DIPOLE HIGH ORDER MODE ANALYSIS IN FZD LIKE SRF GUNS

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Abstract

Dipole High Order Modes (HOM) in a superconducting RF gun (SRF gun) could affect the quality of the electron beam and cause instabilities. The characteristics of dipole HOMs including trapped HOMs are calculated here for a FZD-like SRF gun up to a frequency of 8.0 GHz. Dependence of the calculated parameters on the cavity longitudinal deformation has been studied. A new concept of the HOM damping is proposed that is consistent with the electron beam focusing in the cavity with a high-order TE mode.

INTRODUCTION

Dipole HOMs in RF cavities is important since they can be the source of BBU instability. Therefore it is important to know the features of dipole HOMs, especially trapped ones.

The frequencies of the trapped HOMs are higher than the cutoff frequency of the beam pipe, but they can not propagate freely through the pipe to an RF load due to the poor coupling with the pipe. This coupling has the same nature as the coupling of notch filter modes. The example of such a filter is examined here (see Fig.7).

We have calculated dipole HOM field distributions up to 8 GHz for a FZD like 3½ cell RF gun cavity using the 2D CLANS2 field solver [1]. External loads (see Fig.1, 5, 6) positioned at the end of the beam pipe are responsible for the dipole HOMs damping with external qualities Qext. All incident RF power is dissipated in the load without reflection.

HOM transversal coupling impedances ($R_{\perp}$) were calculated (for HOM properties demonstration only) in a conventional manner for ultra relativistic particles. The actual impedances for RF gun beams are considered in the other paper [2] of this conference.

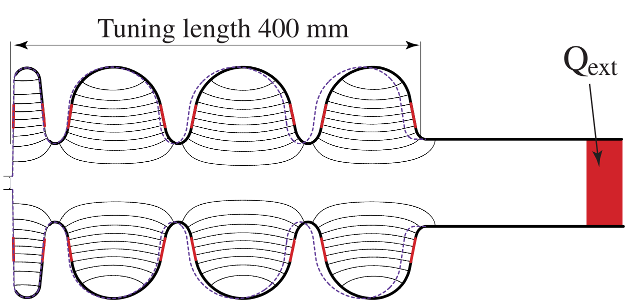

Figure 1: The 3½ cell cavity of FZD like SRF gun. The detuning cavity length principle is demonstrated.

DIPOLE HOM SPECTRUM VS. CAVITY LENGTH

In this section we examine the instability of the obtained result during cavity shape detuning with the simple mechanical model. SRF gun is equipped with the detuning mechanism of the main resonance frequency $\omega_0=2\pi\cdot1300$ MHz. All other HOM frequencies are also detuned. This detuning is due to the changing of the total length of the 3½ cell cavity. In the simulations, we model the change in the cavity shape by changing the inclination of the straight parts of the cavity cells marked by red colour in Fig.1. The shapes of other parts remain unchanged.

The bunch repetition frequency is coupled to the fundamental frequency therefore it is also detuned. The sum of all dipole HOM voltages, calculated as

$$\mathrm{Re}\left[I_{beam} \cdot \sum \frac{(R_{\perp i}/Q_i)Q_i}{1-2j\cdot Q_i\cdot\Delta\omega_i/\omega_i} \right]$$

for different repetition frequencies ω_0/n, are depicted in Fig.3. Here $\Delta\omega_i=\omega_i-k\cdot\omega_0/n$, and $k\omega_0/n$ is close to ω_i.

Some HOM voltages are changing significantly during the cavity detuning. This is due to the resonances approached at $\Delta\omega_i\sim0$.

This result shows that a HOM can affect the beam quality for a given cavity shape (cavity length) and repetition frequency. We can avoid these situations by switching between different repetition rates as visually demonstrated in Fig.3.

Trapped Dipole HOM Qualities

The loaded quality factors of some HOMs change significantly during the deformation. The external quality factors of three trapped dipole HOMs vs. cavity deformation is depicted in the Fig. 2. It should be noted, that frequency behaviour of all HOMs is close to linear.

This shows the high sensitivity to the cavity deformation of the coupling of some trapped HOMs to the external load. As it is shown in Fig. 2, some trapped HOMs can have a high Q-factor during cavity deformation and invoke BBU instability.

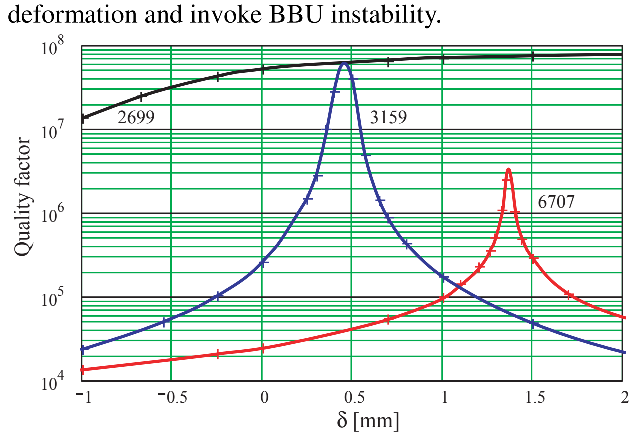

Figure 2: Trapped dipole HOM external quality factor versus the cavity longitudinal deformation.

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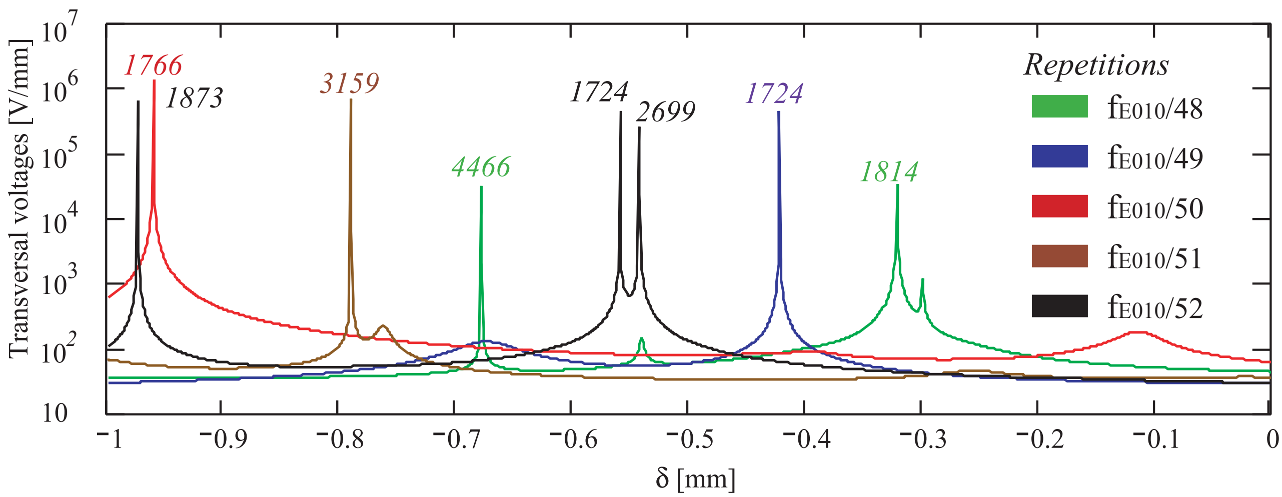

Figure 3: Transversal voltage of all dipole HOMs excited by a 2 mA beam of different repetition frequencies versus the cavity detuning (δ parameter).

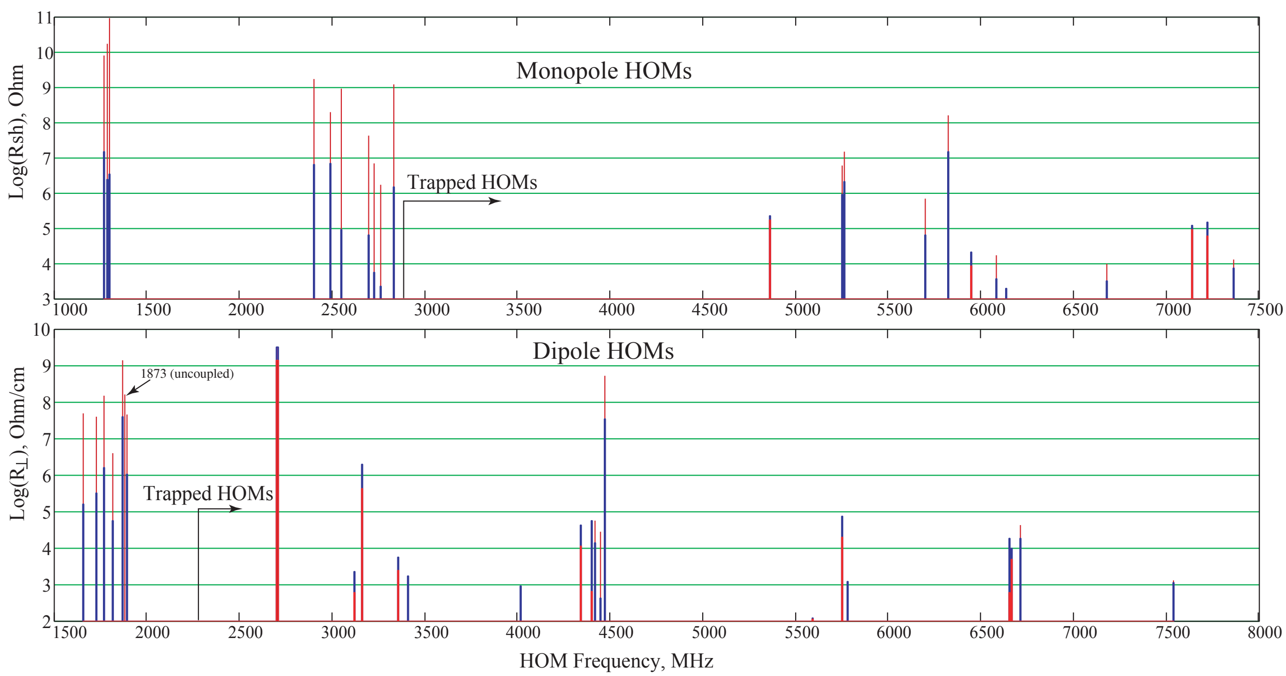

Figure 4: Monopole [3] and dipole spectrums in the RF gun cavity: red - without the insert (see Fig.1), blue - with the insert that is shown in Figs. 5, 6.

NEW DESIGN OF HOM DAMPING

In the new design the HOM damping effectively suppresses both monopole and dipole HOMs and is well coupled with some trapped HOMs. This is due to the special insert which is an inner conductor of a coaxial line into the beam pipe with the matched ferrite load at the opposite end. Such a design successfully suppresses HOMs in the normal conducting VEPP2000 cavity [4].

The insert serves as the fundamental mode RF power input. The insert could be longitudinally tuned by a motor to change the external quality factor and match the cavity with a klystron. The RF power is uncoupled with the HOM load by the 1300 MHz notch filter.

The other notch filter for a dipole mode having frequency of TE focusing mode is positioned as shown in Figs. 5 and 6. It traps the TE mode. The axial symmetry is broken by the couplers. Therefore, this mode is partially transformed to a dipole mode [5] and propagates into the beam pipe due to the low cutoff frequency of the dipole mode.

The insert is thermally isolated from external equipment such that it could be cooled with liquid nitrogen or (in second variant) helium.

In figures 5, 6 two designs of HOM damping are illustrated. The results of dipole and monopole HOM simulations are shown in Fig. 4 and Table 1. These results were calculated for the external quality of the fundamental mode $Q_{ext}=\omega_0 J/P=4.27\cdot 10^5$. This allows RF power P=100 kW to be transmitted to the beam of 26 mA current and accelerate it to an energy of 3.74 MeV. Maximal electric field at the cavity axis is 20 MV/m

(E_{acc}~10 MV/m) which corresponds to the stored RF energy J=5.23 joules. Such a field allows a cw operation due to a sufficiently low RF power dissipated in cavity walls.

Although the external quality of the main mode is matched through the insert position as Q_{ext}~E_{acc}^2/P the quality factors of untrapped HOMs (with N=1-5, 7 in table 1) will be only approximately $Q_{ext\text{-}N}$ ~$E_{acc}/P^{1/2}$.

The dissipated power in a thin wall of the cylindrical insert having Cu coating (see Fig.5) is less then 17 W, corresponding to a power density of 0.08 W/cm^2. This is sufficiently low to cool the insert with liquid nitrogen. The insert in Fig.6 has a very low dissipated power and can be cooled with liquid helium.

The external quality of the dipole HOM is limited (see the graphic depicted in top of the Fig.5) due to the power dissipated in the normal conducting notch. This limit is much higher in the variant of Fig.6 with a superconductive notch.

The inner diameter of the insert (44 mm) defines the cutoff frequency, here close to TE mode frequency.

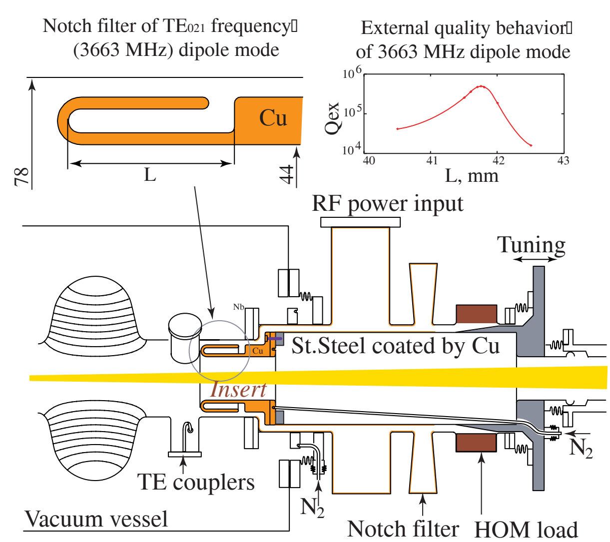

Figure 5: First variant of HOM damping with RF power input and the notch outside the cryostat.

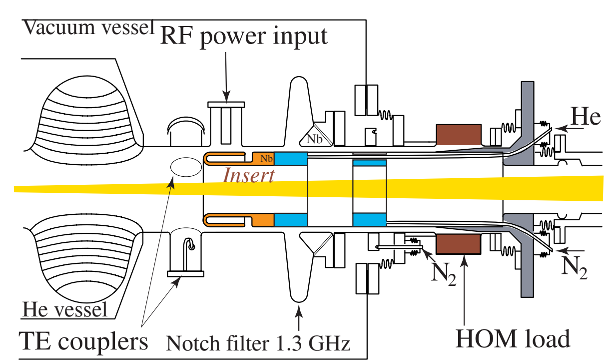

Figure 6: The second variant of HOM damping with superconductive insert, conventional RF power input, and the notch inside the cryostat.

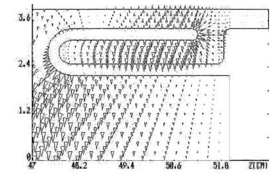

Figure 7: The electric dipole field distribution in the dipole notch filter (CLANS2 output).

Table 1: Dipole HOMs External Qualities and Frequencies

N	Without the insert		With the insert	
	F’, MHz	Q’$_{ext}$	F ,MHz	Q_{ext}
1	1655.24	6.20e+7	1655.36	1.95e+5
2	1724.43	1.77e+7	1724.7	1.32e+5
3	1766.16	7.71e+6	1766.69	7.97e+4
4	1814.06	9.72e+5	1817.22	1.45e+4
5	1865.55	4.65e+8	1865.55	1.39e+7
6	1873.64	1.06e+9	1873.64	5.40e+8
7	1887.55	8.06e+7	1887.57	1.85e+6
12	2699.3	6.73e+8	2699.3	1.49e+9
20	3159.14	7.72e+5	3159.09	3.70e+6
37	4466.8	4.61e+9	4466.8	2.94e+8
65	5746.98	8.80e+5	5746.93	3.60e+6
89	6709.45	2.83e+4	6710.19	2.43e+4
115	7534.61	9.21e+4	1655.36	1.02e+5

CONCLUSION

It is shown in this work that some dipole HOMs in superconducting RF gun multi-cell cavities (like FZD 3½ cell RF gun) can have significant Q-factors. These can affect the beam parameters and cause BBU instability. To avoid this problem, a unique HOM damping strategy is proposed. The simulation results presented in Fig.4 show, that both monopole and dipole HOMs are significantly suppressed by the insert (2-4 orders of magnitude). With this insert a relatively large Q-factor for the TE focusing mode can be reached, while having low Q-factors for all other HOMs. Therefore, application of RF focusing to suppress BBU instability with trapped dipole HOMs is attractive. Since the insert allows the TE mode in the cavity, both the emittance compensation and BBU instability suppression [2] can be achieved due to TE mode focusing.

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