COMB-TYPE RF-SHIELD FOR HIGH CURRENT ACCELERATORS

Y.Suetsugu[#], M.Shirai and K.Shibata, KEK, Tsukuba, Japan

Abstract

A new RF-shield structure for high current accelerators is proposed. The RF-shield has no thin fingers but nested comb teeth instead at the inner surface of beam duct. The comb-type RF-shield has a higher thermal strength structurally compared to the conventional finger-type. The simulation also indicates its lower impedance. Especially, the leak of TE mode like HOM through the slits is almost suppressed. A preliminary test with a prototype RF-shield transmitting a 508 MHz microwave in the atmosphere shows no abnormal heating or arcing.

INTRODUCTION

Several vacuum components like bellows chambers and gate valves in accelerators are usually equipped with the RF (Radio Frequency) shield structures inside. The RF-shield bridges the gap to reduce the beam impedance and to avoid the heating of components due to the extra HOM (Higher Order Modes) excited there. The conventional RF-shield is a finger-type, which consists of lots of narrow and thin fingers surrounding the inner surface of beam duct [1-4].

Recent high current accelerators, however, put much severer conditions than ever before on the RF-shield structure. The storage current of ampere orders brings high wall current density. The high bunch current and the short bunch length lead to intense HOM excitation. Especially, the TE-mode like HOM easily couples with the space between the RF-shield and the outside structure through the axial slits between fingers. These are likely to result in the heating of components.

Proposed here is a new RF-shield, that is, a comb-type RF shield, for high current accelerators. The RF-shield is no more than the finger-type and will have a higher thermal strength than the conventional one. The calculated loss factor is lower than the conventional finger-type. In the following, the structure of the comb-type RF-shield is described at first and then the some calculated RF properties and the results of the preliminary tests are presented and discussed.

STRUCTURE

The inside view of a comb-type RF-shield for a circular beam duct is presented in Fig.1(a). The RF-shield is no more than thin fingers but nested comb teeth. In a typical model, the length (*a* in the sketch in Fig.1, the same way in the following), the width (*t*) and the radial thickness of a comb tooth are 10 mm, 1 mm and 10 mm, respectively. The gap between adjacent teeth (*c*) is 2 mm and, therefore, the gap between the nested teeth is 0.5 mm. At the nominal position, the total length of the RF-shield structure (*b*) is 15 mm. For the circular beam duct with an inner diameter of 94 mm, for an example, the number of teeth is 100. The combs will be made of pure copper.

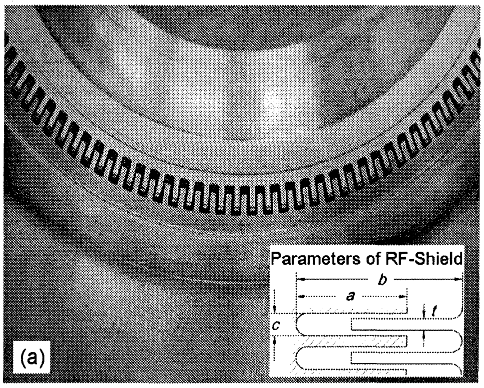

Figure 1(a): Inside view of a comb-type RF shield.

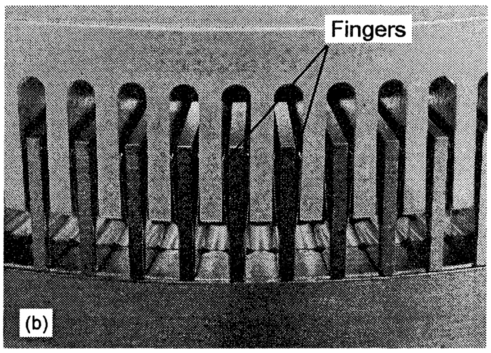

Figure 1(b): Outside of the comb-type RF shield. The back-up fingers are between the nested teeth.

In principle, the high frequency wall current accompanied with a bunched beam flows via capacitance between nested teeth (a gap of 0.5 mm). To ensure the flow of DC or low frequency wall current, small fingers (back-up fingers) are prepared at outer half between the nested teeth (see Fig.1(b)). The back-up fingers also have an important role to block the leakage of HOM as described later. The back-up fingers will be made of silver coated Inconel alloy.

The advantages of the comb-type RF-shield are as follows: (1) The RF-shield has a high thermal strength. (2) There is no radial step on the inner surface of beam duct and the shield has a low impedance. (3) The TE mode like HOM hardly goes out through the RF-shield due to the large thickness (10 mm) of the teeth. (4) There is no sliding point on the inner surface of beam duct, which otherwise could be a source of arcing or heating. (5) The RF-shield can fit for beam ducts with various cross sections.

[#] yusuke.suetsugu@kek.jp

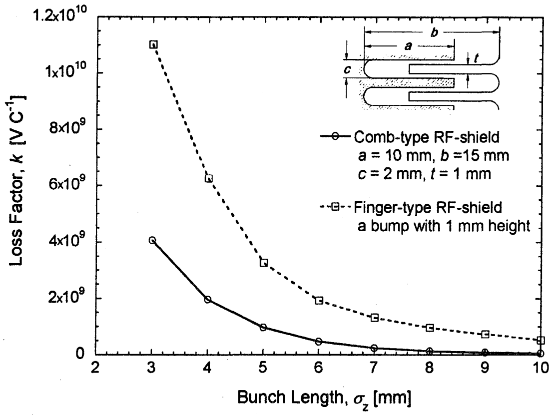

Figure 2: Dependence of loss factors of the comb-type and the finger-type RF-shield on the bunch length for a circular beam duct with a diameter of 94 mm.

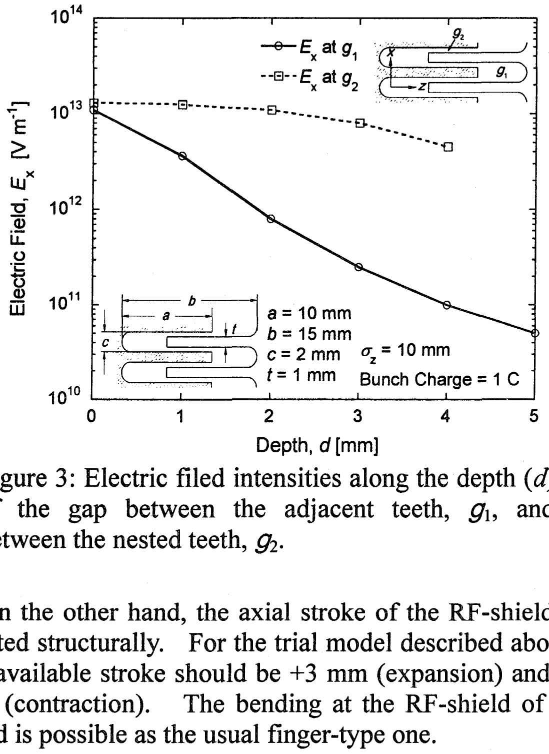

Figure 3: Electric filed intensities along the depth (d) of the gap between the adjacent teeth, g_1, and between the nested teeth, g_2.

On the other hand, the axial stroke of the RF-shield is limited structurally. For the trial model described above, the available stroke should be +3 mm (expansion) and -4 mm (contraction). The bending at the RF-shield of 20 mrad is possible as the usual finger-type one.

RF PROPERTIES

Loss Factors

Using the MAFIA simulation code, the loss factors of the comb-type and the finger-type RF-shield were calculated for several conditions. The outer half of the nested teeth part is short-circuited assuming the back-up finger. The dependence of the loss factors, k [V C^{-1}], for both types on the bunch length, σ_z [mm], are shown in Fig.2 for the beam duct with a diameter of 94 mm. The loss factor of the comb-type is smaller than that of the finger-type by a factor of 3 or 4. The loss factor reduced as contracting the RF-shield. That is because the length of nested part increases, that is, the capacitance gets large, and the slot length decreases at the same time. As increasing the gap (t), furthermore, the loss factor increases because the flow of wall current is more steered.

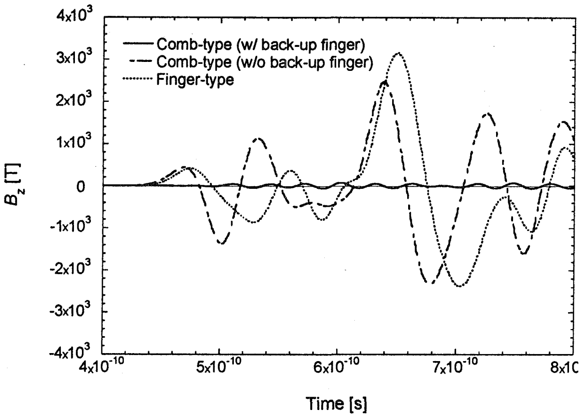

Figure 4: Intensities of the axial (z) components of magnetic fields for the comb-types (w/ and w/o back-up finger) and the finger-type RF-shields.

Electric Field between Teeth

Figure 3 presents the change of electric filed intensities in the gaps between the adjacent teeth and the nested teeth, g_1 and g_2 in the sketch, as a function of depth, d [mm]. The electric fields in the figure are the peak values just after a bunch with a length (σ_z) of 10 mm and a charge of 1 C passed at the center of duct with a diameter of 94 mm.

In the gap g_1, the intensity of electric filed decreases rapidly as the position goes outside. Plotted is the transverse electric field but the other components also behaves similarly. Since the gap g_1 is the only way for the HOM to go outside since the back-up fingers (see Fig.1(b)) block it in the gap g_2, that indicates the HOM will hardly leak outside through the thick teeth.

In the gap g_2, on the other hand, the maximum electric field does not change so much with the depth. The mode has a frequency of about 14 GHz and seems an eigen mode excited in the gap. The mode, however, damps rapidly with time. The intensity decreased to a half within 0.3 ns.

HOM outside of RF-Shield

The HOM intensities outside of the RF-shield were calculated for both types of RF-shields. The time variation of the axial component of magnetic field (B_z) is presented in Fig.4. The intensity for the comb-type with back-up fingers is much smaller than those for the finger-type by one order of magnitude. Since the B_z represent the TE mode like HOM, it can be said that the TE mode like HOM is well damped by the thick comb-type RF-shield.

Note here, however, that the B_z for the case of comb-type RF-shield without the back-up fingers is almost the same as that of finger-type. That means that the leakage of TE mode like HOM is comparable to the case of finger-type if the comb-type has no back-up fingers. The mode excited between the gap g_2 (see Fig.3) seems to go

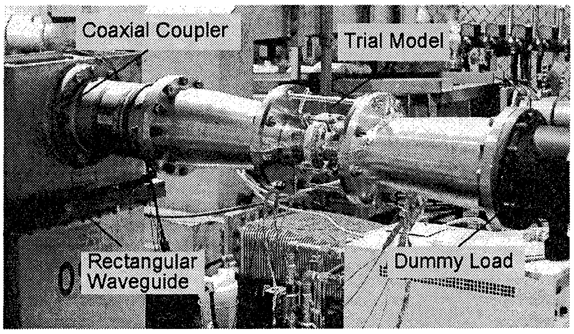

Figure 5: Set up of heating test transmitting a 508 MHz microwave.

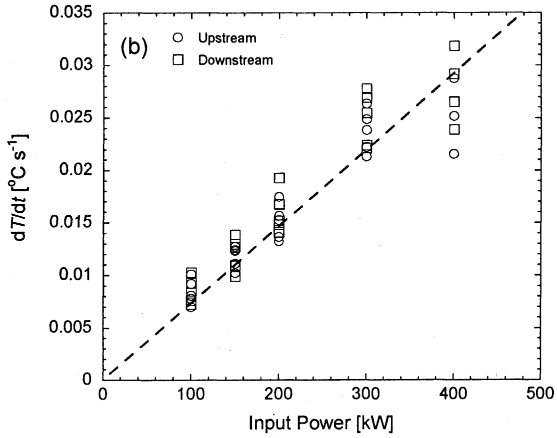

Figure 6: Temperature rises of RF-shield part as a function of the input power of 100 – 400 kW, where the dashed line is those calculated from the joule loss at 100 mm region centered on the RF-shield.

through the gap and emitted to outside. To suppress sufficiently the HOM outside the RF-shield, the back-up fingers, or some other measures to short-circuit the nested teeth just outside, will be indispensable for the comb-type RF-shield in high current machines.

PRELIMINARY HEATING TESTS

The heating of the comb-type RF-shield by wall current was examined transmitting a high-power microwave in atmosphere [3]. Figure 5 shows the partial layout of the experimental setup including the trial model of the RF-shield. Utilized is a 508 MHz klystron used for the RF accelerating cavities in a KEKB. The TE_{10} mode in the rectangular waveguide was transformed to the TEM mode in the coaxial line by a coaxial coupler. The CW microwave is transmitted through the model and finally absorbed in the dummy load. The size of the comb-type RF-shield is the same as described above. The temperatures at 8 points near the root of the teeth and 2 points on the body of the duct were measured by thermo couples.

In the experiment, the input power was stepped up gradually up to 400 kW at the flat top of wave form. At 400 kW, for an example, the RMS current density is larger by 1.5 times than those of the designed beam current in the Super KEKB [6]. The experiments were performed changing the length of the RF-shield (b) from 12 mm to 18 mm.

The temperature rises at several power levels are presented in Fig.6 for the case b = 15 mm. Two data are those at the upstream and the downstream side of the opposed comb teeth. The dashed line is the calculated temperature rise considering the joule loss of about 100 mm centered on the RF-shield. Although the data were scattered due to the small temperature rise, the measured temperature rise was almost in agreement with the expected ones. The reflected power was always less than about 2 % of the input power, which was comparable to that from the dummy load itself.

After the experiments the inside and outside of the RF shield was checked and no trace of abnormal local heating or arcing was found. The arcing in atmosphere, however, will not likely occur compared to the case in vacuum. It should be also noted that the frequency of HOM will be higher than that used in the test. No arcing in the present test, therefore, should be considered as a minimal result.

SUMMARY

The simulation and the preliminary test of the comb-type RF-shield gave promising results as described above. The availability to the accelerators, however, should be studied using a real beam, where the frequency spectrum of the excited HOM and the wall current is different from the preliminary test. Two prototypes of the bellows chambers with this new RF shield are under manufacturing and will be installed in the KEKB positron ring this year to see the basic properties of the comb-type RF-shield.

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