ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPOGE12

CAVITY R&D FOR HBS ACCELERATOR

N. F. Petry*, K. Kümpel, M. Schwarz, S. Lamprecht, O. Meusel, H. Podlech[1]
IAP, Goethe University Frankfurt, Frankfurt am Main, Germany
[1]also at Helmholtz Research Academy Hesse for FAIR, Frankfurt am Main, Germany

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. The main part of the accelerator consists of about 45 CH-type cavities. As the current beam dynamic layout is still work in progress the number of cavities can change for the final design. For this beam dynamic layout the design of the CH-type cavities was optimized to handle the high accelerating gradient. The results of the performance of the CH-type cavities will be presented in this paper.

HBS

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

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 µs
Repetition rate	96/24/48 Hz

The initial approximated design consisted of 36 cavities. Due to the high proton current the first cavities need a lower acceleration gradient in order to keep the emittance of the beam as low as possible and the acceptance of the linear accelerator as high as possible. Furthermore additional CH-type cavities are needed as rebuncher cavities to assure a sufficient beam quality.

CH-TYPE CAVITIES

The 176.1 MHz linac should be as efficient as possible while being easy to maintain, as modular as possible and have a low R&D effort. To meet those requirements with normal conducting accelerating cavities CH-type cavities will be used for the linac. The proposed design is shown in Fig. 1. The expected thermal load for the cavities will reach a maximum value of 25 kW/m. Therefore a cooling design was initially developed for the CH cavities and has been improved to handle the high acceleration gradient. The cooling design consists of one cooling channels for each stem, one for each tuning device, one for the power coupler, two for the lids and 24 for the tank. A view of the front of the cooling design is shown in Fig. 2. The highest thermal load and thus the most cooling effort will be on and around the stems, since those are the regions with the highest current inside the cavity. Hot spots are also in the middle section of the tank possible due to the mode used for acceleration, which is the TE_{211}-Mode. To account for the high acceleration gradient changes to the cooling design of the stems were made. The results of a thermal simulation and thus the operation of the enhanced cooling design is shown in Fig. 3. For a better comparison between the new design and the old design the enhanced design was applied only on the stem in the middle

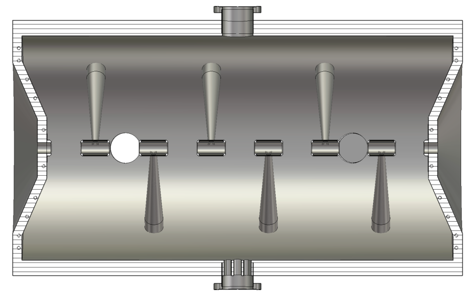

Figure 1: Side view of cross section of the used design for the HBS CH-type cavities.

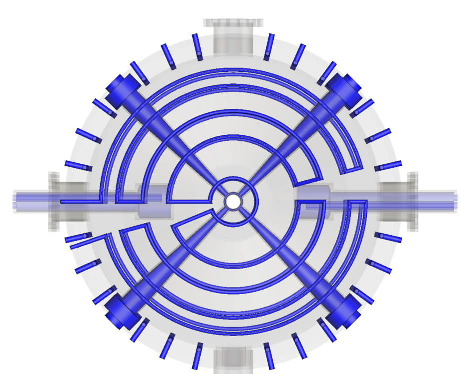

Figure 2: Front view of the enhanced cooling design from the CH-type cavities.

* petry@iap.uni-frankfurt.de

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPOGE12

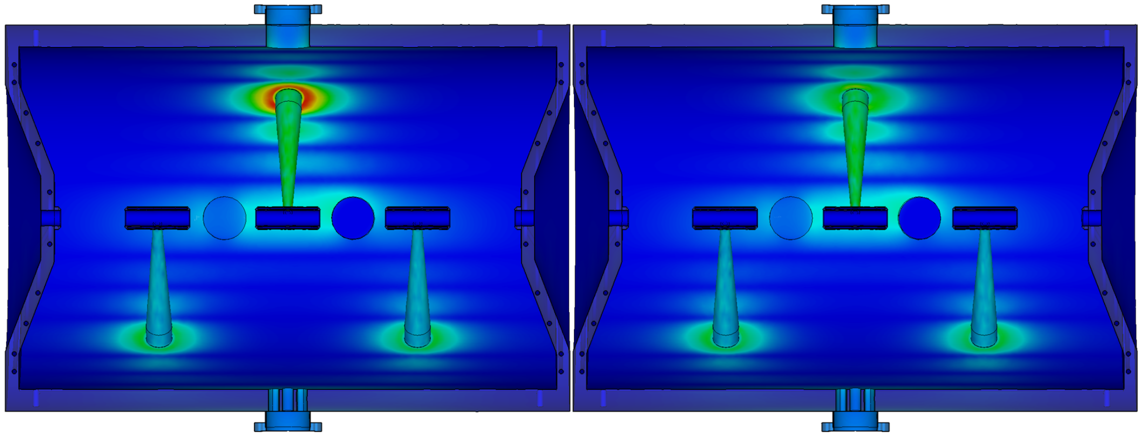

Figure 3: Results of thermal simulation of the enhanced cooling design for the stem in the middle in comparison to the old cooling design of one CH cavity. Low temperatures are displayed in blue and the highest temperatures are displayed in red. The hot spots around the stems have disappeared and the highest temperature inside the cavity has dropped by around 20 °C.

of the cavity. The optimization of the cooling design lead to an additional water volume inside the tank at the beginning and the end of each stem, which can be seen in the view of the side of the cavity, shown in Fig. 4. Due to the enhanced design the hot spot around the stems disappeared and the highest temperature reached inside the cavity has dropped by around 20 °C.

PROGRAM FOR DESIGN ITERATION

A python program is in development to handle the design of approximate 45 CH cavities. The idea behind the program is the process shown in Fig. 5. After designing a first version of the beam dynamic simulation one will get an ideal gap voltage distribution as a result. This gap voltage distribution acts as input file for the program. In this case the program LORASR [4], a multi-particle tracking code for beam dynamic designs, is used. For the output files of LORASR the python program can automatically create an input file from which one can generate the designs for the approximate 45 CH cavities required. The CH cavity designs are created as CST Studio Suite [5] files, from which the program will 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. Besides the real gap voltage distribution the program will calculate several other key parameters which are important for the design process for the CH-type cavities.

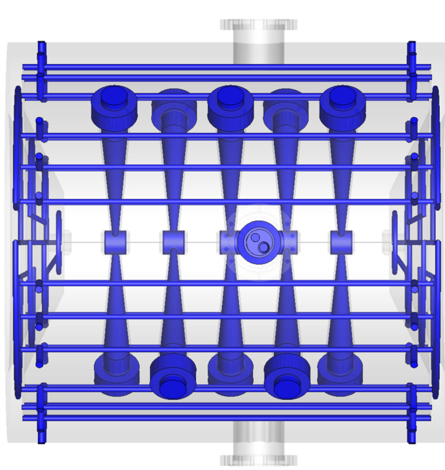

Figure 4: Side view of the enhanced cooling design from the CH-type cavities.

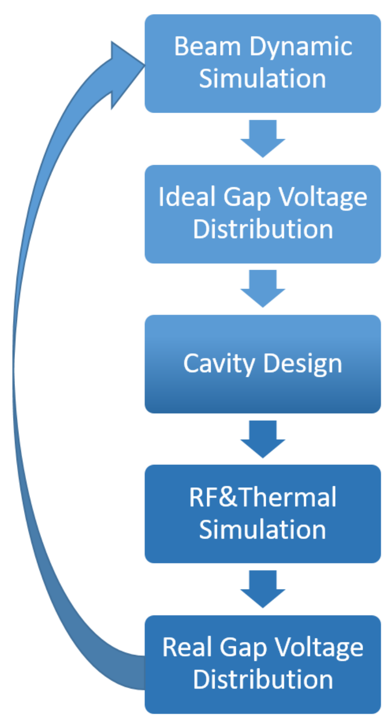

Figure 5: Concept of iterations process for the HBS main linac.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPOGE12

CURRENT RF RESULTS

With the assistance of the python program under development the 45 CH cavities of the WIP beam dynamic design from mid 2022 could be created, simulated and evaluated. As stated before, the RF and thermal simulations are done with CST Studio Suite. Several relevant RF properties of the cavities will be calculated and exported from the program after the RF simulations have finished, for example the shunt impedance Z_{eff}, shown in Eq. (1). Furthermore the Kilpatrick factor and the frequency gap between the fundamental mode and the next higher mode are calculated. To include imperfections from manufacturing the values of Z_{eff} used in this proceeding are 90 % values. The subsequent thermal simulations are calculated with an additional power safety margin of 20 % and a duty cycle of 20 %. Due to this safety margin in terms of power the hottest spot in the hottest cavity reached around 63 °C.

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

The shunt impedance of the 45 cavities along with the corresponding temperature of the hottest spot inside the cavity is plotted in Fig. 6. Due to the design of the cavities the length in Eq. (1) is not the total length but the sum of the $\beta\lambda/2$ lengths, which represents the length on the beam axis. The total length was used for the thermal load. The results of the simulations are summarized in Table 2 along other key parameters.

CONCLUSION

With the high acceleration gradient needed for the final beam energy of 70 MeV the temperature around the stems of the CH-type cavity reached uncritical, but high values. To compensate those hot areas a new cooling design was introduced. The temperature around the stems could be significantly reduced with the new enhanced cooling design. The WIP design from mid 2022 needs 45 CH-type cavities to reach 70 MeV, of which 3 cavities are rebuncher cavities. This design is not the final design since the particle distribution and therefore the beam dynamic design is still undergoing optimization [6].

Table 2: Simulated Parameters of the 45 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	19 – 51 MΩ/m
Aperture diameter	35 mm
Voltage	0.5 – 2.4 MV
Gradient	1.5 – 2.4 MV/m
Amplifier power	100 – 500 kW
Total power per cavity	70 – 405 kW
Thermal load	8 – 25 kW/m
No of cavities	≈ 45
RF Structure	CH-DTL

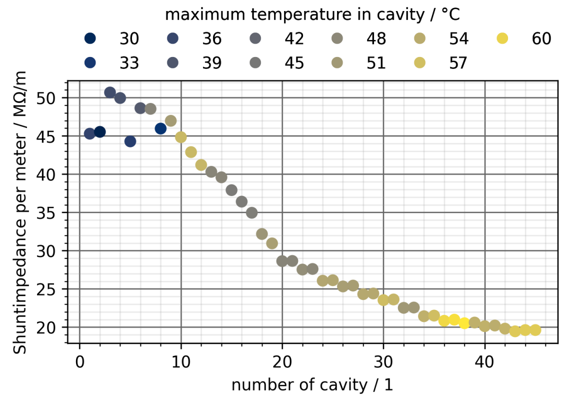

Figure 6: Results of the WIP mid 2022 design with 45 CH-type cavities.

REFERENCES

[1] U. Rücker, T. Cronert, J. Voigt, J. P. Dabruck, P. -E. Doege, J. Ulrich *et al.*, "The Jülich high-brilliance neutron source project", *Eur. Phys. J. Plus*, vol. 131, p.19, 2016. doi:10.1140/epjp/i2016-16019-5

[2] J. P. Dabruck, T. Cronert, U. Rücker , Y. Bessler, M. Klaus, C. Lange *et al.*, "Development of a moderator system for the High Brilliance Neutron Source project", UCANS-V, 2015. doi:10.1393/ncc/i2015-15192-0

[3] M. Schwarz *et al.*, "Proton Linac Design for the High Brilliance Neutron Source HBS", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 90–93. doi:10.18429/JACoW-IPAC2022-MOPOST016

[4] R. Tiede, G. Clemente, S. Minaev, H. Podlech, U. Ratzinger, and A. C. Sauer, "LORASR Code Development", in *Proc. EPAC'06*, Edinburgh, UK, Jun. 2006, paper WEPCH118, pp. 2194–2196.

[5] CST Studio Suite, https://www.3ds.com/products-services/simulia/products/cst-studio-suite/

[6] S. Lamprecht *et al.*, "Beam Dynamic Simulations for the DTL of the High Brilliance Neutron Source", presented at the LINAC'22, Liverpool, UK, Aug.-Sep. 2022, paper TUPORI05, this conference.