

# THE REGAE ACCELERATOR VACUUM SYSTEM

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## Abstract

Since 2011 the Relativistic Electron Gun for Atomic Exploration (REGAE) is operated at DESY in Hamburg. The accelerator consists mainly of a high gradient S-band RF-gun, which generates ultra-low emittance electron bunches, and an S-band RF-buncher cavity for bunch compression. In this contribution we describe the vacuum system of the REGAE accelerator. We will cover design aspects, applied cleaning and installation procedures as well as operation experience over the last years.

## INTRODUCTION

REGAE is a small accelerator dedicated to provide electron bunches suitable for electron diffraction experiments [1, 2]. To achieve the required transverse emittance in the order of 10 nm low charge beams in the order of 100 fC are required. The electron bunches at REGAE are generated by photoemission in an S-band RF-gun which is operated at up to 100 MV/m. These bunches are compressed in an S-band ballistic bunching cavity and transported to the experiment.

In Fig. 1 an overview of the REGAE accelerator is shown, electron beam direction is from right to left. It starts with the photocathode transfer system and the RF-gun. Following diagnostic and collimation devices an RF-buncher is located. Electron beam energy can be measured by means of a 90° dipole magnet. The experimental station (not shown in the figure) follows after a small drift in straight direction.

## GENERAL DESIGN OF THE VACUUM SYSTEM

Due to the very small bunch charge at REGAE dark current emitted from the RF-gun and the photocathode is a severe issue as it disturbs the diffraction experiments. To minimize possible dark current sources the complete vacuum system is designed to be particle free in accordance to ISO 5 [3]. In addition to the dark current issue, the particle cleanliness of the RF-structures yields advantages in their operation itself.

The most critical requirements to the accelerator in terms of vacuum pressure originate from the photocathodes. Since REGAE should be able to be operated with metal as well as vacuum sensitive semiconductor photocathodes (e.g. Cs<sub>2</sub>Te), the pressure in the RF-gun during operation should be in the order of 10<sup>-9</sup> mbar or better.

The requirements on particle cleanliness and vacuum pressure during operation are comparable to the ones in the RF-gun section of FLASH (free-electron laser user facility at DESY). Therefore the design concepts of FLASH have been applied to REGAE. Only all metal components have been installed. Materials and cleanliness of components are in full accordance with the DESY vacuum specification [4]. The vacuum chambers of the diagnostic stations are fully compatible to FLASH. They are optimized for pumping speed while keeping effects of geometrical wake fields reasonable low. A model of a so-called double diagnostic cross (DDC) is exemplary shown in Fig. 2. These chambers allow for precise connection of up to six components (e.g. screens, collimators, mirrors) perpendicular to the electron beam axis. In addition, a the body of a button BPM is included as well. A titanium sublimation pump (TSP) or a sputter ion

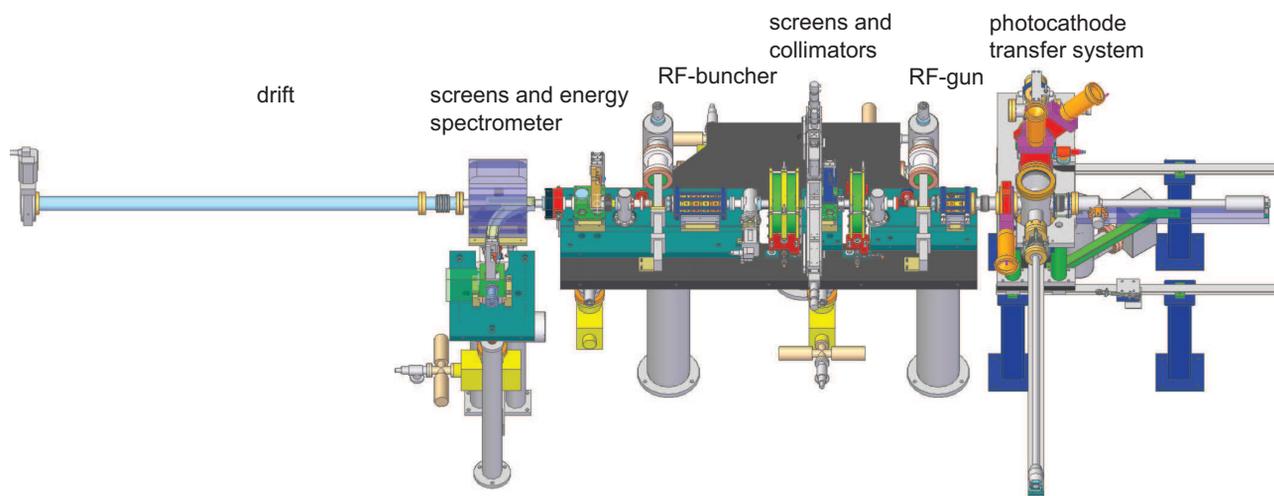


Figure 1: Overview of the REGAE accelerator.

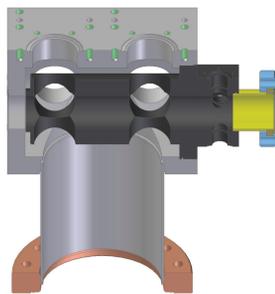


Figure 2: CAD model of a double diagnostic cross (cut view), details see text.

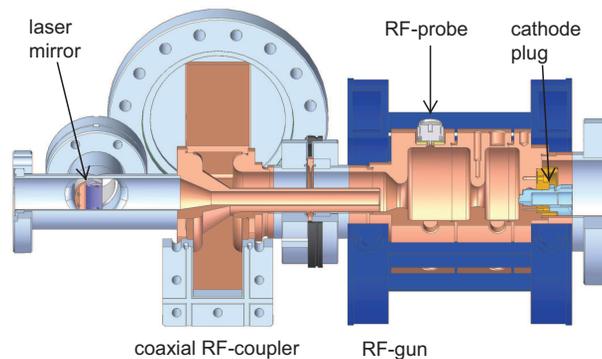


Figure 3: Sketch of the RF-gun including coaxial RF-coupler (cut view).

pump (SIP) is connected to the DN 100 ConFlat® flange at the bottom.

The accelerator vacuum system is separated into several sectors by all metal gate valves. As the RF-structures need to be protected during maintenance work a high segmentation rate was chosen. Thus the condition states of RF-structures may consequently be preserved by being kept under vacuum in case screen stations need to be vented for maintenance.

The vacuum system is pumped by 6 TSP's and 13 SIP's (5 SIP's are used in the wave guide vacuum system).

## MAIN COMPONENTS

### *RF-gun and RF-buncher*

The RF-gun is a 1.5 cell S-band ( $f = 2.9979$  GHz) normal conducting cavity. The RF-buncher is based on the same frequency but consists of 4 cells. The fabrication process was adapted from the long-term DESY experience in the production of S-band structures for the LINAC II and the L-band RF-guns for FLASH. Base material of the cavities is 3d-forged Cu-PHCE and for the flanges 3d-forged 1.4429 ESR stainless steel (based on a DESY specification [5]). To reduce negative effects of a high temperature brazing on the copper material the structures have been joined in several steps. After the mechanical production of all sub-components, the stainless steel and copper tubes for the flange transitions have been brazed with a CuSn 12 filler at about 1015 °C. Afterwards the cells and the transition pipes have been brazed by means of a Ag72 filler at 830 °C. Brazing of the water cooling to the structures was done with the same filler at 820 °C. Finally the flanges and the RF-probes have been welded to the cavities.

In Fig. 3 a sketch of the first REGAE RF-gun together with its high power coaxial RF-coupler is shown. In addition the photocathode plug and the laser in-coupling mirror are included in the figure.

### *Photocathode Transfer System*

To enable REGAE to be operated with different types of photocathodes the machine was equipped with an cathode transfer system. It is based on the concepts developed for FLASH [6]. The system allows cathode exchanges under UHV-conditions and is fully compatible to the DESY photocathode preparation system as well as the cathode transfer

systems of FLASH and the European XFEL. Cathodes are prepared on site at the preparation system and transferred in UHV transport boxes to the accelerator. Transfer in vacuum is done by means of magnetically coupled transfer arms and a cathode carrier, capable of storing of five cathodes.

## CLEANING AND INSTALLATION

To achieve the required particle cleanliness for the high gradient operation with low dark current all components installed at the REGAE accelerator have been prepared in a dedicated clean room facility [7]. Exceptions were the RF-components, like RF-gun, RF-buncher and power coupler. Experience gained from operating dry-ice cleaned L-band RF-guns has shown, that these components produce significantly less dark current as compared to conventionally cleaned ones [8]. Consequently, all of the components mentioned before have been dry-ice cleaned [9].

Installation of the components in the accelerator tunnel was done under local clean room conditions in accordance to ISO 5 [3]. Even though all components are cleaned and installed under clean room conditions the vacuum system is assumed to be not fully particle free. As an example a few particles are produced during the movement of gate valves. To avoid the transport of these particles into the RF-cavities during venting and pump-down special units are used [10]. These units ensure a laminar flow so that particles are not detached from surfaces and will not be transported.

The photocathode transfer system underwent a vacuum bake-out at 120 °C. For this component the bake-out is required because of the two long magnetically coupled transfer arms. All other components have been installed without an additional baking and the required UHV conditions have been achieved within a couple of days.

## CONTROLS

The complete vacuum system of REGAE is remote controlled and based on the concepts of PETRA III. The SIP's are operated by in-house developed power supplies (Fig. 4 upper part) at a high voltage of 5 kV. These can be fully remote controlled by electric signals and allow for monitoring

the ion pump current and high voltage by means of either 0-10 V or 5-24 mA analogue output signals.

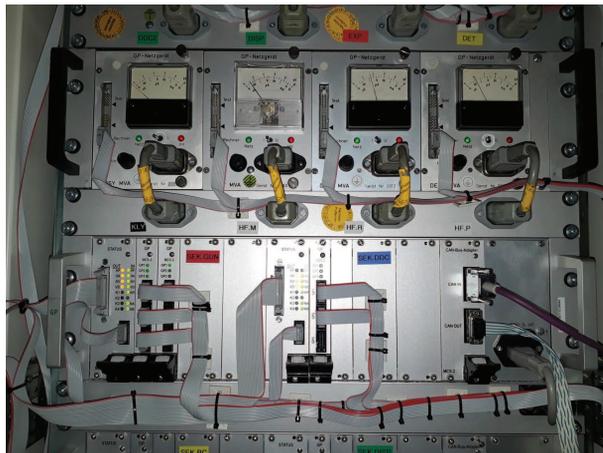


Figure 4: High voltage power supplies for operation of ion pumps (upper part) and micro controller (lower part), for details see text.

The vacuum control electronics is based on dedicated micro-controllers [11] (Fig.4 lower part) controlling the high voltage power supplies and collect their analogue signals. Their programming ensures the proper conditions for the operation of the segmenting gate valves. In addition the micro-controllers generate output signals used at other accelerator sub-components, e.g. interlock for RF systems.

All components of the vacuum system are remote controllable via the TINE control system [11]. The graphical user interface is based on jddd [12].

## OPERATION EXPERIENCE

During the seven years of accelerator operation only few components showed issues. The first one was an RF-window installed at the coaxial coupler of the RF-gun. At this window a leak in the ceramic appeared. The second component was the feed-through for the RF-probe at the RF-gun. In two different RF-guns leaks appeared in the SMA-connector between inner conductor and ceramic insulator. To continue operation the leaks have been sealed by Vacseal<sup>®</sup>. Even though this worked from the vacuum point of view, operation was limited by higher dark current [13]. Finally an exchange of the RF-guns was necessary since the RF-probes were welded to the RF-guns. Based on this experience a new RF-gun was designed and built with an exchangeable RF-probe (see Fig. 5). This RF-gun is in operation since February 2017.

Except for these leaks the vacuum system operated fully reliable. A base pressure of below  $10^{-9}$  mbar has been achieved and maintained. When the RF-cavities are fully conditioned their pressure is independent from RF-operation. The electronic components work reliable as expected. Since the beginning of the operation only one HV power supply was exchanged. The micro-controllers have not been exchanged at all.

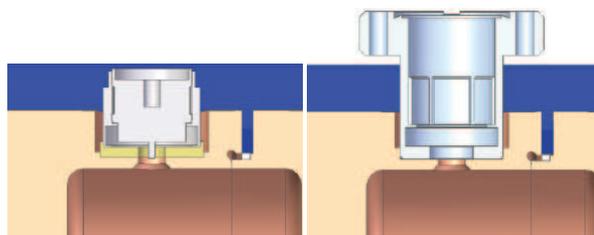


Figure 5: Schemes of the original welded (left) and new exchangeable (right) design of the RF-probe.

## SUMMARY AND OUTLOOK

In this contribution we presented design concepts of the REGAE accelerator vacuum system from the mechanical and controls point of view. Cleaning and installation techniques have been described and the operation experience has been addressed.

Currently parts of the REGAE accelerator are modified to allow for future studies on external injection into laser driven plasmas [14] in addition to the electron diffraction experiments.

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