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HOM DAMPING IN MULTI-CELL SUPERCONDUCTING CAVITIES FOR THE FUTURE ELECTRON SOURCE BriXSinO

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Abstract

High order modes (HOMs) in multi-cell superconducting cavities are of particular concern in beam dynamics of linear accelerators, mainly those operating in CW mode with high current and high repetition rate. These undesired modes may invoke beam instabilities, beam breakup and increase the energy spread if not correctly pulled out and damped. The study reported in this paper is applied for damping the HOMs in the main Linac of BriXSinO, an ongoing project of an Energy Recovery Linac at LASA INFN laboratory. We developed a numerical model to study the interaction of monopole HOMs with the beam in long timescale. The presented model, named HOMEN (High Order Modes Evolution based on eNergy budget), allows the inclusion of loss factors k_{loss}, crucial for evaluating the effect of the perturbing modes. At the same time, electromagnetic simulations of the standing wave multicell cavity, highlighted the dangerous modes and revealed a tolerable beam energy spread induced by HOMs. This method allows us to distinguish all dangerous modes of our interest for implementing the necessary damping mechanisms.

INTRODUCTION

The LASA (Laboratory for Accelerators and Applied Superconductivity) INFN (National Institute for Nuclear Physics) laboratory is currently developing a test-facility, BriXSinO, which will address the challenges created by the Energy recovery Linac (ERL) generation. BriXSinO is dual high flux radiation Inverse Compton Source (ICS) of X-ray and Free-Electron Laser (FEL) in the THz range, devoted to medical applications and applied research [1–8]. The machine will allow studies of applications of electron accelerators, and eventually to demonstrate a high peak and high average brightness beam generation and acceleration. BriXSinO is following the same philosophy of other projects born on the MariX conception [9–11]. A key component of this project is the ERL as a driver of both FEL and ICS experiments, hosted by an arc compressor [12–14]. The proposed BriXSinO's ERL is designed to operate in CW at 1.3 GHz, 5 mA average current in each of the accelerating and decelerating beams with an energy ranging from 22 MeV up to 45 MeV. The recirculated beam in the arc will be later decelerated within the SW (Standing Wave) SC (Superconducting) linac back to the injector beam energy. The beam will pass in two directions, first in the two-pass two-way acceleration mode, then in ERL mode with an opposite phase. This proposed scheme is intended to double the energy exchange in the Linac and promote the efficiency. In high current machines like BriXSinO, the excited HOMs need to be damped in an efficient way to bypass beam break up and avoid any additional cost regarding linac operation. In this paper, our investigations will mainly focus on cavity spectrum simulation, wakefields calculation and HOMs damping in the main linac cryomodule of BriXSinO's ERL.

SCOPE OF HOM INVESTIGATION

HOMs are always problematic in SC cavities and mainly those operating in CW regime. These parasitic modes are not only source of beam instabilities, but will also increase the cryogenic losses due to the power dissipated in the cavity walls [15]. In a previous work, we presented a new model called HOMEN, composed of a set of differential equations, solved numerically to study the consequence of HOMs on beam dynamics and stored energy inside SC cavities [16].

The main goal of the present paper is to underline which HOMs exactly are dangerous and need to be damped, instead of evaluating all the modes together.

WAKEFIELD SIMULATIONS IN 7-CELL CAVITY

The performance of any accelerator is related to wakefields, therefore, the evaluation of the loss factor k_{loss} is essential in order to study HOM damping. This factor is related to the amount of energy lost in modes when the beam traverses the resonator leaving behind a wakefield.

Usually HOMs whose frequencies are above the beam pipe cut-off are not of particular concern as they can be easily extracted or damped using couplers or absorbers once they propagate into the pipe. In case of coupled cavities, some of these propagating modes may still be problematic, as they can couple between the structures inducing trapped modes in the pipes. For a reliable beam dynamics study and for an effective HOM damping strategy, an electromagnetic study of the cavities is necessary to focus on the properties of the modes which are trapped in either the cavity or the beam-pipe region. With this aim, we used an eigen-mode study together with the wakefield simulations resorting to

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CST Particle Studio Eigen and Wakefield solvers [17]. Due a particle bunch finite length, the induced wake potential is calculated in time domain and then the coupling impedance of the structure is obtained by applying a Fourier transform of the wake potential.

In BriXSinO, the ERL SC linac is composed by three 7-cell cavities of 1.5 m long each. We first simulated a single cavity with pipes at both ends, later called module.
From longitudinal wakefield simulations of one module, we evaluated the impedance up to 30 GHz. The impedance spectrum shows some important peaks which corresponds to HOM whose frequencies are presented in Table 1.

Figure 1 shows the distribution of electric fields of the accelerating mode and the first trapped high order monopole mode inside the cavity structure. The fundamental mode, being below the cut-off frequency, is clearly well inside the cavity, meanwhile the first HOM partially propagates in the pipes.

Table 1: Frequencies and k_{loss} Values of HOMs

HOMs	Frequency [GHz]	k_{loss} [V/pC]
Mode 1	2.46	0.60
Mode 2	3.84	0.61
Mode 3	5.45	0.33
Mode 4	5.93	0.17
Mode 5	6.70	0.15
Mode 6	7.01	0.47
Mode 7	10.70	0.51

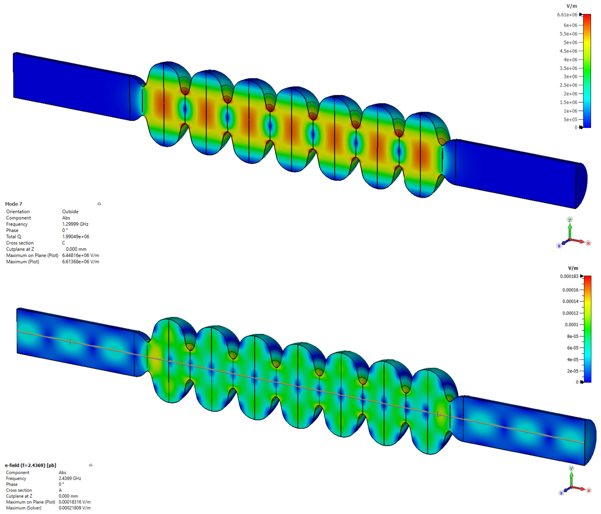

Figure 1: Schematic of the fundamental mode on the top and of the first HOM ($f = 2.43$ GHz) on the bottom in the 7-cell cavity CST simulations.

Figures 2 and 3 show the real part of the longitudinal and transverse impedance respectively, evaluated from the wakefield for one module, using a bunch of length $\sigma_z = 2.2$ mm.

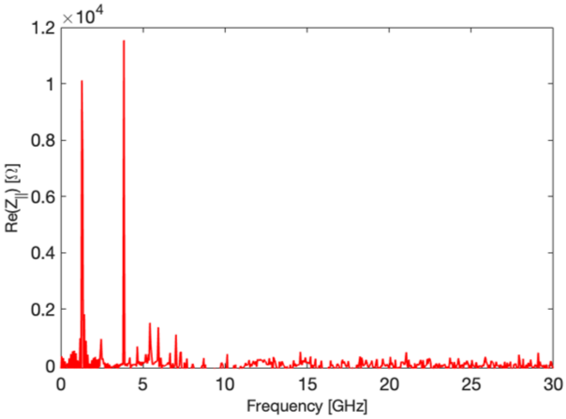

Figure 2: Real part of the longitudinal Impedance up to 30 GHz.

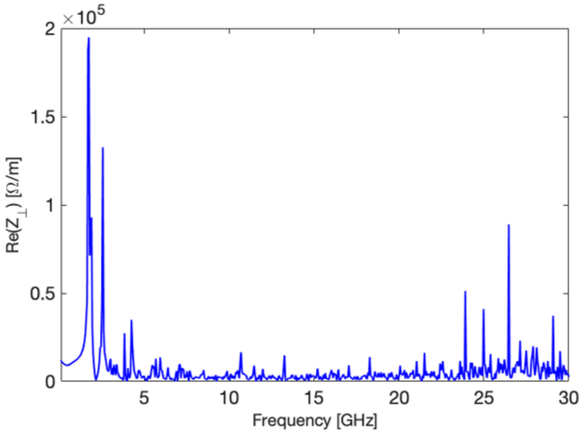

Figure 3: Real part of the transverse Impedance up to 30 GHz.

Each of the sharply peak frequencies corresponds to a cavity mode which has been excited by the beam. For each specific mode, in the longitudinal case the simulations allow to calculate the loss factor presented in Table 1. The total longitudinal loss factor is 3.5 V/pC for one 7-cell cavity module.

HOM ANALYSIS AND DAMPING

Accurate simulations of the wakefield lead to more reliable evaluation of the variation of stored energy in the cavity as well as of the bunch energy distribution. According to HOMEN model, the stored energy in the n$^{\text{th}}$ mode is represented by the following expression:

$$\frac{dU_n}{dt} = P_{\text{Kly}} - P_{\text{diss}} - P_{\text{av}} + P_{\text{HOM}} \tag{1}$$

where P_{Kly} is the power source, P_{diss} is the power dissipated on the cavity walls, P_{av} is the average power transferred to the electron bunch during acceleration and P_{HOM} is the power lost to HOM by the beam according to the loss factor.

Figure 4 shows a comparison of the growth in the stored energy oscillation for two different values of k_{loss}, one calculated from wakefield simulation (0.61 V/pC) and one (0.90 V/pC) used in our previous beam dynamics simulations [16]. For $k_{\mathrm{loss}} = 0.61$ V/pC, the results are more accurate as we stored less energy, 0.20 mJ rather than 0.34 mJ, inside the parasitic mode at $f = 3.84$ GHz, in the same characteristic time. Regarding the bunch energy distribution, we obtained a better relative energy spread, 2×10^{-3} instead of 1×10^{-3} which is important for the FEL injection in our application.

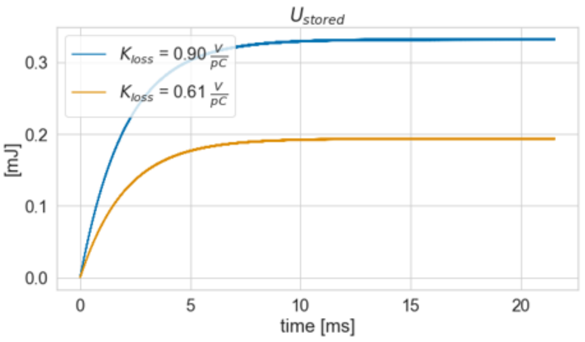

Figure 4: Stored energy in the cavity for simulated and estimated k_{loss}.

In case of high current, HOMs damping is of the utmost importance. The absorbing material suggested for this purpose is direct graphite-sintered silicon carbide SC-35 from Coorstek, which is the same used at Cornell [18]. The Silicon Carbide (SiC) HOM absorber is 125mm long with hollow cylindrical shape and is placed in the middle of the connecting pipes.

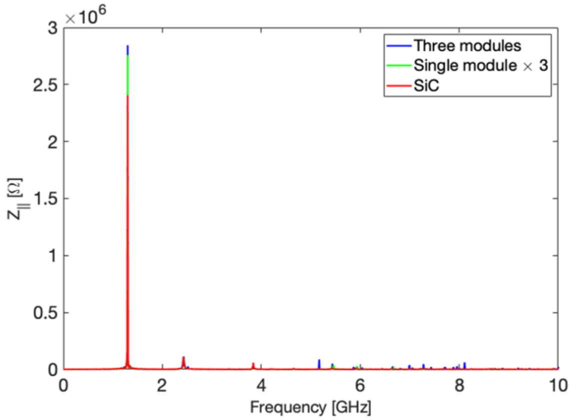

Figure 5: Longitudinal impedance of three modules compared with three times the single module evaluation and the three modules with SiC absorber.

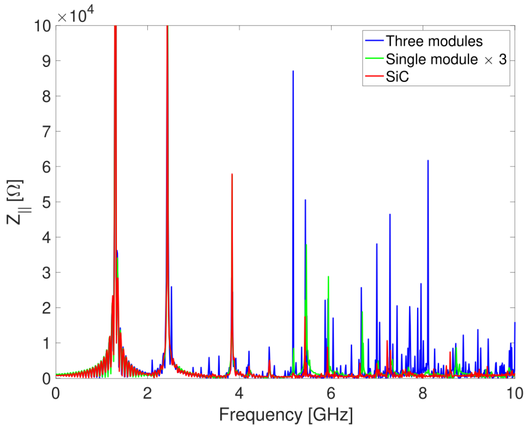

Figure 6: Longitudinal impedance with an enlarged view of Fig. 5.

To visualize the effectiveness of these HOM dampers, we evaluate the cavity impedance with and without SiC absorbers. Figure 5 shows the longitudinal impedance for the three coupled cavities without (blue peaks) and with SiC installed as HOM damper in the pipes (red peaks). The spectra are compared with the one considering three times the single module impedance (green peaks). In the enlarged view of the impedance in the three cases (Fig. 6), the blue curve clearly presents more peaks compared to the green one due to the modes propagating inside the pipes. The presence of SiC absorber (red peaks) does not have an effect on the first three modes, but it is effective on the modes that are fully inside the connecting pipes.

Moreover, HOM damping act on both the stored energy in the cavity and the bunch energy distribution at the cavity exit in terms of energy spread. Considering the 2nd HOM, we achieve an equilibrium for a characteristic time $t_{\mathrm{ch,n}} = 12.91$ ms in case of damping as shown in Fig. 7. On the other hand, for a normal quality factor ($\sim 10^{10}$) , reaching stability requires more days of simulations and more RAM in order to show an accurate timing comparison. Since in our case we are not interested in undamped quality factors, we can say that HOM damping shows a favorable results.

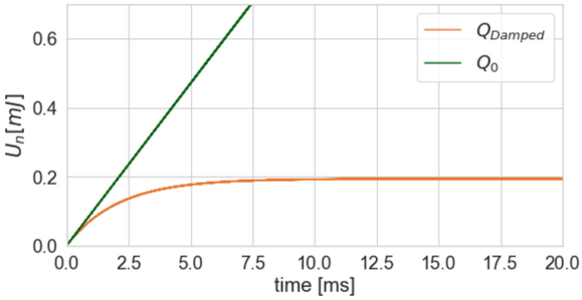

Figure 7: Stored energy variation for damped and undamped quality factors.

CONCLUSION

We investigated high order modes in the SC CW linac of the ongoing studies of BriXSinO project. The principal goal of this study was to simulate the loss factor parameter looking at its effect on the stored energy variation and the bunch energy distribution within the cavity. We reported the first studies on the damping of the evaluated HOMs using SiC absorbers.

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