THE STATUS OF THE SARAF PHASE-I LINAC

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Abstract

Phase I of the Soreq Applied Research Accelerator Facility - SARAF is under operation at the Soreq Nuclear Research Center. The status of Phase I main components is reported as well as the beam operation experience accumulated in the recent months. The latter include acceleration of a 1 mA CW protons beam up to 3.9 MeV and 1 mA pulsed, duty cycle of few %, deuterons beam up to 4.7 MeV. Recent and future improvements in the current facility are discussed.

INTRODUCTION

Phase I of SARAF [1] consists of a 20 keV/u ECR Ion Source (EIS), a Low Energy Beam Transport (LEBT) section, a 4-rod Radio Frequency Quadrupole (RFQ) injector, a Medium Energy (1.5 MeV/u) Beam Transport (MEBT) section, a Prototype Superconducting Module (PSM), a Diagnostic plate (D-plate), beam dumps (BD) and temporary beam line (Fig. 1).

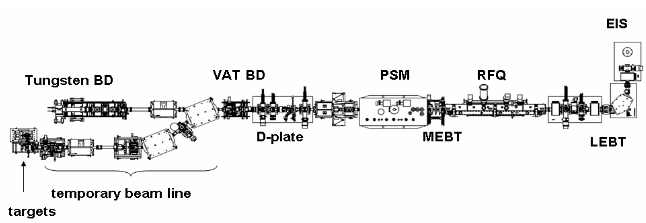

Figure 1. Layout of SARAF Phase I and the temporary beam line.

According to Phase I design specifications; SARAF superconducting linear RF accelerator should yield 2 mA CW beams of protons and deuterons, at energies up to 4 and 5 MeV, respectively. These specifications have not been achieved yet. Nonetheless, during the last two years, alongside with continuous development of the facility, the accelerator has been operated extensively at each opportunity and significant new experience in beam operations has been accumulated.

In the current proceeding we report the accelerator status, improvements of the accelerator subsystems, as well as experience in beam operations that has been accumulated since the last reports [1,2].

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STATUS OF MAIN COMPONENTS

EIS/LEBT

The SARAF ECR ion source has been in operation during six years effectively without any maintenance. We experienced two failures connected to the magnetron supply which were promptly resolved. The source could provide up to 6 mA beams of proton or deuteron, in DC or pulsed mode, at the RFQ entrance. The latter mode is used for tuning the accelerator and for beam line optics. The performance of the EIS/LEBT system has been previously reported in detail ([2] and references therein).

First experience with the slow LEBT chopper and plans regarding the fast LEBT chopper are discussed in [3]. Introduction of the chopper would allow for more flexible working range of the beam duty cycle and also allow abandoning pulsed operation of the ion source magnetron.

Reduction of the beam transmission through RFQ at higher LEBT current [2] is still one of the important unresolved issues. It is difficult to explain this reduction without an assumption that the emittance at the RFQ entrance is significantly larger than the value measured upstream the RFQ. . Alternatively, it might be possible that emittance measurements performed with a slit/wire apparatus are dominated by systematic errors which are not yet fully understood. We have performed several measurements aiming at understanding the correlation between the beam emittance in the LEBT and the transmission through the RFQ, as well as attempts to understand the degree of beam neutralization in the LEBT region [4,5]. Further studies are currently in progress.

An additional new water cooled beam-blocker/ collimator has been installed recently in the LEBT, just in front of the RFQ entrance. Installation of this element allows for separate operation of the EIS/LEBT system regardless of the status of the downstream elements.

Increase of hydrogen partial pressure in the RFQ and MEBT was observed when the ion source was operated. To resolve the problem of hydrogen diffusion along the accelerator, hydrogen pumping in the EIS and LEBT sections will be upgraded in the near future.

RFQ/MEBT

The SARAF RFQ is a 176 MHz ~3.8 meter four-rod CW RFQ. The details on the RFQ can be found in [6].

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The RFQ can be readily operated at the voltage and power required for a CW proton beams (~60 kW/32 kV). However, the main challenge in this RFQ is to condition it for the range of 250-260 kW (65 kV voltage), required for CW deuteron operation. Several RF conditioning campaigns have been carried out during 2007-2010. However, despite these extensive experimental campaigns, we have not succeeded to bring the device to the level needed for CW deuteron operation.

Since that time we have focused on proton beam operation and limited deuteron beam operation (a few per cent duty cycle). No RFQ conditioning campaign was performed since summer 2010.

During the previous conditioning campaigns, several technical drawbacks in the RFQ design were encountered, that hinder the high power operation. Some of these problems and the corresponding technical modifications were described in [2,7].

A few hundred Viton O-rings are utilized for vacuum sealing between the RFQ body and tubes delivering cooling water for the electrodes. Some of these O-rings were found to be damaged or even destroyed during the RFQ conditioning, as a result of RF field penetration into these regions and, hence, one may expect poor vacuum in these regions. Early in 2012, new flanges were installed in the RFQ. In these new flanges, the RF connection between the water tubes and the RFQ body has been improved at the vicinity of the Viton seals.

This improvement as well as other modifications [2,7] give rise to some optimism on improving RFQ status. However, if the future conditioning campaign will not meet our expectations, options for major modification of the rods structure or even replacement of the entire RFQ should be considered.

Five x-ray detectors were installed in 2011 at viewports positions along the RFQ barrel. The initial objective of installing these detectors was monitoring x-ray flux at various positions of the RFQ during the conditioning. During operation of intense beams it has been noticed that the x-ray detector placed approximately 70 cm downstream the RFQ entrance is sensitive to the beam loss. According to the simulations, beam losses take place primarily in that area. Minimization of the radiation dose rate measured in this detector allows for moderate improving of the RFQ transmission.

New water cooled collimator and beam blocker were installed in the MEBT chamber just in front of the PSM. The collimator works as a beam scrapper and is used for minimizing the interactions of beam tails with cryogenic surfaces. The beam blocker allows for an independent operation of the accelerator's injector, regardless of the status of the cryogenic linac. The partial hydrogen pressure rises significantly in the MEBT region when an intense beam is introduced therein. In the near future the hydrogen pumping in the MEBT section will be significantly upgraded to overcome this hurdle.

PSM

The PSM module includes six $\beta = 0.09$ Half Wave Resonators (HWR) made of bulk Nb and three superconductive solenoids [8]. The SARAF HWRs were found to be sensitive to fluctuations in the Liquid He (LiHe) pressure (60 Hz/mbar compared to designed value 15 Hz/mbar). The ±1.5 mbar pressure variation at the SARAF cryogenic system is manifested by frequency detuning that easily exceeds the cavities loaded bandwidth of 130 Hz. This detuning brings forth challenging demands on the cavities' tuners. These tuners include a stepper motor for coarse tuning and a piezo electric actuator (Pst150 [9]) for fine tuning. In 2009, a dramatic reduction of the piezo range was observed; leading to the replacement of the piezo devices by modified ones [10]. In 2011 the piezo tuners suffered once again from significant reduction of the tuning ranges. During the winter maintenance period, the tuners were replaced by another type of piezo activators (Pst1000 [10]), which operates at higher voltage and have superior mechanical strength. So far, no deterioration of the tuning range has been observed with the new activators.

In 2011, the 2kW RF solid state amplifiers [11] were replaced by 4 kW ones. The latter were designed and built in-house [12]. The operation of cavities with new power suppliers has proven to be more stable, since the higher available power provides a better compensation capability against detuning.

After improving the tuners and RF amplifiers, the remaining warming of the RF coupler has become the main limiting factor in operating the accelerator at high fields. The phenomena of the warming couplers has been recognized earlier [2] but not yet resolved. Thus, we are compelled to reduce the field in the 2^{nd}, 3^{d} and 6^{th} cavities in order to keep the external coupler's temperature below 120 K during long operation. An example of the tuning used for 3.9 MeV is shown in Table I. It is noteworthy that no significant warming is observed at the 5^{th} cavity coupler. This cavity could be operated at a nominal voltage value, just before onset of x-ray emission. Solving the problem of couplers warming will allow one to comfortably operate the PSM at beam energies of 4.5 and 5.5 MeV, for protons and deuterons, respectively.

Table 1. The resonators parameters used for CW proton beam operation. Nominal HWR voltage value is 840 kV.

HWR #	Voltage (kV)	Eacc (MV/m)	Phase (deg)	limiting factor
1	230	1.5	-90	Used for bunching
2	460	3.1	+30	Warming coupler
3	460	3.1	-30	Warming coupler
4	720	4.8	-30	Warming coupler
5	830	5.5	-20	x-ray emission
6	425	2.8	0	Warming coupler

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BEAM OPERATION

Several experiments, including beam-on-target ones, have been performed at SARAF with proton and deuteron beams of various beam energy and intensities.

Proton beams at the highest available energy of ~3.5-3.9 MeV were mainly used for the tests of thin (20-30 μm) foil targets cooled by liquid metal [13]. Targets of such types will be used in the future for producing of radiopharmaceuticals isotopes, which will eventually be a major activity at the facility. The maximum current that was delivered to these targets was about 0.3 mA. The thin foil targets were delicate and there were several incidents of target-foils being damaged. Following the insight gained from the first experiments, numerous improvements of the target arrangement and beam diagnostics quality were implemented. We expect a significant progress at this arena in the near future.

Another important direction for the extended future will be production of strong neutron sources by impinging an intense proton beam on the Liquid Lithium Target (LiLiT [14]). Choosing beam energy just above of the ^{7}Li(p,n) reaction threshold (1.880 MeV) allows for producing neutrons with an energy spectrum similar to that of the neutron spectrum in the stellar environment (kT~25 keV). As a first step in that direction, several tests were performed with evaporated LiF targets. The objectives for these tests were accurate measurements of the beam properties (energy and spread), study of the obtained neutron spectra and gaining experience with neutron activation methods. Accurately determining the beam properties is critical for producing a valid astrophysical neutron source. Monitoring of radiation yields from resonance or threshold nuclear reactions while scanning the beam energy have proven to be a valuable method for determining or calibrating the beam energy and spread.

The production of intense high-energy neutrons sources with deuteron beams is another important objective of the SARAF project. Such intense sources will be utilized to produce radioactive beams for multi-disciplinary fundamental research and applications. The first step in this direction was testing a production of high energy neutrons via the LiF(d,n) reactions at 4.75 MeV beam energy. The experiment was performed by bombarding a LiF crystal target with a pulsed deuteron beam. The spectrum of the produced neutrons was measured on-line, employing a liquid scintillator, as well as, off-line, employing a stack of foils in which neutron activated species were counted [15].

CONCLUSION

A significant progress was achieved during 2011-2012, while overcoming numerous hurdles while bridging gaps of knowledge. Improvements and modifications were introduced in practically all the components of SARAF. A temporary beam line was constructed and commissioned, and first scientific experiments were performed. The accumulated experience showed that even at the present stage the SARAF project, it has the challenging potential of becoming a user facility with an intense beam viable schedule and high beam availability. More details on the present status of SARAF can be found in [16,17] and in [18] one can find a report on the design progress of SARAF phase II.

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