A High Intensity Proton Linear Accelerator for the German Spallation Neutron Source (SNQ)

The Linear Accelerator Working Group, Kernforschungszentrum Karlsruhe. Presented by

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Summary

A proton linac of 1100 MeV energy and 100 mA peak beam current and 5 to 10% duty cycle is proposed for the German Spallation Neutron Source (SNQ). Low beam loss, excellent stability of the accelerating fields and high rf-power conversion efficiency are the major design aspects. Basic parameters and layout are given.

Introduction

An accelerator-based neutron source is the subject of a study at the nuclear centres of Karlsruhe and Jülich with participation of industry and other accelerator centres such as SIN and CERN. The SNQ-project aims at time average fluxes of thermal neutrons equivalent to high flux reactors and at peak fluxes exceeding the capability of research reactors by at least one order of magnitude. As a dedicated source for neutron scattering research, the main parameters were optimized to the needs of these experiments. With the energy and intensity specified, the SNQ provides abundant fluxes of protons, high energy neutrons, mesons and neutrinos.

The basic machine consists of the 1100 MeV proton linac, experimental areas for nuclear physics and medicine and the spallation-target. This target consists of a rotating wheel containing water cooled lead as the reaction material. In a second step of construction, a compressor ring shall be added to the linac to deliver proton pulses of <1 μs duration, 2.5×10^14 ppp intensity and 100 Hz repetition rate. Pulses with this time structure are of particular interest for hot (>100 meV) neutron and for neutrino experiments.

Requirements

The desired thermal neutron flux of 7×10^14 cm^-2 s^-1, as produced by the proposed target-moderator system, required a time averaged beam power of 5.5 MW. A proton energy of 1100 MeV was chosen as a compromise between different arguments such as target heat density, neutron yield, linac cost, and the option to inject the full beam into a compressor ring. At this energy, a time averaged beam current of 5 mA yields the required neutron flux. An increase to 10 mA is considered as an option. While only some of the experiments will use the source in a stationary mode, most of the experiments will be optimized for peak fluxes. Neutron scattering instruments require a pulse length of <500 μs comparable to the time constant of thermal neutron moderators, and repetition rates around 100 Hz. From these requirements a peak current of 100 mA was indicated for the linac.

Table I: Main SNQ-linac parameters and options

| Particles | P | H |
| Final energy/MeV | 350, 1100 | 350, 1100 |
| Beam current/MA | 5 | 10 |
| Beam pulse length/μs | 500 | 1000 |
| Repetition frequency/Hz | 100 | 1000 |
| Peak beam current/MA | 100 | 1000 |

Linac Layout

A schematic layout for the accelerator is given in Fig.1. The linac consists of a magnetic multipole ion source, dc preacceleration to 450 keV, low energy
accelerator >500 MeV). SMQ-studies have shown, that the additional means to cope with higher dose levels will increase the construction cost of the facility by only a few percent.

**Beam Dynamics**

Beam dynamics in the Alvarez accelerator were studied analytically to decide on the main injection and accelerator parameters. Detailed studies of beam behaviour in the Alvarez part were performed with multiparticle codes of CERN origin. The essential results are as follows:

- The injection energy should be as high as possible. However, limitations are given by the reliability of preaccelerators, 450 kV was therefore chosen.
- A low frequency (108 MHz) was favoured because of large transverse and longitudinal acceptances and more effective phase damping required for the jump in frequency by a factor of 3 at 105 MeV.
- Stable motion and tolerable emittance growth were found for normalized transverse emittances > 2 m mm mrad at injection.
- About 10% of the particles bunches were found to be lost in the accelerator, but none of the 2000 macro-particles, simulating a beam current of 100 mA, were lost beyond the first tank (i.e. >15 MeV). (Fig.3).

**Table II: Beam dynamics parameters and beam quality**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Alvarez-accelerator</th>
<th>DAW-accelerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton energy (MeV)</td>
<td>105</td>
<td>1100</td>
</tr>
<tr>
<td>Acc. field strength (MeV-1)</td>
<td>2</td>
<td>1.4</td>
</tr>
<tr>
<td>Synchronous phase (°)</td>
<td>-30</td>
<td>-25</td>
</tr>
<tr>
<td>Transverse tune (°)</td>
<td>12.8</td>
<td>12.0</td>
</tr>
<tr>
<td>Long-time, 100 mA/°</td>
<td>150</td>
<td>40</td>
</tr>
<tr>
<td>Energy spread (MeV)</td>
<td>0.24</td>
<td>0.15</td>
</tr>
<tr>
<td>Normalized trans. emittance/2 m mrad</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

1) 1% of beam, 2) 100% of beam

**Accelerator Components**

In the magnetic multipole ion source, under test at KfK, current densities of up to 500 mA/cm² were obtained and found homogeneous over several cm² of extraction area. Extracted currents showed noise levels of <10⁻⁵ within 1 MHz bandwidth. On the 100 kV test stand, 70 mA of ion current were accelerated to 90 keV and transported over 1.5 m distance. A normalized transverse emittance of <1 μm mrad was estimated from aperture sizes passed by the beam. Ion currents of 250 mA are expected from changes of the extraction electrode system.

The low energy beam transport (LEBT) was designed after the new CERN linac. An ultrafast (<10 ns rise time) chopper is inserted in front of the 3 gap buncher system to allow for variable time structures of the particle beams as needed by the experiments. Principle and function correspond to the LAMPF system.

In our concept for the Alvarez accelerator tanks, it was tried to combine the virtues of the GSI and the new CERN linac designs. Drifttubes are suspended from 4 m long girders (Fig.3) to facilitate access for repair and alignment. Mode stabilization is achieved by post couplers, adjustable to influence the field profile for optimum matching to the beam, which is of particular use in the first section of the Alvarez accelerator.

**Fig.2** Beam envelopes along the Alvarez accelerator. The beam contours contain the indicated fractions of the transmitted beam. About 12% of the injected beam is lost in the first gaps.

**Fig.3** First Alvarez tank. Drift tubes are mounted on a girder to facilitate adjustment and repair.

The length of the DAW tanks is given by focusing demands. Separation of acceleration and focusing conditions was preferred in spite of some trade-off in shunt impedance because of better handling. DAW-parameters were calculated with the SUPERFISH code, stem corrections were made by perturbation calculations. The outer radius was chosen constant along the accelerator with a value compromising shunt impedance and unambiguous mode distribution in the dispersion diagram. Fig.4 shows a schematic of a DAW double tank consisting of 3 channels, which guide the beam to the dump, to the nuclear physics area and to the main neutron target, respectively. A combination of a kicker and a Lamberton-type septum is used for fast beam switching. Gradients of bonding magnets were chosen to allow for optimal H⁻ transport. Addition of a future compressor ring is considered in the HEBT design and will need only minor modifications.
Fig. 4: DAW-tanks, consisting of two resonators individually fed with rf. DAW-tanks are between 3.3 and 8.5 m long and are designed for remote handling.

RF-Amplifier and Control Systems

The rf amplifiers provide a total power of 300 MW peak, ~17 MW average. High efficiency, high power, grid modulated klystrons were chosen to feed the DAW sections, which require more than 90% of the total rf power.

Design of the SNQ-control system for the accelerating field started from two main requirements:
- to optimize the cavity filling time, and
- to maintain a high stability of the field amplitude (±1%) and phase (±0.2°) during the beam pulse.

The filling time of the cavity can be optimized by appropriate amplitude and phase steps of the generator. Transients of amplitude and phase of the unloaded cavity can thus be suppressed.

Field stability with beam loading can be significantly improved by a feed-forward-control system, supporting the operation of the amplitude and phase control loops. As shown in Fig. 5, the amplitude error can be reduced by an order of magnitude during the transition of the beam pulse. Computer simulations of the control response have been performed, experiments are underway.

Acknowledgements

This paper is a summary of the work of many contributors of the KfK staff. We gratefully acknowledge that our colleagues at CERN, CRNL, GSI, LANS, and from industry have contributed to this study with their experience and work.

References


2. R. Catti, J.P. Delahaye, K.H. Reich, PS-Beam Measurement at Flat-Top Fields near Transition Energy, these proceedings


5. G. Hochschild, E. Denmel, RF Power Source Development for the High Current Linear Accelerator of the Spallation Neutron Source (SNQ), these proceedings

6. D. Scholae, Dead Beat Filling of a Detuned RF-Cavity, Kernforschungszentrum Karlsruhe, to be published