Study of cryogenic bi-periodic accelerating structure with TM02 mode and schematic design of the low temperature system

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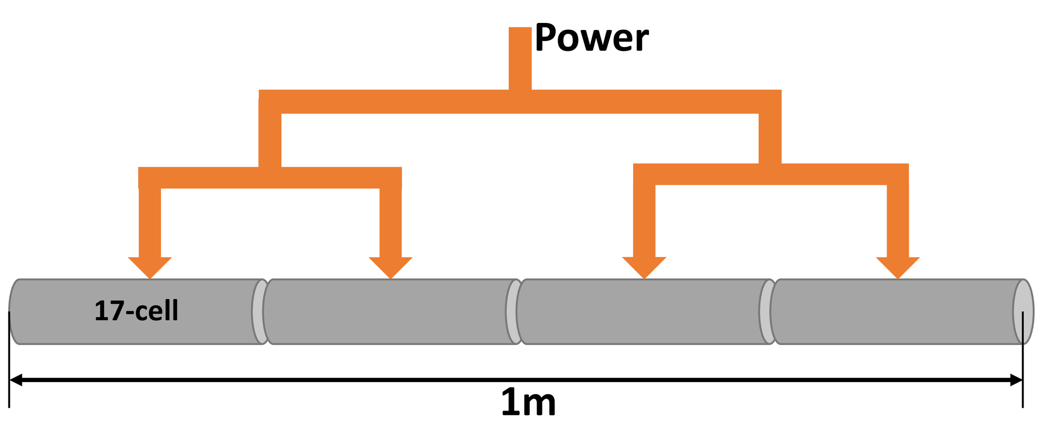
INTRODUCTION

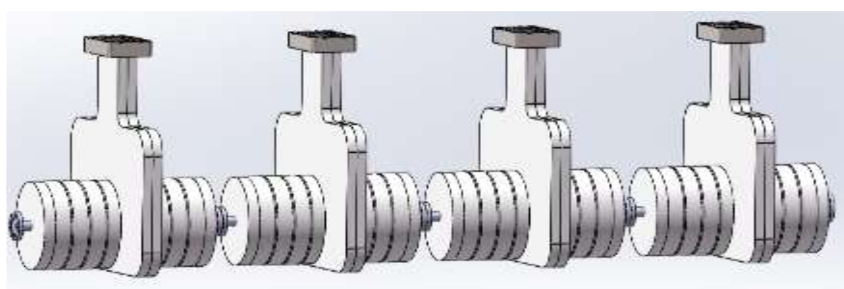
- A high gradient accelerating structure is an important part of accelerators.
- Many studies have shown that the cryogenic accelerating structure can effectively improve the accelerating gradient.
- The design of the cryogenic accelerating structure is completed for SXFEL energy upgrading.
- Design a bi-periodic accelerating structure, magnetic coupling , which operates at 40K, and the accelerating gradient can be raised to 80MV/m.
- The mode in the coupling cavity is set to TM02 innovatively, which further reduces the cavity's sensitivity and helps dissipate heat.

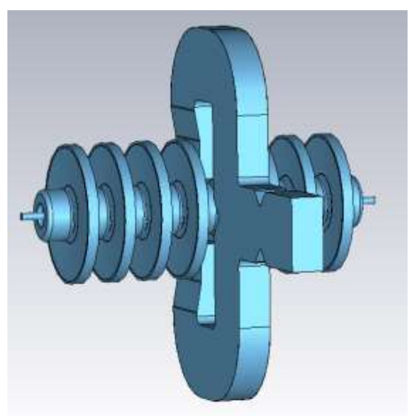
OVERALL DESIGN

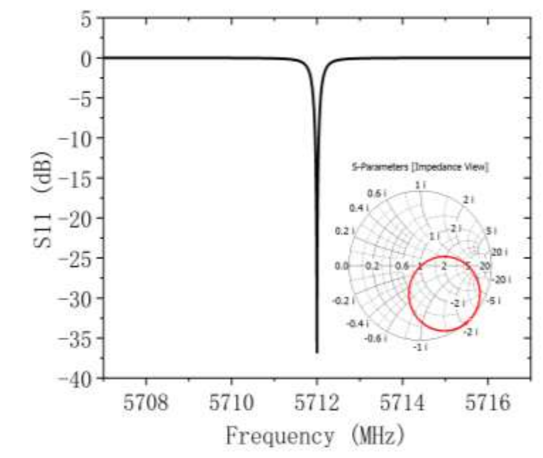
- At low temperatures, the electric conductivity and hardness of copper material are significantly improved, which can effectively reduce the breakdown rate, thus elevating the accelerating gradient to a new level.
- Considering all factors comprehensively, 40K is selected as the working temperature.
- The temperature rise caused by pulse heating is related to the residual resistance ratio (RRR) of copper. When RRR is high, the change of temperature rise tends to be gentle.
- Considering that copper with a high RRR is expensive, common copper with RRR=300 in the market is selected.
- We designed a cryogenic standing wave accelerating structure with a total length of 1m and four accelerating sections. Each accelerating section consists of 9 accelerating cavities and 8 coupling cavities, which are fed from the middle cavity in a double-fed way.

Parameter	Value	Unit
RF frequency	5712	MHz
Working temperature	40	K
Surface resistance@20K	0.005	Ω
Surface resistance@273.15K	0.0188	Ω
The target E_{acc}(SW)	65/80	MV/m
Type of Structure	Bi-periodic	
Operating Mode	SW / $\frac{\pi}{2}$	
Material	Copper	
RRR	300	
Coolant	Liquid helium	



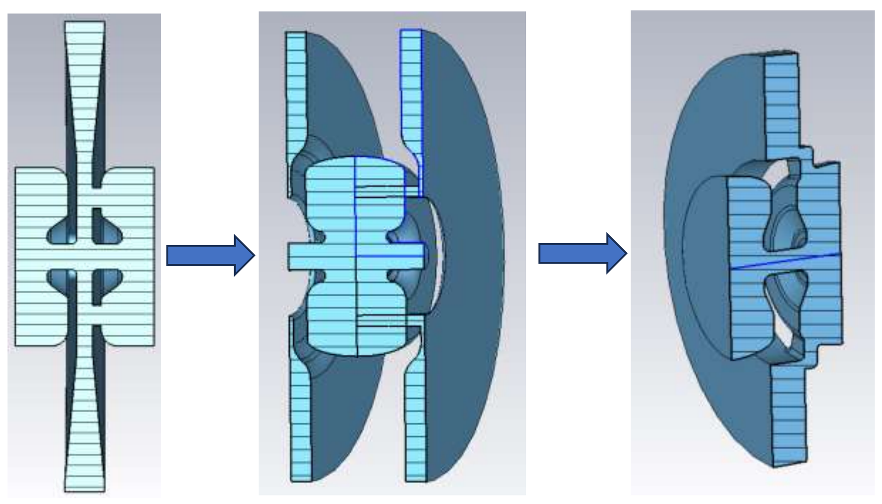


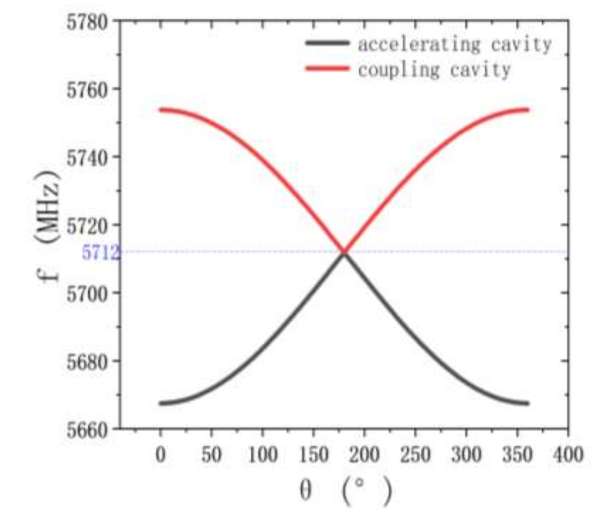


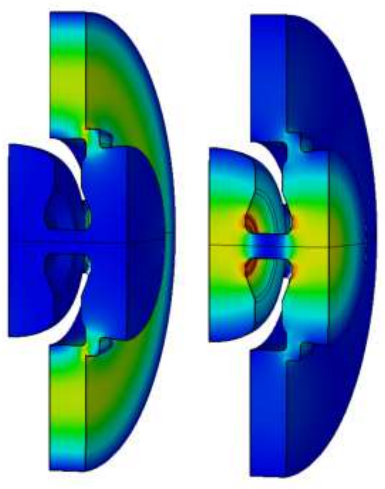


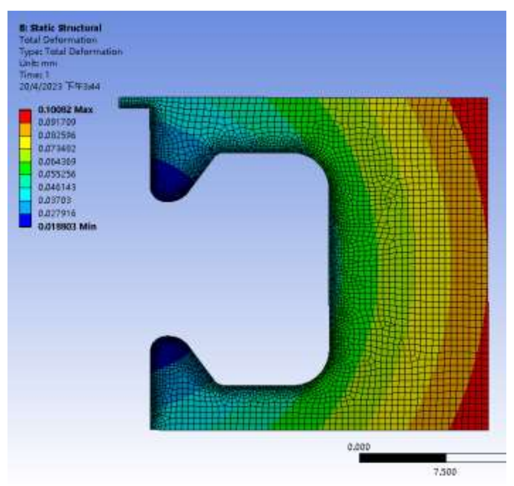
Bi-periodic cell with TM02 mode

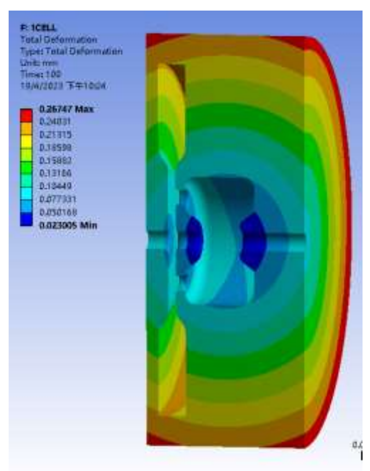
- The cavities are magnetically coupled.
- Compared with conventional bi-periodic structures, the microwave is transmitted in TM02 mode in the coupling cavities.
- We designed the coupling cavities to be thin in the middle and thick on the outside, so that it becomes a tunable cavity.
- The shape of the coupling cavity has been modified twice.
- The field distribution and dispersion curves in this model were then calculated and the size of the cavity was optimised to form a passband.

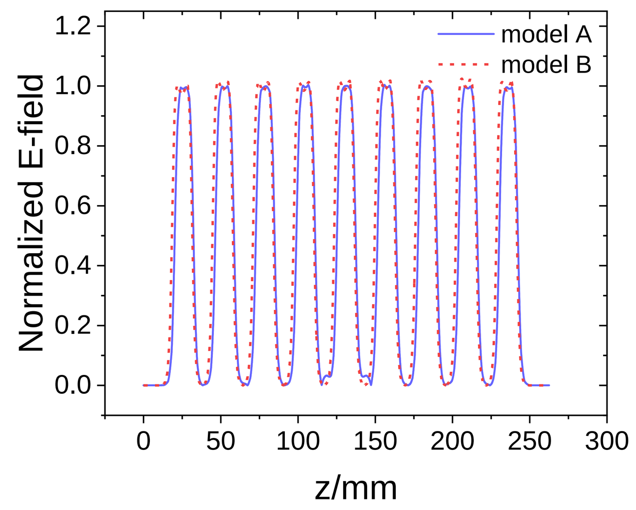












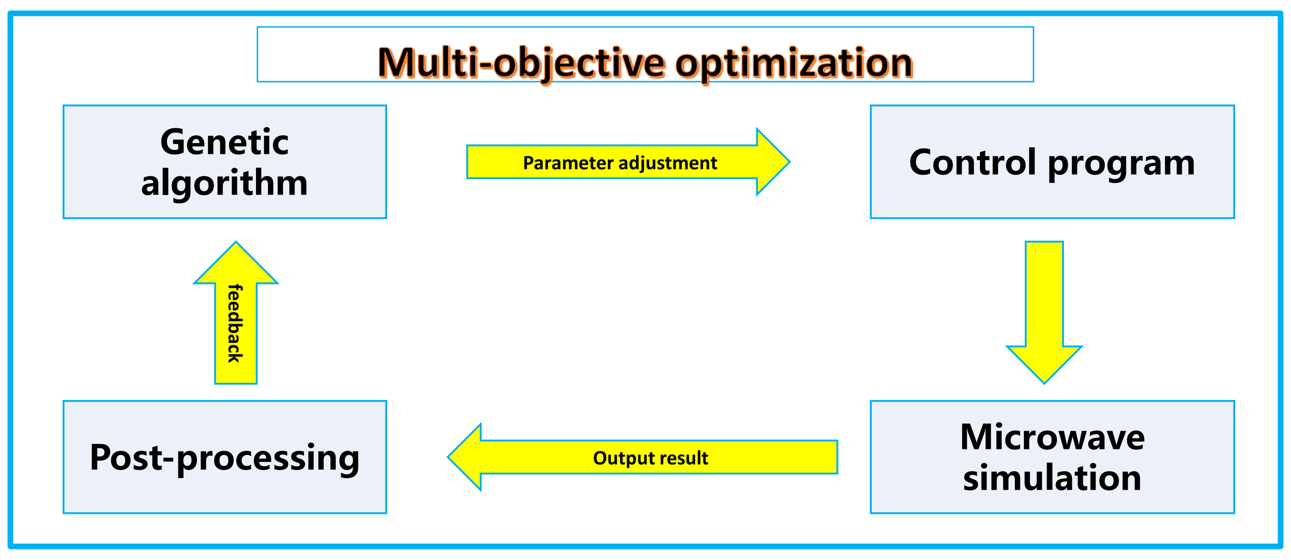
Multi-objective optimization applied on accelerating cavity

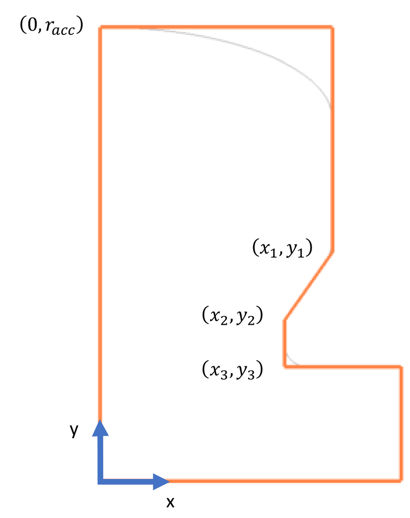
- The whole optimization program consists of four parts: genetic algorithm; Control program; Microwave simulation; The post-processing program.
- There are three optimization objectives: modified Poynting vector; Lorentz force; R/Q.

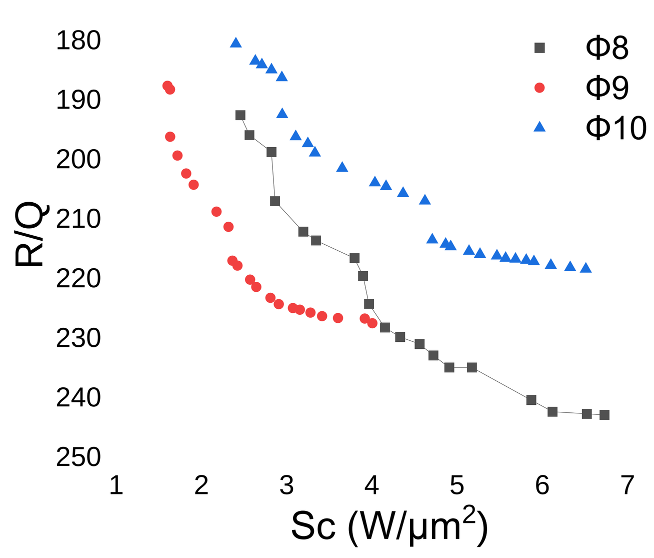
$$S_c = ||\mathrm{Re}(\bar{S})|| + g_c \cdot ||\mathrm{Im}(\bar{S})||$$

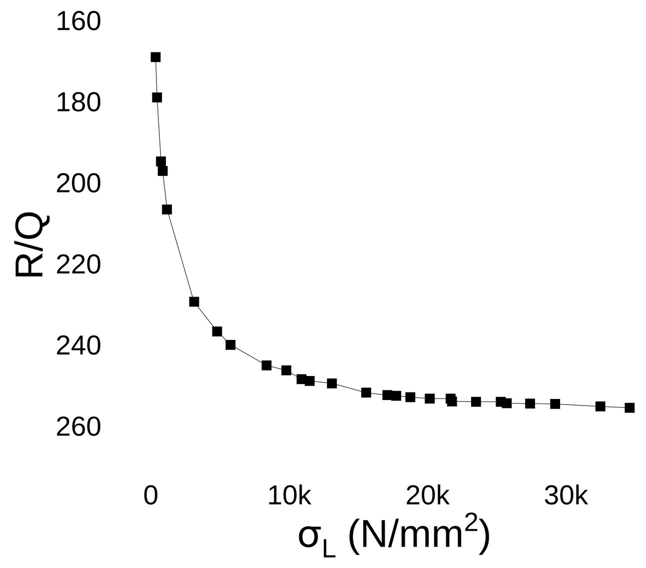
$$\sigma = \frac{\epsilon_0(\beta E)^2 - \mu_0(H)^2}{2} + ZGb\rho = \sigma_L + ZGb\rho$$

- On the pareto front, individuals that meet the requirements are selected as the final optimization result.
- The number of parameters is 6, which can be simplified to 4.









Cryo-module

- The structure dynamic thermal load is 80W@40K.
- Static thermal load 20W/40K,
- Plus 50%, total thermal load 150W@40K
- GM chiller, cold head conduction cooling method
- The number of chillers is 4