IMPLEMENTATION OF A HIGH LEVEL PHASE CONTROLLER FOR THE SUPERCONDUCTING INJECTOR OF THE S-DALINAC*

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Abstract

The S-DALINAC is a recirculating electron accelerator with a design energy of 130 MeV. Before entering the 40 MeV main accelerator the electron beam passes both, a normal-conducting injector beamline for beam preparation and a superconducting 10 MeV injector beamline for preacceleration. The phase of the beam which is injected into the main accelerator is crucial for the efficiency of the acceleration process and the minimization of the energy spread. Due to thermal drifts of the normal-conducting injector cavities this injection phase varies by about 0.2 degree over a timescale of an hour. In order to compensate for these drifts, a high level phase controller has been implemented. It adjusts the phase measured at an rf-monitor at the exit of the superconducting injector by changing the phase of a prebuncher in the normal-conducting injector beamline. We will present the used hardware, the control algorithm as well as measurements showing the phase stabilization achieved by this controller.

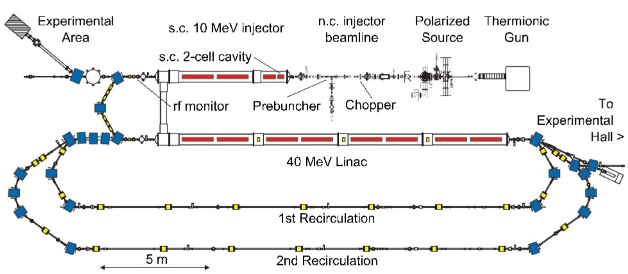

Figure 1: Floor plan of the S-DALINAC.

MOTIVATION

The Superconducting DArmstadt LINear ACcelerator S-DALINAC (see Fig. 1) is a recirculating electron accelerator with a design energy of 130 MeV that delivers electron beams with beam currents between several nA and 60 μA in cw-mode for nuclear and astrophysical experiments since 1987 [1]. The beam can be provided either thermionically and therefore unpolarized or by the photo effect from the Spin Polarized INjector SPIN [2] with a polarization of up to 86%. After beam preparation in the normal-conducting part of the injector including chopper and prebuncher cavities the electrons enter the superconducting 10 MeV injector beamline where they get preaccelerated by niobium cavities working at a resonance frequency of 3 GHz. The preaccelerated electron beam can then either be used to produce bremsstahlung for nuclear resonance fluorescence experiments at the Darmstadt High Intensity Photon Setup DHIPS [3] or be injected into the 40 MeV main accellerator. By recirculating the beam up to two times the maximum energy of 130 MeV can be reached.

It has been shown that the energy spread of the beam can be reduced significantly by using a non-isochronous recirculating mode [4]. In this case the remaining energy spread heavily depends on the correct injection phase into the main accelerator. A phase mismatch of 2° can increase the relative energy spread from $8 \cdot 10^{-5}$ to $3 \cdot 10^{-4}$. Experience shows that the beam phase behind the superconducting injector drifts and oscillates over several hours. An example measurement of the unadjusted beam phase can be seen in Fig. 2. This dynamic might either be caused by instabilities of the high voltage supply of the source or could come from thermal drifts of the normal-conducting beam preparation cavities. To compensate for these drifts a high-level phase controller has been developed.

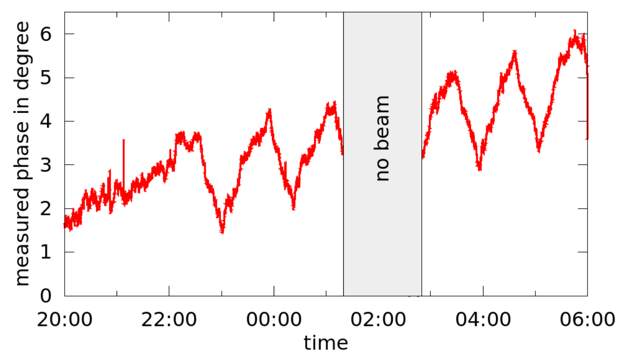

Figure 2: Measured beam phase behind the s.c.-injector with visible phase drift and oscillation.

PHASE ADJUSTMENT DEVICES

To adjust the beam phase behind the s.c. injector three devices have been tested:

Chopper

The chopper cavity converts continuous beams into bunched beams by forcing the electrons on a cone shaped trajectory and slipping them over an aperture. In this manner the chopper defines the reference phase of the beam and therefore of every adjacent rf device.

Prebuncher

The prebuncher decelerates the early electrons inside a bunch and accelerates the later ones in order to longitudi-

* This work has been supported by the DFG through CRC 634
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nally focus the beam. This is achieved by injecting the bunch exactly during the zero-crossing of the accelerating longitudinal electrical field inside the cavity. By adjusting the phase of the buncher one can achieve an additional acceleration or deceleration of the whole bunch. Since the electrons have low energy while passing the buncher these processes lead to different arrival times respectively different phases at the s.c. injector.

S.c. 2-Cell Cavity

Since the s.c. cavities of the injector are not sufficiently β-graded the first cavity is used to preaccelerate the low-energy electrons and could be used similarly to the prebuncher to adjust the phase at the exit of the s.c. injector using time-of-flight effects.

The results of test measurements shown in Fig. 3 motivate the use of the buncher for beam phase adjustments since it is the most efficient and linear device that was tested.

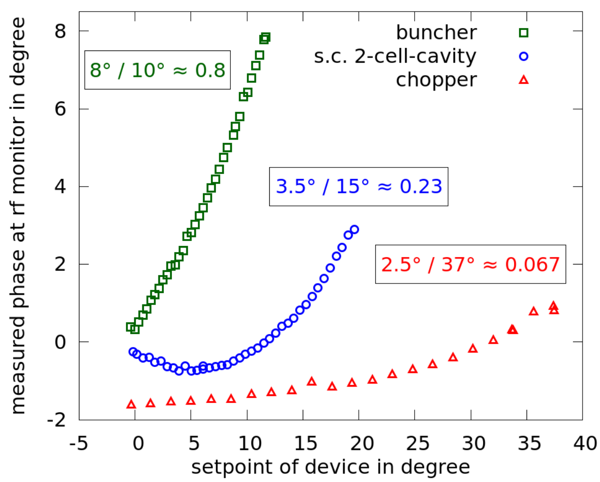

Figure 3: Measurement of the influence on the beam phase behind the s.c. injector.

IMPLEMENTATION

Hardware

The low-level control of the rf cavities is done by an in-house developed board [6] containing a Xilinx Spartan-6 FPGA. The probe signal from the cavity is mixed down to the baseband and fed to the controller board, where it is analysed. The FPGA chip uses a proportional and integral control algorithm with a high sample rate of 1 MS/s to adjust both the amplitude and the phase of the measured signal and produces a new input signal for the cavities. Additionally the board provides process data with a low sample rate of up to ten samples per second via CAN-bus.

Software

The process data provided by the low-level baseband control board over CAN-bus is read and managed by a PC acting as a EPICS-IOC (Input-Output-Controller) [5] which converts the data into a human readable format to be shown to the operators. The new developed injector phase controller is implemented as a software control-loop on this IOC.

Algorithm

The phase controller algorithm reads the measured phase from the buncher and compares it with the desired exit phase of the s.c. injector. The phase offset is then fed to the phase controller itself, that consists of a parallel proportional and integral controller (see Fig. 4). Most of the phase compensation is achieved by the proportional controller with its relatively small time constant of about 0.1 s while the weak integral controller with its time constant of over 1 s only compensates for the remaining offset that the proportional controller leaves systematically.

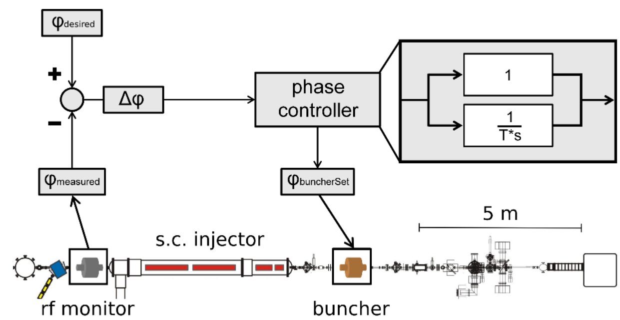

Figure 4: Schematic view of the injector phase controller algorithm.

FIRST RESULTS

Measurement results of the first test of the injector phase controller are shown in Fig. 5. The controller has been activated and monitored over several hours. It is clearly visible that the whole dynamics of the measured phase is shifted to the phase setpoint of the buncher leaving the measured phase constant. To quantify the phase stability behind the s.c. injector with and without high level controlling the beam

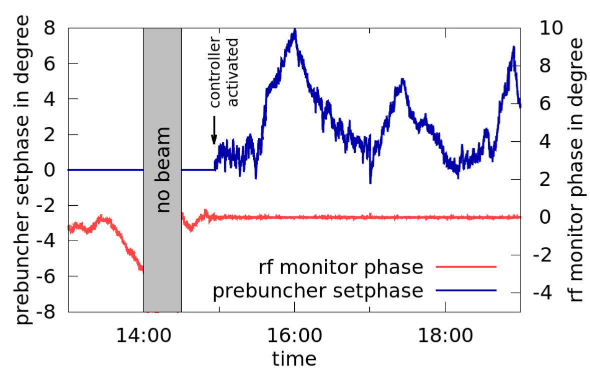

Figure 5: Comparison of the measured beam phase behind the s.c. injector and the controlled setphase of the n.c. prebuncher.

ISBN 978-3-95450-168-7

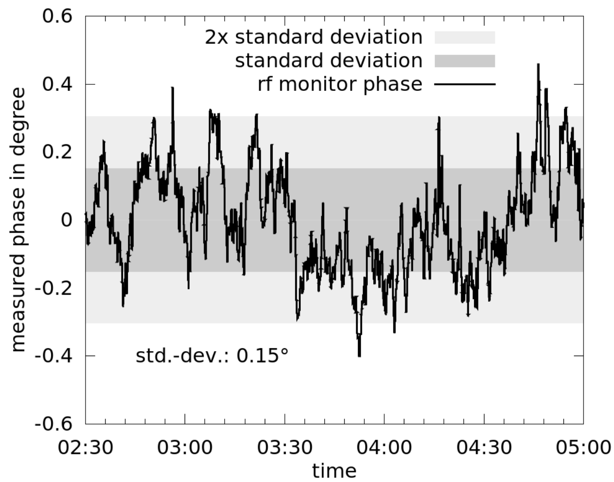

Figure 6: Measured phase behind the s.c. injector without phase controlling.

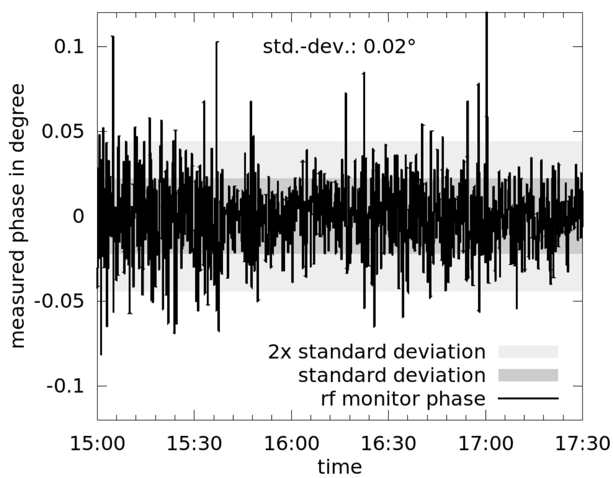

Figure 7: Measured phase behind the s.c. injector with activated phase controller.

phase has been monitored over 2.5 hours. The results are plotted in Fig. 6 and 7. The uncontrolled dataset shows a relevant time structure consisting of the already known phase drifts and oscillations on a timescale of several minutes. The controlled dataset in comparison mainly shows phase noise on a much smaller scale. Comparisons of the standard deviation of the measured phase show an improvement from $\sigma = 0.15°$ without phase stabilization to $\sigma = 0.02°$ with an active controller.

CONCLUSION AND OUTLOOK

A new injector phase controller has successfully been implemented in the control logic of the S-DALINAC electron accelerator in order to stabilize the crucial injection phase to the main linac. First test measurements show an impressive improvement of the beam phase stability by a factor of about 7.5 in terms of standard deviation. The influence on the energy spread of the beam needs to be determined and should be investigated during the next available beamtime at a spectrometer. Furthermore, the controller will be enhanced by some additional features to improve its robustness and increase its usability.

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