STUDY ON HOM POWER LEVELS IN THE BESSY VSR MODULE

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Abstract

The BESSY VSR project represents a novel approach of SRF cavity application in the storage rings. To provide a high overvoltage for bunch compression L-band SRF cavities are equipped with strong waveguide and beam tube HOM dampers necessary for stable operation. The expected HOM power and spectrum has been analyzed for the complete module. This study is performed for various BESSY VSR bunch filling patterns. In the module different cavity arrangements are analyzed to reach the optimal operation conditions with equally distributed power portions in warm HOM loads and tolerable beam coupling impedance.

INTRODUCTION

The BESSY Variable pulse length Storage Ring (VSR) project [1, 2] is a future upgrade of the 3th generation BESSY II light source. The key feature of the project is the simultaneous storage of long (ca. 15ps) and short (ca. 1.7ps) electron bunches under "standard" user optics. This challenging goal requires the installation of SRF higher harmonic cavities of the fundamental 500MHz at two different frequencies. Therefore four new SRF cavities (2x1.5GHz and 2x1.75GHz) are considered and currently are in the design stage. These cavities will operate in CW mode at high field level (E_{acc}=20 MV/m). The combination of these factors with a high beam current (I_b=300 mA) make the cavity design a challenging goal, since stable operation must be ensured. Thus special attention must be paid to the damping of HOMs excited by the beam that may otherwise lead to coupled bunch instabilities.

The technique for calculation of RF power propagation of HOMs excited by the circulating beam in SRF cavities is presented. The method makes use of long range wakefield simulations using the CST [3] wakefield solver and an external post-processing of the port signals. The calculations were performed for different bunch filling patterns of the BESSY VSR project. The RF power of propagating HOMs is obtained by spectral weighting of port signals (calculated with a single bunch excitation) with the bunch train spectrum. In this manner the cavity resonances excited by the periodic bunch pattern will be detected. The evaluation procedure is used for the calculation of the expected HOM powers (broadband) to be absorbed in the RF loads and of the efficiency of HOM dampers in terms of power flow balance between FPC, HOM waveguides and beampipes. Then this technique was applied to analyze different cavity arrangements in the module to reach the optimal operation conditions with equally distributed power portions in warm HOM loads

and tolerable beam coupling impedance. The corresponding HOM power spectrums for single cavities and complete module with 4-cavities are presented as well. The system resonances are discussed based on long range wake potential calculations.

THE BESSY-VSR SRF MODULE & FILLING PATTERN

The realisation of the BESSY VSR project implies installation of a single superconducting module with four cavities in one of the straight sections of the existing BESSY II ring (Fig.1). The module integration is challenging engineering task because of strict space limitations of the ring-straight to ~4.2m. The complete module design is currently in the development stage. The detailed analyses of module assembly components and neighbouring elements shows that the 5-cell SRF cavities [4] considered in technical design report [1] will not fit into the existing ring and the decision was made for reduction to 4-cell cavities [5]. In this paper we present the main EM characteristics of those 4-cell cavities, but omit the details on the actual design process.
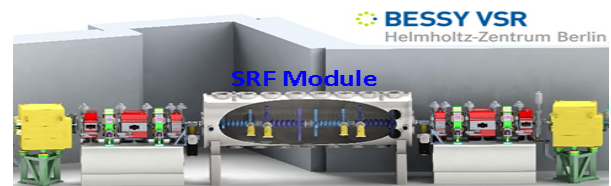

Figure 1: Schematic view of BESSY VSR cavities in ring straight.

The nominal BESSY VSR filling pattern of the 240m circumference ring is shown in Fig. 2 where the short and long bunches will be stored simultaneously. In total 400 RF buckets with 2ns bunch spacing are available.
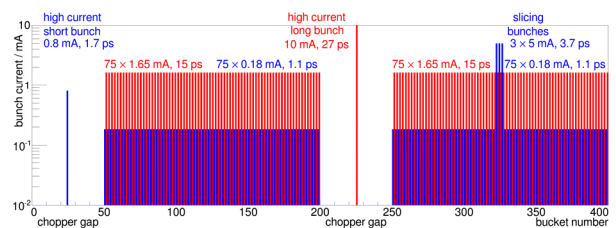

Figure 2: BESSY VSR filling pattern including short (blue) and long (red) bunches.

Two type of bunch filling patterns are considered, so-called "Extended" shown in Fig. 2 and "Baseline" with omission of 150 short-pulse, low-charge bunches. The repetition rates of 500MHz and 250MHz are defined by according bunch spacing in each pattern, respectively. In estimated HOM power levels given in this paper we present results for "Baseline" pattern as the highest

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contributor. Note that in case of single bunch operation the bunch repetition rate will be 1.25MHz defined by ring circumference of 240m corresponding to 800ns revolution time.

HOM POWER LEVELS & SPECTRUM IN SINGLE SRF CAVITIES

Due to the kW HOM power levels the decision was made to use waveguide damped cavities. The RF loads located at the end of waveguides will be water cooled [6]. The design of SRF cavities (Fig. 3) consists of four Tesla type cells supplied with two end-groups where the five HOM Waveguide (WG) dampers and Fundamental Power Coupler (FPC) are located. The cavities are supplied with enlarged beam pipes (BmP) for efficient HOM extraction. Although these pipes and WG-dampers has cut-offs above the fundamental mode frequency, the field penetration of fundamental mode into those parts are considered for positioning the intercepts to avoid Q-drop and to estimate heat load levels.

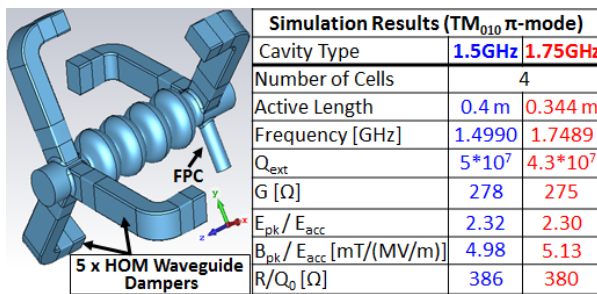| Simulation Results (TM$_{010}$ π-mode)		
Cavity Type	1.5GHz	1.75GHz
Number of Cells	4	
Active Length	0.4 m	0.344 m
Frequency [GHz]	1.4990	1.7489
Q$_{ext}$	5*10^7	4.3*10^7
G [Ω]	278	275
E$_{pk}$/ E$_{acc}$	2.32	2.30
B$_{pk}$/ E$_{acc}$ [mT/(MV/m)]	4.98	5.13
R/Q$_0$ [Ω]	386	380

Figure 3: Schematic view of SRF cavity design with summarised accelerating mode properties of 1.5GHz (blue) and 1.75GHz (red) cavities.

The accelerating mode properties of the optimised 1.5 GHz and the 1.75GHz cavities are summarised in Fig. 1. Since the cavities will be operated in storage ring it is very important to keep the HOM spectrum under control and fulfil off-resonant condition with the circulating beam.
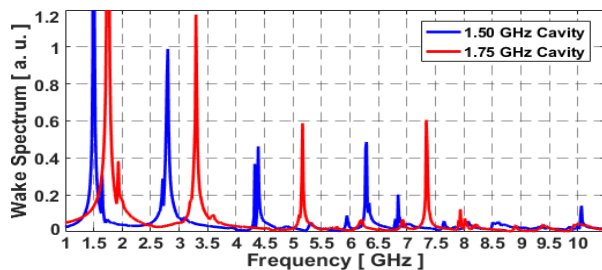

Figure 4: Longitudinal wake spectrum of 1.5GHz (blue) and 1.75GHz (red) cavities.

In order to analyse the excitation of HOMs in each cavity, long range (20m) wakefield simulations with σ=4mm (~13ps) bunch where performed using CST Studio Suite [3]. In those simulations port boundaries were used in order to model the extraction EM field energy from the system. In Fig. 4 the wake potential spectrum obtained for the optimised cavity designs are

presented. As can be seen the wake spectrum is not hitting any of beam resonances which are located at multiple of 250MHz for "Baseline" filling pattern. This class of simulations contains also the information on HOM power levels, spectrum and modal distribution at each port. The latest is important for special RF load design with broadband and multimode absorbing properties. The spectral power levels of the stored beam (filling pattern) are estimated by applying spectral weighting technique to each port signal given as

$$P(\omega) = \left| \frac{\tilde{I}_b(\omega)}{\tilde{I}_0(\omega)} \cdot \mathcal{F}(\omega) \right|^2,$$

where $\tilde{I}_0(\omega)$ and $\tilde{I}_b(\omega)$ are the current spectrums of simulated single bunch and stored bunch train, respectively. The function $\mathcal{F}(\omega)$ is the spectrum of time signal belonging to each mode at given port. Note that the weighting technique takes into account the phase (position) of each individual bunch in the train and in case of hitting even a single beam harmonic will be reflected in the power level and observed in the spectrum.

In Fig. 5 is presented the expected HOM power spectrum for each cavity and indicates the highest power level defined as maximum of the five WG loads at given frequency. The power spectrum contains also the information on mode distribution at every frequency used for RF load optimisation.
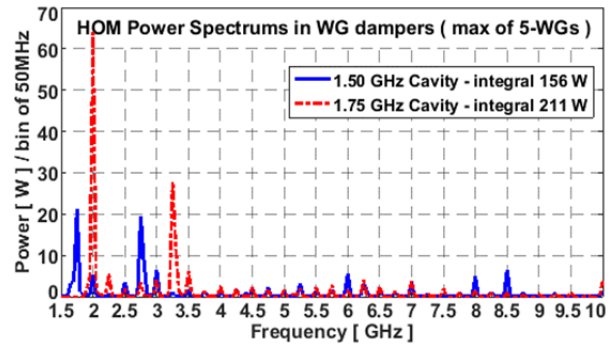

Figure 5: HOM Powers in WG-dampers obtained for "Baseline" filling pattern.

In Table 1 the total HOM powers at each port of individual cavity is presented. In table the ports are grouped in two end-grouped given by upper index (1, 2).

Table 1: HOM Power Levels for 'Baseline' Filling Pattern

Cavity type	1.5GHz	1.75GHz
Port No.	HOM Power [W]	
1 – FPC$^{(1)}$	37.9	33.8
2 – WG$^{(1)}$	105.3	154.7
3 – WG$^{(1)}$	103.8	151.4
4 – WG$^{(2)}$	88.5	108.3
5 – WG$^{(2)}$	90.2	109.8
6 – WG$^{(2)}$	90.6	111.6
7 – BmP$^{(Upstream)}$	235.4	200.5
8 – BmP$^{(Downstream)}$	327.1	275.9
Total	1079	1146

The HZB VSR input coupler design is a coaxial type high power coupler derived from the Cornell injector coupler for the ERL [7]. The detailed analyses shows that the HOM power at FPCs are mainly concentrated at higher coaxial mode TE11 while the cavity will be fed by the TEM mode. Hence, to protect the RF windows that are part of the FPC design [7], the coax dimensions of both couplers are optimised to decouple the HOMs and push those powers more into WG-dampers. Detailed analyses of HOM power levels and corresponding spectrums of individual cavities are very important for further understanding and optimisation of complete module that can include additional intermediate elements like bellows, transitions and collimators.

OPTIMUM ARRANGMENT OF THE SRF CAVITIES IN VSR-MODULE

In this section we discuss the different cavity arrangements in the module to reach the optimal operation conditions with equally distributed power portions in warm HOM loads. In the simulations the cavities are connected with cylindrical pipes and according tapered transitions between 1.5GHz (L) and 1.75GHz (S) cavities (Fig. 6). Since this class of simulations are very time consuming, a Gaussian bunch of σ=9mm rms length was used to calculate 20m long wake potential. Various cavity arrangement as LSSL, SSLL, LLSS, SLSL and LSLS where analyzed. The optimum cavity arrangement was found to be the setup LSSL which distributes equally the HOM powers (WG-dampers) along the module while keeping it at FPCs in low level (<100W). In this setup two 1.75GHz cavities are located in the center of the module.
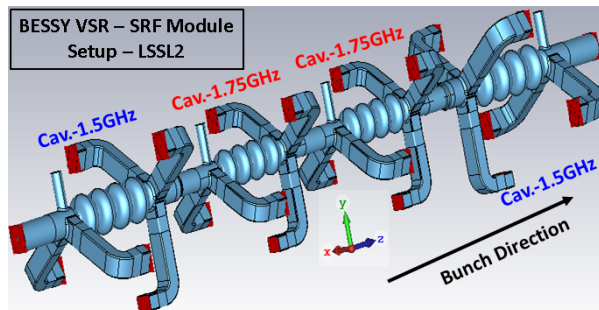

Figure 6: Schematic view of the optimum 4-cavity arrangement in BESSY VSR Module.

Finally, for optimal LSSL cavity arrangement, different FPC locations (upstream / downstream) of each cavity in the chain were analysed. The last optimisation is important to reduce the HOM powers flowing in the FPCs.

From many analysed setups in Table 2 is shown the HOM power levels in the module for only two setups -LSSL1 (blue) and LSSL2 (red). The table is structured in a way that the sequence of the cavity appearance (columns) along the beam path is preserved (Fig. 6). The difference between these two setups is the upstream and downstream FPC locations of last 1.5GHz cavity in the chain, i.e.

different longitudinal positions of the end-group with FPC. As can be seen the setup LSSL2 reduces the HOM power flow in FPC by factor of four while this additional power is handled by 3-WG end-group (in Table 2 – 3xWG [(2)]). Note that for optimised setup the FPC/ BmP powers in the 4-cavity chain and in single cavities (Table 1) are at the same level and the additional HOM power appearing in concatenated cavity setup is well damped in WG-dampers. During this study it was observed that the HOMs reflected from any tapered transition are handled mainly by closest end-group, i.e. after each opening transition a 3-WG end-group is preferred.

Table 2: HOM Power Levels in BESSY VSR Module Obtained for 'Baseline' Filling Pattern

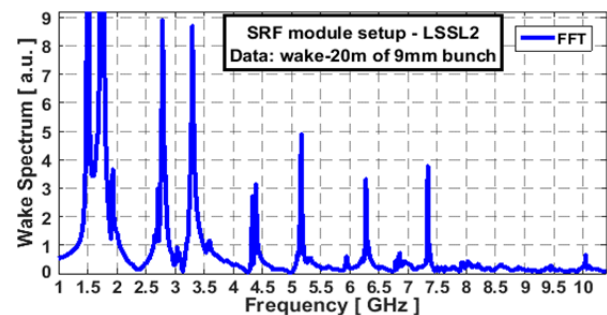| Port	HOM Power [W] in Each Cavity			
	1.5GHz	1.75GHz	1.75GHz	1.5GHz
FPC[(1)]	29 / 29	46 / 45	53 / 52	96 / 24
WG[(1)]	102 / 102	230 / 227	250 / 261	201 / 114
WG[(1)]	102 / 102	230 / 227	250 / 261	201 / 114
WG[(2)]	157 / 157	163 / 204	185 / 227	86 / 152
WG[(2)]	157 / 157	163 / 204	185 / 227	86 / 152
WG[(2)]	196 / 197	222 / 255	234 / 277	97 / 215
BmP	247 / 246 (Upstream)		269 / 332 (Downstream)	
Total	LSSL1 - 4246 W / LSSL2 - 4558 W			

Figure 7: The spectrum of longitudinal wake potential.

In Fig. 7 the spectrum of longitudinal wake potential (20m) of the 4-cavity chain with LSSL2 arrangement is presented. As can be seen the spectrum of the complete chain follows the single cavity resonances (Fig. 4), i.e. there are no additional resonances that can belong to cavity intersections. This optimised cavity arrangement has an advantage that the HOMs will not be localised in the cold module and has more probability to outward propagation where can be handle by addition HOM beampipe warm absorbers.

OUTLOOK

In this paper we have presented the results on ongoing studies on HOM power levels for BESSY VSR project. The stable machine operation requires HOM impedances not exceeding the threshold defined by the operating BESSY II feedback system [1]. Hence, to resolve accurately the resonances of each cavity, eigenmode (mode atlas) computations are currently in process. In the final module assembly we expect also some shielded

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bellows and further study on their impact in terms of HOM excitations is foreseen.

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