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COMMISSIONING AND FIRST BEAM MEASUREMENTS WITH A NEW BEAM DIAGNOSTICS FOR MEDICAL ELECTRON ACCELERATORS

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Abstract

A new beam diagnostics system was developed and built at the Siemens Healthcare Sector facility in Rudolstadt, Germany. The project goal was to develop, commission and operate a complete beam diagnostics system to fully characterize the compact medical linear electron accelerators. An overview of the whole system including the beam diagnostics, linear accelerator and control and supply unit is given. The system was successfully commissioned in July 2013. We report on initial experiences and first experimental results on current measurements, transverse beam size, transverse emittance and momentum and momentum distribution gained during the commissioning phase.

INTRODUCTION

The compact medical linear electron accelerators are built at the Siemens Healthcare Sector facility in Rudolstadt, Germany. They operate at S-band (2998 MHz) and are employed in the medicine field of radiotherapy in the energy range of 5-21 MeV. With some modifications, they can also be employed for non-destructive testing (NDT) purposes, in the lower region of their energy range. To fully characterize all linear accelerators from our portfolio [1], a complete and versatile beam diagnostics system was developed and built [2]. The operating parameter range of the electron accelerators is presented in Table 1.

Table 1: Main specifications of the Siemens S-Band compact linear electron accelerators [1]

Parameter	**6 MeV**	**21 MeV**
Output Electron	6 MeV	5-21 MeV
Output Current	max. 85 mA	max. 120 mA
Operating Frequency	2998 MHz	2998 MHz
RF-pulse length	4.2 μs	4.2 μs
RF-repetition rate	up to 300 Hz	up to 220 Hz

SYSTEM OVERVIEW

The whole diagnostics system comprises 3 main components. A high power rf supply unit together with its control console. Second, the device under test consisting of a side-coupled accelerating structure equipped with a thermionic triode electron gun. Finally, the diagnostics beamline, consisting of a Fast Current Transformer (FCT) and two Faraday Cups (FC) for beam current measurements, a steering magnet, three optical stations for transverse beam size measurement, two quadrupole magnets and a spectrometer magnet. The beam diagnostics employs also a control cabinet enclosing power supplies to energize the magnets and provision for data acquisition and communication with a control PC for data processing. A simplified schematic overview of the diagnostics beamline is depicted in Fig. 1.

COMMISSIONING RESULTS

The beam diagnostics was commissioned with a 7.5 cell linear accelerating structure. The rf power fed to the accelerator was set between 1.4 to 2.4 MW, while the initial accelerating voltage of the triode gun was set between 11 and 14 kV. During the initial commissioning phase the current injected into the accelerator was varied between 0 and 500 mA. However, the triode gun is able to provide currents in excess of 1000 mA.

Beam Current

For beam current measurements, two device types are employed. First, a non-intercepting and commercially available FCT [3] mounted on a ceramic gap at 20 cm downstream of the accelerator. The systematic uncertainty of the measurements with the FCT, while also taking machine operating point variations into account, is estimated to be about 1%. At the end of the diagnostics beamline in the straight section 250 cm downstream from the accelerator and also in the dispersive section after the spectrometer two FCs are mounted for current measurements and serve also as beam dumps. Their measurement accuracy is estimated to be ±10% [4]. Measurement results with the FCT for three rf power levels, with the injection current varied between 50 and 500 mA are depicted in Fig. 2. The measurement values represent the average current over the whole rf pulse length of about 4.2 µs.

Transverse Beam Size / Profile

Three optical diagnostic stations for transverse profile measurements are positioned along the beamline. Two in the straight section at about 50 and 250 cm from the accelerator output, respectively. The third one is mounted in the dispersive section and employs larger vacuum beam pipes compared to the other two, in order to accommodate for the dispersion of the spectrometer. All three stations are equipped with YAG:Ce scintillating crystals [5] mounted on linear stages.

The linearity of the YAG:Ce light yield to our electron beam was measured at different machine operating points. Fig. 3 depicts the YAG:Ce light yield only for an rf power level of 2.4 MW, 14 kV initial acceleration and an injection current between 50 and 500 mA. The light yield measured at lower

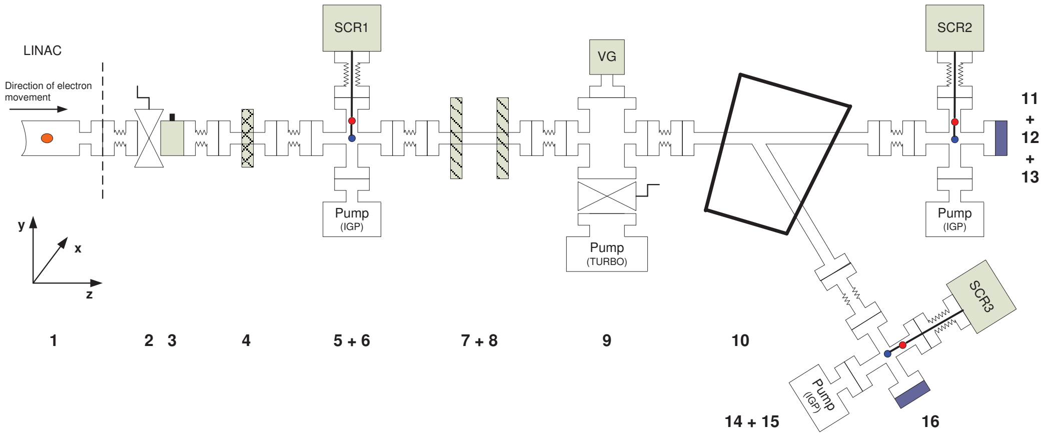

Figure 1: Schematic overview of the modular diagnostics beamline, including (1) the electron gun with the accelerating structure, (2) a gate valve, (3) FCT, (4) steering magnet, (5, 6, 11, 12, 13, 14, 15) transverse beam profile measurement stations with screen holders on linear stages together with ion getter pumps, (7, 8) quadrupole magnets, (9) turbomolecular pump with vacuum gauge and gate valve, (10) spectrometer magnet, (13, 16) beam dumps.

rf power levels would overlap with the ones already depicted. The measurements were performed at the first optical station SCR1 with the camera being operated in 12bit acquisition mode and 0 dB sensor gain.

Furthermore, a comparison between expected transverse beam profile from ASTRA simulations [6] with real beam profile measurements acquired at SCR1 is depicted in Fig. 4. A Gaussian fit of the measurement result is also depicted. The discrepancy between simulation and measurements is due to the fact that the simulations evaluate transverse beam profiles for particles with different longitudinal coordinates within the bunch.

Transverse Beam Emittance

Analytical calculations and simulations with Particle-In-Cell tracking codes were performed over the whole range described in [2]. The electron beam is over the whole operating range, described in Table 1, emittance and not space-charge dominated. Therefore, the quadrupole scan method was employed for transverse emittance measurements [7]. The beam was focused by the quadrupole magnet Quad1 and images were acquired at the optical station SCR2 about 1.35 m downstream. Expected rms beam size values from ASTRA simulations together with rms beam size values from measurements versus quadrupole currents are depicted in Fig. 5. The increment in quadrupole current was 0.25 A, with 20 signal and background images being acquired for every quadrupole current step. The predicted values for normalized transverse emittance from ASTRA quad scan simulations at 2.4 MW rf power level, 14 kV initial acceleration and 50 mA injection current amount to 55 πmm mrad. The evaluation of the quad scan measurement for the same machine operating point results in a normalized emittance of 60 πmm mrad.

During quad scans the electron beam did always go through a waist at SCR2. At no time was a saturation of the YAG:Ce light yield noticeable. However, at the highest rf power, acceleration voltage and injection current and with the available quadrupole no charge densities of the order of 0.04 pC/μm^2 as reported in [8] could be achieved.

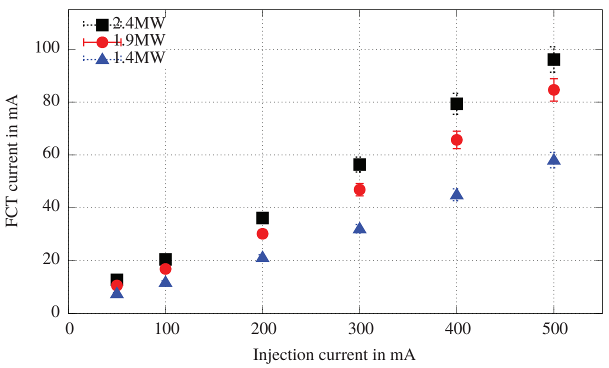

Figure 2: Beam current measurements with the FCT for an injection current between 50 to 500 mA.

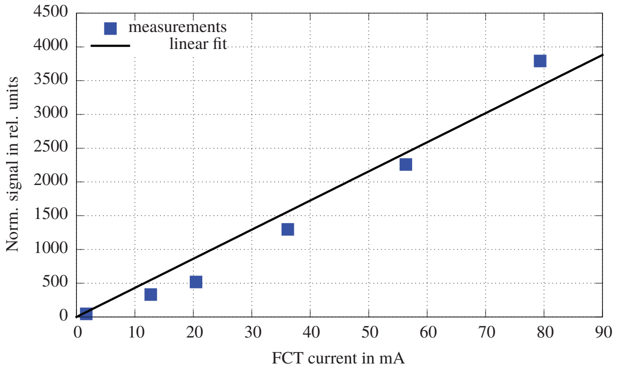

Figure 3: Light yield linearity of the YAG:Ce scintillating screen measured at SCR1.

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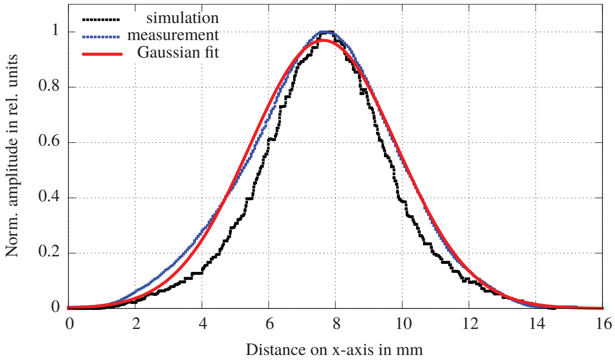

Figure 4: Comparison between simulated and measured transverse beam profiles. A Gaussian fit of the measured transverse profile is also depicted.

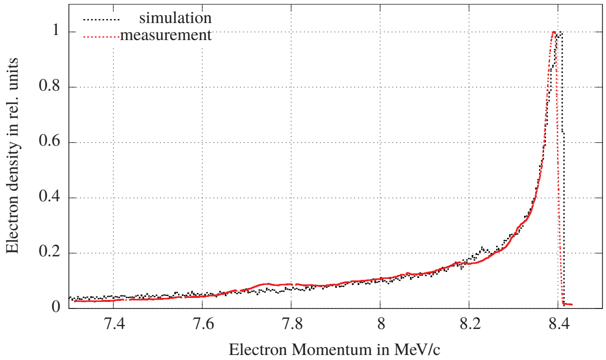

Figure 6: Comparison between simulations and measurements for a momentum distribution at 2.4 MW rf power, 14 kV initial acceleration and 50 mA injection current.

Momentum and Momentum Distribution

The momentum and momentum distribution are determined by means of a spectrometer magnet combined with the optical measurement station SCR3. The electron beam is deflected by an angle of 60° and imaged on a YAG:Ce scintillating screen. The momentum distribution is reconstructed from vertical coordinates and light intensities at the imaging screen during a sweep of the magnetic field amplitude. The total systematic uncertainty during momentum measurements is estimated to be about 2%.

A measured momentum distribution at 2.4 MW rf power level, 14 kV initial acceleration and 50 mA injection current is presented in Fig. 6 together with an expected momentum distribution from ASTRA simulations. The maximum field amplitude of the rf field in the accelerator used during simulations reads 51.80 MV/m.

The same 7.5 cell linac structure used during the commissioning phase of the beam diagnostics was also characterized using the method described in [9]. This method relies on measurements of depth dose profiles of electrons in water. The electron energy measured for the same parameters was not comparable to the results measured with the spectrometer dipole. The discrepancy between the two methods for the same machine operating point cannot be explained at the moment and has to be further investigated.

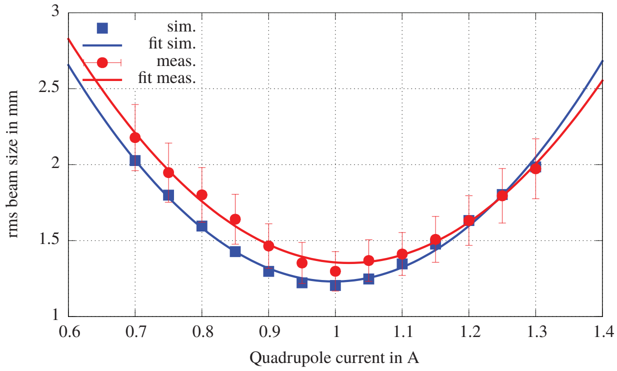

Figure 5: Comparison between simulations and measurements results for a quad scan at 2.4 MW rf power level, 14 kV initial acceleration and 50 mA injection current.

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