SINBAD - The accelerator R&D facility under construction at DESY

U. Dorda, R. Assmann, R. Brinkmann, K. Flöttmann, I. Hartl, M. Hüning, F. Kärtner, A. Fallahi, B. Marchetti, Y. Nie, J. Osterhoff, H. Schlarb, J. Zhu^a, A. R. Maier^b

^aDESY, Hamburg & Zeuthen, Germany

^bUniversity Hamburg, Germany

Abstract

The SINBAD facility (Short **IN**novative **B**unches and **A**ccelerators at **DESY**) is a long-term dedicated accelerator research and development facility currently under construction at DESY. It will be located in the premises of the old DORIS accelerator complex and host multiple independent experiments cost-effectively accessing the same central infrastructure like a central high power laser. With the removal of the old DORIS accelerator being completed, the refurbishment of the technical infrastructure is currently starting up.

The presently ongoing conversion of the area into the SINBAD facility and the currently foreseen layout is described. The first experiment will use a compact S-band linac for the production of ultra-short bunches at hundred MeV. Once established, one of the main usages will be to externally inject electrons into a laser-driven plasma wakefield accelerator to boost the energy to GeV-level while maintaining a usable beam quality, ultimately aiming to drive an FEL. The second experiment already under planning is the setup of an attosecond radiation source with advanced technology. Further usage of the available space and infrastructure is revised and national and international collaborations are being established.

Keywords: SINBAD, Accelerator R&D, Research facility, DESY

1. Introduction

At the end of 2012, the DORIS accelerator at DESY was shut down after more than 40 years of successful operation as high-energy physics collider as well as synchrotron light source. The SINBAD project intends to reuse these premises to set up a dedicated, long-term accelerator R&D facility with multiple independent experiments in ultra-fast science and high gradient accelerator modules accessing a common infrastructure. The following lists the initial project goals:

- Production of ultra-short electron bunches for ultra-fast science.
- Construction of a plasma accelerator module with usable beam quality for applications.
- Setup of an attosecond radiation source with advanced technology (AXSIS collaboration).

A common feature of all advanced acceleration methods is the extremely short period of the accelerating field and the very strong transverse focusing to the micrometer scale required to either match into the very small apertures or to the strong transverse focusing strengths inside the structures. If used with externally injected beams, this results in very stringent requirements on the allowed bunch focusing, length and arrival time jitter.

As shown in Figure 1a, the SINBAD facility is located at the heart of the DESY Hamburg campus. The 290 m long, race-track shaped radiation shielding tunnel varies between 5 and 9

meter wide and features two long straight sections of ≈ 70 meter length. The thickness of the shielding tunnel varies with an average of 1 m thickness allowing for acceleration to several GeV electron beam energy for the foreseen repetition rates and bunch charges. Several adjacent rooms and a 650 m² central hall are available (Fig. 1b) and will be used to host the new infrastructure (e.g. precision water cooling systems, racks, klystrons, ...) and a high-power laser system, allowing multiple independent experiments to access it. In addition, some of the former synchrotron light user areas on the outside will be used for laser-labs and test photon-user experiments. The

(a) Location of the SINBAD facility on the DESY Hamburg site.

(b) 3D illustration of the available race-track shaped radiation shielding tunnel and the associated main hall.

Figure 1: Overview over the location and premises of the SINBAD facility

removal of the old beam lines and associated infrastructure is almost completed by now with the renovation of the building structure finishing in spring 2016. Subsequently the new technical infrastructure will be installed within the coming year.

Figure 2: Layout of the SINBAD facility with the two initial experimental setups and the associated technical infrastructure shown. The gray areas mark space allocated to other users. The two laser labs indicated opaque on the upper outside are operated by collaborating groups at DESY and the respective lasers will be used in common experiments.

In the initial phase, SINBAD will host two independent experiments (Fig. 2): The SINBAD-ARES experiment, consisting of a linac and associated research beam lines, will be located in one of the long straight sections. Secondly the AXSIS experiment will be installed in one of the arcs and direct X-rays into the outside user areas.

2. AXSIS

The AXSIS experiment is only briefly described here as it is presented in more detail in a separate contribution to these proceedings [1]. It is a collaboration between DESY, CFEL and the University of Arizona funded by an ERC-synergy grant aiming to set up an accelerator based on a THz-driven, dielectric loaded waveguide [2]. It plans to accelerate electron bunches of 0.1 - 5 pC charge to 15-26 MeV. Due to the high frequency and high acceleration gradient it is anticipated that sub-fs bunch durations can be achieved in an ultra-compact setup. The electrons are subsequently focused and collide with a high power laser to create 4 keV (upgrade: 12 keV) photons. These photons are transported into user-areas at the outside of the shielding tunnel. One of the first objectives is to study the photosynthesis. The required THz radiation will be generated by optical rectification [3] allowing for kHz repetition rate.

Figure 3: Conceptual sketch of the various parts of the AXSIS experiment

Figure 4: Sketch of the SINBAD-ARES-linac layout. Electrons are extracted from an S-band RF-gun and subsequently accelerated in 2 (upgrade: 3) S-band RF-structures. Subsequently the electrons can be optionally compressed in a magnetic bunch compressor with a slit or directed into a second beam line via a dog-leg.

3. SINBAD-ARES-linac

At the core of the SINBAD-ARES experimental setup, the SINBAD-ARES electron linac (Fig. 4) will accelerate and compress ultra-short electron bunches to 100 MeV. Electrons are extracted from an S-band RF-Gun like the one used at the DESY-REGAE experiment [4]. Depending on the use-case, the Yb doped mJ-level photo-cathode laser will extract electron bunches of 0.2 - 10 ps duration with 0.1 pC - 1 nC charge from the photocathode (Cs_2Te or metallic). The electrons are then accelerated in the 1.5 cells of the gun to ≈ 5 MeV. In the subsequent compact diagnostic and solenoid-focusing section the bunch is prepared for injection into two (upgrade: three) consecutive traveling wave S-band structures (TWS) similar to the ones used in the DESY-LINAC II. For optimal stability, each RF-structure will be powered by an individual RF-station and temperature stabilized to few mK. While each of the foreseen 5 m long TWS could accelerate the beam by ≈ 100 MeV if operated on-crest, the targeted end energy is ≈ 100 MeV in total (upgrade: 200 MeV) leaving an significant amount of RF power available for bunch manipulation in the longitudinal phase-space. In the initial stage, the linac itself will be the object of study, aiming to produce ultra-short bunches. For this purpose, various compression mechanism are implemented and the achievable performance will be studied and compared:

- Simulations of velocity bunching [5, 6] show that it will be possible to compress the 0.5 pC-bunches down to 2 fs while simultaneously focusing them transversally to few μm [7] which is sufficient for most of the intended applications.
- Magnetic compression with a slit [8, 9] downstream of the linac in a chicane with selectable momentum compression factor R56. In this case a separate subsequent transverse focusing section is needed [10].
- A hybrid compression of the two.

At the same time the system is designed to also allow acceleration of higher bunch charge (up to 1 nC) required for some of the foreseen applications at the cost of longer bunch lengths. Extensive simulation studies are performed and components are carefully chosen in order to achieve the minimum beam arrival time jitter (< 10 fs requiring a phase stability of ≤ 8 milli-degree) which is essential for some of the foreseen applications (see sec. 3.1). Requests for funding for additional upgrades are submitted which would allow the procurement of e.g. an X-band transverse deflecting structure for bunch length measurements.

3.1. Envisaged research topics

Once the goal of accelerating ultra-short bunches is achieved, the beam will be transported to the downstream research beam lines. On the long term, it is foreseen to have up to three beam lines - one in the straight extension of the linac with optimal beam parameters and two side lines connected via a dog-leg. The ultra-short bunches are ideally suited to be injected into high gradient advanced acceleration schemes which typically have RF-bucket-equivalent lengths of a few tens of fs. This will on the one hand allow to sample the phase-space of the acceleration stage with a well defined beam and on the other hand accelerate the electrons to higher energies while preserving a reasonable small energy spread. Currently, the following research topics are envisaged:

- Laser-plasma wakefield acceleration (LWFA) with external injection. For this application it is foreseen that the 5 J - 25 fs-laser currently used in DESY at the LAOLA-LUX facility is moved to SINBAD. In order to minimize the energy-spread growth during acceleration, the bunch may only occupy a small fraction of the plasma wavelength, which is fulfilled for fs-bunches in the plasma densities of $n_e = 10^{17}$ [11]. The plasma stage is meant to boost the energy to 1 GeV. If ongoing funding-applications are successful, a Free-Electron Laser is the most prominent first pilot application of this plasma accelerator module. Shrinking the facility size, and with it the costs, would have enormous impact on many scientific disciplines. Based on stable and reliable acceleration of electron bunches through the upstream plasma accelerator stage, we perform advanced beam manipulation schemes, such as decompression [12], and then match the beam into an undulator section. First simulations indicate that demonstration of FEL gain is possible with this setup, and even saturation of a few-nm FEL over the available undulator length could be achieved.

These experiments will be based on the experience gained in the currently ongoing activities [13, 14, 4] of LAOLA, which is a collaboration between DESY and the university of Hamburg on plasma wake-field acceleration. Furthermore, if approved SINBAD would be one of the two flagship projects of the ATHENA proposal which is a request for funding by 7 Helmholtz centers for joint research on PWA.

- Like for LPFA, ultra-short and transversally strongly focused beams are also important to Dielectric Laser Acceleration [15]. Combined with the directly adjacent laser labs of collaboration partners, SINBAD will thus be an ideal test-site for the recently funded “accelerator on a chip” collaboration.
- An imaging beam line where the high power laser beam collides with the electron beam to produce photons by inverse Compton scattering.

Exemplary, the suitability of the ultra-short bunches accelerated in the ARES-linac for external injection into an advanced,

Figure 5: Simulation of a beam accelerated by the ARES-linac and then injected into a 300 GHz dielectric loaded waveguide

high gradient accelerator structure is shown in the simulation of the injection into a THz-driven dielectric loaded waveguide, similar to the one foreseen in the AXISIS experiment (Figure 5). A standard working-point foreseen for the ARES-linac with velocity bunching was simulated using ASTRA [16] accelerating the beam to 100 MeV while compressing it longitudinally to $z_{RMS} = 0.7 \mu\text{m}$ and $x_{RMS} = y_{RMS} = 10 \mu\text{m}$ transversally. This beam is then injected into a 300 GHz structure with 240 MV/m peak gradient. It can be seen that acceleration can be achieved while keeping the increase in energy spread and transverse beam size reasonably small.

4. Summary & outlook

Practical work on the SINBAD facility has started by removing the old DORIS accelerator and by initiating the building renovation. Installation of the technical infrastructure will take place in 2016. The layout of the linac of the SINBAD-ARES experiment is fixed. It will allow to compare various compression techniques to deliver single-/few-fs long electron bunches with 100 MeV to research lines in 2018. Preliminary studies for the experimental plans are progressing and collaborations are established. First preliminary ideas for usage of the remaining free space are being formulated including a LPWA with internal injection and experiments with a high energy beam delivered from the DESY II synchrotron.

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