

THE PolariX-TDS PROJECT: BEAD-PULL MEASUREMENTS AND HIGH-POWER TEST ON THE PROTOTYPE

P. Craievich*, M. Bopp, H.-H. Braun, A. Citterio, R. Ganter, F. Marcellini, T. Kleeb, M. Pedrozzi, E. Prat, S. Reiche, PSI, 5232 Villigen, Switzerland
A. Grudiev, W. Lee Millar¹, N. Catalan-Lasheras, G. McMonagle, S. Pitman, V. del Pozo Romano, K. T. Szypula, W. Wuensch, CERN, 1211 Geneva 23, Switzerland
B. Marchetti, R. W. Assmann, F. Christie, R. D'Arcy, U. Dorda, M. Foese, P. Gonzalez Caminal, M. Hoffmann, M. Huening, R. Jonas, O. Krebs, S. Lederer, V. Libov, D. Marx, J. Osterhoff, M. Reukauff, H. Schlarb, S. Schreiber, G. Tews, M. Vogt, A. de Z. Wagner, DESY, 22607 Hamburg, Germany
¹also at Cockcroft Institute, Warrington, Cheshire

Abstract

A collaboration between DESY, PSI and CERN has been established to develop and build an advanced modular X-band transverse deflection structure (TDS) system with the new feature of providing variable polarization of the deflecting force. The prototype of the novel X-band TDS, the Polarizable X-band (PolariX) TDS, was fabricated at PSI following the high-precision tuning-free production process developed for the C-band Linac of the SwissFEL project. Bead-pull RF measurements were also performed at PSI to verify, in particular, that the polarization of the dipole fields does not have any rotation along the structure. The high-power test was performed at CERN and now the TDS is at DESY and has been installed in FLASHForward, where the first streaking experience with beam will be accomplished. We summarize in this paper the status of the project, the results of the bead-pull measurements and the high power test.

INTRODUCTION

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 [1]. In this context, a collaboration between DESY, PSI and CERN has been established to develop and build an advanced modular X-Band TDS system with the new feature of providing variable polarization of the deflecting force [2]. The prototype of the novel X-band TDS, the Polarizable X-band (PolariX) TDS, has been fabricated at PSI following the high-precision tuning-free production process developed for the C-band Linac of the SwissFEL project and already used for the fabrication of the tuning-free X-band structure prototypes for CLIC [3–5]. Bead-pull RF measurements has been performed at PSI between December 2018 and January 2019 in order to verify that the polarization of the dipole fields does not have any rotation along the structure. Figure 1 shows the detail of the input and output couplers (left), the whole TDS prototype (middle) and the basic disk geometry (right). The main RF parameters of the TDS and RF pulse

compressor are summarized in Table 1. High power test on the prototype has been performed at CERN between March and April 2019. In this paper we summarize the status of the collaboration focusing on the results of the bead-pull measurements and the high power tests.

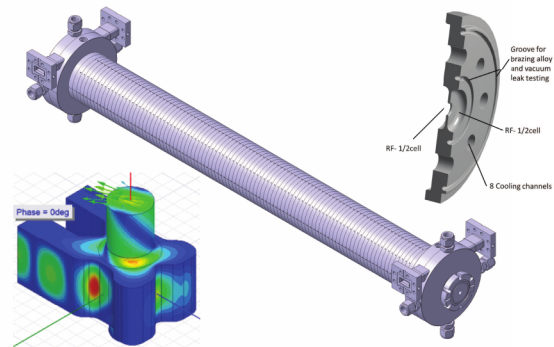


Figure 1: Left: detail of the input/output coupler. Middle: whole TDS prototype. Right: basic disk.

BEAD-PULL MEASUREMENTS

The dipole field flatness and polarization were measured with the bead-pull method. The structure was allocated in a vertical frame and a stepper motor was used to drive along the structure a 2 mm diameter dielectric sphere fixed to a dielectric wire with diameter of 0.16 mm. The bead pulling has been repeated for different offsets, both in the XZ and YZ planes, in ± 2 mm range. The measurements were performed with a 4-port VNA and the reflection coefficient resulted to be less than -35 dB with an insertion loss of -5.5 dB. Figure 2 (upper plot) shows results of the bead-pull measurement with offset 0 mm both in X and Y and phase difference between ports of 0 deg. Cell-to-cell phase advance (lower plot) resulted to be $2\pi/3$ with a dispersion of 0.8° rms at the working frequency of 11995.2 MHz with a temperature of 33.9°C . It is worthwhile noting that same results for the phase advance was obtained varying the relative phase between ports, namely for different polarizations. A spherical and dielectric bead perturbs only the electric field, but cannot distinguish between longitudinal and transverse components. However, since the longitudinal component has the largest

* paolo.craievich@psi.ch

Table 1: RF parameters for short and long X-band TDS. Both structures are constant impedance and backward traveling wave structures. More details on the XBOC designed and fabricated at PSI are in [6]. t_k is the klystron pulse width and the frequency corresponds to an operational temperature of 30° for the ATHOS beamline [7,8].

Cell parameter		Unit
Frequency	11995.2	MHz
Phase advance/cell	120	°
Iris radius	4	mm
Iris thickness	2.6	mm
Group velocity	-2.666	%c
Quality factor	6490	
Shunt impedance	50	MΩ/m

TDS parameter	Short	Long	Unit
n. cells	96	120	
Filling time	104.5	129.5	ns
Active length	800	1000	mm
Total length	960	1160	mm
Power-to-voltage	5.225	6.124	MV/MW ^{0.5}

TDS + BOC	Short	Long	Unit
BOC Q ₀	145000	145000	
BOC $\beta@t_k=1.5\mu s$	7	7	
Power-to-voltage	12.010	13.626	MV/MW ^{0.5}

amplitude in the middle of each cell while the transverse component in the iris region, it is possible to have a separate measurement of both the field components. In the upper plot of Fig. 2 it is shown a measurement performed with the wire centred on the axis structure. With this set up only the transverse component of the electric field E is measured.

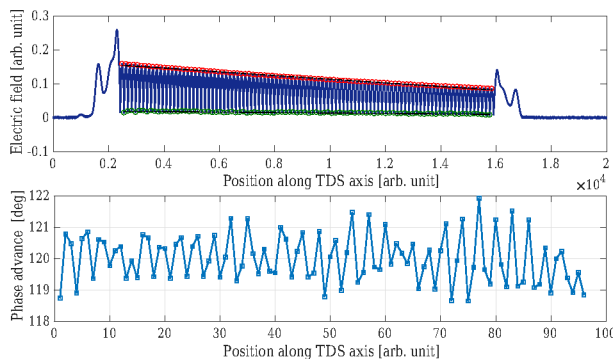


Figure 2: Bead-pull result for an on axis measurement. The green dots identify the points in each cell where the field is minimum and the red dots where it is maximum.

In order to verify if the different polarizations are also well tuned, bead-pull measurements were performed for different offset values and relative phases between ports (polarizations). Figure 3 shows an example of measurement with an offset in one transverse plane of 1 mm with different orientations of the polarization between 0° and 180°. Changing the polarization, the transverse component of E rotates but

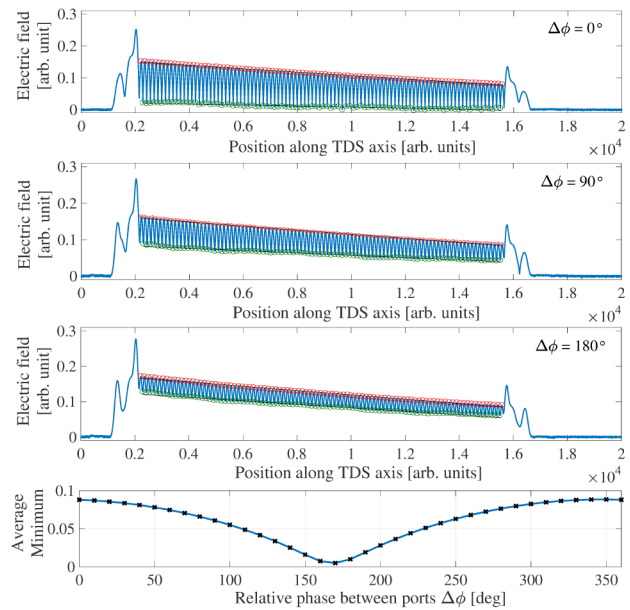


Figure 3: Bead-pull results: first 3 plots on the top: electric field along the TDS axis with offset in one transverse plane of 1 mm for different polarizations. Bottom plot: average minimum (green dots) vs. phase difference between input ports.

its amplitude remains constant. On the contrary, the longitudinal component varies from zero to its maximum when the polarization changes from one plane to its orthogonal one. This behaviour is clearly visible scrolling Fig. 3 from the top. With 0° phase difference between the input coupler ports only the transverse field is measured. Increasing the phase difference, i.e. changing the polarization, also the longitudinal component of E appears and its amplitude reaches the maximum for 180° phase difference (plane of polarization rotated of 90°). Since for a given phase difference the longitudinal component of the electric field (E_z) along the TDS has a linear behaviour (as shown by the green dots in Fig. 3), it is possible to conclude that the polarization of the dipole fields does not have any rotation along the structure. The bottom plot in Fig. 3 shows the mean value of the green dots values as a function of the input port phase difference. More details on the technique and results of the bead-pull measurements will be reported in a future publication.

HIGH POWER TEST

Following low power measurement, the structure was installed in CERN's XBOX2 facility for high power testing [9]. XBOX2 is equipped with a 50MW CPI klystron with a repetition rate of 50Hz and at the time of testing a pulse compression scheme comprised of a prototype BOC (Barrel Open Cavity) [6] and CCC (Correction Cavity Chain) [10]. The high-power variable phase shifter for varying the polarization had been previously conditioned in XBOX3 [11]. As the XBOX2 test stand is a facility without beam capability the polarization during testing was instead inferred via the delta phase measured between two directional couplers connected to the structure output coupler as shown by the

experimental set-up in Fig. 4. Similar to previously tested components an automated conditioning algorithm was used to gradually increase the input power while maintaining a fixed BDR (Breakdown Rate) of 3×10^{-5} bpp (breakdowns per pulse) [12]. Typically, during structure conditioning the pulse length is increased in steps, however due to the short window available for testing it was fixed at 100 ns pulse as this corresponds approximately to the fill time of the structure. With conventional accelerating structures operating in the like-TM₀₁₀ mode the internal field pattern is azimuthally symmetric and so the surface conditions evenly, however in the case of the PolariX-TDS the position of the peak surface fields within the cavity varies with polarization. To ensure the structure is capable of high-power operation in different polarizations the variable phase shifter was moved several times during the conditioning. Figure 5 shows the full conditioning history alongside the polarization for each period. The phase shifter was moved remotely twice during testing

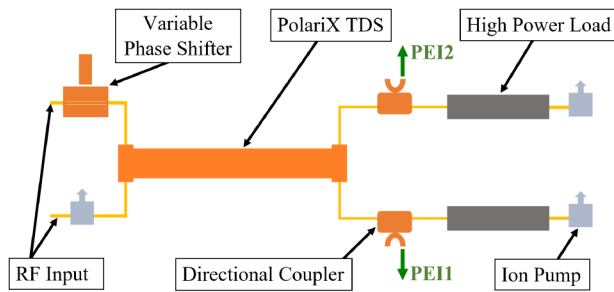


Figure 4: Diagrammatic representation of the experiment setup and signals PEI1 and PEI2 which were used to measure polarization.

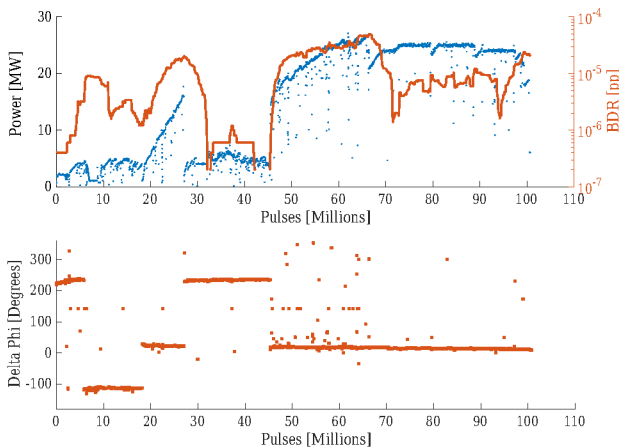


Figure 5: Conditioning history and BDR (top) with phase difference between signals PEI1 and PEI2 (bottom).

after approximately 10 and 30 million pulses. After each of these movements a change in phase was observed however the conditioning immediately follow-ing was then limited by high vacuum levels in the region surrounding the phase shifter. Attempts to remotely move the phase shifter back were unsuccessful due to what is believed to be a problem with the magnetic coupling of the mechanical drive system. Interventions to remove and manually reset the phase

shifter were performed at 20 and 45 million pulses. Due to these problems it was decided not to vary the polarization again for the remainder of the testing period. The FLASH-Forward [13] beamline at DESY operates 6MW Toshiba E37113A klystrons with plans to eventually install a pulse compression scheme to increase the peak power by a factor of 4 [14]. The peak input power reached during testing was 26.5 MW at a polarization of ≈ 10 degrees however as this exceeds the requirements of the FLASH facility it was then decided to cease ramping and run at a fixed input power and decreased BDR for the remainder of the test to avoid the possibility of damaging the structure. No limit emerged during the test and results indicate that the structure is capable of high-power operation sufficient for installation in the FLASH beamline.

INSTALLATION IN FLASHFORWARD

In July 2019 the prototype-structure has been installed in the FLASHForward [13] beamline at FLASH [15], where the first measurements with electron beam are foreseen to take place. The cavity has been connected to its RF station constituted by a 6 MW Toshiba E37113A klystron and an Ampegon Type- M-class modulator. The klystron has been installed inside the tunnel, whereas the modulator rack is located in an external adjacent corridor. The RF network will be installed in two stages, as already described in [14]. For the PolariX TDS prototype commissioning the maximum deflecting voltage in the TDS will be about 14 MV. It is worthwhile noting that the working frequency is 11988.8 MHz that corresponds to a temperature of 65.9°. In the second stage of the installation an RF pulse compressor will be installed allowing for an increase in peak power by a factor of 4 [14]. The possibility of changing the streaking direction of the beam opens new opportunities for a more complete characterization of the electron bunches to be tested during the commissioning of the structure. Besides the applications in fs-level longitudinal diagnostics of the beam [16, 17], it is planned to perform first experimental measurement of 3D charge density reconstruction of the electron bunch [18]. Simulations performed in preparation to this test [19] have shown the feasibility of the reconstruction of the typical FLASH-beam distribution with the expected longitudinal resolution for the prototype commissioning.

CONCLUSION

In this paper we have summarized the recent results from the bead-pull measurement and high power test performed on the first prototype of the PolariX-TDS system. The results have fully demonstrated the feasibility and the quality of the design and fabrication. In particular, the results in terms of machining, assembly and brazing are excellent. During the first high-power test the prototype performed very well although there were some issues with the phase shifter. Now, the prototype is installed at DESY where the first measurements with electron beam are foreseen to take place in this autumn.

REFERENCES

- [1] B. Marchetti *et al.*, “X-Band TDS project”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, paper MOPAB044, pp. 184-187.
- [2] A. Grudiev, “Design of compact high power RF components at X-band”, CERN, Geneva, Switzerland, Rep. CLIC Note 1067, May 2016; also presented at the *CLIC workshop 2017*, March 2017, Geneva, Switzerland
https://indico.cern.ch/event/577810/contributions/2484990/attachments/1423352/2182280/CLIC17_DesignofXbandTDS.pdf
- [3] P. Craievich *et al.*, “Consolidation and extension of the high-gradient Linac RF technology at PSI”, in *Proc. LINAC’18*, Beijing, China, Sep. 2018, paper THPO115, pp. 937-940.
- [4] U. Ellenberger *et al.*, “Status of the manufacturing process for the SwissFEL C-band accelerating structures”, in *Proc. FEL’13*, New York, USA, paper TUPSO17, pp. 246-249.
- [5] R. Zennaro *et al.*, “High power tests of a prototype X-band accelerating structure for CLIC”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, paper THPIK097, pp. 4318-4320.
- [6] R. Zennaro, “Overview of RF activities at PSI”, presented at the International Workshop on Breakdown Science and High Gradient Technology, Chamonix, France, June 2019,
https://indico.cern.ch/event/766929/contributions/3439426/attachments/1857126/3050744/RZ_HG2019.pdf
- [7] R. Abela *et al.*, “Athos Conceptual Design Report”, Report No. PSI Bericht Nr. 17-02 ISSN 1019-0643, 2017.
- [8] R. Ganter *et al.*, “Status of Athos, the Soft X-Ray FEL line of SwissFEL”, presented at FEL’19, Hamburg, Germany, Aug. 2019, paper THP085, this conference.
- [9] B. J. Woolley, “High Power X-band RF Test Stand Development and High Power Testing of the CLIC Crab Cavity”, Lancaster University, United Kingdom, 2015, <https://eprints.lancs.ac.uk/id/eprint/76926>
- [10] P. Wang, H. Zha, I. Syratchev, J. Shi, H. Chen, “RF design of a pulse compressor with correction cavity chain”, *Phys. Rev. Accel. Beams*, vol. 20, p. 112001, Nov. 2017, doi:10.1103/PhysRevAccelBeams.20.112001
- [11] V. d. P. Romano *et al.*, “High Power Conditioning of X-Band Variable Power Splitter and Phase Shifter”, in *Proc. IPAC’19*, Melbourne, Australia, May 2019, pp. 2964-2967, doi:10.18429/JACoW-IPAC2019-WEPRB064
- [12] N. Catalan-Lasheras *et al.*, “Experience Operating an X-Band High-Power Test Stand At CERN”, in *Proc. IPAC’14*, Dresden, Germany, June 2014, pp. 2288-2290, doi:10.18429/JACoW-IPAC2014-WEPME016
- [13] R. D’Arcy *et al.*, “FLASHForward - A future-oriented wakefield-accelerator research and development facility at FLASH”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, paper TUPIK006, pp. 1692-1695.
- [14] P. Craievich *et al.*, “Status of The Polarix-TDS Project”, in *Proc. IPAC’18*, Vancouver, BC, Canada, May 2018, paper THOAL068, pp. 3808-3811.
- [15] <https://flash.desy.de>
- [16] R. D’Arcy *et al.*, “Longitudinal Phase Space Reconstruction at FLASHForward Using a Novel X-band Transverse Deflection Cavity, PolariX TDS”, in *Proc. IPAC’18*, Vancouver, Canada, May 2018, paper TUPML017.
- [17] F. Christie *et al.*, “Generation of Ultra-Short Electron Bunches and FEL Pulses and Characterization of their Longitudinal Properties at FLASH2”, in *Proc. IPAC’17*, Copenhagen, Denmark, 14-19 May, 2017, paper WEPAB017.
- [18] D. Marx *et al.*, “Reconstruction of the 3D charge distribution of an electron bunch using a novel variable polarization transverse deflecting structure (TDS)”, *Journal of Physics: Conference Series*, 874(1):012077, 2017.
- [19] D. Marx *et al.*, “Simulations of 3D charge density measurements for commissioning of the PolariX-TDS”, *Journal of Physics: Conference Series*, 1067(7):072012, 2018.