OPERATION OF THE S-DALINAC, RELATED TOPICS AND DEVELOPMENTS[1]

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Abstract

The recirculating electron accelerator S-DALINAC with its superconducting cavities provides a continuous wave (cw) beam up to 130 MeV for a wide range of nuclear and radiation physics experiments and works as a driver for the Darmstadt Free-Electron-Laser. During one decade of operation experience has been gained concerning cavity parameters, beam dynamics and diagnostics. For improvement of the online diagnostics wide band rf monitors were developed measuring the electron beam intensity with a resolution of 10 nA and the location with a resolution of 0.1 mm @ 1 µA and are in use very successfully. Studies of the transverse phasespace were performed using optical transition radiation and tomographic techniques. A setup for electron bunch length measurements using electrooptical sampling of the electric fields in a ZnTe cristal with a Ti:Sa laser has been developed and tested. Longitudinal and transverse beam dynamics calculations led to an optimisation of the acceptance and stability of the S-DALINAC beam transport system by converting the recirculating system from isochronous to nonisochronous operation. A 2 K testcryostat was commissioned to perform systematic measurements on the influence of different treatments on the Q value of the superconducting cavities.

1 INTRODUCTION

The S-DALINAC [1] is a sc electron accelerator having been developed and being used in the environment of a university for research in low energy nuclear and radiation physics. Since 1987 the S-DALINAC has delivered some 20.000 hours of beam time for a large variety of experiments. The requirements on the electron beam parameters differ very much, i.e. continuous 3 GHz electron beams with energies between 2.5 and 120 MeV and intensities from 1 nA to 50 µA have been produced as well as high intensity beam with a 10 MHz time structure for Free-Electron-Laser (FEL) [2] operation. New experiments are planned which will further expand the range of the parameters. For optimizing the beam quality under the very different conditions of every single experiment it was and still is necessary to improve beam diagnostics and dynamics as well as the properties of the superconducting niobium cavities. It has been experienced that investigations and new developments for a single experiment may improve the quality of experimental results in completely different fields by synergy effects. Some special topics and results of the last two years of S-DALINAC operation are reported here.

Following a brief description of the accelerator in Sec. 2 we turn to properties of the sc cavities in Sec. 3. Improvements of diagnostics equipment and beam dynamical properties are covered in Sec. 4 and 5 respectively.

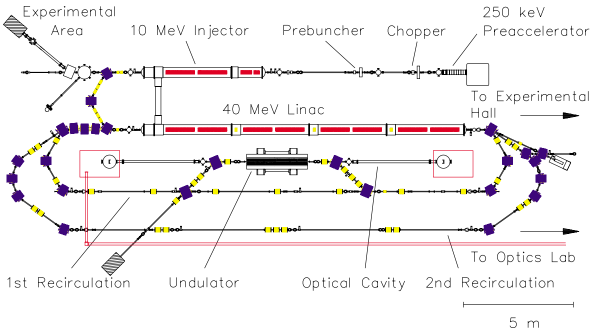

Figure 1: Layout of the S-DALINAC (see text).

2 S-DALINAC

The principle of operation of the superconducting recirculating electron accelerator S-DALINAC is illustrated by the layout shown in Fig. 1. The electrons are emitted by a thermionic gun and then accelerated electrostatically to 250 keV. The required time structure of the electron beam for rf acceleration in a 3 GHz field is prepared by a chopper/prebuncher system operating at room temperature. The sc injector linac consists of one 2-cell, one 5-cell, and two standard 20-cell niobium structures, cooled to 2 K by liquid helium. The maximum electron energy behind the injector linac is 10 MeV. The electron beam can either be delivered to radiation physics

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or nuclear resonance fluorescence experiments or bent isochronously by 180° for injection into the main linac consisting of eight 20-cell cavities, and reaching a maximum energy gain of 40 MeV per pass. Thus, using two recirculations, a maximum electron energy of 130 MeV can be achieved. The electron beam can be used for different types of experiments such as high energy radiation physics or electron scattering experiments in two electron spectrometers. Additionally, in the first recirculation beamline, the FEL is located and can make use of the electron beam with 50 MeV maximum energy.

3 ACCELERATING CAVITIES

The design parameters of the S-DALINAC assumed for the 1 m long, 20-cell cavities an accelerating gradient of $E_{ac} = 5$ MV/m and an unloaded Q of $Q_0 = 3\cdot10^9$. For the gradient this seemed rather challenging in the late 70s, the figure for Q_0 seemed reasonable, even though it is less than a factor of two below the BCS limit. Operation of the S-DALINAC over almost ten years now has shown that all of the installed cavities easily exceed 5 MV/m. On the other hand none of them has reached $Q_0 = 3\cdot10^9$ yet when installed in the accelerator but only $1\cdot10^9$, even using different kinds of preparation techniques.

In order to find the reason for this still unexplained phenomenon we have set up an external vertical 2 K cryostat which allows us to perform systematic studies without interfering with accelerator operation. It is planned to use ‘first generation’ (low RRR) cavities and in a later stage of the project also the two spare cavities of the S-DALINAC as samples. One goal is the development of a magnetic shielding, optimized for the complicated geometry of a ‘real world’ cavity, equipped with tuner, rf couplers, and beam tubes. Separately we intend to take a systematic second look into the application of well proven chemical, mechanical, and thermal preparation methods. Since the slim geometry of a 3 GHz, 20-cell cavity is rather unfavorable for any preparation method, it might turn out that we need modifications in the application of the different preparation techniques.

4 BEAM DIAGNOSTICS

4.1 RF Monitors

A combination of 3 GHz rf cavities has been developed to obtain non destructive online diagnosis of beam intensity and position in different locations. They had to have good UHV properties and should be rather insensitive to ambient temperature changes of ± 2°C, in order not to need tuning devices or temperature stabilization. The result is a combination of cylindrical TM_{010}- and TM_{110}-cavities as shown in Fig. 2. The cavities are fabricated from stainless steel, they have a common center piece and two covers which connect to the beam line. The rf outputs use ceramic feedthroughs. All seals are standard CF copper gaskets, except one which differs in diameter. The cavities are operated at loaded Qs of less than 1000, which ensures that no frequency tuning is required.

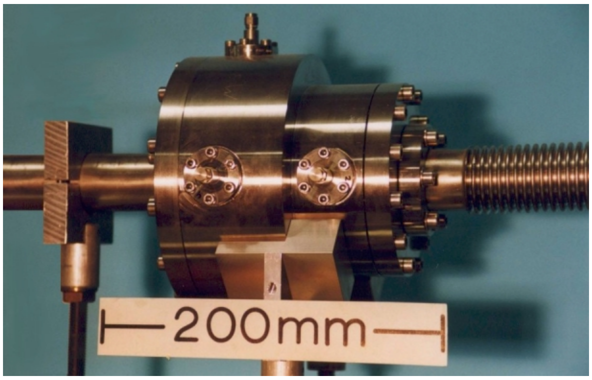

Figure 2: Non intercepting 3 GHz rf monitors.

The resulting sensitivities amount to 15 nW/(μA)^2 for the intensity monitor and to 15 pW/(mm μA)^2 for the position monitor. For signal processing dedicated electronics were developed. Lockin technique is used to compensate for the rather low sensitivities of the rf cavities. Using an effective bandwidth of 1 Hz, changes of the beam current of 10 nA or 0.1 mm in position (at a current of 1 μA) are clearly detectable. Monitors have been installed in front of the injector linac, behind the main linac, at the beginning and at the end of the straight sections of both recirculations, and in the beam line to the experimental hall.

4.2 Transverse Phase Space Tomography

For diagnosis of the transverse beam parameters a setup for imaging the transverse intensity distribution of the elctron beam consisting of an optical transition radiation (OTR) target, a CCD camera and a PC with framegrabber card is used. As an additional tool this setup was expanded by a computer code written in the Interactive Data Language (IDL) for reconstructing the transverse phase space with tomographic algorithms. The advantage of this method is the capability of reconstructing the beam distribution in phase space without assuming any shape.

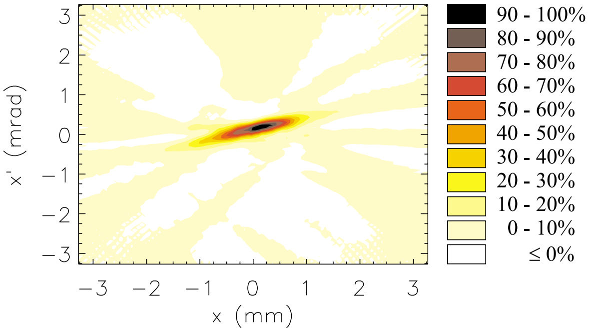

Figure 3: Reconstruction of the horizontal phase space.

The accuracy of the filtered backprojection algorithm was properly investigated. In simulations with 18 projections interpolated to 90 projections an unsymmetrical phase space distribution could be reconstructed with an emittance error of less than 15%. First measurements at the injector linac of the S-DALINAC at an energy of 8 MeV showed good agreement of the emittance with respect to the common method. Figure 3 shows the reconstruction of the horizontal phase space distribution with an emittance of $\varepsilon_n = 2.14\,\pi$ mm mrad.

4.3 Bunch Length Measurement

A recently developed method for electron bunch length measurement based on electrooptical detection of the bunch's coulomb field has been build up in an experimental section behind the injector linac. A ZnTe crystal has been placed some mm near the electron beam to become temporarily berefringent while the 2 ps long electron bunches with 6 pC charge pass by. With a synchronised Ti:Sapphire laser with 60 fs pulse duration and suitable polarisation optics a change in the laser light polarisation with the time structure of the electron bunch distribution should be detectable.

Nevertheless no electrooptical signal was found in a first experiment, even though the expected change in polarisation was in the order of 10^{-4} whereas the detection limit was 10^{-5}. Also, the remaining phase error of the synchronisation was 4 – 5 ps, but will be decreased with a new synchronisaton setup.

5 BEAM DYNAMICS

A review of the longitudinal as well as the transverse beam dynamics in the two recirculating beam lines of the S-DALINAC clearly indicated possible improvements. Longitudinally the recirculation scheme was isochronous. Following the considerations of H. Herminghaus [3] we investigated numerically to which extend a deviation from the isochronous scheme could be beneficial. It turned out that even in the special situation of the S-DALINAC (only two recirculations and only three passes through the linac) the influence of amplitude- and phase jitter on the energy spread of the beam can be suppressed considerably. The combination of a synchronous phase of -9.5° and a longitudinal dispersion of $r_{56} = -1.5$ mm/% still ensures an energy spread of $(\Delta E/E)_{FWHM} = 10^{-4}$ even if an amplitude jitter of $\pm 10^{-3}$ for the accelerating fields in the main linac is assumed.

In order to obtain experimental proof for the result of the simulations we used the existing quadrupole lattices with modified settings to approximate the non isochronous situation. The electron beam, after passing through a momentum defining slit system, was analysed with respect to its energy distribution in an elastic scattering experiment, using a magnetic spectrometer. This experimental test showed that in the isochronous case the energy spread of the beam increased when the width of the slits was increased, whereas it remained constant in the non isochronous case (which means that the energy spread of the beam was indeed smaller, when accelerated in the non isochronous scheme).

The transverse properties of the straight sections of the recirculating beam lines, each consisting of two quadrupole dubletts and one triplett were investigated systematically with respect to their acceptance and their tolerance versus field errors (e.g. due to remanent fields). The acceptance could be increased by more than a factor of four. Sensitivity to field errors was reduced by a factor of two to three. We have therefore already modified the quadrupole lattice in the beam line of the first recirculation (arcs and straight section). Conversion of the second recirculation is scheduled for the next shutdown.

6 CONCLUSION

For the S-DALINAC considerable improvement was achieved with respect to the beam dynamical properties of the two recirculating beamlines. In addition, 3 GHz rf cavity monitors and the necessary electronics for non destructive monitoring of the beam intensity and position have been developed and are incorporated in the accelerator at seven locations. A computer code for reconstruction of the transverse phase space distribution was written and tested and can be used as an additional tool in transverse diagnostics. First measurements of the bunch length by electrooptical sampling led to further improvement of the experimental setup. For efforts, necessary to improve on the unloaded Q of the accelerator's sc cavities, an external 2 K cryostat has been set up, to allow for systematic studies without interfering with accelerator operation.

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