HIAF-bring magnetic alloy loaded RF system design and testing

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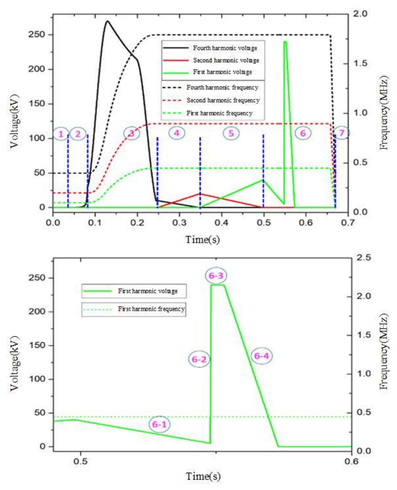
After nearly a decade of technological breakthroughs, our team has solved a series of core technical problems of the National "the 12th Five-year Plan" key project High Intensity heavy-ion Accelerator Facility (HIAF) from materials to processes, In addition, we have established a high-performance automated production line with independent intellectual property with collaborative manufacturers, achieving mass production of MA rings. The first domestic low-frequency, wide-band, oil-cooling MA RF system has achieved a cavity voltage gradient of>30kV/m (peak voltage of 66kV) and a harmonic suppression of>23dBc in operating frequency(0.29-2.1MHz), laying a foundation for HIAF to achieve international leading indicators.

Introduction

The RF Technology Office of Institute of Modern Physics, Chinese Academy of Sciences needs to design a fast-response, wide-band, high-gradient RF system for HIAF BRing. This system includes 6 oil-cooling iron based nanocrystalline soft MA loaded coaxial resonant cavity, referred to as oil-cooling MA RF system.

Physical requirements for HIAF BRing MA RF system

parameter	value
frequency	0.29~2.1 MHz
maximum repetitive frequency	3 Hz
maximum duty ratio	69%
operating mode	sweep frequency
peak voltage	285kV/ring
speed of response	≤10μs
number of cavities	6
inner diameter of pipeline	Φ170 mm
vacuum	≤1×10^{-11}mbar



The RF voltage and frequency

MA RF System

The Bring RF system has requirements such as high acceleration voltage, wide operating frequency and fast response time. Each RF system consists of four main parts: an oil-cooling MA-loaded cavity, a high-power pulsed amplifier, a LLRF system and a computer monitoring system. In addition, the RF cavity adopts an iron based nanocrystalline soft MA ring coaxial resonant structure with 3-acceleration gaps, the amplifier adopts high-power tetrode TH558 push-pull operating mode.

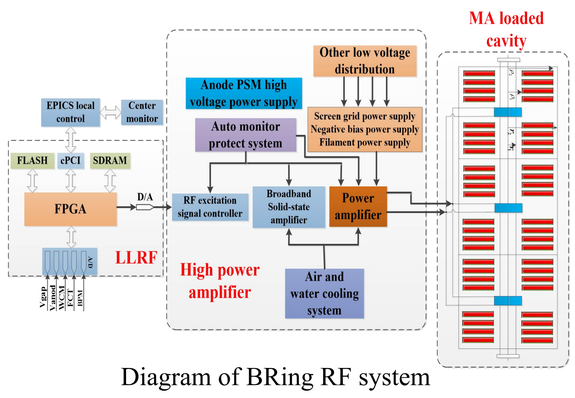


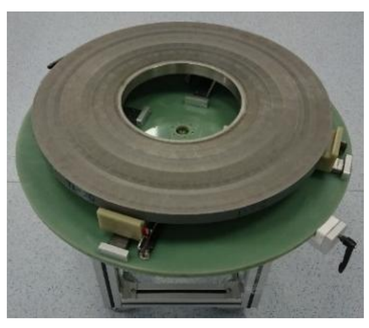
Diagram of BRing RF system

	length	**2210mm**
Cavity	voltage	50kV
	frequency	0.29~2.1MHz
	material	iron based nanocrystalline soft MA
	peak power	500kW
	average power	120 kW
	cooling method	oil-cooling
Amplifier	tetrode type	TH558×2
	peak power	500 kW
LLRF	amplitude stability	|△A/A|≤1%
	phase stability	|△ϕ|≤ 1°

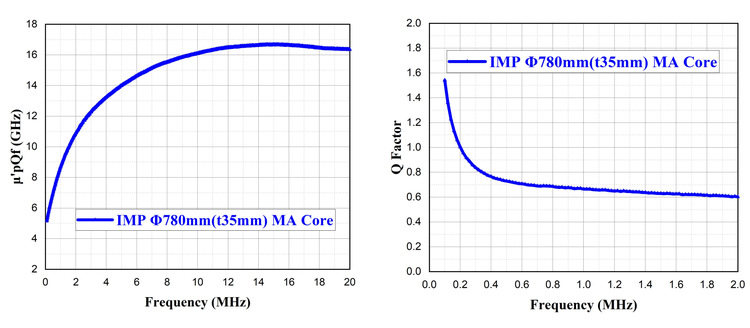
Main parameters of BRing RF system

Domestic large-size MA Core

We have solved a series of core technical problems of magnet rings by collaborating with domestic companies and establishing a magnetic ring process verification and performance testing platform, and has built a high-performance automated production line, achieving complete localization from materials to magnet rings. This ring has a flatter Q-value(0.8-0.5) in 0.1-20MHz, and has better characteristics in wide-band.



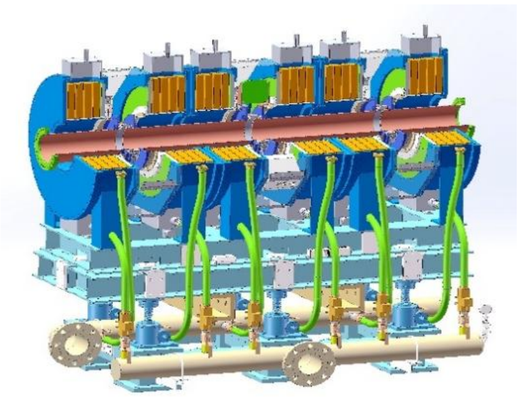
Domestic large-size oil-cooling MA core



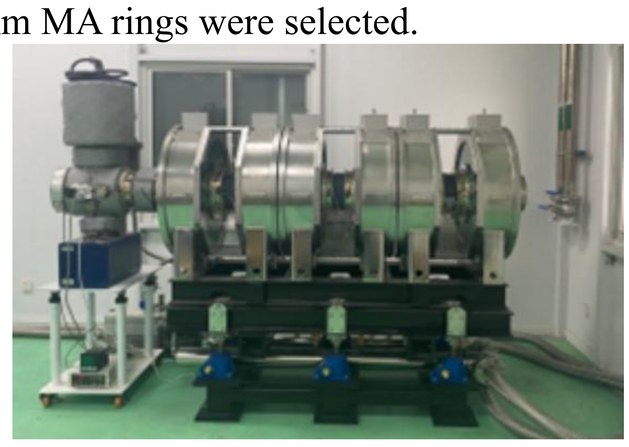
Performance of domestic MA cores

MA-Loaded Cavity

The BRing RF system MA-loaded cavity adopts a 3-acceleration gap structure, with a total cavity length of<2210mm. One MA-loaded cavity contains three acceleration cells, each cell is composed of two λ/4 coaxial resonant cavities. In order to reduce the longitudinal length of the cavities and the number of MA rings, outer diameter of Φ 780mm, inner diameter of Φ 350mm and thickness of 35mm MA rings were selected.



3-dimensional diagram of BRing MA cavity



Picture of BRing MA cavity

500kW Tetrode Amplifier

The wide-band tetrode power source system adopts the dual tetrode TH558 push-pull mode operation. the design innovatively adopts gate power modulation technology, which is beneficial for reducing static tube consumption, improving efficiency and extending the life of tetrode. The maximum peak power of the tetrode can reach 500kW.

500kW tetrode power source system

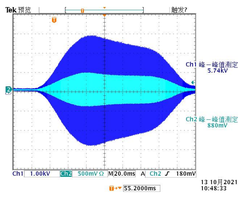
Picture of tetrode

LLRF & Commissioning Results

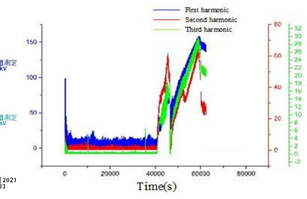
The first domestic low-frequency, wide-band, oil-cooling MA RF system was successfully developed in October 2022 and achieved 1Hz high-power stable operation. Based on above, we further increased the power capacity of the anode power source, optimized the amplifier and cavity cooling, and achieved a repetitive frequency increase from 1Hz to 3Hz, a cavity peak voltage of 60kV, and a duty ratio of 67%, laying a foundation for achieving high repetitive frequency in HIAF.

VPX LLRF system

DSP board

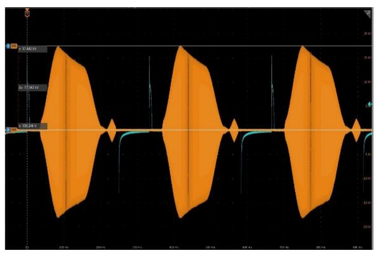


Cavity voltage

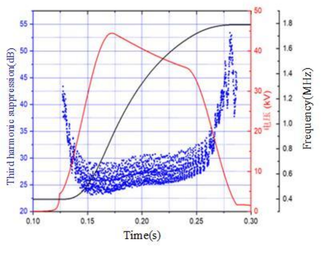


harmonic components

MA RF system prototype



Gap voltage of cavity



Third harmonic suppression

Poster ID: 40

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LOW LEVEL RADIO FREQUENCY WORKSHOP 2023
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