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DESIGN OF A TRIPLE SPOKE CAVITY FOR THE HIF DEMO INJECTOR*

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Abstract

A 325 MHz triple spoke type superconducting cavity for lead beams with beta=0.3 is designed for the heavy ion inertial fusion (HIF) Demo facility. The design and simulations of the triple spoke will be reported in this paper, including the electromagnetic (EM) design and mechanical study using CST microwave studio (MWS) and ANSYS workbench.

INTRODUCTION

In the 1970s, the accelerator scientists proposed several HIF projects to solve the energy problem, such as HIBALL[1] in USA, HIDIF[2-3] in Germany and HIBLIC [4] in Japan. As shown in Fig. 1 [4], the heavy-ion beams were used to irradiate the deuterium-tritium (D-T) target and to increase the plasma temperature and density to reach the Lawson criterion. All above proposed HIFs were large scale facilities and were too large to be built.

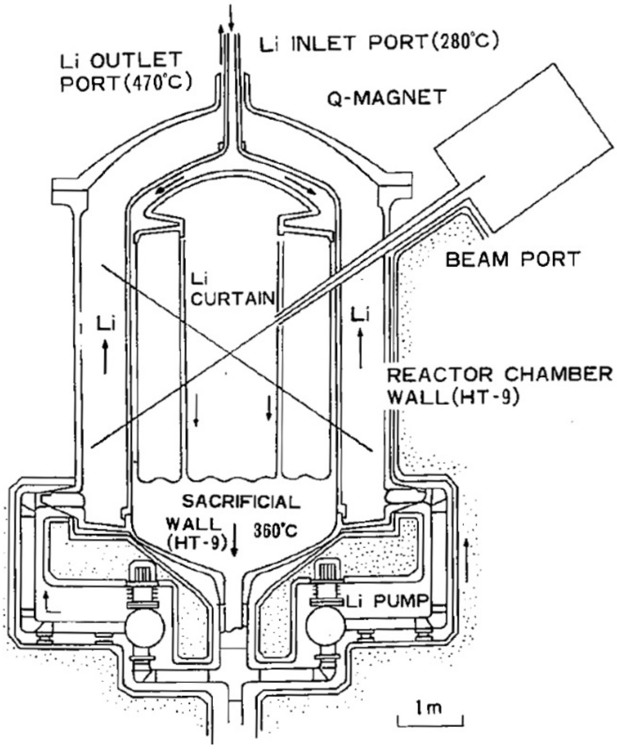

Figure 1: The principle of the heavy-ion inertial fusion. This image is designed for the HIBLIC reactor.

We propose a demo facility shown in Fig. 2 for these researches. In this demo facility, a 240 mA heavy ions beam will be accelerated up to 10 MeV/u and 50 MeV/u by a 600-meter-long linac driver and downstream heavy-ion synchrotron systems. There is a four-times storage ring where RF storage, electron cooling and stochastic cooling technologies can be developed. After bunch compressors, the bunched heavy ions will be injected into four induction bunches for recompressing and strengthening. Finally, the recompressed beams will be delivered to the experimental fusion facilities. The width of the final bunch is 10~20 ns, which requires superconducting focusing technologies for target heating.

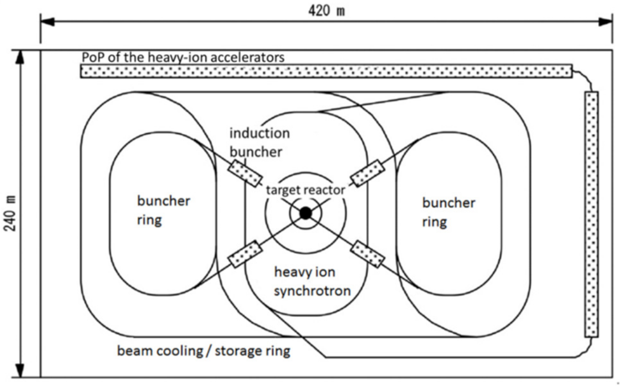

Figure 2: DEMO facilities of a multi-beam cavity type linac-based HIF system.

We are trying to design a new HIF driver linac, using the direct plasma injection scheme (DPIS) technologies and multi-beam acceleration [5]. A simple layout of HIF driver system is shown in Fig. 3. In this system, a powerful laser will split to four and produce four high-intensity Pb+ ion beams (115 mA/channel), which will be directly injected to a four-beam type Interdigital H-mode (IH) RFQ [6], where four 125 mA beams will be accelerated to 300 keV/u from 3 keV/u at an operation frequency of 40.625MHz. Two beams funneling system will be adopted to funnel the accelerated ion beams from the RFQ. The beam intensity will be enhanced to 220 mA/channel before injecting to a two-beam type drift tube IH (DT-IH) linac system. The two-beam type IH-DTLs will accelerate 220 mA/channel ions up to 1.2 MeV/u at an operation frequency of 81.25 MHz. The system could also offer one-beam type DT-IH linacs, which will accelerate 410 mA/channel ions up to 4.7 MeV/u at an operation frequency of 162.5 MHz. Finally, superconducting (SC) linacs will offer high accelerating field to accelerate 400 mA ions up to the 50 MeV/u at the operation frequency of 162.5MHz and 325 MHz. Comparing with the initial proposed HIF driver, the total length of the new HIF injector based on the multi-beam linac is only about 2.5 km, which is constructible.

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The spoke cavity in the HIF Demo facility is chosen as β0.03 niobium triple spoke cavity, operating at 2K and a frequency of 325 MHz. The accelerating field is 9MV/m.

The choice of spoke cavity for the HIF Demo injector is for its advantages as following [7]: high efficiency, large beam aperture, multi-gap capability, compact, wide beta range and high longitudinal acceptance.

Table 1: The Parameters of the Triple Spoke

Parameter	**Value**
Frequency (MHz)	325
Optimal beta	0.3
Beam tube diameter (mm)	50
Eacc (MV/m)	9
Temperature (K)	2

In this paper, the design of the triple spoke cavity for the HIF Demo injector with parameters in Table 1 will be presented.

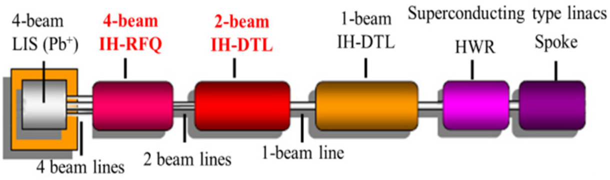

Figure 3: Layout of HIF Demo injector.

ELECTROMAGNETIC DESIGN

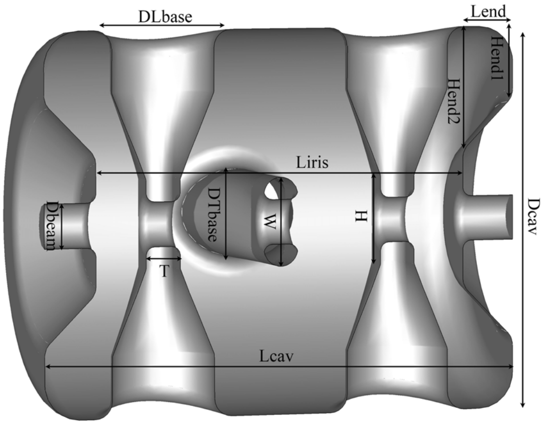

Figure 4: The triple spoke model with the main geometric parameters. The parameters are as following: Lcav - cavity length, Dcav - cavity diameter, Liris - iris to iris length, DLbase and DTbase - elliptic diameters at the spoke base, T - spoke thickness, W - spoke width, H - spoke height, Dbeam - diameter of the beam tube.

The EM design of the triple spoke cavity is based on the operating frequency and the optimum beta. The operating frequency of the triple spoke is 325 MHz and the optimum beta is 0.3. Because the HIF beam current in the spoke is 400 mA and will have a big transversal beam size, the beam tube diameter is chosen as 50mm. The main purpose of the RF design is the optimizations of the peak surface electric and magnetic field to the accelerating field ratio.

CST MWS [8] was used to design and optimize the triple spoke cavity. The model used in the simulations is shown in Fig. 4. The shape of spoke base is ellipse and the shape of spoke center is racetrack. The impacts of the model parameters on the Epk/Eacc and Bpk/Eacc have been studied. With the optimized parameters listed in the Table 2, the electric and magnetic field distributions are shown in Fig. 5 and the RF parameters are listed in Table 3. The Epk/Eacc is 4.06 and the Bpk/Eacc is 8.19 mT/(MV/m), the locations of them are shown in Fig. 5.

Table 2: Optimized Geometric Parameters

Parameter	**Value (mm)**
Lcav	554
Dcav	433
Liris	433.85
DLbase	60
DTbase	50
T	40
W	50
H	50
Dbeam	50
Lend	60
Hend1	80
Hend2	140

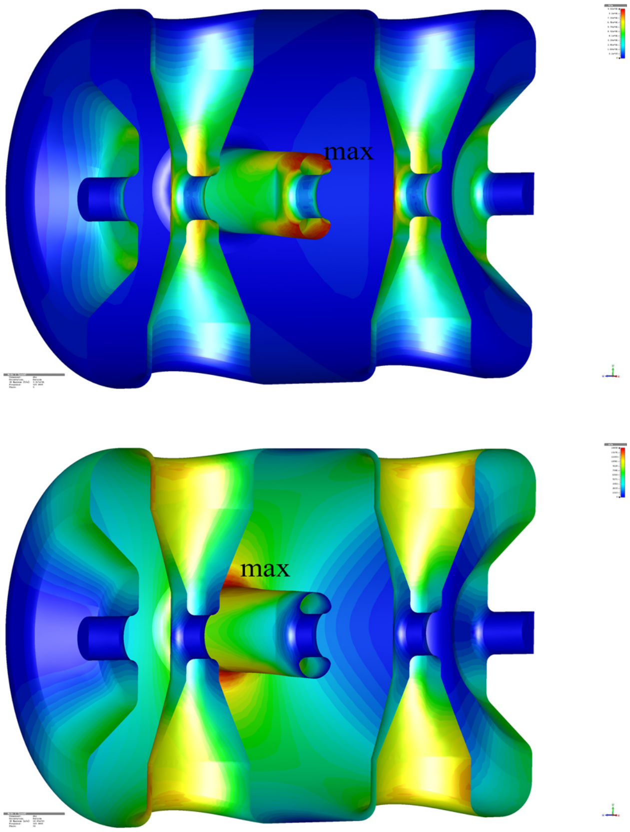

Figure 5: The electric (top) and magnetic (bottom) field distributions of the triple spoke cavity.

Table 3: RF Parameters of the Triple Spoke Cavity

Parameter	Value
Optimal beta	0.3
Cavity length (mm)	554
Cavity diameter (mm)	433
R/Q (Ω)	439.91
G (Ω)	86.08
Epk/Eacc	4.06
Bpk/Eacc (mT/(MV/m))	8.19

MECHANICAL ANALYSIS

The wall of the triple spoke cavity will be formed with 3 mm thick niobium. The mechanical property was studied with ANSYS HFSS and workbench [9]. The simulation results of the deformation and equivalent stress under one bar helium pressure are shown in Fig. 6 and Fig. 7. The observed maximum deformation is 0.31 mm and is tolerable. The pressure sensitivity simulations are the RF and mechanical coupled process. The calculated helium pressure sensitivity df/dP is -82 Hz/mbar without any ribs.

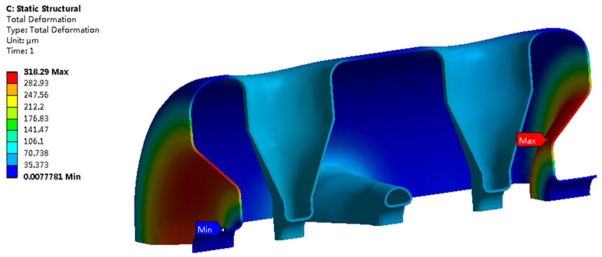

Figure 6: The deformation distribution under one bar helium pressure.

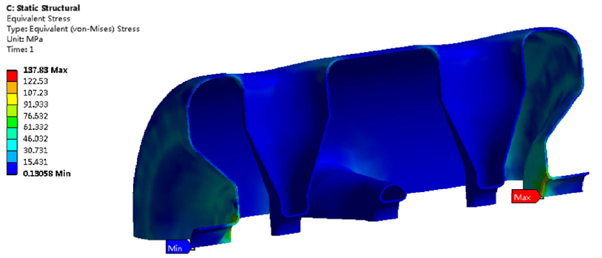

Figure 7: The equivalent stress distribution under one bar helium pressure.

FUTURE PLAN

The mechanical analysis of cavity with ribs and multimpacting analysis will be taken out in the future. With the ribs, the pressure sensitivity df/dP will decrease. Through the multimpacting analysis, the electromagnetic distribution will be optimized in the spoke cavity. Moreover, the design of the power coupler, the helium and vacuum vessels will be considered. Following these designs, the fabrication, post processing (including vertical test) and assembly will be carried out in the future.

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[8] CST Simulation packages, `http://www.cst.com`

[9] ANSYS, `http://www.ansys.com`