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PROTON LINAC DESIGN FOR THE HIGH BRILLIANCE NEUTRON SOURCE HBS

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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. High-Current Accelerator-driven Neutron Sources (HiCANS) could fill 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 13.6 % (15.3 % RF duty cycle) and can simultaneously deliver three pulse lengths (208 µs, 833 µs and 2 ms) 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 section with 44 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 952 kW, particular attention is paid to beam dynamics. In order to minimize beam losses, a quasi-periodic lattice with constant negative phase is used. This paper 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 HBS [1,2] belongs to the HiCANS class. Their beam energy is significantly lower than the one of spallation neutron sources and therefore opens up other research areas. 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 beam macro pulse lengths result from the experimental requirements and are envisaged at 208 µs (96 Hz), 833 µs (24 Hz) and 2 ms (48 Hz), see Fig. 1, resulting in a total average beam power of up to 952 kW (13.6 % beam duty factor).

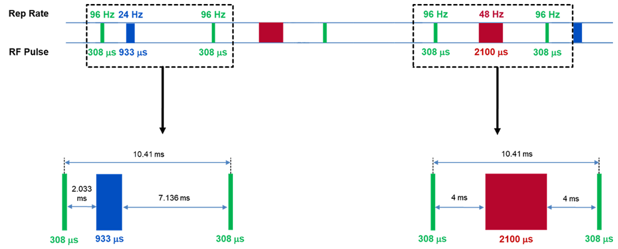

Figure 1: Possible HBS proton pulse structure as generated by the chopper.

Because of the filling time of the cavities the RF duty factor is about 15.3 %. 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 [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 cryomodules and suitable power couplers a room temperature solution has been chosen for HBS.

Table 1: HBS Top-Level Requirements

Parameter	**Specifications**
Particle type	Protons
Peak beam current	100 mA
Final energy	70 MeV
Duty cycle (beam/RF)	13.6/15.3 %
Beam pulse length	208/833/2000 µs
Repetition rate	96/24/48 Hz
Peak beam power	7 MW
Average beam power	952 kW

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.

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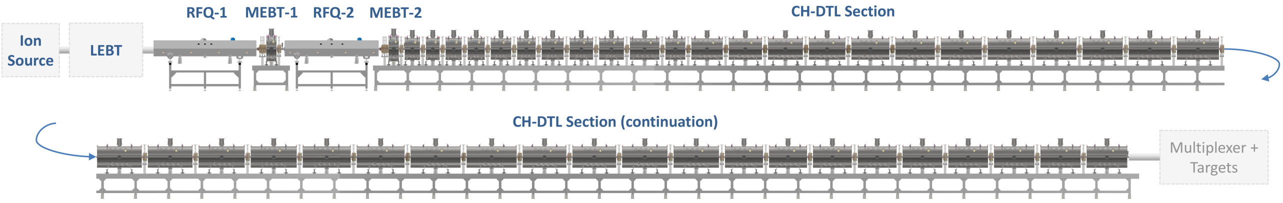

Figure 2: Conceptual layout of the HBS linac. It consists of an ECR ion source, LEBT, 2 RFQs, 2 MEBTs each with a CH-Rebuncher and a CH-DTL section with 44 cavities.

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 15.3 % 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]. For MYRRHA, reliable CW operation with a thermal load up to 35 kW/m has been well demonstrated. 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 same RFQ RF structure design concepts can be adopted [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 2 shows the recent 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. 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]. 100 keV is envisaged as the extraction energy. 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 a 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.

RFQ and MEBT

The 4-Rod RFQ is a transmission line resonator, i. e. the frequency depends (almost) not at all on the tank dimensions, but only on the geometry of the internal resonance structure. Due to 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. 3) [6].

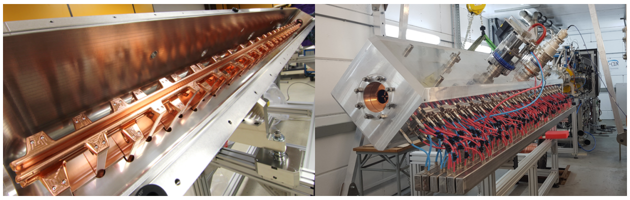

Figure 3: The MYRRHA RFQ which is very similar to the HBS RFQ uses the same technology.

For energies well above 2 MeV, the total length of the 176.1 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 [10]. Advanced beam dynamics simulations showed that an inter-electrode voltage of 85 keV is reasonable. With the expected shunt impedance of 72 kΩm, this corresponds to a specific RF power of 100 kW/m.

For the MEBT, an approach is envisaged in which both the BPMs for beam diagnostics and steerer (dipole) magnets are integrated directly into the quadrupole magnets (see also [11]). This will result in a substantial space saving, which is needed given the high dissipative space charge forces at 100 mA, especially at low energies in MEBT-1/-2.

CH-DTL Section

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 [12]. The technology has been successfully tested and requires a manageable development effort. Iteratively, the beam dynamics and cavity design are currently taking place in parallel in order to obtain the most realistic results already in this early design phase, which is mandatory for this highly demanding linac, especially due to the high beam current. Details on the recent design progress of the CH cavities can be found in [13].

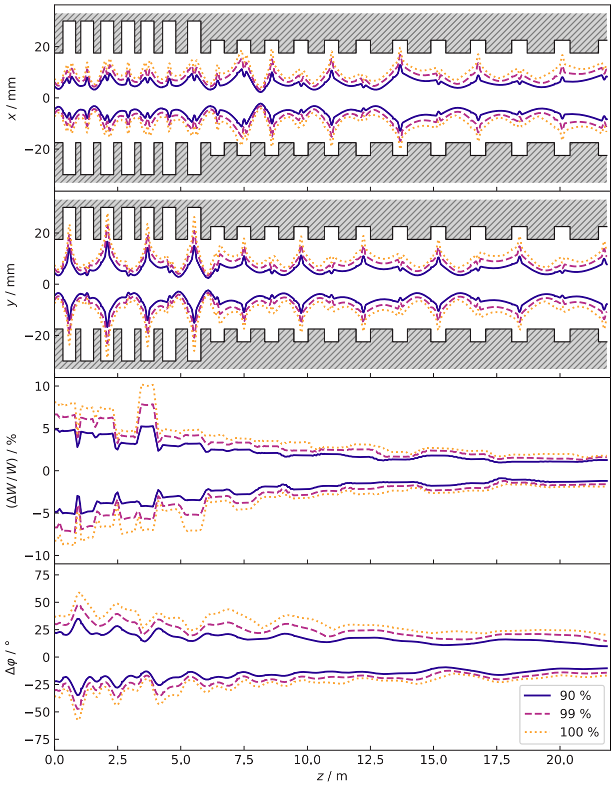

Figure 4: Simulated beam envelopes of the current beam dynamics layout draft along the HBS CH-DTL section up to cavity #19 of 44.

Figures 4 and 5 provide a glimpse of the current beam dynamics simulations, starting at the beginning of the CH-DTL section (2.5 MeV) up to the 19th of an expected total of 44 CH cavities, reaching an proton beam energy of 24.6 MeV. The CH linac is realized by a quasi-periodic lattice. Up to an energy of about 25 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 also narrows the emittance growth despite the high beam current.

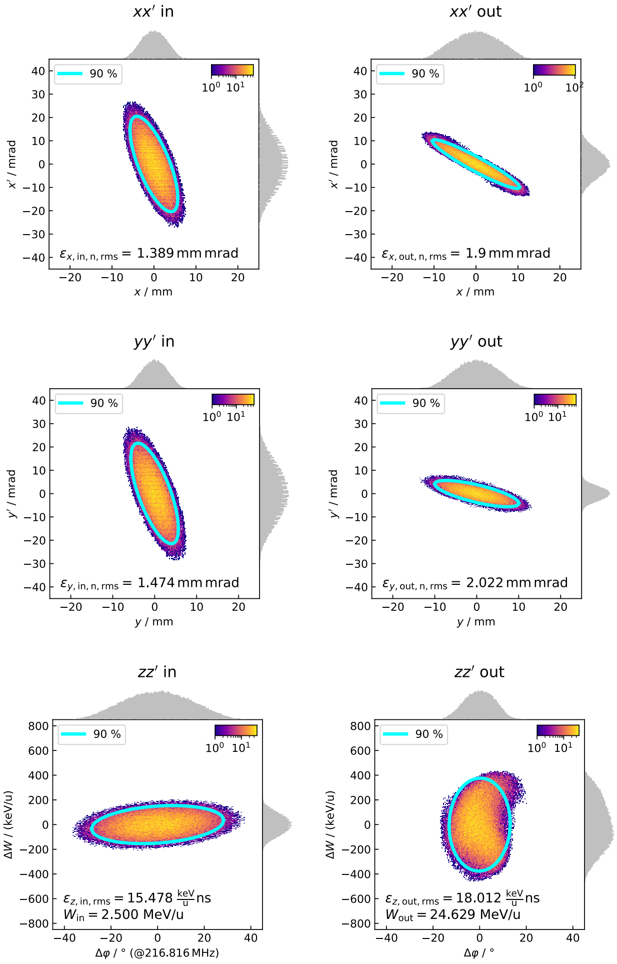

Figure 5: Simulated transverse and longitudinal phase space portraits at CH#1 input *(left)* as well as downstream CH cavity #19 *(right)*. The particle density is logarithmically color-coded.

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 [14]. 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 MEBT-part as well as a rt CH-DTL section. 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.

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