DESIGN AND CONSTRUCTION OF A HOM-DAMPED TM_{020} TYPE HARMONIC CAVITY FOR LUMINOSITY ENHANCEMENT IN RI-ELECTRON SCATTERING

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Abstract

The RIKEN SCRIT facility that involves an electron storage ring (SR2) is a dedicated RI-electron scattering experiment. In the SCRIT system, the target RI ions are confined at high density on the beam axis by the focusing force provided by the electron beam itself. Therefore, electron beam stability is essential to increase the luminosity and maintain it for a sufficient time during scattering experiments. Since the current RF cavity induces beam instabilities due to higher order modes (HOM), a new HOM damped cavity is being designed and constructed and will soon be replaced. Here, we adopted the TM_{020} type harmonic cavity, which has recently been developed and first practically used at the NanoTerasu synchrotron light source. The cavity has coaxial slots at both the front and rear ends with ferrite absorbers inside. It is a very simple and compact design, yet it efficiently damps most resonant modes except for the TM_{020} mode. The design frequency of the TM_{020} is 956.220 MHz, which is the fifth harmonic of the current drive frequency 191.244 MHz, and accordingly the harmonic number in SR2 is changed from 14 to 70. As revealing from simulation studies, an increase in the harmonic number makes the trapping lifetime of the target RI ions longer, and this effect, coupled with the stabilization due to the disappearance of HOMs, is expected to significantly improve the luminosity performance in RI electron scattering.

INTRODUCTION

Electron scattering from atomic nuclei is one of the most important and reliable tools for precise nuclear structure studies and has long been awaited in the study of unstable nuclei. The key issue was how to make a small number of unstable nuclei with finite lifetime into sufficiently thick targets for electron scattering. SCRIT is a target formation technique that utilizes ion trapping, a well-known phenomenon that occurs within electron storage rings. The strong focusing force generated by an electron beam confines RI ions and forms a high-density RI ion cloud along the electron beam axis. [1] The first electron scattering for online produced RI has been successfully performed in recent year [2]. At that time, the target thickness was 10^8 cm^{-2} and the achieved luminosity was 10^{26} cm^{-2}s^{-1} with 10^7 target RI ions, and they were unfortunately maintained only for a few seconds. One of the main reasons for the short lifetime and relatively low luminosity is the instability of the electron beam caused by HOMs excited in the currently operating RF cavity. Therefore, HOM damped cavity is now necessary to improve SCRIT's performance in terms of target thickness, luminosity, and target lifetime.

HOM DAMPED CAVITY

A compact and simple HOM damping cavity, with the TM_{202} mode selected as the acceleration mode, was proposed more than 10 years ago [3, 4] and has recently been put into practical use at KEK [5] and NanoTerasu [6]. In a normal reentrant-type cavity with the radius of R_c, TM_{020} mode has a magnetic field node at a_2 in radius, where the differential of Bessel function is $J_0'(j_{02}a_2/R_c) = 0$. Figure 1 shows a schematic diagram of the cavity structure designed in this time. The cavity has two circumferential slots along the magnetic field nodes in the front and rear ends, and ferrite absorbers are put deep within the slots. While the TM_{020} mode remains unaffected, the magnetic fields for most other modes are significantly absorbed by the ferrite absorber, resulting in a drastic decrease in the Q values.

Electromagnetic Design

Acceleration frequency required in this cavity is f_0 =956.220 MHz which is the fifth harmonic of the currently operating frequency of 191.244 MHz, and it was chosen to ensure a reasonable cavity size. After optimizing characteristics such as resonant frequency, Q value, gap distance,

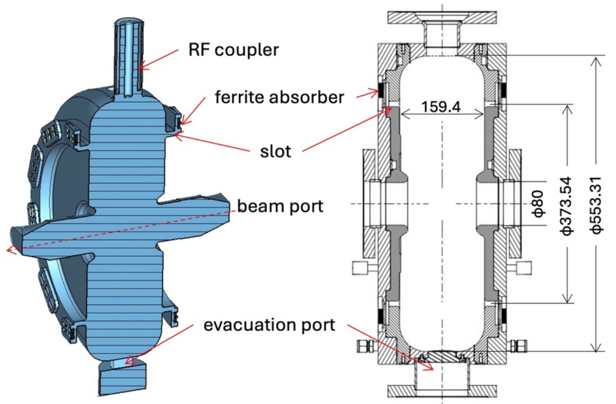

Figure 1: Conceptual structure of the HOM damped cavity.

and nose shape using SUPERFISH to form a cylindrically symmetric cavity shape, the three-dimensional details were optimized using CST studio. Each time a necessary component such as a coupler, tuner, exhaust port, loop pickup, or view port was installed in the cavity, the cavity shape was precisely adjusted to optimize the resonant frequency, Q value, and shunt impedance. Finalized design values and electromagnetic properties, which are the target values for actual construction, are listed in Table 1. When the ferrite absorber is placed in the slot to a depth of 33 mm, the Q values decrease drastically in most modes except TM_{020}, as shown in Fig. 2. The Red circles and Blue crosses indicate the Q values with and without ferrite absorbers, respectively. While some modes exhibit high Q values even with ferrite absorbers, they are not serious problem as the kick factor is known to be safely small.

Table 1: Designed Characteristics of the TM_{020} Mode in the Cavity

Resonance frequency	956.220	MHz
Unloaded Q_0 value	46 000	
Shunt impedance R_{sh}	3.2	MΩ
Cavity radius / length	276.675 / 159.435	mm
Slot radius / width	186.77 / 10.0	mm
Power feeder	loop coupler	
Coupling constant β	1.0 - 2.0	variable
Frequency tuning range	±200	kHz

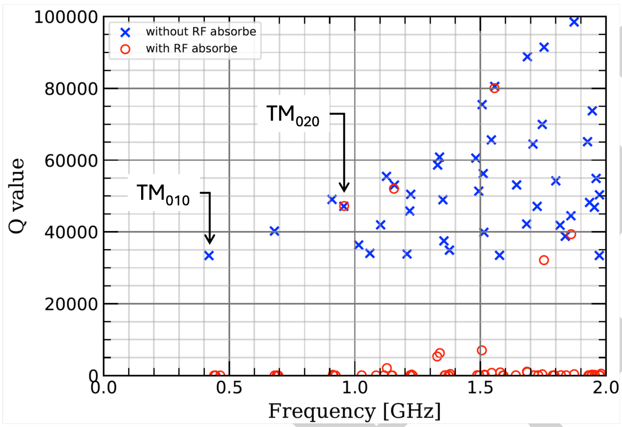

Figure 2: Designed Q values with and without ferrite absorbers for every mode existing bellow 2 GHz.

A loop coupler was adopted as an RF power feeder in this cavity as shown in Fig. 3(a). The radial position and angle of the coupler are adjustable to control the coupling constant β within the range of 1.0 to 2.0. Because the RF coupler is an asymmetrical component, the azimuthal magnetic field of TM_{020}, which should not normally exist along the slot, is distorted. This distortion causes partial absorption of the TM_{020} mode, resulting in a significant decrease in the Q value. The idea to eliminate this problem is to place fixed tuners, each 30 mm in diameter and 7.5 mm in height, on both sides to compensate for the field distortion (see Figure 3(a)). The diameter and height of fixed tuners were

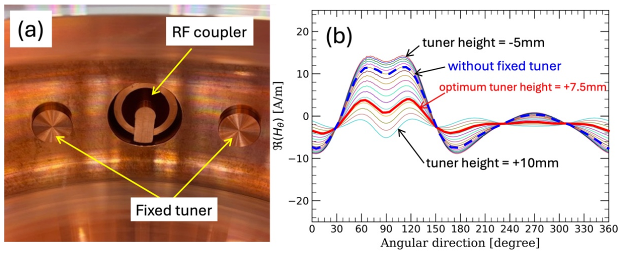

Figure 3: RF coupler and fixed tuners (a) and magnetic field along the slots in several cases for the fixed tuner hight within the range of -5 mm to +10 mm (b).

optimized to minimize the integrated magnetic field along the slot and maximize the Q value as shown in Fig. 3(b).

Two movable resonant-frequency tuners with a diameter of 40 mm were positioned on a horizontal axis perpendicular to the RF-coupler insertion axis. The resonant frequency can be changed within a range of ±200 kHz by the tuner moving in a range of -5 mm to +7 mm without a significant decrease in the Q value. In addition, two RF monitors, which are small loop couplers with a coupling coefficient of -40 dB, and a view port were installed.

Fabrication of the Cavity

The cavity consists of a cavity center brazed by included components, two outer blocks, two inner blocks, and 20 ferrite absorber blocks as shown in Fig. 4(a). The cavity body is constructed by brazing precisely machined high-purity copper parts with reinforcing stainless steel parts.

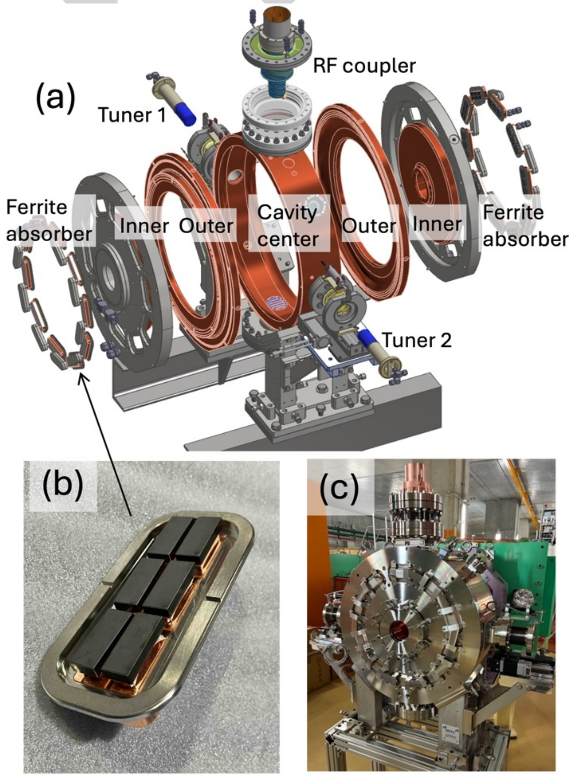

Figure 4: Cavity fabricational structure (a), ferrite absorbers brazed on a copper block (b), and the exterior of the temporarily assembled cavity (c).

Ferrite absorber is one of the most important parts in this HOM cavity. The ferrite absorber block was made by pure copper, and six ferrite pieces, HF70 (TDK Co. Ltd.) with the size of 25.5 × 10.26 × 4 mm^3, were brazed on it (see Fig. 4(b)). Ten blocks are electron-beam welded onto each side, and 120 ferrite pieces in total are used. Since ferrite absorbs most of the excited parasitic modes except for TM_{020}, the thermal conductivity between the ferrite and the water-cooled copper block must be high to avoid thermal breakdown. By applying a special metallization treatment on the surface of the ferrite pieces, the brazing process between the ferrite and the copper block was successful, resulting in excellent thermal contact. The power capacity of the ferrite is estimated to be 10 W/cm^3 [6], and a total of 1.2 kW is within our acceptable range. The power absorption for the parasitic modes is estimated to be 250 W at the electron beam current of 300 mA and the total, including that for TM_{020} at the maximum input RF power of 10 kW, is sufficiently smaller than the capacity, provided that the Q value shown in Table 1 is realized.

Low Power Test

Since the fabrication of the cavity, including the brazing of all components, has not yet be completed, we performed low-power test measurements using a temporarily assembled cavity shown in Fig. 4(c), in particular to check the damping effect by the ferrite absorbers. The S parameters in the frequency rage below 3 GHz were measured both with and without a ferrite absorber. Figure 5 shows S21 spectra without (a) and with (b) ferrite absorber below 2 GHz. As shown in Fig. 5 (b), resonances in the frequency range below TM_{020} are completely disappeared, and many other HOMs in higher frequency range are also well damped. It is clearly demonstrating excellent damping effect on resonant modes except for TM_{020}. Figure 5 (c) shows the ratio of loaded Q values roughly estimated from the S21 spectra with and without the ferrite absorber. The ratio for the TM_{020} mode is nearly one as expected. While there are several undamped resonances in the higher-frequency region, they are not single mode but rather composed of multiple modes, and therefore the Q-value estimation might be unreliable.

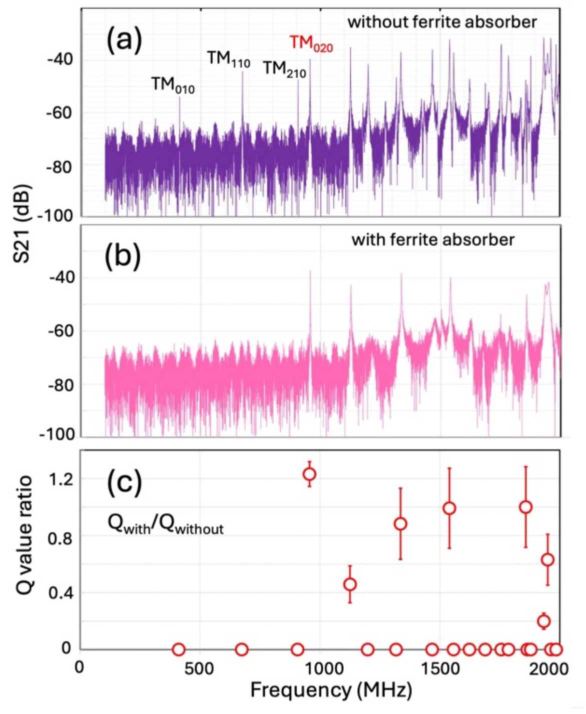

Figure 5: S21 spectra without (a) and with (b) ferrite absorbers, and the ratio of Q values between them (c).

After the resonator fabrication is completed, we plan to perform more detailed measurements of its RF characteristics and compare them with the designs.

EXPECTED SCRIT PERFORMANCE

It is expected that installing a HOM cavity in SR2 will increase the harmonic number by a factor of five, while also eliminating the instability caused by HOMs. Both significantly contribute to the stabilization of ion trapping in SCRIT. Figure 6 shows the estimated ion-trapping stability plotted in two dimensional plane of the dipole mode beam oscillation amplitude and the number of accumulated charges in SCRIT. In the case of HOM cavity (h=70), even if small oscillations remain, the red area indicating a trapping lifetime of 1 s or more is significantly expanded. Simulation results showed that a highly stabilized electron beam forms a higher-density and more stable ion cloud in SCRIT, so a luminosity reaching 10^{28} $cm^{-2}s^{-1}$ is expected to be maintained for a longer period than the current trapping time. This will significantly improve the performance of SCRIT, and that will soon be confirmed.

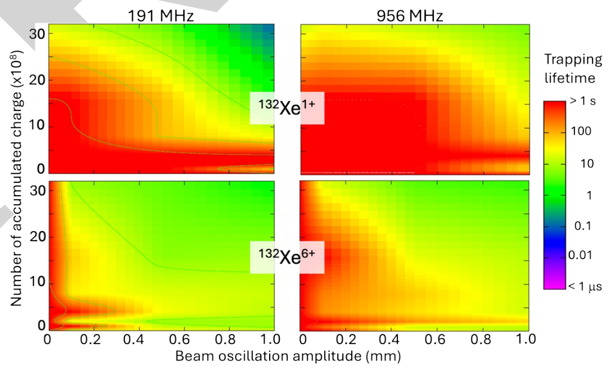

Figure 6: Comparisons of the target-ion trapping lifetime in SCRIT between the currently used frequency of 191.244 MHz and the newly replaced frequency of 956.220 MHz.

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