ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS027

CONCEPTUAL DESIGN OF THE PROTON LINAC FOR THE HIGH BRILLIANCE NEUTRON SOURCE HBS

H. Podlech[1]*, J. Baggemann[2], S. Böhm[3], T. Brückel[2], T. Cronert[2], P. E. Doege[2], M. Droba[1], T. Gutberlet[2], J. Li[4], K. Kümpel[1], S. Lamprecht[1], E. Mauerhofer[2], O. Meusel[1], N. Petry[1], U. Rücker[2], P. Schneider[1], M. Schwarz[1], P. Zakalek[2], C. Zhang[5]
[1]Institute for Applied Physics (IAP), Goethe University Frankfurt, Frankfurt, Germany
[2]JCNS, Forschungszentrum Jülich GmbH, Jülich, Germany
[3]NET, RWTH Aachen, Aachen, Germany
[4]Institut für Energie- und Klimaforschung, Forschungszentrum Jülich GmbH, Jülich, Germany
[5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Abstract

Due to the decommissioning of several reactors, only about half of the neutrons will be available for research in Europe in the next decade despite the commissioning of the ESS. Compact accelerator-based neutron sources (CANS) could close this gap. The High Brilliance Neutron Source (HBS) currently under development at Forschungszentrum Jülich is scalable in terms of beam energy and power due to its modular design. The driver Linac will accelerate a 100 mA proton beam to 70 MeV. The Linac is operated with a beam duty cycle of up to 6% (11% RF duty cycle) and can simultaneously deliver three pulse lengths (52 μs, 208 μs and 833 μs) for three neutron target stations. In order to minimize the development effort and the technological risk, state-of-the-art technology of the MYRRHA injector is used. The HBS Linac consists of a front end (ECR source, LEBT, 2.5 MeV double RFQ) and a CH-DTL with 35 room temperature CH-cavities. All RF structures are operated at 176.1 MHz and are designed for high duty cycle. Solid-state amplifiers up to 500 kW are used as RF drivers. Due to the beam current and the high average beam power of up to 420 kW, particular attention is paid to beam dynamics. In order to minimize losses, a quasi-periodic lattice with constant negative phase is used. The presentation describes the conceptual design and the challenges of a modern high-power and high-current proton accelerator with high reliability and availability.

DESIGN PHILOSOPHY

The High Brilliance Neutron Source belongs to the Compact Accelerator based Neutron Sources (CANS) class [1] [2]. The term compact must be seen here in comparison with spallation sources, which typically require an order of magnitude higher beam energy.

The beam is sent simultaneously to three different targets by means of a multiplexer in the High Energy Beam Transfer (HEBT) [3]. Each individual beam behind the multiplexer must have a specific time structure in order to use the optimum resolution of the different instruments behind a specific target. The macro pulse lengths result from the experimental requirements and were fixed at 52 μs (384 Hz), 208 μs (96 Hz) and 833 μs (24 Hz) (Fig. 1), resulting in a total average beam power of 420 kW (6% beam duty factor). Because of the filling time of the cavities the RF duty factor is about 11%. Table 1 summarizes the top-level requirements of the HBS-Linac. One of the most important issues of high-power hadron Linacs is the choice of technology with respect to superconducting or room-temperature operation. In general, the higher the duty factor and the lower the beam current, the smaller the transition energy between room temperature and superconducting cavities (Fig. 2) [4]. Because of the high beam current for HBS the required RF power is dominated by the beam power even for room temperature cavities. Because of the much simpler technology avoiding a cryogenic plant, the development of cryo-modules and suitable power

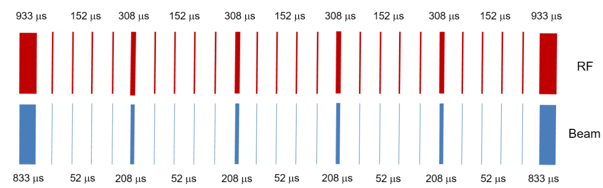

Figure 1: Pulse scheme of the HBS Linac. The spacing between beam pulses is 1.56 ms.

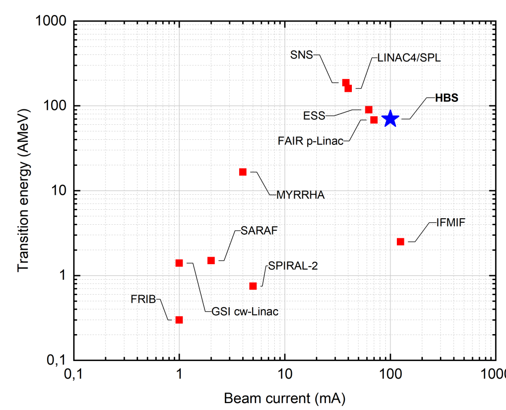

Figure 2: Transition energy of modern hadron Linacs as function of the peak beam current. For fully room temperature Linacs the transition energy is the final energy.

* h.podlech@iap.uni-frankfurt.de

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS027

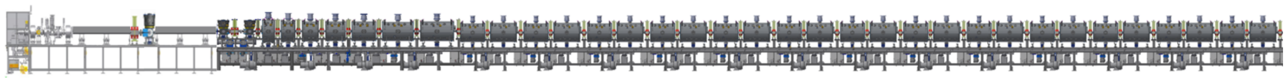

Figure 3: Conceptual layout of the HBS-Linac. It consists of an ECR-source, LEBT, RFQ, MEBT and the CH-DTL.

couplers a room temperature solution has been chosen for HBS.

The realization of high-power proton accelerators is usually associated with a large R&D effort with corresponding resources regarding man power, prototyping and testing infrastructure. In the case of HBS, this development effort should be minimized by using already developed technology. This lowers the costs and the time frame of the development and minimizes risks regarding construction costs, technological difficulties and time schedule. The HBS Linac should be as efficient as possible (length, RF power) and as reliable as possible as a user facility. High availability can be achieved by implementing a modular design that allows easy access to all components for repair and maintenance. Furthermore, all components should be operated well below their technical and physical limitations. Redundancies in critical components can significantly increase reliability and availability. Since further accelerator-based neutron sources will be needed in the future, it is advisable to design HBS in a modular and scalable way. Duty cycle, beam current, pulse lengths and energy can then be varied over a wide range without fundamentally changing the design. If necessary, only the front end has to be adapted for smaller beam currents. The drift tube Linac can consist of exactly the same lattice and is only adapted in length to the required energy.

ACCELERATOR CONCEPTUAL DESIGN

The RF duty factor of 11% already leads to significant thermal loads in the cavities. For the 17 MeV injector of the MYRRHA project cw capable CH-cavities and the corresponding RFQ were developed [5]. The thermal loads for this project add up to 35 kW/m. The technology for the MYRRHA Linac has been successfully tested and is now also available for accelerator-based future neutron sources. Just like MYRRHA, the frequency of HBS should be 176.1 MHz. Thus, the RFQ RF structure can be adopted without any changes [6]. The CH-cavities only have to be adapted to the beam dynamics of HBS with regard to cell number and cell length. The basic geometry and the cooling system can be adopted. The RF amplifier power has been limited to 500 kW which makes the use of solid state amplifiers possible. A smart design of these amplifiers using parallel power supplies can increase the reliability of the whole system significantly. Figure 3 shows the conceptual design of the HBS Linac.

Front-End

The Front-End consists of the proton source and a Low Beam Energy Transport (LEBT) section with integrated chopper system (Fig. 4). As proton source an ECR source has been chosen because of their high reliability, easy handling and maintenance, high proton fraction and high intensities [7] [8]. The extraction energy has been set to 100 keV. This value is sufficient high for the beam transport and low enough to keep the RFQ length to reasonable values. The LEBT is divided into two sections with an E×B-chopper in between. Beam focusing is planned to be provided by four solenoids. This lens type allows space charge compensation by secondary electrons captured in the beam potential [9]. For the production of the time structure of the beam (Fig. 1) the chopper is required, because the repetition rate and the shortest pulse length do not correspond with the plasma rise time in a pulsed ECR-source. In conventional LEBT-systems the chopper is located at the entrance of the RFQ. In the case of a beam current of 100 mA and a beam power of about 10 kW the unwanted beam portion has to be dumped carefully with respect to power deposition and secondary particle production. The chopper system consists of an E×B-chopper followed by a septum magnet to ensure a safe deflection of the unwanted beam portion into a dedicated beam dump [10].

Table 1: HBS Top-Level Requirements

Parameter	Specifications
Particle type	Protons
Accelerator type	RF Linac
Peak beam current	100 mA
Final energy	70 MeV
Beam duty factor	6%
RF duty factor	11%
Pulse length	52/208/833 μs
Repetition rate	384/96/26 Hz
Peak beam power	7 MW
Average beam power	420 kW

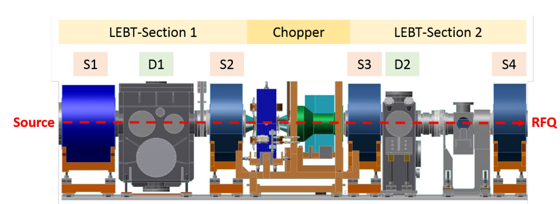

Figure 4: Scheme of the low energy beam transport for HBS. It consists of two sections with an E×B-chopper in between.

RFQ

The 4-Rod RFQ is a transmission line resonator, i.e. the frequency does not depend on the tank dimensions, but only on the geometry of the internal resonance structure. Due to

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS027

the excellent possibility of frequency and field tuning, the modular design and the possibilities for maintenance and repair, clear advantages are seen for this RFQ type and therefore proposed as RF structure for HBS. In recent years, the 4-Rod RFQ has been further developed in terms of high current acceleration at high duty cycle up to cw operation (Fig. 5) [6].

Table 2: HBS RFQ Parameters

Parameter	**Specifications**
RF structure	4-Rod RFQ
Frequency	176.1 MHz
Peak beam current	100 mA
Final energy	1.25/2.5 MeV
Input energy	100 keV
R_p	72 kΩm
Specific power loss	100 kW/m
Length	2x2.5 m
power losses	2x250 kW
total power	2x400 kW
Amplifier power	2x500 kW
Electrode voltage	85 kV

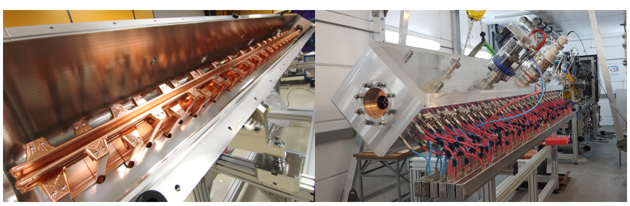

Figure 5: The MYRRHA RFQ which is very similar to the HBS RFQ uses the same technology.

For energies well above 2 MeV, the length of the 176 MHz RFQ reaches a value that makes production and tuning considerably more difficult. In addition, the required power is then very high. Therefore, it is planned to divide the RFQ into two shorter structures. In addition, a short MEBT is then used between the individual RFQ accelerators to match the beam from one RFQ to the other. First simulations showed that an electrode voltage of 85 kV is reasonable. With the expected shunt impedance of 72 kΩm, this corresponds to a specific RF power of 100 kW/m (Tab. 2).

CH-DTL

Various RF structures are available for a normal conducting HBS-Linac. Basically, the Linac should be as efficient as possible in terms of power consumption. Furthermore, beam dynamic aspects, modularity, maintenance, repair, R&D effort, availability of suitable amplifiers and investment costs also play a role. As in case of the RFQ, it has been decided to adopt the DTL-technology from the MYRRHA-project using 176.1 MHz CH-cavities (Fig. 6) [5]. The technology has been successfully tested and requires a manageable development effort. The frequency tuner, power couplers and the cooling system of the cavities can be taken over. Only the RF structures have to be designed according to the field distribution and the frequency. The design of the CH cavities is essentially influenced by two factors, the beam dynamics and the available RF power.

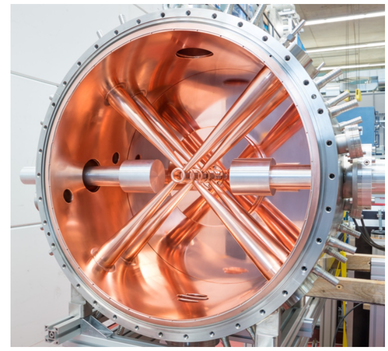

Figure 6: CH-Cavity operated with 100% duty factor.

Table 3: Preliminary Parameters of the CH-Linac

Parameter	**Value**
RF Structure	CH-DTL
Frequency	176.1 MHz
No of cavities	≈ 35
E_{in}	2.5 MeV
E_{out}	70 MeV
Z_{eff}	25-60 MΩ/m
Specific power loss	100 kW/m
Thermal load	11 kW/m
Aperture diameter	35 mm
Gradient	1.5-2 MV/m
Voltage	0.5-2.5 MV
Total power per cavity	50-350 kW
Amplifier power	100-500 kW

The CH-Linac is realized by a quasi-periodic lattice. Up to an energy of about 20 MeV there is a magnetic quadrupole doublet between the cavities for transverse focusing. For energies above this, two identical cavities are combined to form a cavity doublet. The lack of internal lenses makes fabrication much easier. The quasi-periodicity leads to a smooth course of the phase advance and thus to low emittance growth. Table 3 summarizes the main parameters of the CH-Linac.

CONCLUSION

The High Brilliance Neutron Source HBS requires a powerful proton-Linac delivering a 100 mA, 70 MeV beam. A conceptual design study has been carried out. To minimize the R&D effort, already available and proven technology developed for various projects will be used. The Linac consists of an ECR source, LEBT with chopper system, a double 4-Rod RFQ and a rt CH-DTL. All RF structures will be driven by solid state amplifiers. In the next project phase the technical design report will be finished including detailed beam dynamics simulations and RF design of the cavities.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS027

REFERENCES

[1] I. S. Anderson *et al.*, "Research Opportunities with Compact Accelerator-Driven Neutron Sources", *Physics Reports*, vol. I654. pp. 1-58, 2016.

[2] C. Andreani *et al.*, "Compact Accelerator-Driven Neutron Sources" *Eur. Phys. J. Plus*, vol. 131, no. 217, 2016, https://doi.org/10.1140/epjp/i2016-16217-1

[3] U. Rücker *et al.*, "The Jülich High Brilliance Neutron Source Project," *Eur. Phys. J. Plus*, vol. 131, no. 19, 2016, DOI 10.1140/epjp/i2016-16019-5

[4] H. Podlech, *Superconducting versus Normal-Conducting Cavities*, CERN Accelerator School on High Power Proton Accelerators, ISBN 9789290833840, pp. 151-170, 2012.

[5] D. Mäder *et al.*, "Construction of the MYRRHA Injector", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 2221-2223, doi:10.18429/JACoW-IPAC2017-TUPVA062

[6] K. Kümpel *et al.*, "Measurements of the MYRRHA-RFQ at the IAP Frankfurt", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 949-951, doi:10.18429/JACoW-IPAC2018-TUPAF090

[7] R. Gobin *et al.*, "Improvement of beam emittance of the CEA high intensity proton source SILHI", *Rev. Sci. Instrum.*, vol. 70, no. 6, p. 2652, 1999.

[8] T. Gutberlet *et al.*, "The Jülich High Brilliance Neutron Source Project – Improving Access to Neutrons", *Physica B*, 2018, in press.

[9] O. Meusel *et al.*, "Beam transport and space charge compensation strategies", *Review of Scientific Instruments*, vol. 87, p. 02B937, 2016, doi:10.1063/1.4939823

[10] C. Wiesner, Ph.D. thesis, Frankfurt University, 2014.