LATEST DEVELOPMENTS AT THE S-DALINAC*

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Abstract

The recirculating superconducting linear accelerator S-DALINAC provides a continuous wave (cw) electron beam of up to 130 MeV for a wide range of nuclear and radiation physics experiments and serves as a driver for a Free-Electron-Laser. Here are the following topics are cosidered: (i) In order to improve the energy spread from presently 50 keV FWHM by a factor of 3-5 a new control system is under development. The concept considered first was a fully digital control system following the concept for the TTFL as a prototype for TESLA, but was later changed into a hybrid system consisting of a fast analog feedback circuit and a DSP-based unit. (ii) For online survey of the radiation background inside the accelerator hall an array of Compton diodes has been installed. The Compton diode was chosen as a detector since it was possible to develop a very compact, rugged, mechanically simple, inexpensive unit with integrated signal processing. (iii) A fast computer code (V-Code) using the model of ensembles to describe the beam properties was implemented to study injector beam dynamics. This is a first step in the development of an online tracking simulation. (iv) Results of measurements performed at the superconducting cavities which revealed the emission of light in conjunction with field emission are presented and discussed.

1 INTRODUCTION

The superconducting (sc) linear accelerator S-DALINAC [1] was developed to deliver a cw electron beam of up to 130 MeV at a current of 20 µA with an energy spread of less than $3\cdot 10^{-4}$ for nuclear and radiation physics experiments.

After a brief description of the accelerator itself in Sect. 2, the present suggestion for an improved RF-Control System is listed in Sect. 3, followed, in Sect. 4, by a description of Compton diodes, developed for photon background detection inside the accelerator vault. Section 5 deals with the adaption of a fast tracking formalism, V-Code [2], for the injector of the S-DALINAC and in Sect. 6 results of meassurements of a cavity that shows field emission at gradients above 5 MV/m are presented.

2 ACCELERATOR

The S-DALINAC uses a thermionic gun located inside a high voltage terminal at 250 kV. After the electrostatic preacceleration the beam enters a chopper-prebuncher section where it gets a 5 ps time structure with a repetition rate of 3 GHz.

Additionally, a 600 MHz subharmonic chopper/buncher section together with a pulsed electron emission provides a 10 MHz time structure with a bunch charge of 6 pC for FEL operation.

The sc injector linac consists of a two-cell capture cavity (ß=0.85), followed by a fife-cell cavity (ß=1.0) and two 20-cell cavities, thus at accelerating gradients of 5 MV/m the injector can deliver an electron beam with a maximum energy of 10 MeV which either may be used for low energy radiation or nuclear resonance fluorescence experiments or it can be bent by 180° for injection into the main linac. The eight 20-cell cavities of the main linac provide a maximum gain of 40 MeV. Two recirculating beamlines allow 3 passes through the main linac, resulting in a maximum beam ernergy of 130 MeV. After each pass the beam can be extracted to the experimental hall for use in electron scattering and high energy radiation experiments. Alternatively the beam can be used as a driver for the infrared FEL, installed along the accelerator as a bypass to the first recirculation.

3 NEW RF CONTROL SYSTEM

In the existing RF control system at the S-DALINAC [3] the 3 GHz probe signals of the 12 superconducting cavities are converted down into base band by a four quadrant vector demodulator, which yields the two components of an RF vector in the frame of the reference oscillator. The control itself is implemented as a self excited loop using proportional amplitude- and phase feedback circuits. The setpoints and gains for the control are currently set by an MC68020 processor, that also keeps track of the amplitude- and phase error signals. This control system has now worked for more than 12 years without major problems, but the energy spread achieved is still larger than specified in the original design. For acceleration on crest the design figure is $\Delta E/E \leq \pm 10^{-4}$, whereas the present system achieves $\pm 10^{-3}$ under these conditions. Only by using non-isochronous recirculation an energy spread of $\Delta E/E = 3\cdot 10^{-4}$ can be achieved. Therefore a new control system is being developed to replace the existing one. Since the operational experience with the existing system is quite satisfactory, the conceptual design is adapted for the new control system, but more expense is paid on improving the energy spread. There will be two measures to reach a more accurate control: First the RF components used in the existing control system will be replaced by modern and more accurate devices. The second measure is to use additional feed forward corrections. While the first replacements can be applied relatively easily, the application of feed forward corrections needs monitoring and diagnostics devices, which have the possibility to feed signals into the control loop. Since long term monitoring is feasible with a digital system, all important

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RF signals will be digitized and fed to a DSP for diagnostic purposes. In order to automate beam phase measurements, loaded Q determination etc., amplitude and phase of forward and reflected power will be measured besides the cavity probe signal. For a more accurate amplitude control there will be a separate control loop consisting of a detector diode and a PIN modulator for the driver signal to the clystron. Thus the amplitude control loop is independend of the quality of the used up- and down converters. By using such a hybrid system as sketched in Fig. 1, a maximum performance of the control loop is achieved, while still keeping the advantages (like

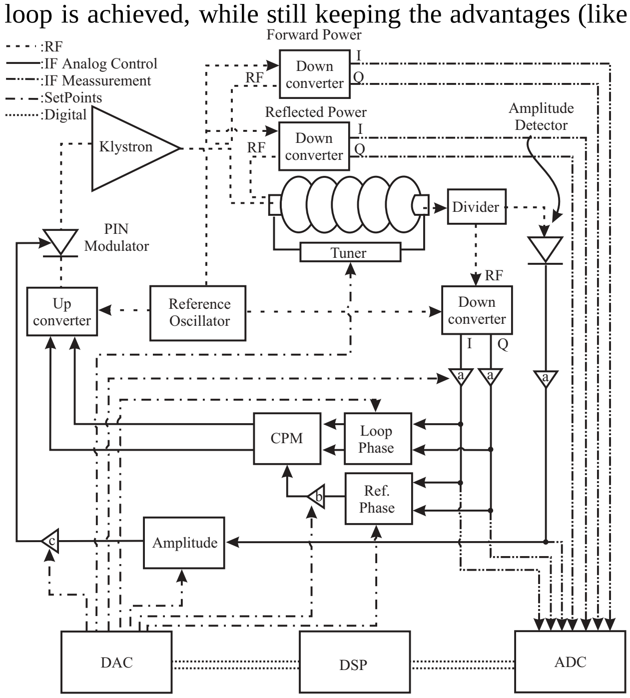

Figure 1: Block diagram of the new RF control system, where a represents the input gain, b the phase gain and c the amplitude gain.

feed forward capabilities) of a digital control system. Since the fast control is analog and additional errors like phase drifts are slow, the required conversion rate of the ADCs and DACs is in the range of a few 100 kHz. Therefore the implementation of the digital part will be easy compared to a pure digital RF control.

4 COMPTON DIODES

Since the S-DALINAC delivers electron beams for many different experiments, a wide range of beam energies and currents has to be covered. To assist the operators in setting up the beam, a distributed bremsstrahlung monitoring system for the accelerator vault has been developed. Based on Compton diodes [4] as detectors, an inexpensive and robust system with a linear response to bremstrahlung flux and minimal maintenance requirements could be established. The mechanical construction of such a Compton diode is shown in Fig. 2.

It consists of an outer aluminum electrode, a Plexiglas insulation layer and an inner lead electrode. The outer aluminum shell is 4 mm thick, the Plexiglas insulation (front part) is 20 mm thick, chosen such that the number of Compton electrons in the electromagnetic cascade reaches its maximum value at the end of the layer. The

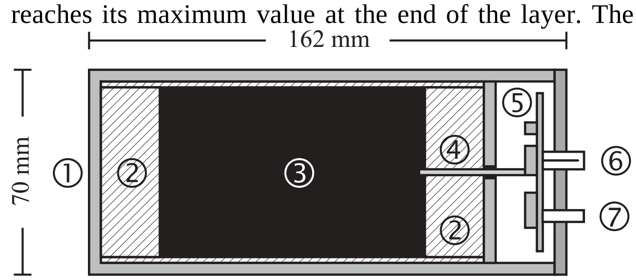

Figure 2: Schematic layout of a Compton diode, 1 Aluminum electrode, 2 Plexiglas insulator, 3 Lead electrode, 4 Copper conductor, 5 Current-to-voltage converter, 6 Signal plug, 8 Power connector.

lead electrode collects the electrons and attenuates the photon flux. Therefore, no electron current at the rear side of the lead electrode counteracting the front current is generated. The lead also shields the current-to-voltage converter located at the back of the Compton diode from bremsstrahlung. The conversion factor of the circuit is 1 V of signal for 1 nA of Compton current induced in the detector. The expected linear response was verified experimentally behind the injector and in the extraction section of the S-DALINAC at beam energies of 6.0 to 9.4 MeV and 72 MeV, respectively. The experimental results agree within ± 30 % with the predictions of the Monte-Carlo code FLUKA [5] used to optimize the design of the detector.

The response of the Compton diode to bremsstrahlung spectra with different endpoint energies were also simulated. It turns out that for endpoint energies between 10 and 130 MeV, the detector signal is approximately proportional to the photon number in the spectrum, independent of the endpoint energy.

5 V-CODE

V–Code is a new beam dynamics simulation that represents the beam as a model of ensembles consisting of six centroid and 21 correlation parameters. The dynamics of the ensemble is described by the Vlassov equation, that can be transformed into a set of 27 linear first order differential equations which can be solved easily. The code which tracks only the ensemble through the accelerator is much faster than conventional tracking codes that calculate the trajectories of several thousand macro particles. Compared to matrix based approaches V-Code is more versatile, covering a wider application field without significant speed penalties. These features make V-Code an attractive alternative to traditional beam dynamics simulations.

V-Code will support the accelerator operator with online information about the longitudinal and transverse phase space distributions of the beam at any position along the accelerator, calculated from the current machine settings. At the S-DALINAC V-Code was implemented as a pilot scheme to cover the injector section. This section consists of a prebuncher cavity, a magnetostatic lens, eleven steerer magnets, one dipole, two quadrupole magnets, and three superconducting cavities. Running on an AMD Athlon™ 800 MHz CPU V-Code needs about 5 seconds to calculate and visualize the beam dynamics of the injector. The starting ensemble is a crucial point since conventional beam measurements of beam properties yield only 9 parameters to describe the beam. Therefore currently the beam properties at the chopper iris are calculated by a seperate simulation and used as a starting ensemble. To determine a starting ensemble experimentally and to compare the simulation with measured results, a new method relying on tomographic techniques to measure transverse phase space distributions was further implemented at the injector of the S-DALINAC.

6 CAVITIES

During operation of the S-DALINAC field emission accompanied by the emission of light was observed in four of the 12 superconducting cavities. This phenomenon under different experimental conditions has been reported by several authors before [6,7]. The observed light sources were located at the irises of the cavities and detected by a CCD camera placed at the beam line exit of accelerator. Three different locations of light spots were determined by means of varying the focal length of the CCD camera. A first light spot was observed starting at an accelerating gradient of 4.1 MV/m. The number of luminous spots and their intensity could be tuned by increasing the electric field in the investigated cavity in a range up to 8.2 MV/m. All the observed spots were very stable during the experiment. Using a spectrometer set up with high resolution the spectrum of the optical radiation (see Fig.3) has been measured. It shows a sharp peak at

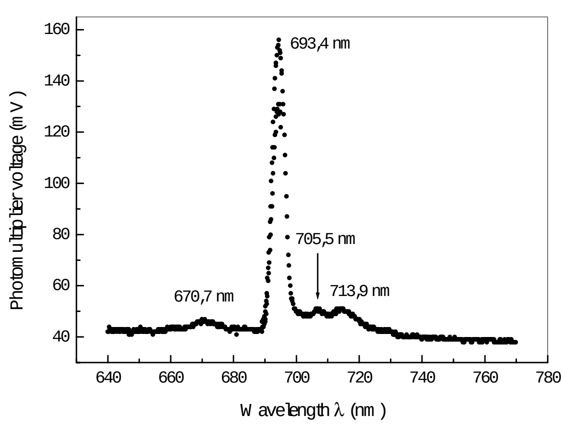

Figure 3: Spectrum of the optical radiation.

693.4 nm and three small ones at about 670.7 nm, 705.5 nm, and 713.9 nm. This spectrum was identified as a fluorescence spectrum of Cr^{3+} in Al_2O_3. However, presently we cannot totally exclude the possibility that the observed lines are due to scattered light from a different source.

The maximum energy of the emitted electrons from the cavity was determined to be 6.5 MeV from the bremsstrahlung spectra measured with a BGO detector for an accelerating field of 8.2 MV/m. This means that the sources of field emission must be located in the first half of the cavity. On the contrary, all the observed spots were located in the second half of the cavity, some of them even in the cutoff region. This leads us to the assumption that the light spots cannot be associated with the field emission sites.

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