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CURRENT STATUS OF THE BEAM DYNAMICS SIMULATIONS FOR THE HBS DRIFT TUBE LINAC

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Abstract

Over the next years, various experimental reactors, which are used for neutron production in Europe, are already or will be decommissioned. Therefore, new neutron sources will be required to meet the demand for neutrons in research and development. The High Brilliance Neutron Source (HBS), planned at the Forschungszentrum Jülich, is one of the sources that will provide these in the future. HBS is an accelerator driven neutron source, the accelerator will accelerate a proton beam of 100 mA up to an end energy of 70 MeV. The drift tube linac of HBS will consist of room temperature CH-type cavities. Due to the high beam current, the beam dynamics concept requires special care. In this paper, the current status of the beam dynamics for the drift tube linac is presented.

OVERVIEW OVER THE HBS ACCELERATOR AND BOUNDARY CONDITIONS

The HBS [1] accelerator front end will consist of an ECR source, LEBT and two RFQs with an output energy of 2.5 MeV [2]. It is followed by a normal conducting drift tube linac [3] with 45 CH-type cavities. The HBS drift tube linac will be designed to accelerate a proton beam with a current of 100 mA up to an end energy of 70 MeV. Table 1 shows the top level requirements of the linac.

Table 1: General Parameters and Top Level Requirements for the HBS Linac

Design parameters	**Value**
Input energy	2.5 MeV
End energy	70 MeV
Beam current	100 mA
Particles	Protons
Resonance frequency	176.1 MHz
Number of cavities	45
Peak beam power	7 MW
Average beam power	420 kW
Duty cycle (beam/RF)	6 / 8 %
Beam pulse length	208/208/833 μs

Because of the high beam current and the resulting space charge forces, the beam dynamics layout requires special attention. This is to keep the emittance growth along the accelerator as low as possible while still accelerating the beam efficiently.

Besides the 42 accelerating cavities, three rebunching cavities will focus the beam longitudinally. The transversal focusing lattice will consist of alternating quadrupole triplets installed in the inter-tank sections between the cavities.

For reasons of technical feasibility, the length of the cavities should not exceed 1.5 m and the maximum magnetic field strength of the quadrupole lenses should be 1.2 T. The beam dynamics calculations for this paper have been performed with the beam dynamics code LORASR [4], developed at the IAP, Frankfurt, Germany.

DESIGN PROCESS AND AUTOMATION OF CALCULATION

Because of the high number of cavities, there are many free parameters to set for the beam dynamics layout. Furthermore, because of the high beam current, non-linear space charge forces make the finding of calculated solutions difficult. Therefore, the design process of the beam dynamics concept has been partly automatized using python routines, which use LORASR in batch mode, read out its calculation results and process them. A particle swarm optimizer (PSO) is used to find optimal solutions for the layout. The PSO algorithm has advantages for beam dynamics optimization: It is gradient-free, as it can not be assumed that a chosen cost function is differentiable for beam dynamics calculations, and it can be parallelized and is therefore time saving.

A particle swarm optimization algorithm which supports multithreading has been coded in Python. The parameters to be optimized are the cavity phases and the magnetic field strengths of the lenses. The Python code optimizes a fixed number of cavities at once and then moves automatically on to the next cavities. The cost function consists of the sum of the percentage growths of the emittance values and a factor to take the losses into account. For the design process the cavity voltages have been set to maximum to accelerate the beam efficiently. The number of gaps of a cavity is limited by the transversal focusing lattice and, at higher energies, by the required maximum length of 1.5 m. The quadrupole lens triplets are set to fixed lengths as short as possible. This minimizes the lengths of the inter-tank sections, which proved to be necessary for the longitudinal matching of the beam coming from one cavity into the next one. A short inter-tank section minimizes the growth of longitudinal phase spread along this distance, which makes it easier to meet the acceptance of the following cavity. The parameters that

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have been optimized are the cavity design phases and the strengths of the quadrupole lenses. The generation of a beam dynamics concept up to 70 MeV beam energy took about four days of calculation for the optimization code.

BEAM DYNAMICS CONCEPT

Previously, a design using a 4D-Waterbag input distribution has been presented [5]. The size of the 100 % input emittance areas for this distribution was based on the output results of the beam dynamics calculations of the MEBT2 section.

The current design uses the calculated output distribution of the MEBT2 section directly as input distribution to gain more realistic results concerning the RMS emittance values. The distribution with originally 10000 particles has been scrapped to exclude halo particles. The resulting beam design consists of 45 cavities, of which the second, fifth and eighth are rebunching cavities. The rebunching cavities are necessary for matching the beam into the next accelerating cavity at low energies. The drift tube linac is 65 m long, from beginning of the first to the end of the last cavity. The resulting RMS emittances are listed in Table 2.

Table 2: Input and Output RMS Emittance Values for the Current Beam Dynamics Design of the HBS Linac

Value	Input	Output
Energy /MeV	2.5	70.0
$\epsilon_{rms,x}$ /mm mrad	0.57	1.53
$\epsilon_{rms,y}$ /mm mrad	0.58	1.41
$\epsilon_{rms,E}$ /keV ns	4.43	5.5

The corresponding phase space portraits are shown in Fig 1.

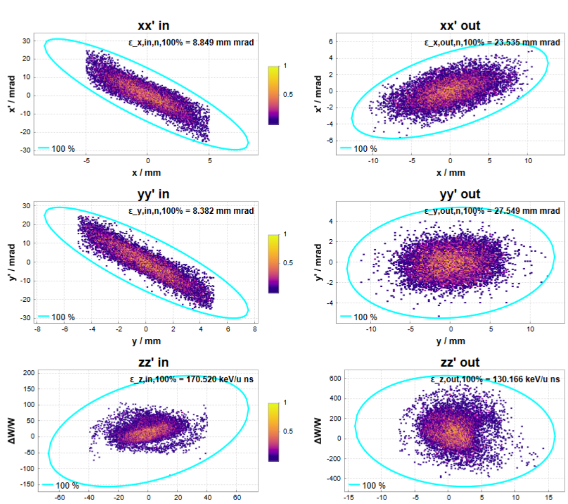

Figure 1: Longitudinal and transversal beam input and output emittances. The input distribution is the calculated output distribution of the MEBT2 section.

The transversal and longitudinal beam envelopes can be found in Fig. 2. The energy gain, synchronous phases and effective voltages of the cavities for the current design are shown in Fig. 3.

For the current design, it can be observed that an RMS emittance output value of about 1.5 mm mrad transversely can be expected. No losses occur, and the longitudinal filamentation is minimal.

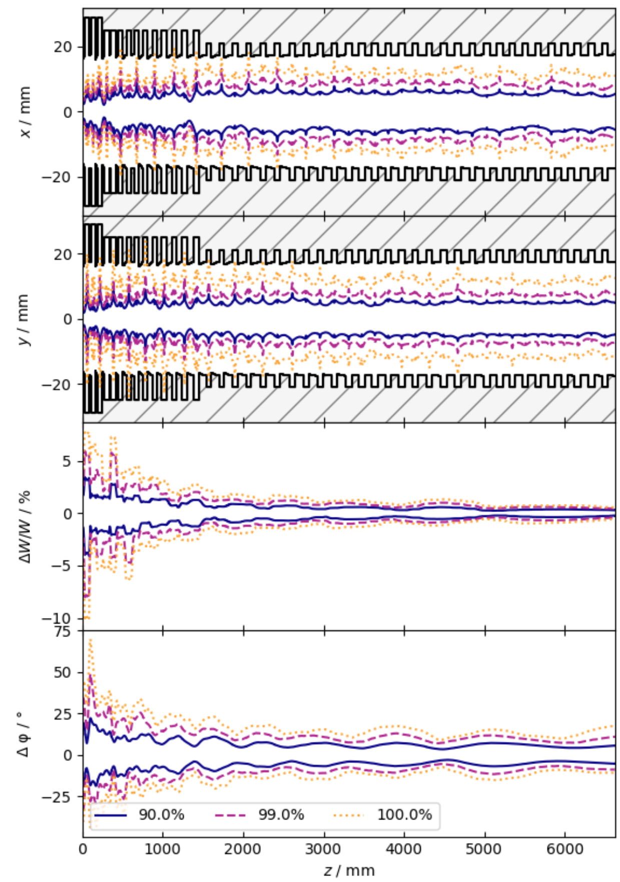

Figure 2: Longitudinal and transversal beam envelopes.

SUMMARY AND OUTLOOK

An optimization algorithm has been used to calculate the beam dynamics concept of the drift tube linac of the HBS accelerator. The current design approach up to 70 MeV end energy consisting of 45 cavities has been presented, with optimized phases and focusing strengths. The used input distribution is the current calculated output distribution for the MEBT2 section.

With a new, improved calculation for the front end section, an updated input distribution has recently been available, and the current design is adapted and improved in respect to this updated distribution.

In parallel to this, a design approach using the EQUUS acceleration scheme will be implemented and tested for possible improvement of the longitudinal beam dynamics. As a

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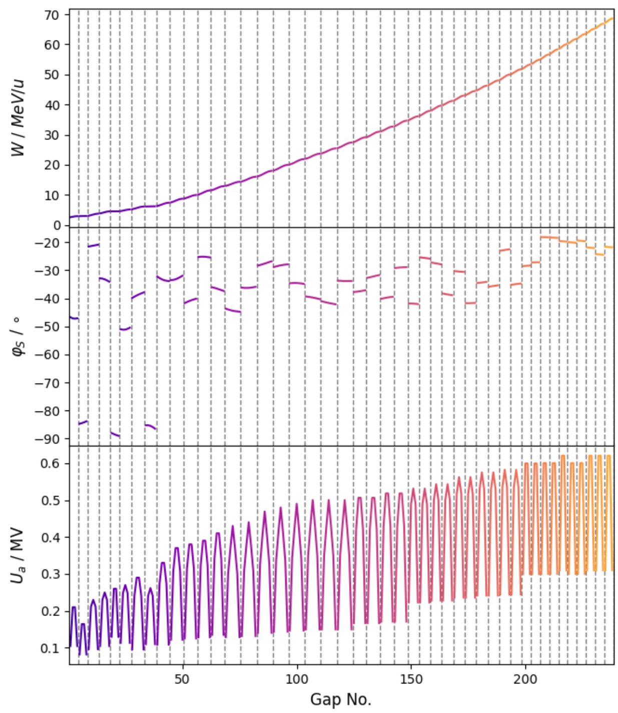

Figure 3: Beam energy, phases and voltages for each cavity.

next step, error studies will be performed using LORASR. Furthermore, benchmarking the design with other beam dynamics code is planned.

Because of the high space charge forces, the beam dynamics are very sensitive to variation of the density of the input distribution. Reliability studies are planned for various distribution densities, to ensure the design is adaptive to such variations and the free parameters of the design, which are still variable with a fixed geometry, can be modify accordingly. Additionally further studies concerning the adaptivity of the design are planned, such as a variation of the beam current, the end energy, or in the case of cavity failure.

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