MULTIPACTING STUDY OF ICHIRO END CAVITY

I. Hwang#, E.-S. Kim, CHEP, Kyoungpook National University, Korea
J. Hong, POSTECH, Korea
Y. Morozumi, K. Saito, KEK, Japan

Abstract

High gradient superconducting RF cavity named Ichiro type in KEK is developing as the Alternatives Configuration Document for the international linear collider. Multipacting is one of the most serious limitations to achieve high gradient. Several simulation research found out that multipacting at the tapered beam pipe is too strong. We investigated multipacting effects in various end cavities with beam tube and compared with experiments.

INTRODUCTION

Multipacting (MP) is a resonant phenomenon of the secondary emission multiplication. Emitted electrons from the surface are driven by RF fields and then collide back and make secondary electrons which can impact again and release more secondary electrons. If this process satisfies a proper condition in RF fields and the surface yield function, the number of electrons grows up resonantly. This electron collision leads to a temperature rise on the wall and eventually superconducting break down. It is one of the serious barriers to achieve the high accelerating gradient.

During high gradient tests of 9-cell prototype at KEK have suffered the multipacting barriers and its source part has found in the end-groups of the cavity from the simulation study [1,2]. In this paper, we will present the simulation and experiment results of the KEK (Ichiro) end cavities.

MULTIPACTING SIMULATION

Ichiro end cavities

Many prototypes for ILC RF superconducting cavities have designed and tested for high accelerating gradient and good properties such as lower surface fields and loss power. Ichiro type in KEK has experienced the multipacting barriers. To investigate the end groups of cavity, single cell cavities with different pipes designed as shown in Figure 1. The cavity parameters listed in Table 1. ISE #1 is connected with 108mm radius pipe, ISE #2 has a step in the pipe and ISE #3 has 80mm radius pipe.

Table 1: Parameters of end cavities

<table>
<thead>
<tr>
<th></th>
<th>ISE #1</th>
<th>ISE #2</th>
<th>ISE #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. (MHz)</td>
<td>1294.6</td>
<td>1294.4</td>
<td>1294.4</td>
</tr>
<tr>
<td>Meas. Freq. (MHz)</td>
<td>1294.1</td>
<td>1294.6</td>
<td>1291.3</td>
</tr>
<tr>
<td>$Q_0$</td>
<td>2.27 $10^{10}$</td>
<td>2.27 $10^{10}$</td>
<td>2.19 $10^{10}$</td>
</tr>
<tr>
<td>$R/Q$</td>
<td>96.0</td>
<td>96.8</td>
<td>120.8</td>
</tr>
<tr>
<td>Geometric factor</td>
<td>294.8</td>
<td>294.8</td>
<td>284.1</td>
</tr>
<tr>
<td>$H_s/E_{acc}$ (Oe/ MV/m)</td>
<td>44.1</td>
<td>45.5</td>
<td>38.4</td>
</tr>
</tbody>
</table>

Figure 1: End cavity structure

Simulation code: Analyst

Analyst is a software package for the design of various microwave devices. It supports two-dimensional and three-dimensional for mode analysis and multipacting study. Typical multipacting oscillations can be obtained by tracking electrons emitted from the surface of the RF cavity.

Numerical Setup

Type ISE #1-3 have no port, therefore 10 degree sector model can be used for time saving instead of full three dimensional tracking. Typically maximum mesh size on surface is 0.2mm and 40000 elements are used. It is rather coarse grid, therefore the peak field has big error but enough to see qualitative behaviour and close to the limit of one personal computer for the multipacting analysis.

The yield function which determines the secondary electron emission is chosen as

\[ \text{Yield} = C_0 C_2 \frac{x}{C_1} \exp \left[ -C_3 \frac{x}{C_2} \right] \]

(1)
where $x$ is the impact energy in unit of eV and
$(c_0, c_1, c_2, c_3) = (1.3, 2.72, 600, 2.0)$ for the standard
niobium surface. The electrons emit with 2 eV starting
energy and are traced with time step of 10 degree phase of
the RF period during 50 RF periods. If the electron
survived during 10–25 impacts, it is regarded as a
resonant electron.

Simulation Result

The counter function is a basic tool to describe the
multipacting effect. It is defined as the number of
resonant particle orbits and the fractional counter function
is the ratio to the total number of the primary particle
emissions.

Figure 2 shows the counter function as a function of the
average accelerating gradient with several minimum
impact options in ISE #2. The multipacting occurs in 20–
30 MV/m and above 40 MV/m. As the minimum impact
required for the resonant decision increases, the number
of the corresponding particles are reduced, especially in
lower field region. The counter function looks saturated at
the impact 20 which is the default value in Analyst
version 10.0 patch 3.

Figure 3: In ISE #2, maximum yield on surface and
several electrons trace at $E_{acc} = 6$ MV/m with 10 minimum
impacts. The traces near the equator resemble one point
resonance.

Figure 4: In ISE #2, maximum yield on surface and
several electrons trace at $E_{acc} = 21$ MV/m. Two point
resonance orbits are formed near equator.

Figure 5: In ISE #2, maximum yield on surface and
several electrons trace at $E_{acc} = 42$ MV/m. Heavy
multipacting occurred in step.

As field strength increases, different parts contribute to
counter function. Trace of some electrons and maximum
yield on surface mesh are shown in Figure 3-5. Maximum
yield map shows the multipacting position and we can
suppose that it is similar with the temperature map [3]. At
6 MV/m one point like multipacting near equator appears
as Figure 3 but very weak below 20 MV/m. Above
20 MV/m there are relatively small effect in the step and
two point multipacting near equator [4]. Due to the
asymmetric structure highly colliding zone (red) is
slightly shifted from the equator which is welding
position. If two regions are separated enough, yield
function of the welding part is not important. In ISE #1,
there is a narrower peak and no effect in pipe, so no more
peaks above 30 MV/m up to 45 MV/m, as shown in Figure
6. The peak center is shifted to higher field and weaker in
ISE #3, as shown in Figure 7. The shift-up of center can
be explained by lower magnetic field near equator. The
shape of the cavity affects the multipacting highly [5].

EXPERIMENT

During increase input power to excite Ichiro end
cavities, the multipacting can be recognized from the
typical noise pattern in power profile and the radiation
detector. In repeated measurement the cavity conditions
are not same and the multipacting occurrences are
different. Therefore the statistical description is obtained
as plotted as stars in Figure 2, 6 and 7. This method does
not require the special device but shows rough estimation.
It is agreed that there is the multipacting in the range of
20–30 MV/m but not understood that high peak at
18 MV/m in ISE #1, #2. That field is the condition of two
point resonance [6]. But it is much stronger than simulation.

![Figure 6: Fractional counter function and observed multipacting effect in ISE #1](image)

![Figure 7: Fractional counter function and observed multipacting effect in ISE #3.](image)

**SUMMARY**

The multipacting effect in Ichiro end cavities were studied numerically by tracking code and observed in the experiment. The step in the pipe is strong source and two point resonance occurred at the equator in the range of the average accelerating gradient 20-30MV/m. ISE #3 which has smaller pipe and 3mm smaller equator, shows weaker effect and center shift-up. It is agreed with the experiment but strong effect at 18MV/m is not shown in the simulation. It should be investigated more. Further study for accurate description of the multipacting is needed.

**REFERENCES**


