FIRST EXPERIENCE AT SARAF WITH PROTON BEAMS USING THE RUTHERFORD SCATTERING MONITOR

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Abstract

The first phase of the SARAF high current proton/deuteron accelerator is currently under commissioning. The first experience with 3 mA, pulsed proton beam included the measurement of the energy spectra of the protons of energies up to 2.2 MeV scattered at 45^{o} from a 0.3 mg/cm^2 thick gold foil. The beam was accelerated by the RFQ and by several superconducting resonators. The energy spectra of the scattered particles were taken for different accelerator settings. The results were compared with time-of-flight and with Monte-Carlo calculations. Monitoring the energy of the scattered particles proved to be a useful tool for beam tune and calibration of the accelerator components such as the RFQ and the superconducting resonators.

INTRODUCTION

SARAF accelerator, a medium energy high current RF superconducting linac of protons and deuterons (2 mA, 40 MeV), is currently under construction at Soreq center [1]. Phase I of the accelerator includes the Electron Cyclotron Resonance (ECR) ion source, Low Energy Beam Transport (LEBT), Radiofrequency Quadruple (RFQ) accelerator-buncher, Medium Energy Beam Transport (MEBT), Prototype Superconducting Module (PSM), Diagnostic plate (D-plate) and beam dumps (Fig. 1). A detailed description of the accelerator is out of scope of this paper and can be found in [1,2] and references therein. At the moment Phase I is fully installed and being commissioned by ACCEL-Research Instruments GmbH, in collaboration with Soreq personnel.

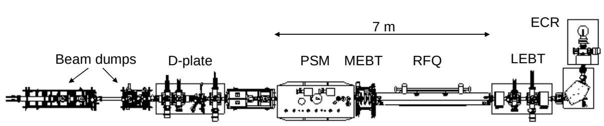

Figure 1: Overview of Phase I of SARAF accelerator.

Most of the beam diagnostics of the SARAF linac are situated on the D-plate. The main diagnostic components are: a slow Faraday cup (FC), set of vertical and horizontal slits and wires for profile and emittance measurements, two phase probes for time-of-flight measurements (TOF), two beam position monitors, a parametric current transformer (from Bergoz) and two fast FCs. Earlier report on the use of the D-plate for proton beam commissioning through the RFQ is given in [3].

Along with traditional beam diagnostics instruments, a Beam Halo Monitor (BHM) station is implemented into the SARAF D-plate [4]. The beam halo is planned to be characterized using a mini FC, on-line and off-line measurements of radiation from LiF target crystals and by monitoring energy spectra of Rutherford Scattered (RS) particles from a thin target gold foil.

The extensive use of the BHM is planned only after full commissioning of Phase I. However, a specific part of the BHM, the RS monitor, was used in the recent commissioning efforts for transport and acceleration of the pulsed proton beam through the RFQ and PSM. In this paper we present results of these measurements.

USE OF THE RS MONITOR FOR TUNING OF THE ACCELERATOR

The Conditions of the Commissioning Tests

Main commissioning tests were done in a mode where both the ECR ion source and the RFQ were pulsed. The timing overlap between these pulses defines the length of the proton pulse. Typically short pulses of 100 μsec duration at a frequency of a few Hz were used. Such low duty cycle (10^{-4}) is necessary for use of interceptive beam diagnostics. The 20 keV pulsed beam from the ECR was transported via the LEBT, bunched and accelerated to 1.5 MeV by the RFQ and further transported and accelerated for the first time by the PSM module. The module contains six Half Wave Resonators (HWR) made of bulk Nb and three 6 T superconducting solenoids inserted among them [5]. The optical elements of the LEBT, MEBT, PSM solenoids and a quadruple doublet after the PSM were set to optimize the beam transmission. However, the beam current measured at the D-plate was 3 mA, corresponding to a 60% transmission from the LEBT, where 5 mA was measured. Most of the beam loss occurred at the low-energy part of the RFQ. This issue will be the subject for further investigations.

Description of the RS Monitor

The energy of the beam as a function of various parameters of the accelerator components was measured at the D-plate by comparing timing signals from the two phase probes (TOF) and the RS monitor measurements (Fig. 2).

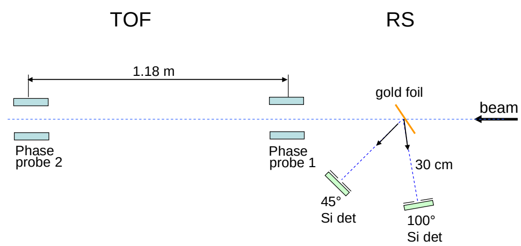

Figure 2.: Schematic presentation of beam energy measurement incorporated into the D-plate.

In the latter case the 0.3 mg/cm^2 thick gold foil was introduced into the beam periphery and the scattered protons were detected by two 500 microns thick Silicon particle detectors (Canberra Inc.), placed at a distance of approximately 30 cm from the target, at the angles of 45 and 100 degrees with respect to the incident beam direction. The gold foil was glued to a graphite frame, which was placed on a target ladder. The foil was introduced slowly in the beam periphery until the counting rate in the Si detectors was satisfactory. The detector signals were amplified and shaped by preamplifiers and spectroscopy amplifiers and were digitized and histogrammed by a data acquisition system. During the first attempts strong pile-up in the detector signals was observed even at very low overall detection rate. This was due to high number of particles in a pulse. This problem was solved by introducing of 2 mm diameter collimators on the detector front, thus reducing its detection solid angle by a factor of 30. In general, use of two detectors provides some experimental flexibility as the detection rate has strong dependence on the scattering angle. In these tests the detector at 45 degrees was mostly used.

Further tests showed various advantages of the RS monitor compared to the TOF technique. The determination of the centroid of the beam energy distribution takes a few seconds, although longer time is needed to obtain good quality spectra. The energy spread of the beam and information on some weak low-energy beam satellites can be obtained from the spectra. At the moment, the disadvantage of RS method is the lack of possibility of independent energy calibration and, hence, the RS energy spectra have to be calibrated using the TOF measurements.

Example of Use of the RS Monitor

Energy spectra were measured for beam traversing through detuned cryogenic resonators, allowing one to study separately the RFQ performance. Evolution of beam energy spectrum as a function of RFQ forward power is presented in Fig. 3. The strong peak at the expected energy (1.5 MeV) appears in the spectrum only at the RF power value higher than 50 kW. The FWHM of the peak is about 20 keV. Contribution to this width comes from the energy spread of the beam, intrinsic energy resolution of the detector, electronic noise and broadening due to finite thickness of the foil. With current energy resolution we have not observed any change in the energy distribution with change of the radial position of the foil. The low energy tail observed in the peak is probably due to propagation of protons during rising of the RF voltage at the beginning of the RFQ pulse. The energy calibration of the RS was done by comparison with TOF results. The spectra are also compared with TRACK Monte Carlo simulations [6]. The various broad peaks observed in the low-energy part of the spectrum of the non-optimal RFQ power are probably due to beams which are not fully synchronised with the RF field. At the moment these peaks are not fully explained by the simulations. These measurements along with the ones done with the standard D-plate instrumentations showed that the optimum RF power for transporting and acceleration of protons through RFQ is above 55 kW.

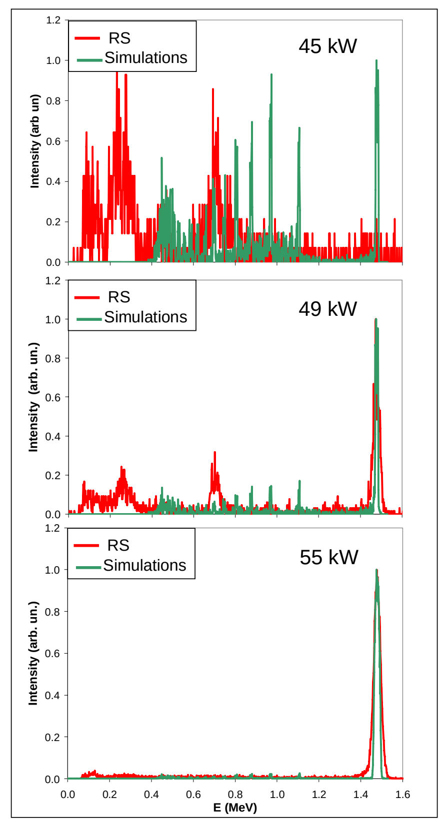

Figure 3: Evolution of proton energy spectrum for the turned off and detuned PSM resonators with increase of the RFQ RF power.

The RS monitor is useful for phasing of individual cavities. For example, energy as a function of the voltage of the first cavity (HWR1) is shown in Fig. 4a. The other five cavities were turned off and detuned. The effect of the cavity accelerating voltage and phase is clearly seen. The energy values determined by the two methods are consistent. As a result of the phasing procedure the synchronous phase of the resonator can be determined. The results are compared with simulation allowing one to calibrate the resonator voltage. Typically the resonator voltages obtained in the phasing measurements differ by 20-40 % from the initial estimations. Due to the sensitivity of the RS spectra to the bunch energy width the bunching effects of the resonators can be studied (Fig. 4b). The intrinsic energy resolution and effects of scattering on the gold foil were not taken into account in the simulation of the beam energy spread.

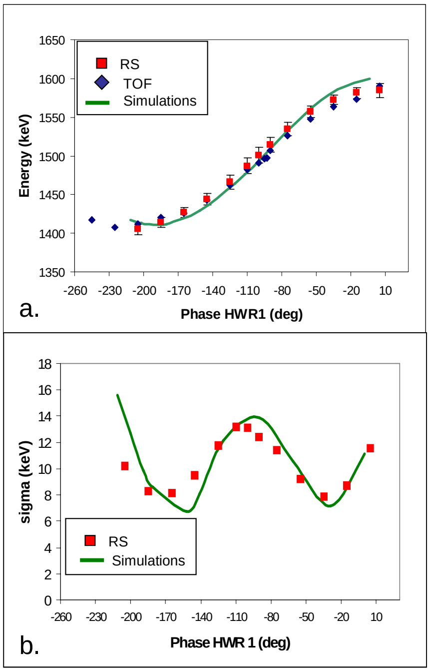

Figure 4: a: Proton energy as a function of HWR1 phase, as determined by TOF and RS b: Gaussian fit width (sigma) of the RS peak as a function of the HWR1 phase. Results are compared to the TRACK simulations.

After performing phasing of individual cavities the parameters of the whole accelerating module can be determined. In the example presented in Fig. 5 the four of the six HWR were operational. The first two resonators were used for bunching of the beam and the other ones for further acceleration. The RFQ power was set to 56 kW. The voltages and phases of the three first resonators were

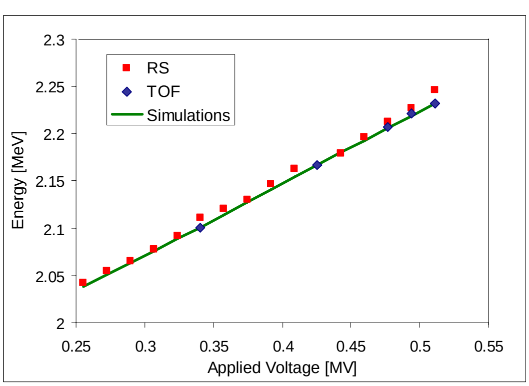

Figure 5: Proton energy as a function of HWR4 voltage, while the three previous resonators also operated.

set to 150 kV and -95°, set to 85 kV and 0°, set to 446 kV and 20° respectively. The phase of the forth HWR was set to -30° and its voltage was increased gradually.

Stable beam operation with all six cavities has not yet been achieved. It became evident that it is necessary to further perform conditioning of the cavities and introduce improvements of their control system. This work is currently in progress.

SUMMARY AND OUTLOOK

The commissioning of Phase I of the SARAF accelerator is on-going. A low duty cycle 3 mA Proton beam has been bunched and accelerated by the RFQ, and consequently re-bunched and accelerated by the PSM up to 2.2 MeV. Monitoring of energy spectra of the scattered protons proved to be a useful tool for tuning of the RFQ and the six superconductive resonators. Prompt determination of the beam energy allows one to perform a fast tune. Details on the energy spread of the beam also can be obtained. The technique is limited to the particle energies corresponding to the stopping range in Silicon smaller than a detector thickness.

Further improvements in the future will include: introduction of an alpha source for in-situ detector calibration, reduction of electronic noise, obtaining information on bunch time distribution using a small diamond detector and fast electronics.

Finalizing the proton and deuteron beam commissioning through the entire Phase I is foreseen for the summer of 2009.

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