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DESIGN OF THE BEAMLINE ELEMENTS IN THE BESSY VSR COLD STRING*

H.W. Glock[†], T. Flisgen, F. Glöckner, J. Knobloch, E. Sharples, A. Tsakanian, A. Velez Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

Abstract

The four SRF cavities in the BESSY VSR module will be linked by bellows, which will be equipped with inner coaxial shielding pipes to prevent both parasitic fundamental mode losses and beam-induced heating. The central bellow will also act as a collimator for synchrotron radiation generated in the closest upstream dipole magnet. Additional bellows at the module's ends are needed to connect with the warm BESSY beam pipe. Outside the module the beam pipe cross section transitions will be located, which will be equipped with toroidal HOM absorbing elements. In the paper the recent design considerations and specifications for all those components will be described.

MODULE OVERVIEW

The BESSY VSR module (See Fig. 1) will contain two cavities operating at 1.5 GHz, two at 1.75 GHz [1], which together with the main 500 MHz RF system will generate a beating voltage pattern, appropriate to store long ($\sigma \sim 15$ ps) and short ($\sigma \sim 1.5$ ps) pulses simultaneously. The module will have to fit into one straight section of the BESSY II ring, which exposes a stringent and indisputable restriction of ~ 4.6 m for its overall length. This length limit has direct consequences both for the cavity design (which for the reason of length saving was changed from a 5-cell to a 4-cell set up), for the shape/length of the beam pipe cross section jump in the warm end group and also for the layout of the connecting bellows. Those will be present in four kinds:

- One *collimating shielded bellow* (See Fig. 2) in the middle of the module, connecting the two 1.75 GHz cavities and also capturing synchrotron radiation, thus protecting the two downstream cavities against ~ 11 W of additional power;
- two *shielded bellows* (See Fig. 3) in between each pair of 1.5 GHz / 1.75 GHz cavities, like the former equipped with a copper-made coaxial chicane, strongly reducing the dissipation of fundamental mode power in the stainless-steel bellow convolutions;
- two *module-end-bellows* separating the exterior warm circular beam pipe from the inner cold part; also made of stainless steel and thus acting as strong thermal resistor;
- two bellows integrated in the *warm end groups*, intended to give space for mounting the module in

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[†] hans.glock@helmholtz-berlin.de

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VSR module, including attached exterior components, which, by their direct RF coupling, are understood as part of the *Cold string*, even though not or only partially operated at cryogenic temperatures. Orange parts are discussed in this paper. The module's ends are indicated by the tank flanges.

between fixed BESSY II beam pipes and to compensate for slight irregularities;

(COLLIMATING) SHIELDED BELLOW

The *collimating shielded bellow* (See Fig. 2) in the centre of the cold string is (like the two *shielded bellows* are) intended both to:

- give space for cooling shrinkage needed for cool down (~ 1 mm);
- compensate for (slight) flange-to-flange angle mismatches, thus reducing cavity stress and ease mounting;
- reduce the acoustical coupling in the cold string.

Main issue of all bellows in direct connection to the cavities is the leakage of fundamental mode field outside the cavities' niobium beam pipe extension, thus reaching normal conducting surfaces at the bellow's convolutions. This – even though being a small effect following a subcut-off exponential field decay – would both reduce the mode's Q-values, heat up the cavities' peripherals (which are only conductively cooled) and introduce a significant additional load of the cryogenic system. With the aid of the shielding this fundamental mode power dissipation can be iff reduced to in total 1.46 W (@ 7 MV/cav.). Obviously the bellow forms a cavity-like structure by itself, which will $\frac{15}{20}$ show own modes.



Figure 2: Collimating shielded bellow (orange) in between the end-groups of two 1.75 GHz cavities. The fourconvolution stainless-steel part is shielded by a coaxial chicane (massive copper) against fundamental-modeeffields. The tapered sections are made of stainless steel with a $\sim 20 \,\mu\text{m}$ copper coating; the latter to reduce the electromagnetic losses, the former for stability reasons and to limit the static heat flow. Each side is actively cooled by a circumferential pipe.



Figure 3: Shielded bellow (here shown with 1.5 GHz cavity to the left). Similar set-up like the collimating shielded bellow, but less reduced inner diameter (Ø 78 mm instead

of \emptyset 52 mm). Same considerations like for the collimating, but only a single localized mode at 927 MHz, 12.9 W HOM power (\emptyset 20 mA single bunch.

Careful design of the geometry parameters has been undertaken in order to avoid that those resonances coincide with the predominant spectral lines of the BESSY VSR filling pattern, which are multiples of 250 MHz. This also had to be ensured for any stretching/compressing within the ± 2 mm compensation capability of the bellow. CST eigenmode analysis [2] resulted in a set of two fully confined modes (See Fig. 4, 5), modes of higher order couple to the cavity waveguide absorber, thus propagating their power outwards.



Figure 4: E-field distribution of the lowest eigenmode of the collimating shielded bellow, found at 422 MHz, $R/Q = 15.8 \Omega$, Q = 497, length dependence: 415.8 MHz (- 2 mm) to 423 MHz (+ 2 mm).



Figure 5: E-field distribution of the second eigenmode of the collimating shielded bellow, found at 2.155 GHz, $R/Q = 4.25 \Omega$, Q = 1490, varying 415.8 MHz to 423 MHz, non-monotonous length dependence: 2125 MHz (- 2 mm) to 2135 MHz (+ 2 mm).

In case of single-bunch (or few-bunch) operation of BESSY II the excitation of the parasitic modes cannot be avoided, since the beam spectrum then populates every harmonic of 1.25 MHz (corresponding to 800 ns revolution time). Assuming a 20 mA average current, the beam looses 6.7 W (mode 1), 9.2 W (mode 2), 2.9 W (mode 3 at 3.923 GHz, already propagating like all higher modes, but accounted), i.e. a total HOM deposition of 18.8 W. Together with the fundamental and synchrotron power, this adds up to in total ~ 32 W (@ single bunch operation, otherwise ~ 13 W), which has to be cooled locally. Thermal simulations (See Fig. 6) showed a nicely confined temperature distribution in the body of the shielding

02 Photon Sources and Electron Accelerators A05 Synchrotron Radiation Facilities elements, even in the surrounding of the 2 x 2 mm²-sized incidence spot of the synchrotron light. Nevertheless the stainless steel bellow itself heats up to \sim 130 K, which may initiate outgassing processes. Also the inner volume could act as a reservoir for particulates, generated during production and occasionally released by movement or temperature changes. Therefore stringent cleaning will be demanded in the manufacturing process.



Figure 6: Simulated temperature distribution in the collimating shielded bellow for 20 mA single bunch operation and 11 W of collimated synchrotron light power, incident at a $2 \times 2 \text{ mm}^2$ spot, located at the left-most number flag. Active cooling is applied through the two circumferential pipes with a rate of 0.002 W/(mm² K) @ 5 K, flange boundaries are kept at 2 K.

WARM END GROUPS

The *warm end groups* (See Fig. 7) will serve as combined devices, functioning as:

- transition between the BESSY II and VSRmodule beam pipe;
- actively water-cooled housing for a toroidal Silicium- -Carbide (SiC) dielectric wake absorber, also shielding the ...
- ... exterior bellow for module mounting/adopting; shielded port for a getter pump directly attached below.



Figure 7: Warm end group.

Because of the hard restriction of the available length the beam pipe taper are much steeper as appropriate for a lowimpedance cross section match (even if the absorber toroid

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length would also be used). Therefore the generation of significant wake power in the transition and also in the inevitable bellow cannot be avoided. Furthermore wake power generated in the cavities propagates outwards the module [3], which should not be reflected backwards. The total average power is computed [4] as 1270 W; in order to acknowledge some computational uncertainty (especially for the applied spectral width, which was limited by computing resources) a specification load of 2 kW (per toroid) is assumed. This was used for a thermal computation (See Fig. 8) resulting in a temperature span of \sim 57 K. That raised concerns both about outgassing and risks of mechanical fatigue of the ceramic, especially since the power dissipation is quite unevenly distributed, mainly concentrated on the inner dielectric surface. A cooling jacket extended over the entire toroid length is recently investigated in order to reduce the temperature spread.



Figure 8: Temperature distribution in the SiC absorber toroid, computed for a total power of 2 kW and following a power load distribution as computed in [4] (courtesy M. Dirsat, HZB).

MODULE END BELLOWS

The *module end bellows* are recently the least matured components of the cold string. Preliminary computations indicate the presence of localized modes with significant shunt impedance. This gave reasons to investigate technical possibilities to introduce RF-tuneability of the bellow, using an intermediate stiff ring, which can be longitudinally shifted during operation while maintaining the overall length. Such a ring also is likely to serve as a cooling intercept support.

CONCLUSION

The design of the VSR cold string components is proceeding. The paramount priority of the limited system length strongly influences all design considerations. Furthermore long-term reliability in a strongly useroriented, existing machine, and thus especially the danger of particulate-caused impairment of cavity performance is of great importance, as well as the reduction of energy deposition in the cold environment. Recently most component designs reached qualifications supported by simulation results; first prototype tests are expected in 2018.

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