploitation of the full longitudinal phase space and to optimize longitudinal bunch parameters for SASE and seeding processes. In contrast to FLASH1, the TDS at FLASH2 will be placed downstream of the undulators (see Fig.2). In such a configuration, the lasing part of the electron bunch can directly be measured and thus provides an estimate of the photon pulse duration as well. The experiment aims for a temporal resolution of less than 10 fs.

Figure 2: Exit of the SASE undulator section at FLASH2. Two TDS cavities are foreseen to be installed in the free space downstream the undulator.

SINBAD

The SINBAD (Short INnovative Bunches and Accelerators at DESY) facility [12] will be dedicated to accelerator research and development, building upon DESY's recent investment in this area in the framework of the Helmholtz ARD programme. It will be used for experiments in Plasma Wakefield Acceleration, dielectric accelerating structures and other novel accelerators. A 100-MeV electron linac, ARES, which will be constructed in phases from 2017 to 2019, will be able to provide very short (sub-fs) electron bunches with low charge (sub-pC), as required for plasma and dielectric experiments. The planned X-band TDS with variable polarization will make the characterization of ARES bunches at the end of the linac possible, which is essential for these experiments.

ATHOS at SwissFEL

The SwissFEL project [13], under commissioning at the Paul Scherrer Institut (PSI), will produce FEL radiation for soft X-rays, at the Athos beamline and hard X-rays, at the Aramis beamline, with pulse durations ranging from a few to several tens of femtoseconds. The goal of Athos is to provide a source of extremely brightness and short X-ray pulses. In order to increase performances in terms of photon beam brightness and bandwidth several innovative lasing schemes and technical developments for some key components are underway. As a diagnostic tool, two TDSs will be installed downstream of the undulators of the Athos beamline, which will allow to indirect measurement of the X-Ray pulse length by analyzing the induced energy spread on the electron bunch due to the FEL process. Furthermore, thanks to the variable polarization of the TDS it will be possible to perform a complete characterization of the 6D phase space by means of measurements of bunch length, energy and transverse slice emittances (vertical and horizontal).

Table 1 summarizes the e-bunch characteristics, the spatial constraints and the specifications for the TDS design for all the experiments listed above. It can be noticed that a common mechanical design for the structure is possible by tuning the temperature of the cavity in order to adjust its resonance frequency.

Table 1: TDS Specifications

	SINBAD	**FLASH2**	**FLASHForward**	**ATHOS SwissFEL**
Charge [pC]	0.5-30	20-1000	20-500 (driver) 10-250 (witness)	10-200
Norm. RMS Emitt. [μm]	0.1-1	0.4-3	2.0-5.0 (driver) 0.1-1.0 (witness)	0.1-0.3
RMS Bunch Length [fs]	0.2-10	<3-200	50-500 (driver) 1-10 (witness)	2-30
β *Function at TDS* [m]	10-50	7-20	50-200	50
Beam Energy [MeV]	80-200	400-1400	500-2500	2900-3400
Rep. Rate [Hz]	10-50	10	10	100
TDS Voltage [MV]	25-40	30-45	25-30	30-60
N.TDS	2	2	1	2
Max.Length [m]	3	<1.92	<2	4
TDS Iris [mm]	4	4	4	4
TDS Frequency [MHz]	11991.6	11988.8	11988.8	11995.2
Temperature Range[°C]	48	62	62	25-35

ISBN 978-3-95450-182-3

RF DESIGN OF THE CAVITY AND TECHNICAL REALIZATION

The variable polarization X-band TDS design was firstly proposed at CERN in 2016 [2]. A sketch of such scheme is shown in Fig. 3.

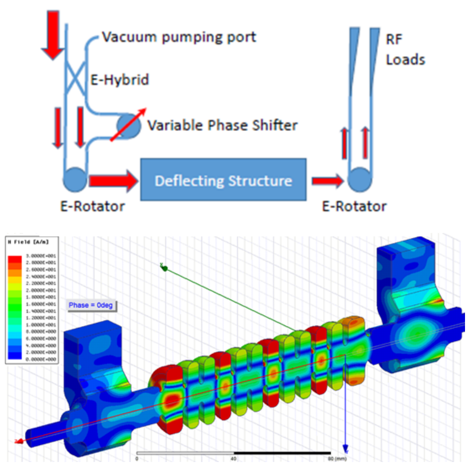

Figure 3: Layout of the TDS system (top) and H-field in Backward Traveling Wave TDS constituted by 10 cells (bottom).

The working principle of the system is as follows. An E-Hybrid splits the incoming power into two branches. The same amount of power flows into each branch. The phase of one branch with respect to the other can be varied by using a phase shifter placed on one of the two branches. An E-Rotator provides a linearly polarized mode out of the two circularly polarized input waves. The orientation of the linearly polarized mode can be varied by changing the phase between the two input branches.

Table 2: RF design of TDS prototype. The following symbols are used. PC: pulse compressor, a: iris radius, R_x: transverse shunt impedance per meter length, $\Delta\phi_0$: RF phase advance per cell, Q: quality factor, v_g: group velocity, c: light velocity, V_d: deflection voltage, P_k: peak power of the klystron.

Cell Parameters	
$a[mm]$	4
$\Delta\phi_0[degree]$	120
Q	6490
$v_g/c[\%]$	-2.666
$R_x[M\Omega/m]$	50
TDS Parameters	
Number of regular cells	96
Active length [m]	0.8
Filling time [ns]	104.5
Transverse Shunt Impedance $[M\Omega]$	27.3
V_d *TDS at* $P_k = 6MW$ [MV]	12.8
V_d *TDS + PC at* $P_k = 6MW$ [MV]	29.5

A RF design of such a TDS system matching the constraints summarized in Table 1 has been presented in [14]. The main parameters corresponding to this design are also summarized in Table 2 and the 3D plot of the field inside a structure constituted by 10 cells is shown in Fig. 3.

As this new cavity design requires precise azimuthal symmetry of the structure to avoid the deterioration of the polarization of the streaking field, the high precision tuning-free assembly procedures developed at PSI for the SwissFEL C-band accelerating structures will be used for the manufacturing [4].

A preliminary study on the effects of geometric errors on both polarizations suggests that a precision of about 2 μm on the finishing of the basic cell shape may ensure an acceptable quality of the streaking field. The mechanical design is currently underway at PSI and further tolerance studies will be performed as iterative process to meet RF and mechanical requirements.

E-BUNCH CHARACTERIZATION

The described TDS design opens new opportunities for extended beam characterization which makes particular use of the variable streaking direction, more specifically:

- Slice emittance measurement [15,16] on different transverse planes by using the same TDS device;
- Full (6D) beam characterization by combining slice emittance measurements on 2 or more transverse directions with a longitudinal phase space measurement using a dipole spectrometer [15, 16];
- 3D charge distribution reconstruction in the real space.

It should be noted that the latter technique, described in [3], could not be realized by using conventional TDS structures and makes special use of the possibility of continuously tuning the streaking direction of the structure.

CONCLUSIONS

Recent progress in the fields of high gradient X-band cavity design (made at CERN) and manufacture (made at PSI) allows us to aim for a new generation of TDS systems with more extended capabilities for a full beam characterization. We have summarized the specifications of the TDS systems needed for various experiments at DESY and PSI and shown the compatibility of the request with a common TDS cavity design and a similar RF station design based on CERN X-band technology. Finally we have discussed how the use of such novel TDS system would allow for extended beam diagnostics capabilities such as a novel measurement technique for 3D e-bunch charge reconstruction.

REFERENCES

[1] C. Behrens et al., “Few-femtosecond time-resolved measurements of X-ray free-electron lasers”, Nat. Comm., vol. 4762, January 2014.

[2] A. Grudiev, “Design of compact high power rf components at X-band”, CERN, Geneva, Switzerland, Rep. CLIC Note 1067, May 2016.

[3] D. Marx et al., “Reconstruction of the 3D charge distribution of an electron bunch using a variable-polarization transverse deflecting structure (TDS)”, presented at IPAC’17, Copenhagen, Denmark, May 2017, paper MOPAB045, this conference.

[4] U. Ellenberger et al., “Status of the manufacturing process for the SwissFEL C-band accelerationg structures”, in proc. FEL’13, paper TUPSO17, pp. 246–249.

[5] P. Emma et al., “A transverse RF deflecting structure for bunch length and phase space diagnostics”, SLAC, California, USA, Rep. LCLS-TN-00-12, Aug. 2000.

[6] V. A. Dolgashev, J. Wang, “RF design of X-band RF deflector for femtosecond diagnostics of LCLS electron beam” AIP Conf. Proc. Vol. 1507, p. 682, AIP, Texas, USA, 2012.

[7] A. Aschikhin et al., “The FLASHForward facility at DESY”, Nucl. Inst. and Meth. in Phys. Res. A, vol. 806, p. 175, 2016.

[8] `https://flash.desy.de/`

[9] C. Behrens et al., “Constraints on photon pulse duration from longitudinal electron beam diagnostics at a soft x-ray free-electron laser”, Phys. Rev. Acc. and Beams, vol. 15, p. 030707, 2012.

[10] M. Yan, “Online diagnostics of time-resolved electron beam properties with femtosecond resolution for X-ray FELs”, PhD Thesis, Hamburg, 2015.

[11] F. Christie et al. “Generation of ultra-short electron bunches and FEL pulses and characterization of their longitudinal properties at FLASH2”, presented at IPAC’17, Copenhagen, Denmark, May 2017, paper WEPAB017, this conference.

[12] U. Dorda et al., “SINBAD —The accelerator R&D facility under construction at DESY”, Nucl. Inst. and Meth. in Phys. Res. A, vol. 29, p.233-236, 2016.

[13] `https://www.psi.ch/swissfel/`

[14] A. Grudiev, “RF Design of X-band TDS with variable polarization”, presented at CLIC Workshop 2017, CERN, Geneva, Switzerland, March 2017.

[15] M. Roehrs et al., “Time-resolved electron beam phase space tomography at a soft x-ray free-electron laser”, Phys. Rev. Acc. and Beams, vol. 12, p. 050704, 2009.

[16] P. Craievich et al., “Implementation of radio-frequency deflecting devices for comprehensive high-energy electron beam diagnosis”, IEEE Transact.on Nucl. Science, vol.62, no. 1, 2015.

ISBN 978-3-95450-182-3