Design of Wall Current Monitor in BRing at HIAF

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Abstract

The Wall Current Monitor (WCM) can monitor the lon-gitudinal beam shape, beam stability, beam longitudinal emittance and intensity, which has been applied widely in the laboratories of high-current proton accelerators. Many accelerators such as CERN-PS, CERN-CLIC, J-PARC and CSNS-RCS have designed different WCMs according to their respective accelerator beam parameters. In order to provide the high-intensity heavy-ion accelerator facility (HIAF)-BRing high-frequency system of with the intensity of each harmonic beam to compensate for wake field; and to observe the changes of the bundle length during the injection, acceleration, and extraction of the bundle, it is planned to place a WCM in HIAF-BRing. According to physical requirements, the lower limit of the WCM work-ing bandwidth is expected to reach 10kHz, and the upper limit can reach 100MHz. According to this bandwidth re-quirement, a WCM structure is designed, and its theoretical bandwidth is 2kHz~400MHz, which fully meets the de-mand. This article gives a detailed and comprehensive in-troduction to the overall design of this WCM, the selection of various components, design calculations and related simulation calculations. At present, the WCM has com-pleted the procurement and processing of various compo-nents, while offline and online testing has not been carried out owing to time constraints. It is expected to be installed on the Heavy Ion Research Facility in Lanzhou-Cooling Storage Ring (HIRFL-CSR) for online testing in August.

PRINCIPLE OF WCM

When the beam passes through the vacuum pipe, its AC component will produce a constant-amplitude and inverse-phase mirror current on the wall of the vacuum pipe. The WCM uses this principle to measure the longitudinal information of the beam.

Cut the vacuum pipe and install a ceramic ring, connecting a resistor across the two ends of the ceramic ring, the induced mirror current will produce a voltage which is proportional to the beam current. By directly measuring the voltage, the intensity signal of the beam can be measured.

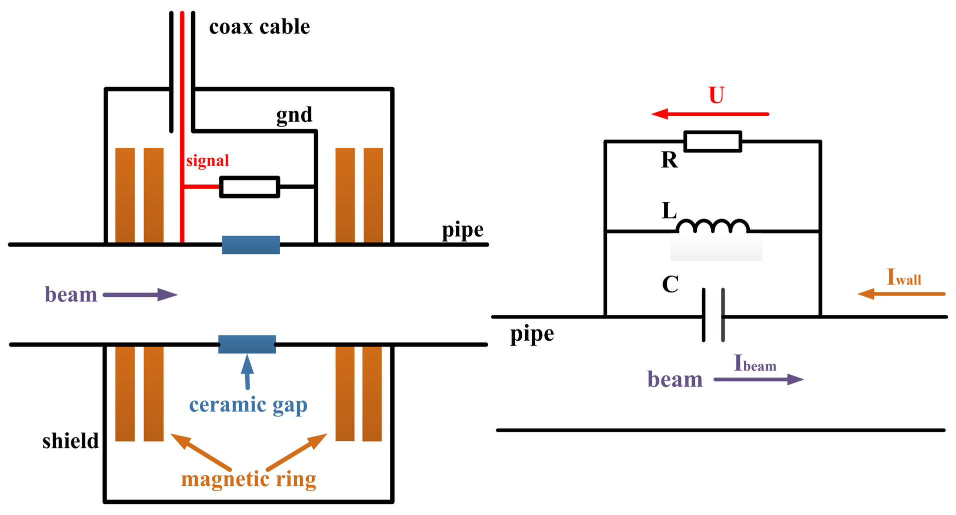


Figure 1: the schematic diagram and the corresponding equivalent circuit of WCM.

- equivalent capacitance value of ceramic gap: $C_{gap} = \frac{\varepsilon_0 \varepsilon_r S}{t}$
- characteristic impedance of the ceramic gap: $Z = 377 \frac{t}{2\pi r_0} \frac{1}{\sqrt{\varepsilon_r}}$
- equivalent inductance value of magnetic ring: $L = \frac{\mu_0 \mu_r}{2\pi} h \ln\left(\frac{b}{a}\right)$
- Working bandwidth

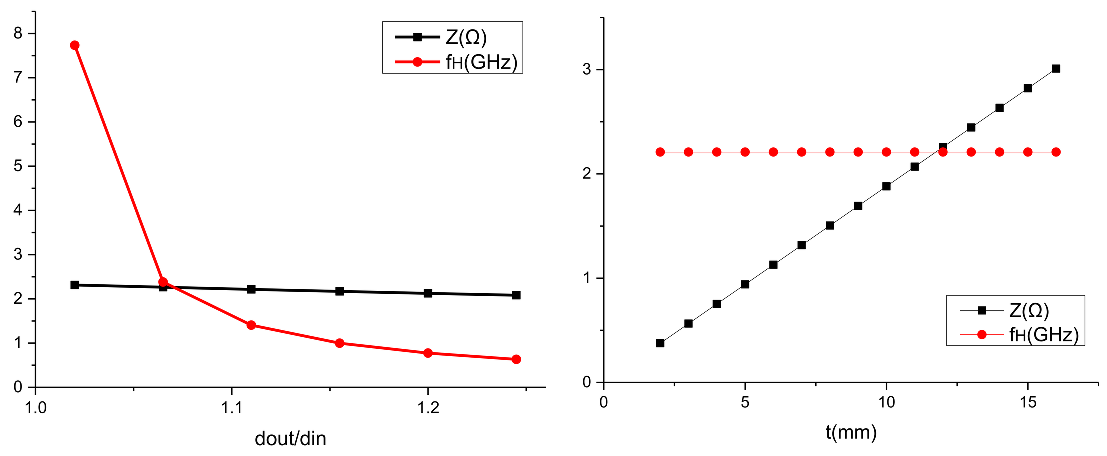
$$f_H = \frac{1}{2\pi C_{gap}} = \frac{r_0}{377 S \varepsilon_0 \sqrt{\varepsilon_r}}$$

$$f_L = \frac{R}{2\pi L} = \frac{R}{\mu_0 \mu_r h \ln\left(\frac{b}{a}\right)}$$

DESIGN OF WCM

➢ Ceramic ring size calculation

The ceramic ring material is 97 ceramic, $\varepsilon_r = 9.5$, the din(inner diameter) = 200mm, equal to the diameter of the vacuum pipe. The various indicators of the ceramic ring are analyzed as shown in Figure 2. Figure 2(a) shows that when t is constant, the influence of dout/din on f_H and Z; Figure 2(b) shows that when the inner and outer diameters are constant , the influence of t on f_H and Z.



the final ceramic ring size parameters are: din=200mm, dout=225mm, t=12mm, at this time, corresponding to f_H=1.2375GHz, c_{gap}=58.494pF, Z=2.1986Ω

Figure 2 : Analysis of the influence of different parameters of ceramic ring

➢ Magnetic ring design

The design of magnetic ring mainly includes material selection, size calculation, and reasonable combination design of different material rings.

According to the investigation, 1K101 and 1K502A are selected. Its size is 220*280*30mm. Since the permeability of magnetic materials changes with frequency, choosing a suitable combination of magnetic rings can greatly improve the working bandwidth of WCM.

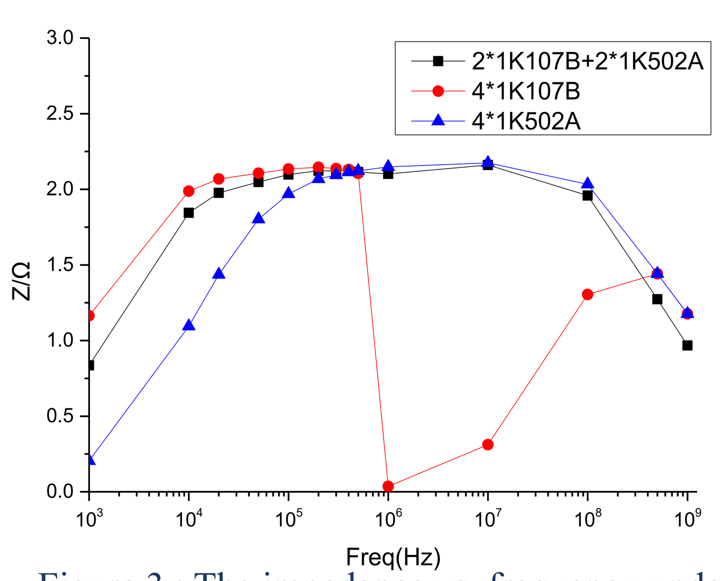


Figure 3 : The impedance vs. frequency under different combinations of four magnetic rings.

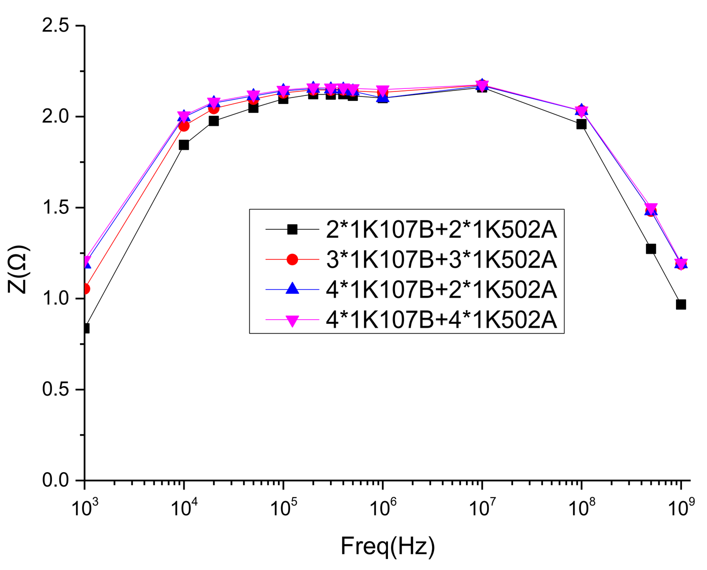
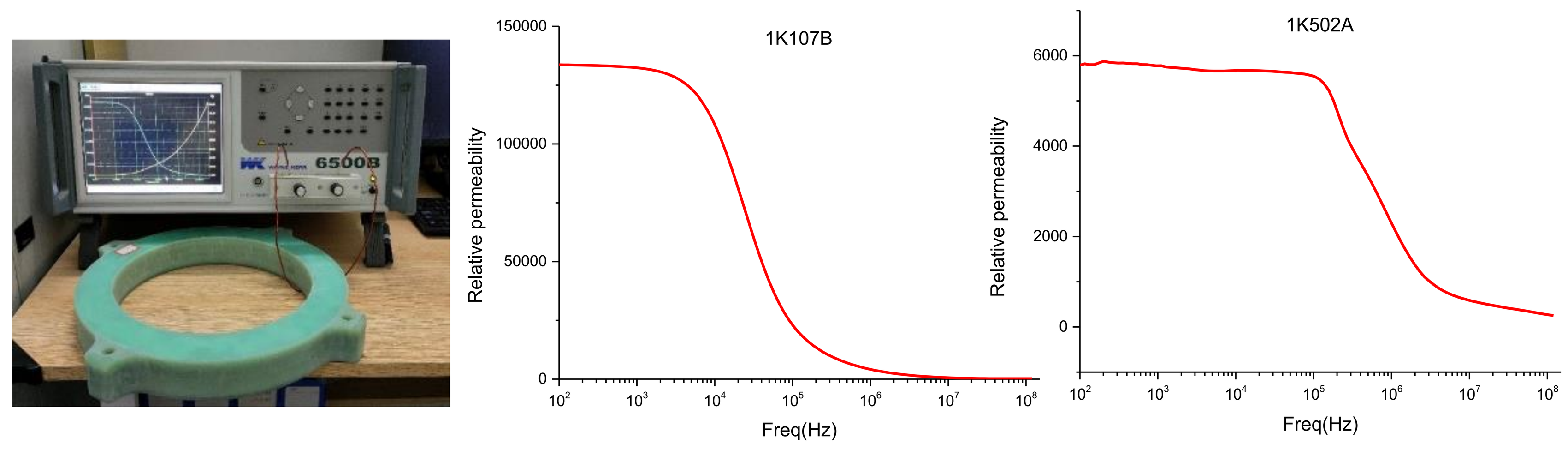


Figure 4 : The impedance vs. frequency under combinations of four/six/eight magnetic rings.

Figure 3 and Figure 4 show that the system impedance vs. frequency curve under different combinations of magnetic rings. It can be seen the system bandwidth of the combination of 4*1K107B and 2*1K502A magnetic rings is best, and the theoretical 3dB working bandwidth of this WCM is 2kHz~400MHz.



(a) (b) (c)

Figure5 : The actual magnetic ring processing and the magnetic permeability test results of the magnetic ring. (a) Magnetic ring finished product; (b) L-f performance test scenario; (c) The magnetic permeability of the two cores and the magnetic ring change curve with frequency..

➢ Signal pick-up resistor design

This part directly affects the accuracy of the final extracted signal. Here, we choose a flexible circuit board to design a resistance band for signal pickup. Its material is Panasonic R-F777, and its equivalent resistance is 2.2Ω. Figure 6 shows two design of the resistance board.

Figure 6: Physical picture of resistance band

01 and 02 use 50 110Ω resistors, and its signal is led out by pads. 03 and 04 use 100 220Ω resistors, and its signal is led out by a patch-type SSMP connector, which can effectively reduce the signal. Besides that the upper and lower copper-clad parts of the circuit board are connected by a number of metallized vias to ensure good electrical conduction between the resistance band and the vacuum pipeline.

Table1: Measured value of equivalent resistance value of flexible resistance band

Number	Tested resistance(Ω)
01	2.199
02	2.202
03	2.199
04	2.202

The actual measured value of equivalent resistance is 2.2±0.002Ω. Its accuracy is controlled within one thousandth, which meets the design requirements.

➢ WCM mechanical structure design

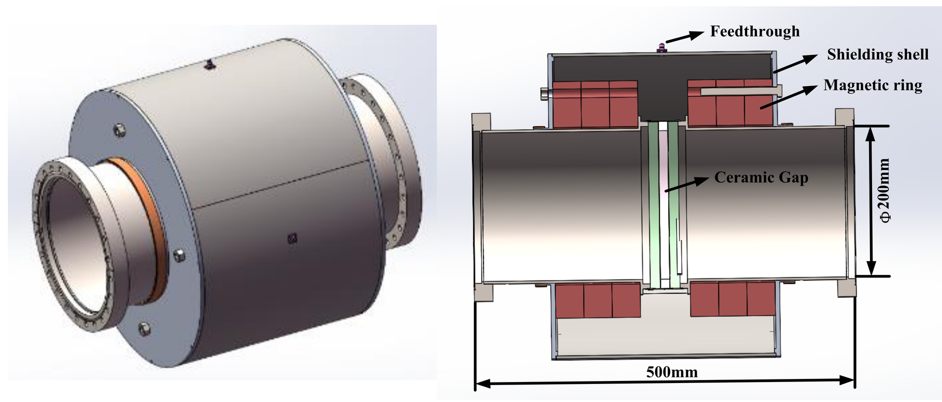


Figure 7: Three-dimensional drawing and cross-sectional view of the mechanical structure of WCM

The mechanical design of WCM is mainly considered from the mechanical processing and assembly, such as: brazing process of ceramic ring, the fixing of the magnetic ring, installation of resistance band, the reasonable installation position of each connector and the filling of the wave absorbing material, etc.

SIMULATION OF WCM

➢ Calibration platform designer and simulation

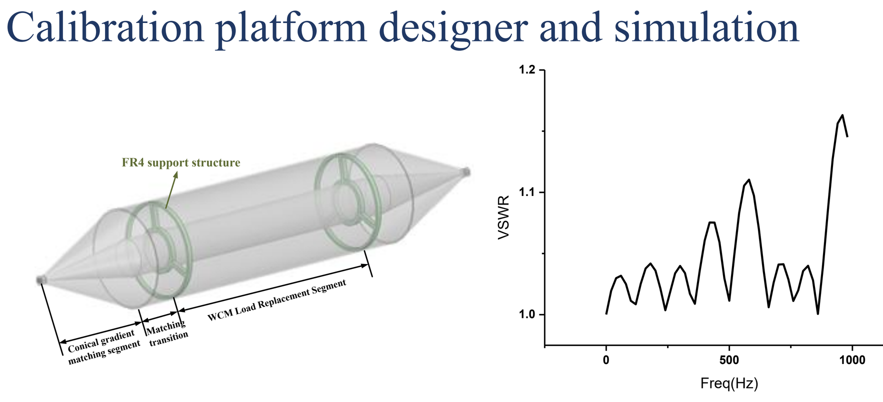


Figure 8: Simulation model and result of calibration structure

A calibration platform is needed to calibrating and testing for WCM, using HFSS to design and simulate. The result shows that in the range of 0~400MHz, VSWR≤1.05, the matching is excellent, which can be used for the calibration of WCM of this design.

➢ WCM simulation analysis

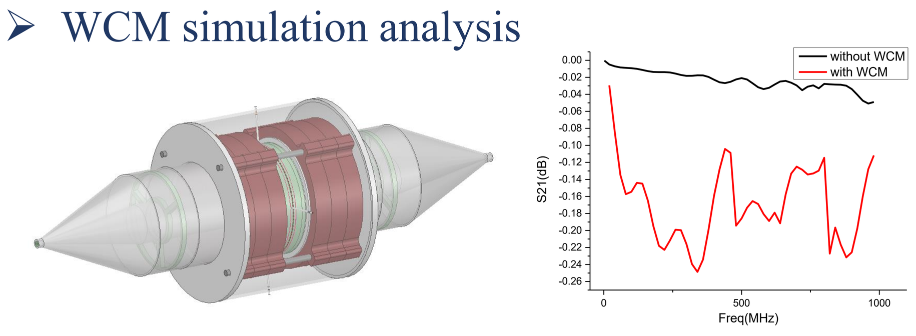


Figure 9: Simulation model and result of WCM

HFSS simulation results show the coaxial conversion structure's S21≥-0.05dB in the range of 0~1GHz. After loading the WCM structure, S21 drops does not exceed 0.25 dB in the range of 10 kHz to 1 GHz, which proves that the high energy transmission efficiency with expectations.

DISCUSSION

There is still room for optimization in this solution. For example, the flexible circuit board designed to bridge the signal pickup resistance can be integrated the function of microstrip power combiner, which can improve the reliability of the structure; The test verifies the current absorbing performance of the absorbing material in the range of 2k~400MHz. If it does not have a significant absorbing effect, we need to consider reducing the size of the cavity without adding absorbing materials or using a ferrite absorbing array solution.

CONCLUSION

This article comprehensively introduces the detailed design process of WCM for HIAF. According to current theoretical calculations and simulation results, the working bandwidth of this WCM is 2kHz~400MHz. However, according to other WCM designs and test results investigated [2][3][4][6], compared with the design results, the measured working bandwidth will be better than the design bandwidth. At present, the WCM has completed the procurement and processing of various components, but due to time constraints, offline and online testing have not been carried out yet. It is expected to be installed at the Heavy Ion Research Facility in Lanzhou-Cooling Storage Ring (HIRFL-CSR) for online testing in August.

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