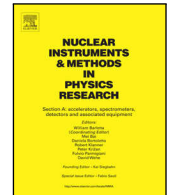




Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Status and objectives of the dedicated accelerator R&D facility “SINBAD” at DESY

U. Dorda^{a,*}, B. Marchetti^a, J. Zhu^a, F. Mayet^a, W. Kuroepka^a, T. Vinatier^a, G. Vashchenko^a, K. Galaydych^a, P.A. Walker^a, D. Marx^a, R. Brinkmann^a, R. Assmann^a, N.H. Matlis^b, A. Fallahi^b, F.X. Kaertner^b

^a DESY, Hamburg, Germany^b CFEL, Hamburg, Germany

ARTICLE INFO

Keywords:

SINBAD
Accelerator R&D
Research facility
DESY

ABSTRACT

We present a status update on the dedicated R&D facility SINBAD which is currently under construction at DESY. The facility will host multiple independent experiments on the acceleration of ultra-short electron bunches and novel, high gradient acceleration methods. The first experiment is the ARES-experiment with a normal conducting 100 MeV S-band linac at its core. We present the objectives of this experiment ranging from the study of compression techniques to sub-fs level to its application as injector for various advanced acceleration schemes e.g. the plans to use ARES as a test-site for DLA experiments in the context of the ACHIP collaboration. The time-line including the planned extension with laser driven plasma-wakefield acceleration is presented. The second initial experiment is AXISIS which aims to accelerate fs-electron bunches to 15 MeV in a THz driven dielectric structure and subsequently create X-rays by inverse Compton scattering.

© 2018 Published by Elsevier B.V.

1. Introduction

The Helmholtz foundation has identified accelerator R&D as one of its core tasks. In line with this objective, DESY is currently setting up the dedicated, long term accelerator R&D facility “SINBAD” in the premises of the old DORIS accelerator complex.

After 40 years of successful operation, the DORIS accelerator at DESY was shut down at the end of 2012. In the past two years the old accelerator has been removed, the building refurbished, and the installation of the required technical infrastructure is currently finishing. Conveniently located at the heart of DESY, the existing 300 m long race-track shaped tunnel, features two 70 m long 5–9 m wide straight sections and two arcs (Fig. 1).

The SINBAD project is the framework for all R&D activities in this area and intends to set up multiple independent experiments in ultra-fast science and high gradient accelerator modules. The first objective includes topics like synchronization R&D, fs to as-regime electron beams, high brightness beams from RF photo injectors as well as sophisticated beam shaping and will be studied in the first of the two initial experiments, the ARES-linac. Moreover, SINBAD will perform experiments on novel acceleration techniques by applying various different

laser-driven approaches with external or internal electron beam injection. This will on the one hand side be done with dielectric structures in the context of the ACHIP collaboration [1] with DLAs at ARES and with THz driven dielectric loaded structures at AXISIS. Finally, laser-driven plasma acceleration as second step behind the ARES linac will be studied in close collaboration with the University of Hamburg and in the context of the Helmholtz wide collaboration on plasma acceleration “ATHENA”.

2. The AXISIS experiment

One of the two initial experiments, the ‘AXISIS’ project [2], is a ERC-synergy grant funded collaboration of 4 groups aiming to develop a THz-laser driven, all-optical, compact X-ray source. The millimeter scale of the driving field promises to offer a favorable compromise between conventional accelerators and other advanced accelerators like plasma-based or laser-driven devices with significantly smaller structure dimensions.

While one part of the team is pushing the amount of achievable THz (300 GHz) power towards the required levels, various different

* Corresponding author.

E-mail address: ulrich.dorda@desy.de (U. Dorda).<https://doi.org/10.1016/j.nima.2018.01.036>

Received 2 November 2017; Received in revised form 21 December 2017; Accepted 11 January 2018

Available online xxxx

0168-9002/© 2018 Published by Elsevier B.V.

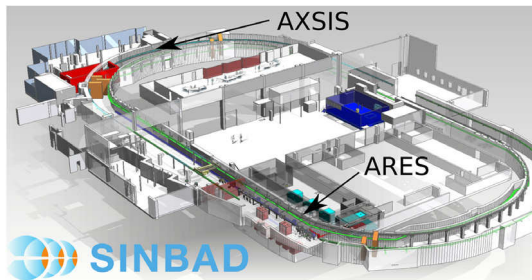


Fig. 1. Rendering of the SINBAD facility with the two initial experiments indicated.

THz-based guns are designed [3]. Initial tests of a prototype THz-gun were performed and produced keV level acceleration of electrons using micro Joule, single-cycle THz pulses. While the performance must still be significantly increased with the next guns, the experimental results are now well understood [4]. With the final gun design, pC level electron bunches will be extracted from a photo-cathode and accelerated to ≈ 800 keV.

In order to not let the space charge effect blow up the bunch, the linac will be located right after the gun. The linac is made from a dielectric loaded waveguide of ≈ 10 cm length [5]. The dielectric loading allows to slow down the phase-velocity of the THz-pulse. In the final stage, the electron beam will be focused and collided with an optical laser to create X-rays.

With the corresponding laser labs being constructed right now and the tunnel area infrastructure being installed, we aim to start experiments in the final AXSIS site, in one of the arcs of the SINBAD facility, in fall 2018.

3. The SINBAD-ARES experiment

The ARES-linac [6] is a S-band (2.998 GHz) linac which accelerates electron bunches to 100 MeV while compressing them to fs-length. These ultrashort bunches can then subsequently be used for experiments.

3.1. The linac setup

A CAD rendering of the linac section can be seen in Fig. 2. The electron bunches of typically 0.3–30 pC are created and accelerated in a 1.6 cell RF-gun (modified version of the one used at DESY-REGAE [7]) to 5 MeV. The electrons are extracted by photoemission by a 1 mJ Yb doped laser at 257 nm with a variable FWHM pulse length between 180 fs and 10 ps. During the first commissioning phase, the first solenoid will be located ≈ 0.4 m after the photo-cathode. A first iteration of a design for an additional solenoid right at the RF-gun exit has already been developed and is planned to be installed together with a bucking coil in 2019 leading to a reduction of the minimal achievable transverse emittances. Several beam diagnostic devices including screens, Faraday cups etc and a spectrometer dipole, cover about 2.5 m until the start of the first of two traveling wave linac structures (TWS). These 4.2 m long TWS with external RF-dump are surrounded by solenoids for emittance compensation. Each one will be powered by a dedicated 45 MW RF station and could – if operated on-crest – provide 75 MV energy gain. In practice one or both will be operated off-crest, to compress the bunch to fs-length [8–10]. The compression will either be done via velocity bunching in the first TWS or via a magnetic bunch compressor after the linac or a hybrid compression scheme. The two structures are separated by a about 1.2 m long intertank section containing the necessary beam diagnostic and orbit correctors. The space reserved for the installation of a third TWS will at the start be used for initial experiments. At the end a dedicated beam diagnostic line allow characterization of the beam and optimization of the linac performance. The linac will run in single bunch mode with up to 50 Hz repetition rate. The beam line design as

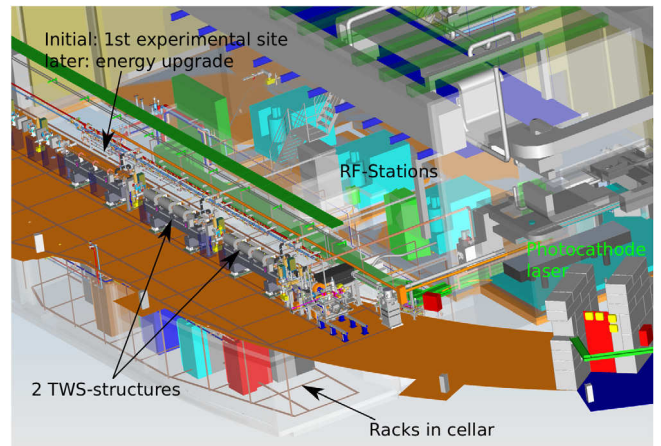


Fig. 2. Rendering of the ARES linac showing the beam line in the tunnel as well as the associated infrastructure (RF-stations, photo-cathode laser and rack room).

well as the whole layout is – within the restrictions of the given building – designed for minimal arrival time jitter. At ARES, the linac itself will be the object of studies including e.g. comparison of various compression methods, synchronization R&D and beam shaping techniques. In parallel it will then be used to provide beams for downstream experiments. The ultra short bunches will be ideally suited for injection into advanced schemes and allow probing their phase space acceptance.

The installation of the gun stage is currently starting up and beam commissioning is aimed for spring 2018. The linac stage will be added in fall 2018, allowing for first experiments in spring 2019.

3.2. X-band TDS for 6D tomography

In collaboration with CERN and PSI, an X-band transverse deflecting structure (TDS) with variable polarization is currently being developed [11]. In addition to its main objective to measure the longitudinal beam profile with fs resolution (to study and optimize the compression methods), this novel device will allow to select the streaking direction. Using the data from multiple shots with different streaking angles, tomographic methods will be applied to characterize the complete 6D phase-space [12].

3.3. Dielectric structure experiments

The SINBAD-ARES linac is one of the intended future test sites for the ACHIP collaboration [1] which studies DLA-type structures. In the first stage it is foreseen to place the experiment at the location which is reserved for a third traveling wave structure (Fig. 3). The required strong focusing of the external beam to the μ -scale structures is provided by the solenoids surrounding the two up-stream TWS structures [13]. Initially, a part of the photocathode laser will be split off and used to power the DLA structures. It is not yet decided if an optical parametric amplifier will be added to convert the laser from $1 \mu\text{m}$ to $2 \mu\text{m}$. Naturally the DLA structure size needs to be adapted accordingly. This setup has the advantage of intrinsic synchronization between the photo-cathode laser- and the DLA drive laser-beams. The relative electron to laser phase jitter at the DLA is hence mainly given by the RF-induced beam arrival time jitter contribution.

In previous acceleration experiments with such structures, the bunch length has been significantly longer than the laser length and thus all electron-to-laser phases have been covered. The shortness of the ARES bunches will allow injecting the bunch only to a limited phase range ($< 90^\circ$ at $2 \mu\text{m}$). While the design of the ARES-linac is optimized to minimize also this RF-induced arrival time jitter, a sub-fs level synchronization will probably still be out of reach. For the shots where

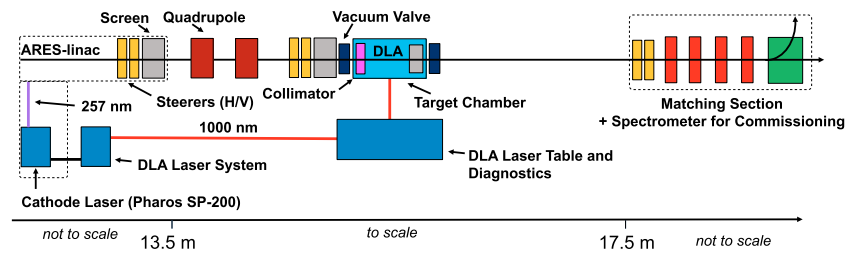


Fig. 3. Sketch of the ACHIP experimental area at ARES and the laser split of from the photocathode laser.

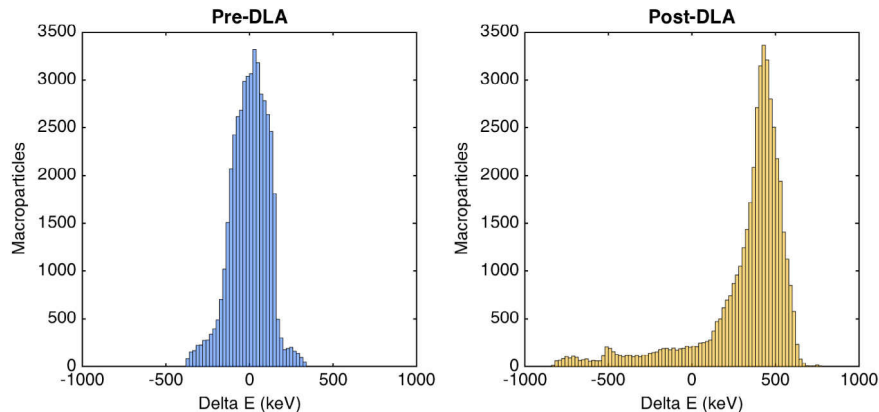


Fig. 4. Beam energy distribution before the DLA and after it showing that the shortness of the ARES-linac beam should allow net-acceleration for selected single shots. Depending on the arrival time jitter from shot to shot, the electron to laser phase will vary and thus also cases with net energy loss be observed. Here the ideal case of maximal acceleration is shown.

the phase happens to be at maximum, net acceleration will be observed (Fig. 4). In other cases, also net-energy loss or only energy modulation will occur [14].

In order to address this issue, in another experiment the DLA-laser beam will be split to not only power the structure but also to micro-bunch the linac beam upstream of the DLA. Similar to the work presented in [15], this will be done by energy modulating the beam by overlapping it in an undulator and then compressing the bunches in a small magnetic chicane. This creates a number of microbunches spaced at the correct distance for the DLA and intrinsically synchronized to it [16,17].

Furthermore, in another planned experiment the suitability of such structures as transverse deflectors will be studied [18].

3.4. THz experiments at ARES

In parallel to the all optical efforts for THz acceleration in the AXISIS experiments, the linac stage may be tested with the well characterized beam from the ARES linac [19]. In addition to these acceleration experiments, the high frequency of the THz fields will be used in testing THz streaking experiments or bunch length measurements via the 3 phase method [20].

3.5. Laser plasma wakefield acceleration experiments

A proposal by 6 Helmholtz centers for a joint laser plasma accelerator research program “ATHENA” has just entered the final approval stage from the Helmholtz foundation. Together with university partners, it aims to push this technology by setting up two flag-ship programs. While studies on laser plasma acceleration of ions will be performed at HZDR in Dresden, the electron activities will be focused at SINBAD. For this purpose, a high power laser lab will be installed in the large central hall in the next few years. The high power laser will then be used to serve multiple experiments. While experiments using the externally injected beam from ARES will be done in one straight section, internal

injection will be studied in the second straight section. Like this SINBAD will be a important preparation step towards the implementation of the EUPRAXIA design study [21,22].

3.6. External access via ARIES TNA

While SINBAD is a DESY project, access will be possible to external researchers. This will mainly be done in the context of collaborations, but also via the ARIES transnational access program free of charge [23]. This EU-funded Integrating Activity project aims to develop European particle accelerator infrastructures and contains the task to open research facilities to external users.

4. Summary/conclusion

We have presented the objectives and status of the SINBAD facility and its two initial experiments, AXISIS & ARES. The installation of the dedicated accelerator R&D facility is progressing well and experiments on ultra-fast science and advanced acceleration schemes are developed.

Acknowledgments

The authors acknowledge the work of all the DESY technical groups involved in the renovation, planning and construction of the facility. In addition, we would like to mention our collaboration partners at LAOLA, ATHENA & ACHIP. The AXISIS related research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007–2013)/ ERC Grant Agreement n. 609920'. Access via the ARIES-TNA program will partially be sponsored via the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 730871. ACHIP related activities are partially funded by the Gordon and Betty Moore foundation (GBMF4744).

References

- [1] R. Ischebeck, et al., The accelerator on a chip international program ACHIP, Nucl. Instrum. Methods Phys. Res. A (2017).
- [2] N. Matlis, et al., Acceleration of electrons in THz driven structures: first steps towards AXSIS, Nucl. Instrum. Methods Phys. Res. A. (2017).
- [3] A. Fallahi, et al., Short electron bunch generation using single-cycle ultrafast electron guns, Phys. Rev. Accel. Beams 19 (2016) 081302.
- [4] G. Vashchenko, et al., Performance of the prototype THz-driven electron gun for the AXSIS project, Nucl. Instrum. Methods Phys. Res. A. (2017).
- [5] E. Nanni, et al., Terahertz-driven linear electron acceleration, Nature Commun. (2015).
- [6] B. Marchetti, et al., Status update of the SINBAD-ARES linac under construction at DESY, in: Proceedings of the 8th International Particle Accelerator Conference, 2017.
- [7] Klaus. Floettmann, et al., REGAE: New source for atomically resolved dynamics, Res. Opt. Sci. (2012).
- [8] B. Marchetti, et al., Electron-beam manipulation techniques in the SINBAD linac for external injection in plasma wake-field acceleration, Nucl. Instrum. Methods Phys. Res. A. 829 (2016).
- [9] J. Zhu, Design Study for Generating Sub-Femtosecond to Femtosecond Electron Bunches for Advanced Accelerator Development at SINBAD(Ph.D. thesis), Hamburg University, 2017.
- [10] J. Zhu, et al., Sub-fs bunch generation with sub-10-fs bunch arrival time jitter via bunch slicing in a magnetic chicane, Phys. Rev. ST Accel. Beams 19 (2016).
- [11] B. Marchetti, et al., X-band TDS project, in: Proceedings of the 8th International Particle Accelerator Conference, 2017.
- [12] D. Marx, et al., New measurement techniques using a novel X-band transverse deflecting structure with variable polarization, Nucl. Instrum. Methods Phys. Res. A. (2017).
- [13] F. Mayet, et al., Using short drive laser pulses to achieve net focusing forces in tailored dual grating dielectric structures, Nucl. Instrum. Methods Phys. Res. A. (2017).
- [14] W. Kuroпка, et al., Full PIC simulation of first ACHIP experiment @ SINBAD, Nucl. Instrum. Methods Phys. Res. A (2017).
- [15] C. Sears, Production, Characterization, and Acceleration of Optical Microbunches (Ph.D. thesis), Stanford university, 2008.
- [16] F. Mayet, et al., Simulations and plans for possible DLA experiments At SINBAD, Nucl. Instrum. Methods Phys. Res. A (2017).
- [17] F. Mayet, et al., A concept for phase-synchronous acceleration of microbunch trains in DLA structures at SINBAD. in: Proc. IPAC'17, 2017.
- [18] W. Kuroпка, et al., Simulation of deflecting structures for dielectric laser driven accelerators, Nucl. Instrum. Methods Phys. Res. A (2017).
- [19] T. Vinatier, et al., Simulations of an hybrid and compact attosecond X-ray source based on RF and THz technologies, Nucl. Instrum. Methods Phys. Res. A (2017).
- [20] T. Vinatier, et al., Possible experiments using dielectric-loaded waveguides on the ARES linac, Nucl. Instrum. Methods Phys. Res. A (2017).
- [21] P.A. Walker, et al., Horizon 2020 EuPRAXIA design study, J. Phys. Conf. Ser. 874 (1) (2017) 012029.
- [22] E. Svystun, et al., Beam quality preservation in a laser-plasma accelerator with external injection in the context of EuPRAXIA, Nucl. Instrum. Methods Phys. Res. A (2017).
- [23] Accelerator research and innovation for European science and society. <https://aries.web.cern.ch/>.