HIGHER-ORDER-MODE DAMPING OF L-BAND SUPERCONDUCTING CAVITY USING A RADIAL-LINE HOM DAMPER *

K. Umemori, M. Izawa, K. Saito, S. Sakanaka, High Energy Accelerator Research Organization(KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

For the energy recovery linacs, strong damping of higher-order-modes (HOMs) is indispensable to avoid beam breakup instabilities. We studied a new HOM damping scheme using a radial-line HOM damper with a choke structure. Both models of the radial-line damper and the TESLA-type 9-cell cavity were prepared and the HOM characteristics of this scheme were experimentally investigated. Measurement results showed a promising performance of the radial-line HOM damper.

INTRODUCTION

The Energy Recovery Linacs (ERLs) are very promising as the next-generation synchrotron light sources since they can produce highly-brilliant and ultra-short synchrotron radiation pulses. In order to preserve an ultra-low emittance of electron beams in the ERLs, it is very important to suppress the beam-breakup (BBU) instabilities. Since the primary source of the BBU is the HOMs in superconducting cavities, strong damping of them is required. A typical requirement for the transverse impedances of dipole modes is evaluated as $(R/Q)Q/f < 1 \times 10^5$ $(\Omega\mathrm{cm}^{-2}\mathrm{GHz}^{-1})$ [1, 2], where f is the resonant frequency, Q is the quality factor, and R/Q is the ratio of the impedance and the quality factor.

Several HOM damping schemes have been developed for the superconducting cavities. Aiming to achieve higher performance, we proposed a radial-line HOM damper which consists of a radial transmission line, a choke filter and an HOM absorber [3]. This idea was derived from original ideas in [4, 5]. A concept of this scheme is shown in Figure 1. The radial-line HOM dampers are attached on both sides of the cavity. Broadband HOMs can transmit in the radial-line and can be dissipated by the microwave absorbers. The characteristic of the choke filters is very important since the Q-value of the accelerating mode should be kept to be higher than 10^8.

Our initial study on a single-cell cavity [3] indicated that this scheme was very promising. Then, our investigations have been extended to a TESLA-type 9-cell cavity. Results of low-power measurements are reported in this paper, together with preliminary results from simulation analysis.

* Work supported by the Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science under a subject number 15540300.

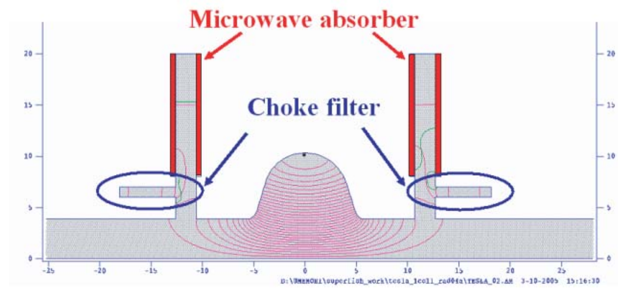

Figure 1: Conceptual design of the radial-line HOM damper.

LOW-POWER MEASUREMENTS

Setup for the Measurement

We fabricated a model of the radial-line HOM damper and that of the TESLA-type 9-cell cavity in order to investigate the HOM damping performance experimentally. The choke filter has not been incorporated so far. The model cavity was made from copper and precisely machined to reproduce the inner dimensions of the TESLA-cavity [6].

Figure 2(a) shows the completed 9-cell model cavity, which is equipped with the radial-line HOM damper. Inside of the damper is shown in Figure 2(b). A microwave absorber, TDK IRL02 (2 mm thick), was used for the measurements. This absorber was glued in the radial-line and covers a radial range of 12–20 cm. Since the performance of HOM damping largely depends on the distance between the cavity and the HOM damper, the distance was designed to be alterable by inserting metallic spacers. From simulation analysis, including a choke structure, it is expected that the Q-value of the accelerating mode can be higher than 10^8 when the HOM damper is located 3 cm apart from the end of the cavity.

The resonant modes were observed using two pickups, locating at vertical and horizontal positions on the end-cells. The radial-line HOM damper was attached on a single side of the cavity at several distances from the end of the cavity. The low-power measurements were carried out under the following conditions: (1) without HOM dampers, (2) with the HOM damper at a distance of 6 cm from the cavity, (3) with the damper at a distance of 3 cm, and (4) with the damper at a distance of 1cm.

Figure 3 shows the mode spectra of the 9-cell cavity, obtained from the transmission coefficients (S_{12}) within 1–3 GHz. The blue and the red lines in the figure indicate the results under the conditions of (3) and (1), respectively. It

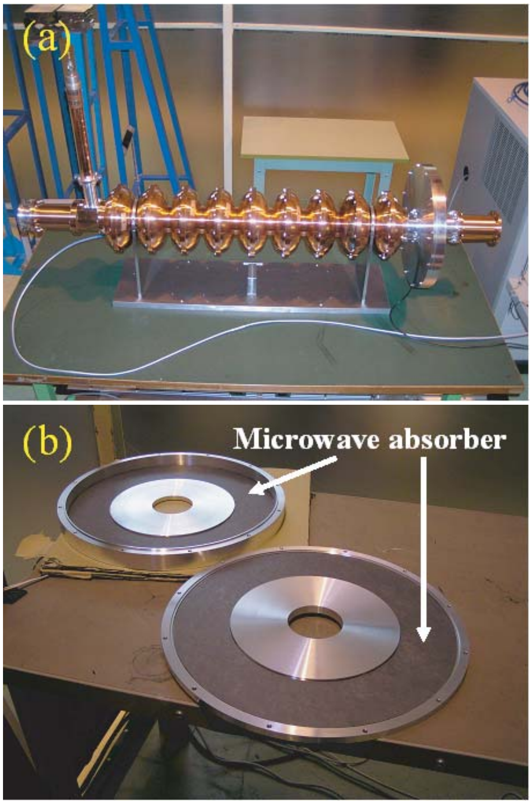

Figure 2: (a) A low-power model of 9-cell TESLA-type cavity with a radial-line HOM damper. (b) Inside of the radial-line HOM damper.

shows that the dipole and monopole modes can be damped effectively.

The Q-values were measured with the reflection and the transmission coefficients. Then, the external Q-values ($Q_{\rm ext}$) were derived from the measured Q-values, with and without the radial-line HOM damper, assuming that the microwave absorption in the HOM damper was ideal. The resonant modes were assigned from their frequencies, and were numbered as TM010-1, ... , TM010-9, from lower to higher frequencies. The measured frequencies agree well with those in [6] within 1–2 MHz. We also plan to measure the field distributions of these modes.

Monopole Modes

Figure 4 shows the $Q_{\rm ext}$ for the TM011 and TM020 modes. The red, green and blue bars indicate the results under the condition (2), (3), and (4), respectively. Note that this figure does not include some modes which could not be measured at a moment due to their small couplings to the pickup probes. At a distance of 3 cm [condition (3)], most of the monopole modes can be effectively damped with their Q-values of about 1×10^4. At a closer distance of 1 cm [condition (4)], these Q-values can be reduced further by factors of 3–5. On the other hand, the Q-values for the accelerating mode are 2×10^5 and 3×10^4 under the conditions of (3) and (4), respectively. In order to keep high

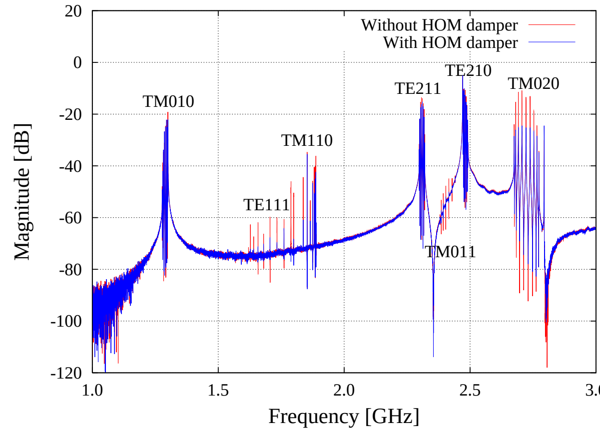

Figure 3: Mode spectra of the 9-cell model cavity. The blue and the red lines indicate the cases with and without the HOM damper, respectively.

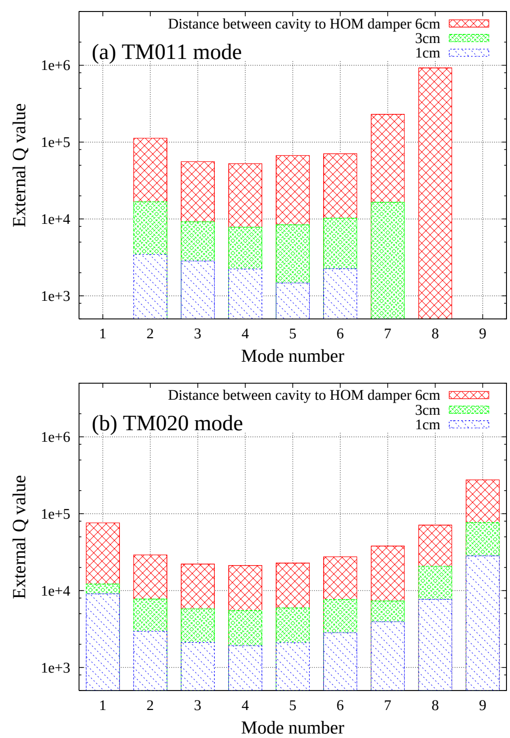

Figure 4: Measured $Q_{\rm ext}$ for the (a) TM011 and (b) TM020 modes. The red, green and blue bars indicate the results under the conditions of (2), (3), and (4), respectively.

Q-value of the accelerating mode while strongly damping the HOMs, the design of the choke filter will be very important.

Dipole Modes

Figure 5 shows the $Q_{\rm ext}$ for the TE111 and TM110 modes, where both polarizations are included. The TE111 modes can sufficiently be damped with $Q_{\rm ext} < 10^4$. On the other hand, some of the TM110 modes having high mode

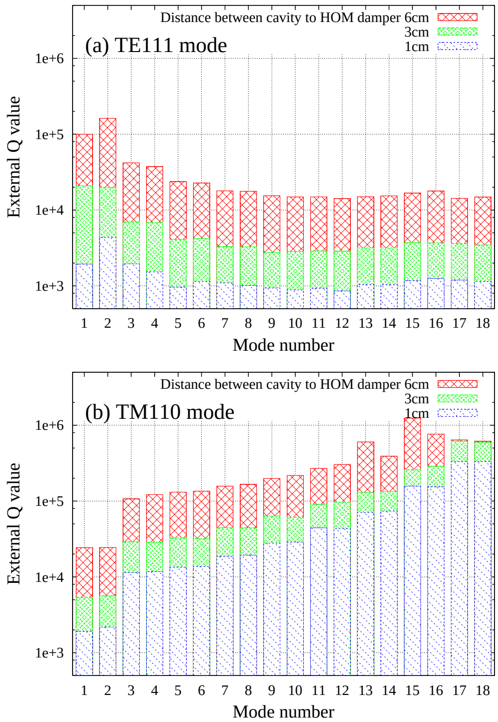

Figure 5: Measured $Q_{\rm ext}$ for the (a) TE111 and (b)TM110 modes. The red, green and blue bars indicate the results under the conditions of (2), (3), and (4), respectively.

numbers can not be sufficiently damped. This is probably due to relatively small leakage of the fields to the radial-line HOM damper, which is under investigation.

Quadrupole Modes

Because of their high external-Q's, precise measurements of the quadrupole modes were difficult. The $Q_{\rm ext}$'s for the TE211 and TE210 modes are roughly 10^6 under the condition (3). It is considered that these Q-values will be enough to avoid quadrupole BBU instabilities [2].

SIMULATIONS

We also carried out preliminary simulations of the HOM damping in the 9-cell cavity using the computer code MAFIA. The Q-values were calculated with a perturbation method, where an electrical conductivity of the microwave absorber was assumed to be 7 $\Omega^{-1}\mathrm{m}^{-1}$. This conductivity was chosen so that it gave consistent results between the simulations and the measurements of the HOM damping in a single-cell cavity.

The calculation results generally followed the measurements. The calculated Q-values of monopole modes agree with the measurements within 30%. The difference for other modes is within a few times. Only some of the TE111 modes, having low mode numbers, show considerable difference; the calculated values are more than an order of magnitude lower than the measured ones. This issue is under further investigation. We are also investigating the insufficient damping for some of the TM110 modes because it is crucial for the ERL requirement.

DISCUSSIONS

We compared the results of the measurements with those of the TESLA design where the HOMs are extracted by TESLA-type HOM couplers [6]. Although the performance depends on each resonant mode, we can roughly say that the performance of the radial-line HOM damper is comparable to or several times better than that of the TESLA-type design, at a typical distance of 3 cm [under the condition (3)]. If we reduce the distance to 1 cm [condition (4)], the Q-values can be reduced further by a few to ten times magnitude. To this end, more sophisticated design of the choke filter is required.

Another important issue is to improve the HOM damping for the TM110 modes. It can possibly be improved by such means as enlarging the beam-pipe radius, reducing the number of cells, and optimizing the cell shapes. These improvements will be studied further.

Search for microwave absorbers and a cryogenic design of this HOM damping scheme are also required.

CONCLUSIONS

We have investigated higher-order-mode damping of the 9-cell cavity by means of the radial-line HOM damper. The Q-values of HOMs largely depend on the distance between the HOM damper and the cavity. The performance of this HOM damper is comparable to or better than the TESLA design at a typical distance of 3 cm. The $Q_{\rm ext}$ of the monopole and dipole modes are typically around 1×10^4. The Q-values of some of the TM110 modes are not sufficiently damped at present. Further improvements of the HOM damping performance are expected by locating the damper close to the cavity, or by incorporating other measures. Investigation of the choke filter is also important.

ACKNOWLEDGMENT

We wish to thank H. Inoue of the Mechanical Engineering Center for his mechanical design and precise mechanical measurement of the model cavity.

REFERENCES

[1] I. V. Bazarov et al., EPAC'04, p. 2197

[2] M. Liepe, Proc. of the 11th Workshop on RF Superconductivity (SRF2003), Lübeck/Travemünde, Germany, 2003.

[3] K. Umemori et al., Proc. of Workshop on Energy Recovering Linacs (ERL2005), Newport News, VA., 2005.

[4] T. Shintake, Jpn. J. Appl. Phys. 31 (1992) L1567.

[5] T. Koseki et al., EPAC'04, p. 1048

[6] *TESLA Test Facility Linac Design Report*, edited by D. A. Edwards, DESY, 1995.