OPTIMIZATION OF THE RF CAVITY OF A LOW-ENERGY STORAGE RING FOR THOMSON SCATTERING X-RAY SOURCE

L. Ovchinnikova*, V. Shvedunov[1],
Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University, Moscow, Russia
A. Ryabov, Institute of High Energy Physics, Protvino, Russia
[1]also at Laboratory of Electron Accelerators MSU Ltd., Moscow, Russia

Abstract

Results of optimization of the RF cavity of a low-energy storage ring for Thomson scattering X-ray source are presented. The geometry of 714 MHz RF cavity was optimized to provide maximum shunt impedance taking into account position of higher order modes (HOMs). The number and position of cooling channels were adjusted to minimize frequency shift due to cavity thermal deformations. The waveguide coupler and frequency tuner were calculated. Special attention was paid to detailed calculations of the HOMs parameters and to study of methods to minimize their influence on the storage ring beam dynamics.

INTRODUCTION

The RF cavity is a part of a storage ring of Thomson scattering X-ray source. It ensures stable longitudinal oscillations of electrons circulating in the storage ring, and compensates for energy losses due to Thomson scattering of laser radiation, coherent synchrotron radiation of the bunch, excitation of the cavity parasitic modes, radiation at inhomogeneities of the vacuum system.

The work was divided into four stages: (1) selecting geometry of the cavity and analyzing its frequency spectrum; (2) calculating the RF power coupler; (3) optimizing the cooling system and evaluating the frequency shift due to thermal deformations of the cavity; and (4) calculating the plunger for operating mode frequency tuning.

GEOMETRY OPTIMIZATION, FREQUENCY SPECTRUM ANALYSIS

We took omega-shape cavity (Fig. 1) as a basis, since it has higher shunt impedance and therefore lower RF power dissipation in the walls as compared to an elliptical one.

Table 1: Main Parameters of the Ring Cavity

Parameter	Value
Operating mode frequency, MHz	714
Quality factor	32 800
Effective shunt impedance, MOhm	11.3
Effective gap voltage, kV	300
RF power dissipated in the walls, kW	8
Maximum electric field strength, MV/m	10.6

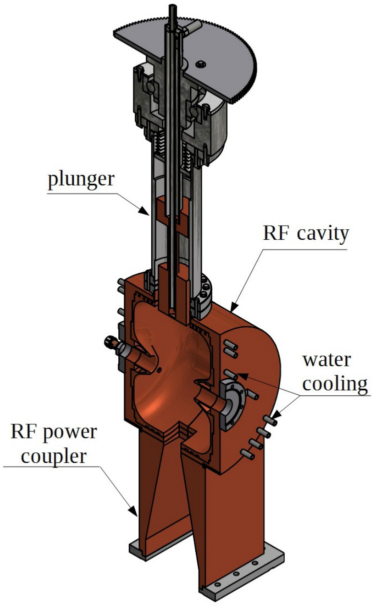

Figure 1: The storage ring RF cavity design.

To achieve maximum shunt impedance, the cavity geometry was optimized using code [1]. Table 1 lists main parameters of the RF cavity.

Calculation of the potentially dangerous HOMs, which can be excited by electron bunches circulating in the storage ring, was performed for the obtained RF cavity geometry. At certain levels of the beam current, interaction of electron bunches with the cavity HOMs can result in longitudinal and transverse instability of the beam and in undesirable emittance growth.

Calculation of the RF cavity HOMs was performed using codes [2, 3]. Impact of HOMs on the beam stability in the storage ring was analyzed using methods described in [4–8].

Longitudinal instability can be caused by the monopole HOMs with non-zero longitudinal electric field at the axis. These are LE (Longitudinal Electric) and LM (Longitudinal Magnetic) type modes. Letters E and M represent type of boundary condition at the transverse plane of symmetry of the cavity. Transverse instability of the beam can be caused by the cavity transverse HOMs of DE (Dipole Electric) and DM (Dipole Magnetic) types. Figure 2 shows frequency spectrum of higher order modes of LE type at the cavity temperature of 30 °C. Potentially dangerous are the modes with graphs lying above the critical value (pointed to by the

---

* lub.ovch@yandex.ru

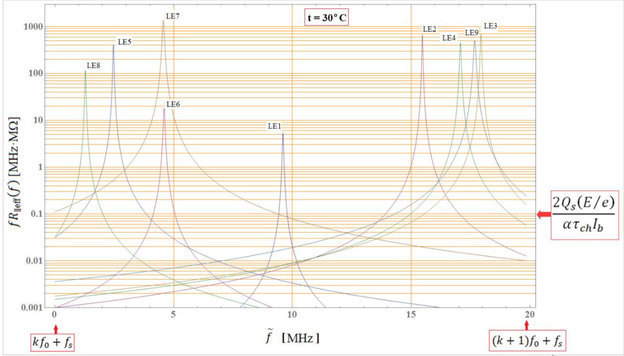

Figure 2: LE type HOMs frequency spectrum of the RF cavity at 30 °C.

arrow in Fig. 2) in at least one end of the frequency range. As can be seen, these are LE3, LE7 and LE9 modes. Similar graphs were plotted for the HOMs of the other types. At the cavity temperature of 30 °C, potentially dangerous turned out to be LM2, DE3, DE6, DE14, DM2 and DM14 modes.

The problem of reducing impact of the HOMs was addressed by shifting their frequencies so that their excitation would not endanger stability of the beam. The shift was achieved through selecting the cavity operating temperature.

Frequency shift of a particular mode of uniformly heated RF cavity made of homogeneous material is determined by the mode frequency value f_R, thermal expansion coefficient α_L, and the temperature increase Δt: $\Delta f_R = -f_R \cdot \alpha_L \cdot \Delta t$, i.e. magnitude of the frequency shift is different for different modes. Using this formula, frequency spectra of HOMs have been analyzed at the cavity temperature in the range of 50 – 70 °C.

The analysis has shown that operating temperature of the cavity, at which the vast majority of the higher order modes become not dangerous, is about 62 °C.

Suppression of the potentially dangerous transverse modes DM4 and DM2 that remain at this temperature is done through withdrawal of their energy to absorbing loads via feeding waveguide (see below).

RF POWER COUPLER

Two options of the RF power input into the ring cavity are possible. These are coaxial input with coupling loop or waveguide input through the window connecting the waveguide and cavity. Selection of high operating frequency of 714 MHz allows us to use for the transmission of RF energy the waveguide WR 1150 intended for the frequency range of 0.64 – 0.96 GHz and having the internal dimensions of 292.1 × 146.05 mm. Relatively small cross-section of the waveguide allows us to supply cavity with RF energy directly from the waveguide through a coupling window (Fig. 1). Size of the coupling window was selected to ensure coupling coefficient of about 1.5. Shift of the cavity operating mode frequency due to coupling window was compensated for through changing the cavity radius. Recalculation of frequencies and characteristics of higher order modes for a cavity with a coupling window revealed that DM2 and DM4 HOMs have higher coupling coefficient with a power coupler waveguide. This decreases the quality factor of the modes due to withdrawal of their energy to absorbing loads.

COOLING SYSTEM

Search for an optimal position of cooling channels was done using software package CST [2], while calculations of elastic deformations and related operating frequency shift were done using code [3].

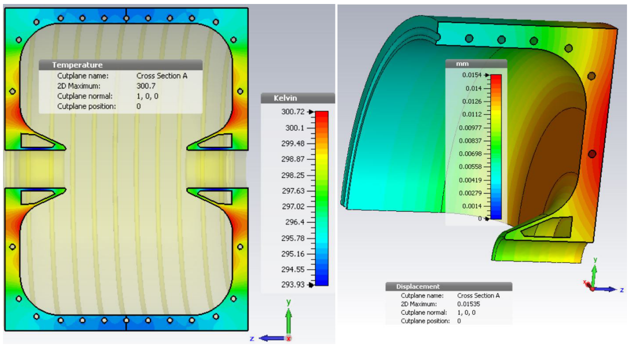

Figure 3: Left – cavity temperature field due to dissipation of the RF power in the walls, right – RF cavity deformation field.

In the process of cooling system optimization, calculations of the cavity temperature field, of elastic deformations and of the operating frequency shift for the rated value of the RF power dissipated in the walls were performed for each specific position of cooling channels. Figure 3 shows temperature distribution for the optimal position of cooling channels, which ensure minimum cavity deformations. For these calculations we assumed that heat transfer coefficient was 15 000 W/(m^2·K) in all the channels, and 2 W/(m^2·K) from the cavity surface.

For the rated cavity temperature range of 30 – 70 °C, operating frequency shift due to RF cavity elastic deformations was calculated to be –0.6 MHz.

TUNING PLUNGER

To compensate for the operating frequency shift, a movable tuning plunger of a choke-type [9] is used. Figure 4 shows relationship between operating frequency and the plunger position. Shift of the operating frequency due to the thermal deformations is ~0.6 MHz, which corresponds to the plunger position of ~10 mm. Just like the cavity, the plunger requires effective cooling. For this purpose, the plunger design provides for a cooling channel (Fig. 5). Calculations of the thermal deformations were conducted similarly to the RF cavity calculations. Figure 6 shows temperature field of the plunger for the rated value of the RF power dissipated in the RF cavity walls and the plunger position that ensures compensation of the cavity operating frequency shift caused by thermal deformations.

ISBN 978-3-95450-147-2

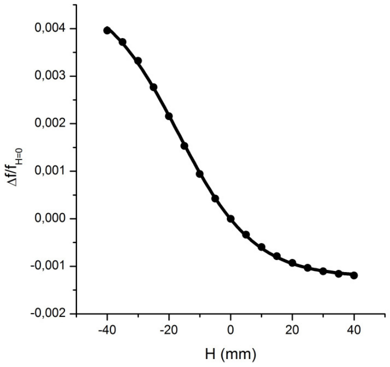

Figure 4: Relationship between operating frequency of the RF cavity and the plunger position.

CONCLUSION

As a result of this work, geometry of the RF cavity of the storage ring in terms of shunt impedance was optimized. We identified the most dangerous HOMs, determined the optimal operating temperature of the cavity, at which these modes would not have significant impact on beam dynamics in the storage ring. The RF coupler was adjusted to ensure coupling coefficient of about 1.5. We evaluated operating frequency shift caused by thermal deformations of the cavity, and proposed design of the plunger with the cooling system to compensate for this shift.

ACKNOWLEDGEMENT

The authors would like to thank Prof. V. Paramonov for useful discussions and his help in using the code [1], and Mr. N. Shvedunov for developing the RF cavity design and drawings.

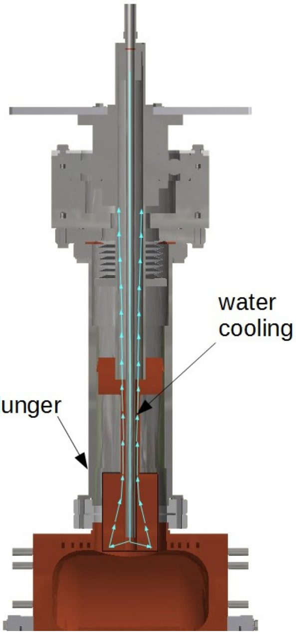

Figure 5: The RF cavity and plunger cooling system.

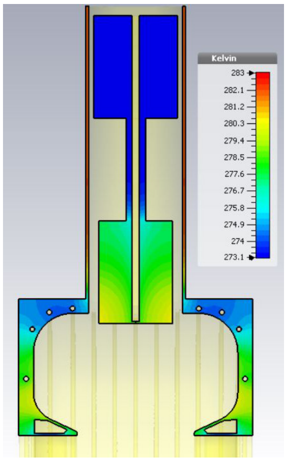

Figure 6: Temperature field of the plunger for the rated value of the RF power dissipated in the walls.

REFERENCES

[1] V. V. Paramonov, “The Data Library for Accelerating Structures Development. RF Parameters of the Drift Tube Accelerating Structure”, in *Proc. XVIII Int. Linac Conf. (Linac96)*, Geneva, Switzerland, August 1996, paper TUP64, Vol. 2, pp. 493–495.

[2] CST, `https://www.cst.com`

[3] ANSYS, `http://www.ansys.com`

[4] F. J. Sacherer, “A Longitudinal Stability Criterion for Bunched Beams”, *IEEE Transactions on Nuclear Science*, vol. 20, issue 3, pp. 825–829, June 1973.

[5] F. Pedersen, “Multibunch instabilities”, CERN/PS 93-36 (RF), Oct. 1993, `https://cds.cern.ch/record/254071`

[6] A. Fabris, C. Pasotti and M. Svandrlik, “Coupled Bunch Instability Calculations for the ANKA Storage Ring”, in *Proc. 6th European Particle Accelerator Conf. (EPAC’98)*, Stockholm, Sweden, Jun 1998, pp. 1011–1013.

[7] A. Fabris, C. Pasotti, P. Pittana and M. Svandrlik, “Coupled Bunch Modes Measurement System at ELETTRA”, in *Proc. 6th European Particle Accelerator Conf. (EPAC’98)*, Stockholm, Sweden, Jun 1998, pp. 990–992.

[8] M. Svandrlik, A. Fabris and C. Pasotti, “Simulations and Measurements of Higher Order Modes on the ELETTRA RF Cavities in view of Coupled Bunch Instability Compensation by Temperature Variation”, in *Proc. 5th European Particle Accelerator Conf. (EPAC’96)*, Barcelona, Spain, Jun 1996, p. 2053.

[9] H. Euteneuer and H. Schöler, “Experiences in Fabricating and Testing the RF-Sections of the Mainz Microtron”, in *Proc. 1986 Linear Accelerator Conf.*, Stanford, California, USA, June 1986, paper TH3-29, pp. 508–511.