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STATUS OF THE CLEAR ELECTRON BEAM USER FACILITY AT CERN

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Abstract

The CERN Linear Electron Accelerator for Research (CLEAR) has now finished its second year of operation, providing a testbed for new accelerator technologies and a versatile radiation source. Hosting a varied experimental program, this beamline provides a flexible test facility for users both internal and external to CERN, as well as being an excellent accelerator physics training ground. The energy can be varied between 60 and 220 MeV, bunch length between 1 and 4 ps, bunch charge in the range 10 pC to 2 nC, and number of bunches in the range 1 to 200, at a repetition rate of 0.8 to 10 Hz. The status of the facility with an overview of the recent experimental results is presented.

INTRODUCTION

The CLEAR facility was built from the probe beam injector CALIFES at CTF3, reusing and upgrading the accelerator part and installing several new experiments [1–3]. The current beamline layout is illustrated in Fig. 1, and a MAD-X model is available [4].

The main purpose of CLEAR is to provide a test-bed for new accelerator technologies including beam instrumentation, plasma devices, X-band accelerating structures, and more. Also hosted is a varied program of irradiation with electron beams, including tests for high-energy electron radiotherapy techniques and validation of electronic components for space applications. This is achieved by having a flexible, easily accessible and modifiable beam-line with a wide span of available parameters. Typically, the tunnel is accessible every Monday for experiment installation and/or modification, which makes the setup and modification experiments very easy and convenient. In cases where more frequent accesses have been needed (e.g. for irradiation), this has also been possible. The radiation levels are generally low, which makes it possible to use a wide range of equipment. Additionally, due to the relative simplicity and flexibility of the machine, it has also been used to provide training for students through programs such as JUAS [5].

As seen from the layout, the CLEAR machine is well equipped with diagnostics [6] for measuring and optimizing the beam parameters such as bunch charge and train length, bunch length, energy- and energy-spread, and Twiss parameters, as well as combinations thereof. This makes it possible to quickly setup a wide variety of beams for the hosted experiments, and to cross-compare different diagnostics including prototype beam instrumentation.

Table 1: Typical Range of Beam Parameters

Parameter	Value
Beam energy	60 MeV – 220 MeV
Bunch charge	10 pC – 2.0 nC
Bunch length	1 ps – 4 ps
Bunch frequency	1.5 GHz
RF frequency	3.0 GHz
Number of bunches	1 – 200
Beam repetition rate	1/(1.2 s) – 10 Hz
RMS energy spread	< 0.2 %
RMS ϵ_N at QFD350 entrance	1 μm–20 μm
Typ. β at QFD350 entrance	5 – 15 m
Typ. α at QFD350 entrance	-1 to +1

CLEAR typically runs during normal work days, for 9 hours or more each day, depending on the experiment being ran and operator availability. In 2018, there was a total of 32 weeks of operation, split over two runs with a shutdown in the summer to prepare for connection of the CLIC X-band accelerating structures to an X-band klystron and for general maintenance of the facility. Unlike the rest of the CERN accelerator complex, CLEAR will be kept running throughout Long Shutdown 2.

OPERATION AND PERFORMANCE

CLEAR can provide a wide range of beams; the typical beam parameters are listed in Table 1. This refers to a beam produced using the photocathode laser, which is the normally used arrangement. Here the number of bunches, the bunch charge, and the train repetition rate is controlled via the laser parameters [7, 8]. Single laser pulses can be picked through a system of fast Pockels cells. Recently, the control and repeatability of the laser system has been significantly improved, by changing the actuators controlling the mirror from picomotors to stepping motors. Furthermore, an adjustable telescope has been added which allows to change the focus of the laser on the photocathode, and

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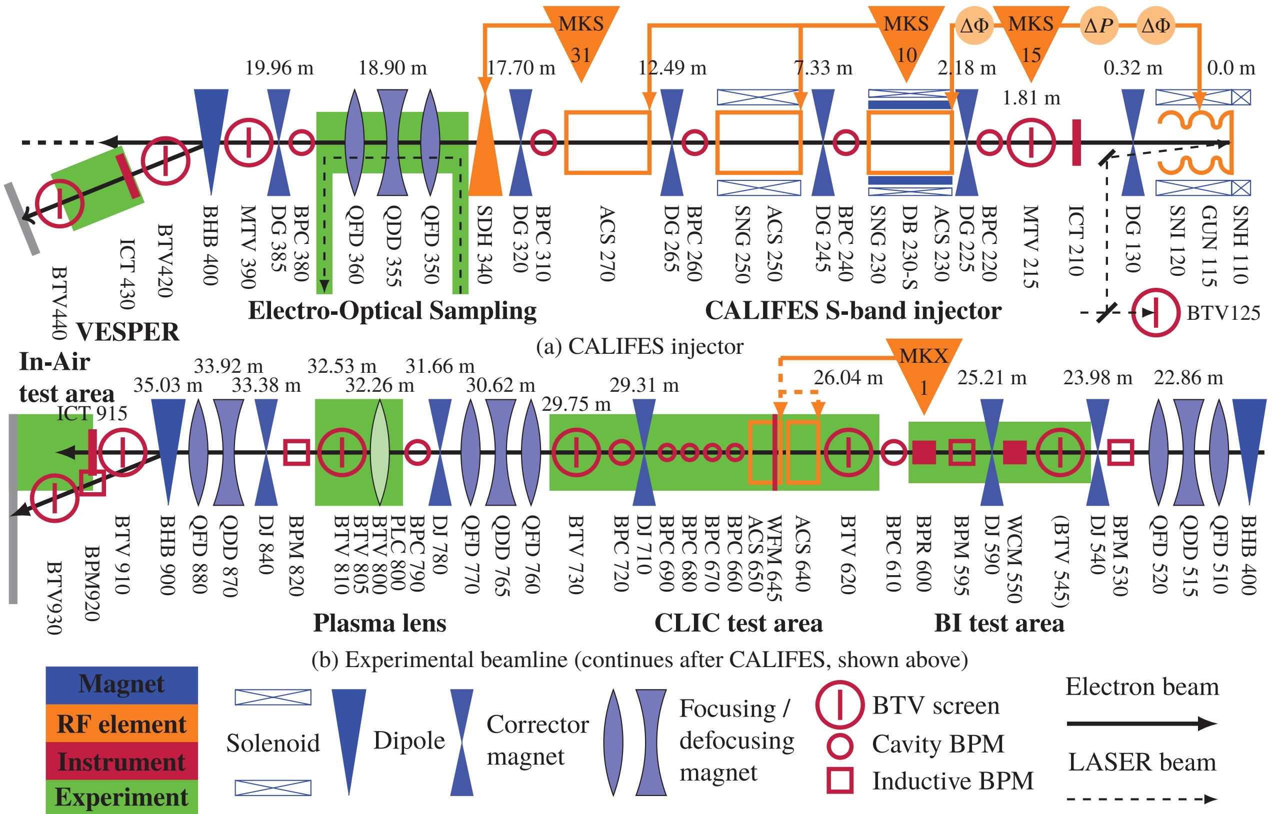

Figure 1: Overview of the elements directly interacting with the beam at CLEAR beamline, and the location of the experimental stations as of April 2019. Element positions indicate the middle of each element, rounded to the nearest cm.

thus increasing the spot size to avoid saturation when working with high-charge bunches. A double-pulse setup has been created, making it possible to double up each pulse of the laser through an optical delay line. This will make it possible to inject two bunches into the same RF bucket, with adjustable distance.

It is also possible to collect and accelerate the dark current produced by the gun in order to make a long train with sub-pC bunch charge. This is sometimes used for radiation hardness testing of electronics.

For the RF system, the connection of the RF deflector to its klystron was completed, making it operational. Further, upgrades of the modulators for the other klystrons were also done, helping RF system reliability and brought the control system in line with current CERN standards.

On the beam-line, two quadrupoles QDD870 and QFD880 have been installed in order to provide a narrow beam-spot into the In-Air test area and to measure the beam emittance after the plasma lens using the quadrupole tuning method. Furthermore, in order for the BPMs in front of the CLIC structure to be more useful, the position of the corrector 590 and the BPMs now named 595 and 610 was swapped. The alignment of the quadrupoles and the accelerating structures has been verified and corrected by the survey group. The beam-pipe vacuum chambers passing through the quadrupoles were then aligned relatively to the magnets using a specialized conical clamp. Based on the alignment of the quadrupole beam-pipes and a point provided on the final dump, the rest of the machine was aligned using a laser passed through the center of the beam pipe from one end to the other. This reduced beam losses, and reduced the time needed to setup a beam, especially for the experiments located after the CLIC test area, which is the main aperture restriction.

An on-line optics model has been implemented, allowing the operators to immediately estimate the impact of beam optics changes [9]. This has been very useful for experiments requiring precise control of beam waists such as the plasma lens experiment and CLIC module tests, as well as greatly simplifying beam setup.

One issue that was found and corrected during the 2018/2019 winter shut-down was the calibration of the beam charge monitors. These devices are Integrating Current Transformers (ICTs) [10], and 3 such devices are installed in the CLEAR linac and used as the main beam charge monitoring devices. The error was due to a misunderstanding of the operation of the self-calibration system, resulting in a measured charge exactly 10 times smaller than the actual. The wrongly reported charge was noticed by experiments, and then confirmed by using the calibration standard normally used to calibrate the inductive BPMs.

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EXPERIMENTAL PROGRAM

A number of experimental stations are installed along the beam line, as marked on Figure 1. Some of these host permanently installed experiments like the CLIC test area and the plasma lens experiment. Others are used by several experiments, such as VESPER and the in-air test area.

The whole or parts of the machine itself are also used for experiments, such as beam dynamics studies of the RF-gun [7], and measurements of typical magnetic stray fields in a linear accelerator tunnel during operation [11].

VESPER Electronic Component Irradiation

The The Very energetic Electron facility for Space Planetary Exploration missions in harsh Radiative environments (VESPER) test area is mainly used for irradiation of electronic components, in order to verify their functionality in radiation environments. The main user here has been the European Space Agency (ESA) for its JUICE mission [12–14], and tests of components for the ATLAS experiment have also been done. These experiments have sometimes been run in automated mode over nights and weekends, requiring only a low-intensity dark current beam.

Medical Irradiation Tests

Several tests of medical irradiation have been done at CLEAR [15], both at VESPER, and at a temporarily constructed target station immediately after QFD 520. This was done to test the effects of FLASH irradiation [16] in biological dosimeters, calibrate ionization chamber dosimeters for ultra-short VHEE pulses, and demonstrate the use of steeply converging energetic electron beams for conformal irradiation.

CLIC Module Tests

The CLIC test area contains two CLIC-type accelerating structures with integrated damping of long range wake fields [17], mounted on a movable girder [18, 19]. These structures were originally installed as part of the two-beam test stand, and are currently not connected to an RF power source. They are currently used for measurements of short-range wake field kicks [20] and characterization of wakefield monitors [21], both important for reaching CLIC performance goals [22, 23].

Furthermore, four modified CLIC-type prototype cavity BPMs are installed just downstream of the accelerating structures. Here, the BPMs themselves as well as the associated electronics are currently being tested, with initial tests indicating that a more robust in-tunnel electronics design is needed [24]. This is currently under development [25] and we expect to test it in 2019.

Plasma Lens

Active plasma lenses is a technology enabling strongly focusing magnetic lenses for charged particle beams. Different from magnetic quadrupoles, they focus the beam radially, i.e. simultaneously in the horizontal and vertical plane. This removes the need for using multiple lenses to control the beam size, and may have important applications for future linear colliders [26] and particle sources [27].

The CLEAR plasma lens experiment [9, 28] has until now mainly focused on showing emittance preservation and (non-)uniformity of the focusing gradient in different gasses. In 2018 the effect of the gas type on the development of focusing non-linearities was demonstrated, showing that a linear focusing field and preservation of emittance can be achieved through the use of argon gas [29].

In-Air Test Stand

This is an optical table at the end of the beam line, before the dump. This is used for experiments in terahertz generation [30] and tests of novel beam instrumentation for measuring beam position, beam profile, and bunch length [31].

NEAR-TERM PLANS

An upgrade of the current analog BTV beam observation system, which is heavily used for both beam setup and experiments, is under testing. A Bassler GigE camera has been installed at BTV 620, sharing the light from that OTR screen using an optical beam splitting mirror. This has shown that such cameras can function in the environment at CLEAR.

The inductive BPMs, which originally were installed on the CTF3 drive beam, have been modified to work with the lower bunch charges of CLEAR, and are currently in the process of being fully commissioned.

The wave-guide line for connecting the Xbox-1 X-band RF station [32, 33] to the CLIC accelerating super-structure has been built [34], however due to technical issues with the klystron it is not yet connected. We expect this to happen during 2019, and will enable to resume high gradient studies with beam, as well as increase the beam energy for the last part of the experimental beamline.

Furthermore, a second experimental beam line is being planned [35], and will be connected at the location of the VESPER spectrometer bending magnet shown in Figure 1. This will enable the installation of more experiments, as well as simplifying experiments needing a strongly focused beam in air, without needing to dismantle parts of the beam-line as was done in 2018.

CONCLUSION

CLEAR has just finished its first two years of operation, and in this time a large number of experiments have been successfully accomplished in a wide variety of fields. Due to increased operational experience and hardware commissioning, the operational efficiency and beam quality is steadily improving. We look forward to continuing this program, including future additions of experiments and capabilities.

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