# S-BAND CHOKE MODE CAVITY FOR LOW ENERGY STORAGE RING

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*Abstract*
Several variants of a low-energy storage ring for Thomson scattering X-ray source were considered in [1]. The most promising variant "C" of the ring with small dimensions and large dynamic aperture has also large momentum compaction factor, which would lead to too long bunches with RF cavity operating at 714 MHz, so shorter wavelength must be used. In this paper we present results of optimization of S-band double-cells cavity with parasitic mode damping by chokes similar to [2]. Interaction of the bunch circulating in the ring with cavity parasitic modes is simulated.

## INTRODUCTION

Thomson scattering of laser photons on relativistic electrons enables generating monochromatic X-radiation with adjustable energy. High average intensity of radiation can be achieved through higher collision frequency of photon and electron bunches with small cross-sectional dimensions at the interaction point. High collision frequency is achieved through circulation of electron bunches in compact storage ring. Four variants of Thomson generator ring with electron energy of ~50 MeV and bunch charge of ~1 nC are presented in publication [1]. For further consideration, we selected option C with the largest dynamic aperture and smallest dimensions. A modified variant of the ring is given in Fig. 1, and its characteristics are given in Table 1.

Distinct feature of this variant is large value of the momentum compaction factor, which along with other parameters determines RMS length of the bunch circulating in the ring:

$$\Delta l_{rms} = \frac{\Delta p_{rms}}{p_s}\sqrt{\frac{cL\alpha\, E_s}{2\pi f_{RF} eV_{RF}\cos\varphi_s}}, \qquad (1)$$

where $\Delta p_{rms}$ is the RMS momentum spread, and other designations are given in Table 1. To ensure acceptable length of the bunch, we increased operating frequency of the RF cavity from 714 MHz [3] to the frequency of the injector of 2,856 MHz [4]. For the ring parameters given in Table 1, such modification results in the following ratio of the bunch length and momentum spread: $\Delta l_{rms} \approx 1.75\frac{\Delta p_{rms}}{p_s}$ (m). It should be noted that such high operating frequency of the cavity was also used in the MIT-Bates storage ring [5].

In the process of the RF cavity optimization and choice of its design, a number of problems must be solved, the most significant ones being suppression of the higher order modes (HOM) and increasing of the cavity efficiency. To solve the above problems, we analyze two variants of the RF cavity: cavity with removal of the HOMs into the beam pipe which walls are covered by RF absorbing material (see e.g. [5]); and cavity with a choke suggested in [2] that has little impact on the operating mode, but ensures absorption of the HOMs.

Table 1: Storage Ring Parameters

| Parameter | Value |
|---|---|
| Operating frequency of the RF cavity, $f_{RF}$ | 2856 MHz |
| Frequency of bunch circulation, $f_0$ | 35.7 MHz |
| Orbit length, $L$ | 8.397 m |
| Momentum compaction factor, $\alpha$ | 0.13 |
| RF voltage, $V_{RF}$ | 300 kV |
| Synchronous particle momentum, $p_s$ | 50.5 MeV/s |
| Synchronous phase, $\varphi_s$ | $0^0$ |
| Bunch charge, $q_B$ | 1 nC |
| Number of bunches at orbit, $M$ | 1 |
| Bunch replacement period, $\tau_{ch}$ | 20 ms |
| Average beam current, $I_b$ | 35.7 mA |
| Synchrotron tune, $Q_s$ | 0.05 |
| $\beta$ –function at cavity position, | 2/2 m |
| Betatron tunes, $Q_x$ / $Q_y$ | 2.7 / 1.8 |

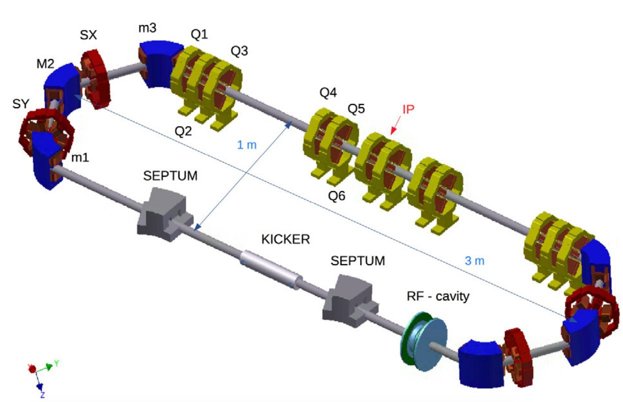


Figure 1: Storage ring layout.

## HOMS SUPPRESSION CRITERION

Electron bunches circulating in the ring excite HOMs of the cavity, subsequent interaction with which at certain values of the beam current can result in two types of instability, longitudinal and transversal. In case of Thomson generator with low energy of the circulating beam (35 – 50 MeV), emittance growth due to intrabeam scattering effect stipulates the need to replace bunches in the ring with the period of $\tau_{ch}$ ≈20 ms, which is much shorter than the dumping time due to synchrotron radiation, the value of which at such low energy is > 1 s. As such, stable motion of bunches in the ring is determined by the condition that



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time constant of the HOMs field amplitude growth is greater than $\tau_{ch}$.

Based on publications [6-8], time constants for developing longitudinal ($\tau_{\parallel}$) and transverse ($\tau_{x,y}$) coupled bunch instabilities can be determined as follows:

$$\frac{1}{\tau_{\parallel}} \approx \frac{\alpha I_b}{2Q_s p_s} f_k^L R_{\parallel}(f_k^L) \quad (2)$$

$$\frac{1}{\tau_{x,y}} \approx \frac{\beta_{x,y} I_b f_0}{2p_s} R_{x,y}\left(f_k^{x,y}\right) \quad (3)$$

where $f_k^L$ and $f_k^{x,y}$ are longitudinal and transverse harmonics of beam current: $f_k^L = (k + Q_s)f_0$, $f_k^{x,y} = (k + Q_{x,y})f_0$, $k$=1,2,…, $R_{\parallel}(f_k^L)$ and $R_{x,y}\left(f_k^{x,y}\right)$ are values of longitudinal and transverse HOMs shunt impedance at the beam current harmonic frequencies:

$$R_{\parallel}(f_k^L) \approx \frac{R_{\parallel}(f_{HOM}^L)}{1+\left(2Q_{HOM}^L \delta_k^L\right)^2} \quad (4)$$

$$R_{x,y}\left(f_k^{x,y}\right) \approx \frac{R_{x,y}\left(f_{HOM}^{x,y}\right)}{1+\left(2Q_{HOM}^{x,y} \delta_k^{x,y}\right)^2} \quad (5)$$

$f_{HOM}^{L,x,y}$ are frequencies of longitudinal and transverse HOMs, $Q_{HOM}^{L,x,y}$ is their loaded quality factor, $\delta_k^{L,x,y}$, is their relative detuning: $\delta_k^{L,x,y} = \left(f_{HOM}^{L,x,y} - f_k^{L,x,y}\right)/f_{HOM}^{L,x,y}$. Other designations are given in Table 1.

Using ring parameters from Table 1, we determine longitudinal and transverse stability criteria:

$$f_k^L R_{\parallel}(f_k^L) < 0.05 \text{ MHz}\times\text{M}\Omega, \quad (6)$$

$$R_{x,y}\left(f_k^{x,y}\right) < 2 \text{ k}\Omega\text{ /m}, \quad (7)$$

which should be met at beam current harmonic frequencies for all HOMs.

## RF CAVITY WITH LARGE BEAM PIPE

Fig. 2 shows geometry of the cavity with large beam aperture (similar to [5]), which ensures coupling out of HOMs from the cavity. Covering of the beam pipe walls by material with high RF energy absorption coefficient ensures compliance with conditions (6), (7).

Calculations of frequencies, Q and shunt resistance values of the cavity modes were done using CST Microwave Studio code [9]. Electric wall type boundary conditions were set at the ends of the beam pipe.

The final variant of the geometry has two longitudinal and one dipole potentially dangerous modes, frequencies of which are lower than the critical frequencies of the beam pipe: 4.4 GHz for TE-waves, and 5.74 GHz for TM-waves. Presence of absorber ensures compliance with conditions (6) and (7) for these modes.

As a result of optimization, RF cavity geometry with removal of HOMs into the beam pipe was found. For the operating mode, the calculated shunt impedance is 1.6 MΩ, and Q is 16,500. To achieve design effective RF voltage of 300 kV at the gap, average RF power loss in the walls reaches ~56 kW. Removal of heat loss of such high level without substantial changes of electrodynamic characteristics of the cavity does not seem possible, moreover so high RF power consumption would drastically decrease the X-ray source efficiency.

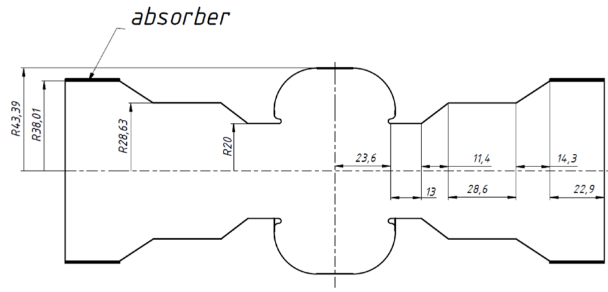


Figure 2: Geometry of the RF cavity with large diameter of the beam aperture.

## RF CAVITY WITH SELECTIVE LOAD

Design of the RF cavity with a choke that has a little impact on characteristics of the operating mode, but allows to lower Q of the HOMs through use of the absorber located near the choke was proposes in [2]. The beam aperture ensuring high shunt impedance of the operating mode can be chosen for such cavity.

With the beam aperture of 10 mm the calculated shunt impedance of the operating mode is 3.8 MΩ, and Q is 14,000. So RF power losses of 24 kW are required to achieve RF voltage of 300 kV at the gap. Since there is sufficient free space in the ring design, to lower dissipated power we install two RF cavities with voltage of 150 kV at each gap. Cavities are fed from a single klystron via a 3-dB coupler, which permits to operate klystron without ferrite isolator. The proper phase difference between RF cavities field is achieved by choice of the distance between cavities. RF power consumption in proposed scheme is decreased to 12 kW.

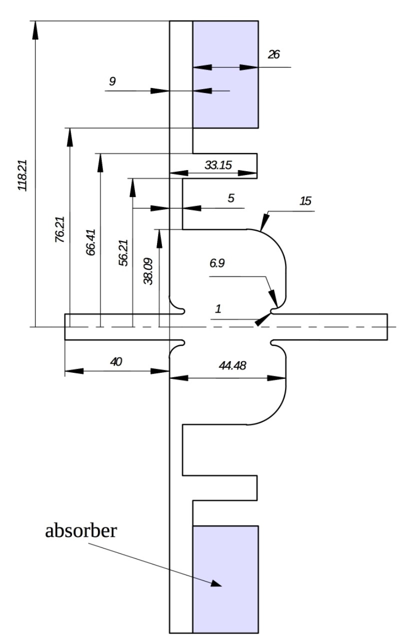


Figure 3: Geometry of cavity with a choke.

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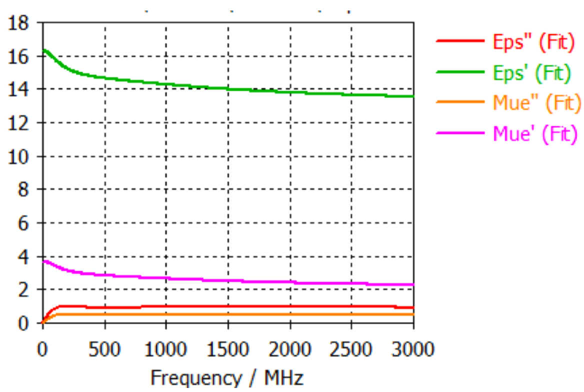


Figure 4: Characteristics of absorbing material.

Choke optimization allowed to lower Q of the HOMs through transmission of their energy to the absorber, which was considered to be a dielectric with characteristics shown in Fig. 4 [10]. Calculations demonstrated that decrease of Q of the operating mode due to presence of the absorber does not exceed 3-4%. Fig. 5 shows time constants of different cavity modes $\tau = \frac{Q}{2\pi f}$ with and without absorber. It is seen that for most HOMs, time constant is an order of magnitude lower than a bunch circulation period in the ring, which is 28 ns. Therefore, presence of such modes will not result in coupled bunch instability. Fig. 5 shows two modes with time constant exceeding the bunch circulation time. The first is the operating mode; the second one is the quadrupole mode, which is not dangerous.

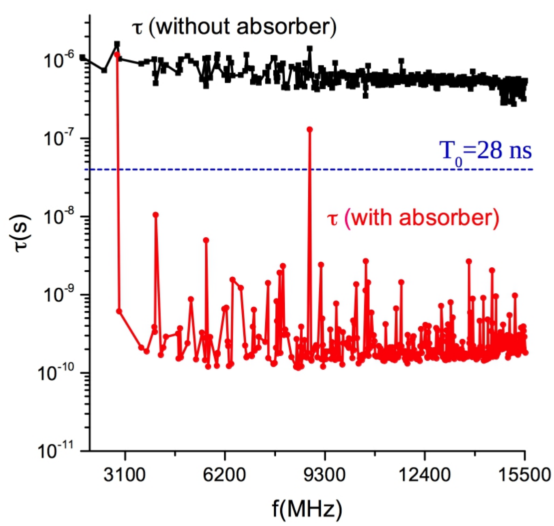


Figure 5: Dependence of cavity modes time constant on frequency without (black curve) and with absorber (red curve).

## CONCLUSION

The study resulted in proposing two variants of the RF cavity for the storage ring of the X-ray Thomson generator free from dangerous longitudinal and lateral modes. From standpoint of minimum power requirements, the optimum variant is the RF cavity with selective load.

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