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CAVITY R&D FOR HBS ACCELERATOR

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Abstract

The demand for neutrons of various types for research is growing day by day worldwide. To meet the growing demand the Jülich High Brilliance Neutron Source (HBS) is in development. It is based on a high power linear proton accelerator with an end energy of 70 MeV and a proton beam current of 100 mA. After the injector and the MEBT is the main part of the accelerator, which consists of about 36 CH-type cavities. The design of the CH-type cavities will be optimized in terms of required power, required cooling and reliability and the recent results will be presented in this paper.

HBS

The High Brilliance Neutron Source (HBS) as a project was first presented and published in 2015/2016 [1] [2]. The goal is to have a source which relies on a proton linear accelerator with a high current to achieve the level of existing medium to high flux neutron sources in terms of neutron brilliance and flux. To reach that goal, the following specification need to be fulfilled by the linear accelerator, summarized in Table 1.

Table 1: HBS Top-Level Requirements [3]

Parameter	Specifications
Final energy	70 MeV
Peak beam current	100 mA
Particle type	Protons
Peak beam power	7 MW
Average beam power	952 kW
Beam duty factor	13.6 %
RF duty factor	15.3 %
Pulse length	208/833/2000 s
Repetition rate	96/24/48 Hz

After the requirements are set the technology for acceleration needs to be specified. In general the shunt impedance is higher for drift tube structures used for acceleration at lower energies. For example are very efficient H-mode drift tube cavities available at low energies. Above 100 MeV superconducting cavities become the better choice in comparison to normal conducting cavities. Because of the inefficiency of normal conducting structures at high energies, this is also valid for accelerators with a low duty cycle. More general, normal conducting cavities are better suited for high currents at low energies and a low duty cycle. The opposite is true for superconducting cavities. Both technologies have

Figure 1: Classification of HBS into three different categories regarding superconducting and normal conducting.

their down and upsides. Superconducting structures need a complex cooling system with an onsite helium infrastructure and R&D of those structures binds a lot of resources for simulations and prototyping. Furthermore they are very sensible to impurities, contamination, etc. While having an accelerator with a high beam current of 100 mA the required RF-power is mainly driven by the required beam power. This even applies for normal conducting structures. Looking at a superconducting cavity, which in case of HBS provides 2.5 MeV, a RF-power of about 250 kW plus an safety margin is needed [4]. In comparison a normal conducting structure will require about 100 kW more RF-power. After looking at the pros and cons and having the rough time schedule in mind, the decision falls on normal conducting cavities.

CH TYPE CAVITIES

The 176.1 MHz linac should be as efficient as possible while being as modular as possible, easy to maintain and

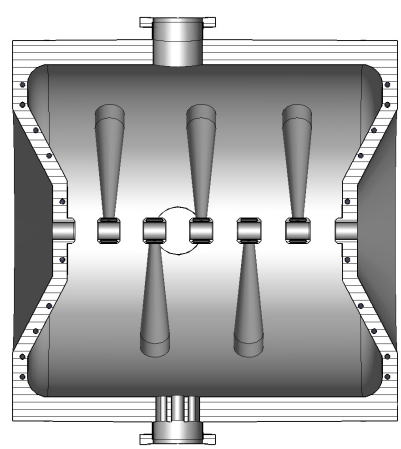

Figure 2: Side view of cross section of the used design for the HBS CH cavities.

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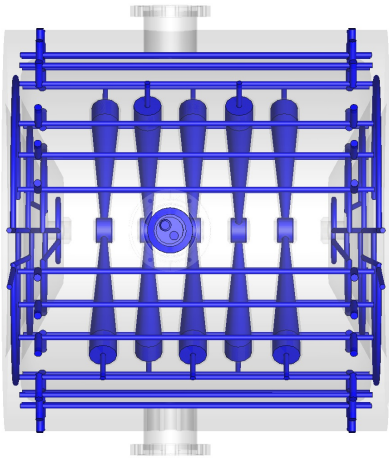

Figure 3: Side view of the cooling design from the CH cavities.

have a low R&D effort. To meet those requirements with normal conducting accelerating cavities the list of types was narrowed down to two, namely IH-structures (interdigital H-mode structure) and CH-structures (crossbar H-mode structure). Due to better thermal handling of CH cavities while only being a little less efficient in comparison to IH cavities CH type cavities will be used for the linac. The proposed design is shown in Fig. 2.

To handle the expected thermal load of 12 kW/m a sophisticated cooling design was developed for the CH cavities. The highest current will be on the stems, and thus the highest thermal load. Also in the middle section of the tank are hot spots possible due to the TE_{211}-Mode, which is used for acceleration. The cooling design consists of 24 cooling channels for the tank, two for the lids, one for each tuning device and one for each stem. A view of the side of the cooling design is shown in Fig. 3 and a view of the front is shown in Fig. 4. The results of a thermal simulation and thus the operation of the cooling design is shown in Fig. 5.

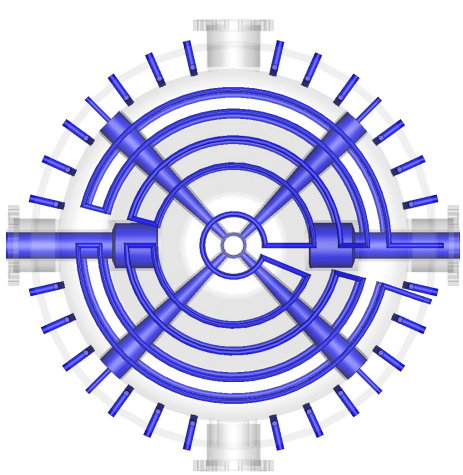

Figure 4: Front view of the cooling design from the CH cavities.

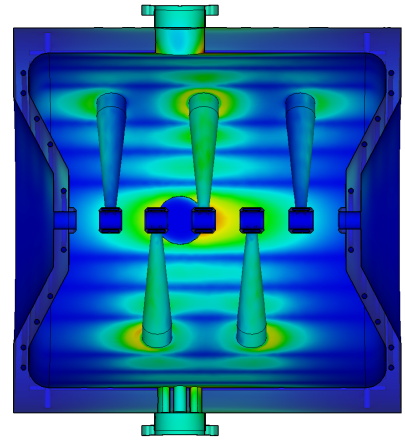

Figure 5: Results of thermal simulation of one example CH cavity. low temperatures are displayed in blue and the highest temperatures are displayed in red. The hottest spot in this example has a temperature of around 61 C.

Due to the high safety margin in terms of power the hottest spot in the cavity reached around 61 C.

DESIGN ITERATION

To handle the design of over 40 CH cavities a python program is in development. The idea behind the program is the process shown in Fig. 6. After creating a first version of the beam dynamic simulation one will have an ideal gap voltage distribution. With this distribution one can generate the designs for the more than 40 CH cavities required. En-

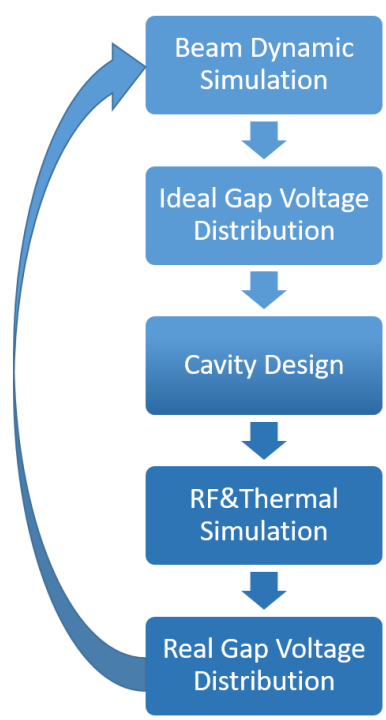

Figure 6: Concept of iterations process for the HBS main linac.

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suing one can start first the RF simulations and afterwards the thermal simulations. As a result one will get the real gap voltage distribution of the CH cavities which then can be used to correct and modify the beam dynamic simulation. This iterative process will converge at some point and one will get the final design for manufacturing.

CURRENT RF RESULTS

With the assistance of the program under development the 43 CH cavities of the prototype beam dynamic design could be created, simulated and evaluated. The RF and thermal simulations are done with CST Studio Suite. After the RF simulations have finished one will get several relevant RF properties of the cavities from the program, for example the shunt impedance Z_{eff}, shown in Eq. (1). The values of Z_{eff} used in this proceeding are 90 % values to include imperfections from manufacturing. The subsequent thermal simulations are calculated with a duty cycle of 20 % and additional power safety margin of 20 %.

$$Z_{\text{eff}} = \frac{U_{\text{eff}}^2}{P_{\text{loss}} L} \tag{1}$$

The shunt impedance of the 43 cavities along with the corresponding Kilpatrick factor is plotted in Fig. 7. The length in Eq. (1) is due to the design of the cavities not the total length but the sum of the $\beta\lambda/2$ lengths, which represents the length on the beam axis. For the thermal load the total length was used. The results of the simulations are summarized in Table 2 along other key parameters.

Table 2: Estimated Parameters of CH Cavities

Parameter	Specifications
Frequency	176.1 MHz
Input energy of first cavity	2.5 MeV
Output energy of last cavity	70 MeV
Shunt impedance	20 – 52 M/m
Aperture diameter	35 mm
Voltage	0.5 – 2.5 MV
Gradient	1.1 – 2.4 MV/m
Amplifier power	100 – 500 kW
Total power per cavity	60 – 380 kW
Thermal load	12 kW/m
No of cavities	≈ 43
RF Structure	CH-DTL

CONCLUSION

The prototype design from late 2021 needs 43 CH type cavities to reach 70 MeV, of which 4 cavities are rebuncher cavities. Since the particle distribution is still undergoing optimization [5] this design is not the final design but a thoroughly estimated proof of principle design.

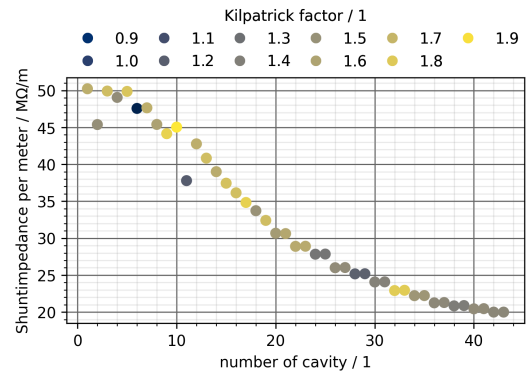

Figure 7: Results of the late 2021 design with 43 CH cavities.

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