Operational Experience at the Superconducting Electron Accelerator S–DALINAC *

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Abstract

The S-DALINAC is a recirculating superconducting electron linac operating at 3 GHz. The accelerator delivers cw-beam to various experiments with energies from 3 to 120 MeV and currents from 1 nA to 60 μA covering a wide dynamic range. Since August 1991, some remarkable progress has been achieved:
The unloaded quality factors of the twelve niobium cavities were increased by chemical treatment, now ranging from $8 \cdot 10^8$ to $2 \cdot 10^9$, while the accelerating gradients of all cavities exceed 5 MV/m by far.
In 1995, all cavities were equipped with new superconducting input couplers providing variable coupling strength. In addition, a superconducting 2-cell capture cavity (β=0.85) was installed as the first element of the injector. Beam transport properties of the main linac were improved by installation of three cold quadrupoles in the cryostat. All devices operate successfully.
Further measures in beam diagnostics were taken. Diagnostic stations for the determination of transverse and longitudinal beam properties, using transition radiation emitted from a thin foil and computer graphics processing, have been developed and are used routinely now. To measure easily even small beam currents without disturbing the beam, rf cavities with low Q have been developed. Using a simple setup, currents down to some nA can be detected.

Introduction

The S–DALINAC [1] is a superconducting recirculating linear electron accelerator at Darmstadt, the layout of which is shown in Fig. 1. The electrons, emitted from a thermionic cathode are electrostatically accelerated up to 250 keV. In the Chopper/ Prebuncher section (at room temperature) the continuous electron beam gets its time structure, which is necessary for the following acceleration in the superconducting S-band cavities. The injector consists of a 2-cell capture cavity (see below), a 5-cell cavity and two one meter long 20-cell cavities fabricated from RRR 280 niobium and operated in liquid helium at 2 K. Within 5 meters, the electrons are accelerated up to 10 MeV and can either be used for low energy experiments or bent by 180° for injection into the main linac. With eigth 20-cell cavities the energy of the beam can be increased by 40 MeV. The beam can either be recirculated twice or extracted after each linac passage. From the first recirculation the beam can be bent and matched to the undulator of the Free Electron Laser.

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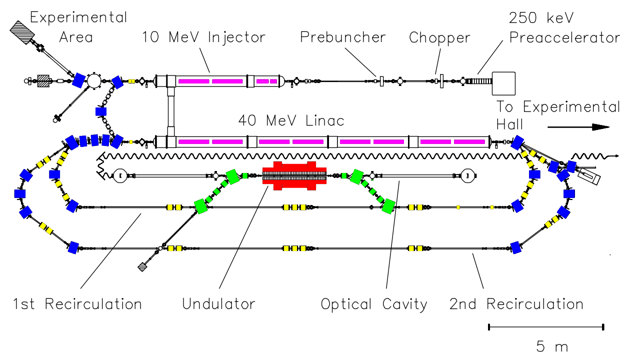

Figure 1: Layout of the S–DALINAC accelerator hall.

Accelerator Operation

Since August 1991 the S–DALINAC has delivered more than 11.500 hours of beamtime for a variety of nuclear and radiation physics experiments. The electron beam produced covers a wide range of energies and currents to fulfill the different needs. Energies up to 10 MeV from the injector are used for nuclear resonance flourescence (NRF) experiments [2], for production of channeling radiation (CR) [3] and parametric X-rays (PXR) [4]. Beam energies from 22 to 120 MeV were used for high energy channeling and parametric X-rays as well as for coincident (e,e′,x) and single arm (e,e′) electron scattering experiments. These experiments use a cw beam with a bunch repetition rate of 3 GHz or 10 MHz for time of flight applications. For driving the Free Electron Laser (FEL) project [5], a bunch charge of 6 pC is

Table 1: Delivered beams from the S–DALINAC.

Experiment	**Energy** *(MeV)*	**Current** *(μA)*	**Mode**
NRF	**2.5**- 10	**40**	3 GHz, cw
CR, PXR	3 - 10	**0.001** - 10	3 GHz, cw
CR, PXR	35 - 85	1	3 GHz, cw
(e,e’), (e,e’x)	22 - **120**	5	3 GHz, cw
FEL	30 - 38	$\mathbf{2.7} A_{peak}$	10 MHz, cw

necessary, which is obtained at a repetition rate of 10 MHz, using a subharmonic chopper/ prebuncher section. The different energies and currents produced by the S–DALINAC together with the coresponding experiments are summarized in Tab. 1. The energy spread of the accelerator is $\Delta E/E = \pm 2.5 \cdot 10^{-4}$.

Cavity Performance

In the fall of 1993 two ceramic windows of rf feedthroughs had developed strong leaks, which caused a degradation of the unloaded quality factor of most of the cavities to the lower 10^8 range. Due to the limited cryogenic cooling (about 100 W at 2 K) this limited the achievable energy to 50 MeV even when recirculating the beam twice. Therefore it was necessary to increase the cavity Q_0 by chemical polishing of the inner surface of all cavities. In two maintenance periods all ten 20-cell cavities and the 5-cell cavity were taken out of the cryostat, chemically treated and reinstalled. Two different cleaning methods were applied: With the help of DESY we were pleased to use the TTF [6] chemistry and clean room infrastructure for two cavities. After ultrasonic cleaning, a layer of 1 μm thickness of the inner surface was removed by BCP (1:1:2). The cavities were rinsed with ultra pure water (18 MΩcm) and dried in a class 10 clean room. The other cavities were treated in our laboratory. After ultrasonic cleaning the inner surface was first oxidized by HNO_3. then the oxide was removed by HF. Finally the cavities were rinsed with ultra pure water and dried with filtered nitrogen. As a result the unloaded quality factors of all cavities increased by at least a factor of two, reaching now $8{\cdot}10^8$ to $2{\cdot}10^9$, but still below the design value of $3{\cdot}10^9$. The accelerating gradients of all cavities exceed the design gradient of 5 MV/m by far, some cavities reach 10 MV/m after a short processing. The average gradient of all cavities is presently 6.7 MV/m, while the mean quality factor is $8.9{\cdot}10^8$. This determines in conjunction with the limited cryogenic cooling the maximum electron energy to 120 MeV at present.
After several warmup and cooldown periods another effect was observed. While all the cavities were not touched in any sense (not removed from the cryostat, held under vacuum), some of them show a certain time dependency of the unloaded quality factor. Directly after cooldown, some cavities start at a rather low Q_0 and show field emission at a certain gradient. After simply operating the cavities at a medium gradient for 15 minutes the Q_0 increases by a factor of 3 and the field emission observed before vanishes completely. This effect was observed many times for certain cavities, while other cavities show no change in the unloaded quality factor during operation.

Accelerator Improvement

Together with the replacement of the sc cavities, several new components were installed in the accelerator. All cavities were successively equipped with new rf input couplers (Fig. 2) providing variable coupling strength ($10^7 \leq Q_{ext} \leq 10^{10}$) by changing the distance between the antenna and the coaxial resonator. This variability has proven to be very useful, since it allows an optimum in matching the different beamloading and microphonic perturbation conditions. For diagnostic purposes one is able to couple critically.

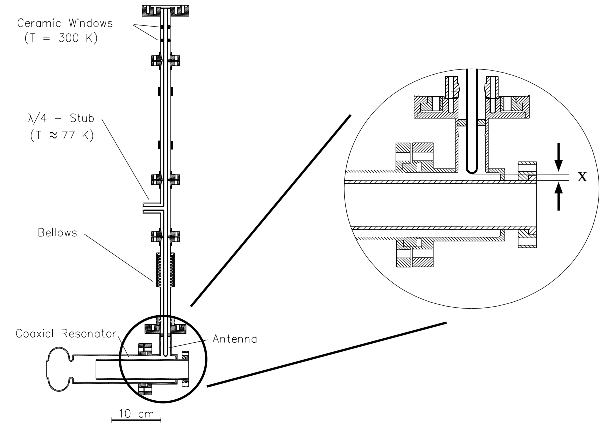

Figure 2: Cut of the tuneable sc input coupler.

As the first element of the sc injector a new 2-cell capture cavity has been installed. The cavity has a reduced phase velocity of β = 0.85 and provides an energy gain of 350 keV over a length of 8.5 cm when operated at a gradient of 5 MV/m.
To improve the transverse acceptance of the accelerator four quadrupoles were installed on the main linac axis. One quadrupole is placed outside the cryostat in front of the linac, while the other three quadrupoles had to be installed inside the insulating vacuum of the cryostat. Therefore they where designed to be superconducting, using a NbTi wire (NbTi filament surrounded by Cu) and special low temperature magnetic material called CRYOPERM 10 to form the poles and return chokes. The maximum gradient is 1.5 T/m, the effective length 5.6 cm. After installation it turned out, that the cooling of these quadrupoles is not sufficient (they only reach 22-25 K). Nevertheless, the resistance of the coils becomes low enough to operate them at their nominal gradient with a dissipation of 0.5 W per quadrupole.

Beam Diagnostics

Since 1994, several new beam diagnostic stations along the accelerator have been installed. A detailed discussion of beam diagnostics at the S–DALINAC using transition radiation can be found in [7, 9]. Therefore only a short description for the determination of transverse and longitudinal beam properties is given. Moreover, a new setup measuring the beam current without disturbing the beam using a low-Q rf-cavity is reported.

Transverse Phase Space

The experimental setup for observation and analysis of optical transition radiation (OTR) is shown in Fig. 3. The radiation emitted from a 25 μm thick aluminium foil being hit by the electron beam is observed through a vacuum window with a CCD camera which is well shielded to avoid radiation damage. The signal from the CCD is digitized by a framegrabber installed in a PC. The analysis of the grabbed picture is performed on a alpha-VAX using the special data language IDL [8]. This setup allows

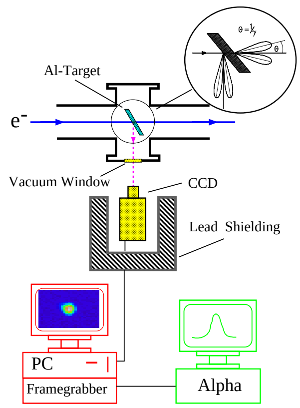

Figure 3: OTR diagnostic station.

within seconds emittance measurements, using the three gradient method, and has been used at energies ranging from 250 keV to 120 MeV. Currently five OTR-setups are installed along the beamline and are used routinely.
The same setup is used to determine the energy spread of the electron beam in a dispersive section of the beamline. The online determination of the energy spread is an important help in optimizing the rf phases of the cavities.

Longitudinal Phase Space

For operation of the FEL, knowledge of the bunch length, i.e. the peak current is essential. The setup shown in Fig. 4 uses the coherent part of the transition radiation in the far infrared. The

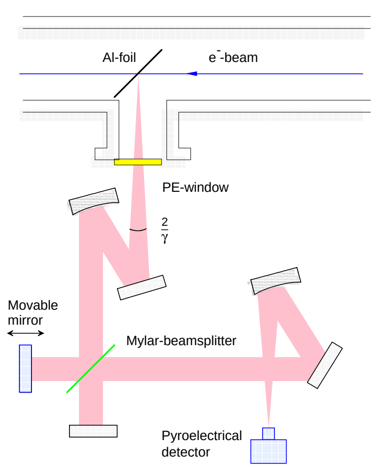

Figure 4: Interferometer setup for bunch length measurement with transition radiation.

radiation passes through a Michelson interferometer consisting of a mylar beamsplitter, one fixed and one movable mirror and is detected in a pyroelectric detector. Analyzing the measured autocorrelation in frequency space taking into account the spectral properties of the setup finally yields a bunch width of 4 ps in a nearly gaussian distribution, which was confirmed by a streak camera measurement using spontaniously emitted ligth from the undulator of the FEL. A detailed description of the setup and the analysis can be found in [9].

Nondestructive Beam Monitoring

To measure the beam current and position without stopping the beam new rf cavities were developped. The low quality factor (1800 for the current monitor, 1000 for the position monitor) of these cavities build from stainless steel 4301 leads to a negligible temperature sensitivity. Once calibrated these monitors operate without temperature control and need no adjustment. With a simple setup using frequency modulation a sensitivity of 20 nA for the current monitor and 0.3 mm/μA for the position monitor could be achieved. Presently two monitors are installed, one in the injector and one in the extraction beamline.

Outlook

For further increase of the quality factors of the sc cavities, a high pressure water rinsing system will be installed and will be available in fall of this year, which will hopefully lead to a $Q_0 = \mathbf{3} \cdot 10^9$. The beam transport system will be further optimized which is expected to result in improved transverse stability and a reduced energy spread by making use of nonisochronous recirculations. Beam diagnostics especially the nondestructive monitoring will be installed in every recirculation and in front of every experimental area.

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