ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO059

CHOKE-TYPE RESONATOR FOR A COMPACT STORAGE RING

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Abstract

We present the results of calculations and measurements of the electrodynamic characteristics of the operating and high order modes of a choke-type resonator, intended for a 35–50 MeV storage ring, which is part of the Thomson X-ray generator.

INTRODUCTION

In [1] a variant of a normally conducting choke type RF resonator [2] was proposed (Fig. 1) for a compact storage ring X-ray source [3]. The resonator operates continuously at a frequency of 2856 MHz, has an effective shunt impedance of 3.8 MΩ, and quality factor of 14,000. The nominal voltage at the gap of the resonator is 300 kV while the level of RF power losses in the walls is 24 kW. With the use of the choke structure, the field of the operating mode is effectively isolated from the outer area of the resonator, where the energy of the higher order modes is absorbed.

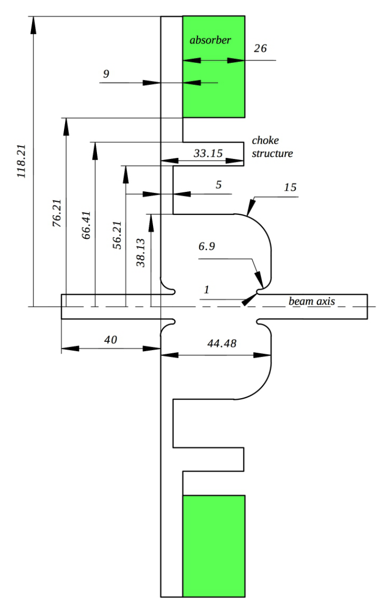

Figure 1: Geometry of the RF resonator.

In this paper we describe the design of a two cavities resonator fed through a 3-dB coupler, which allows to significantly reduce the RF power consumption and get rid of the ferrite isolator in the RF power supply system. The results of calculation of the RF coupler and of cavities thermal conditions with CST [4] and ANSYS [5] codes, as well as the results of measurements of characteristics of higher order modes performed for an aluminum prototype of the RF cavity are presented.

TWO CAVITIES RESONATOR

The presence of sufficient free space in the orbit of our Thomson generator storage ring [3] allows, with the aim of reducing the RF power consumption, to install resonator comprising two RF cavities fed from a single RF source.

The supply of the two cavities from a single RF source can be realized in several ways. For example, a structure comprising two cavities coupled by a magnetic field, which operates at π-mode, or uncoupled cavities fed through a 3-dB coupler [6] can be used. We chose the second solution, since it allows to get rid of the ferrite isolator in high power RF system, and, as it follows from our calculations, requires less RF power to achieve a given effective voltage at the accelerating gap. The design of the two cavities resonator fed through a 3-dB coupler is shown in Fig. 2.

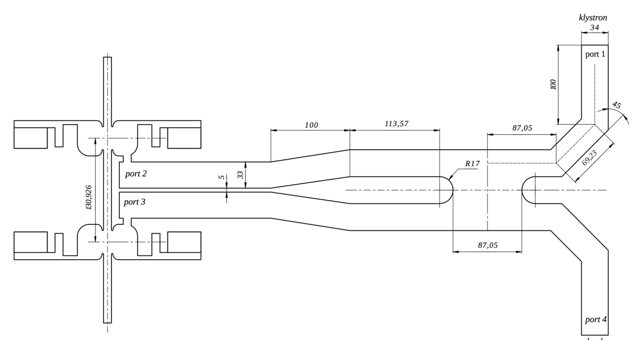

Figure 2: The design of the two cavities resonator fed through a 3-dB coupler.

The two cavities resonator operates as follows. An RF signal from the klystron is fed to port 1 of the 3-dB coupler, this signal is divided equally with the phase difference of 90° between ports 2 and 3, to which the cavities are connected. The signals reflected from the cavities enter port 4 with a phase difference of 180° compensating each other, due to which the klystron is protected from the reflected RF power.

In the chosen design, the RF power is transferred to the cavity via a coupling window cut at the side wall. The cavity coupling window dimensions were tuned to provide coupling factor 1 by adjusting the angle of the window (Fig. 3, parameter a_{sh}); the quality factor of the cavity decreased by 14% due to cutting window, which resulted in a corresponding increase in the RF power consumption. The total RF power consumption for generating effective voltage of

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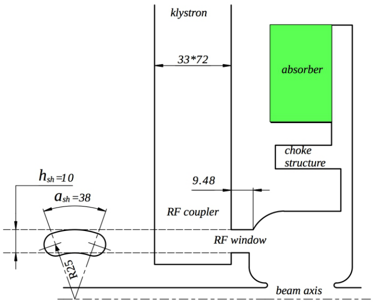


Figure 3: Arrangement of RF energy input.

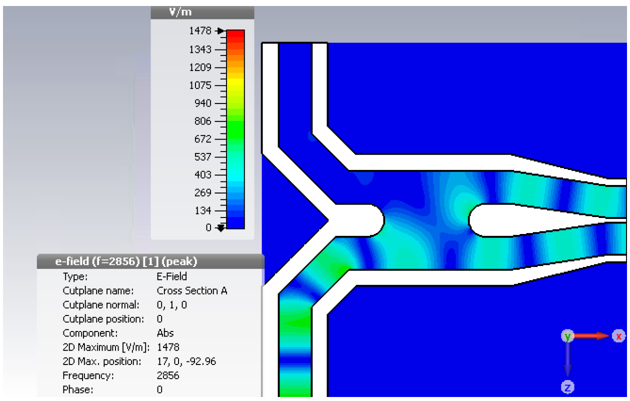


Figure 4: Distribution of the electric field component in the cross section of the 3-dB coupler.

300 kV when using two cavities is 14 kW. The distribution of the electric field in the waveguide for the tuned 3-dB coupler is shown in Fig. 4.

It should be noted that in the alternative case of a resonator comprising two coupled cavities, the decrease in the quality factor due to the coupling slot between the cavities is 21%.

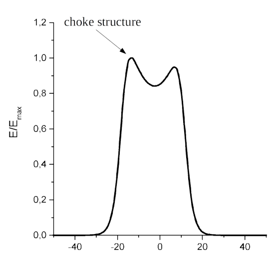
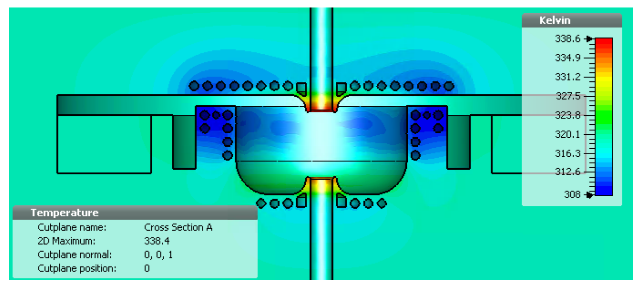


Figure 5: Distribution of the electric field of the operating mode along the axis of the cavity.

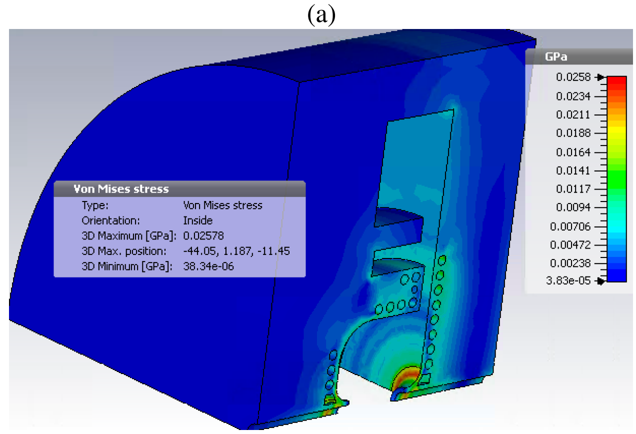
When choosing the optimum distance between the centers of the cavity gaps, which ensures the maximum change in the energy of the relativistic particle for a given RF source power, it is necessary to take into account both the phase shift between ports 2 and 3, and the asymmetry of the distribution of the field of the operating mode along the axis (Fig. 5). Given these two circumstances, the optimal distance between the centers of the gaps is 130.93 mm.

CALCULATION OF THERMAL CONDITIONS

The high average level of RF power losses in the walls, amounting to 7 kW per cavity, leads to the resonance frequency shift due to walls heating and their deformations due to nonuniform temperature distribution. To reduce the frequency shift, optimization of the cooling channels position was carried out (Fig. 6(a)). Maximum temperature gradient and, accordingly, maximum stresses take place near the cavity noses, which requires the channels to be placed as close to them as possible.



(a)



(b)

Figure 6: (a) Temperature distribution in the walls of the RF cavity for the voltage at the gap of 150 kV. (b) Distribution of mechanical stresses.

The temperature distribution in the cavity walls for the optimized channels arrangement and for the heat transfer coefficient of 1.5×10^4 W/m^2/°K calculated using CST code [4] is shown in Fig. 6(a); the distribution of mechanical stresses is shown in Fig. 6(b).

The shift of the frequency of the operating mode at the nominal RF power is about −700 kHz. The maximum stress is 25.8 MPa, which is below the elastic strain limit for copper.

A relatively small decrease in the cavity resonance frequency can be compensated by a decrease in the coolant fluid temperature by approximately 15.5 °C. This makes it possible to dispense with a tuning plunger, stabilizing the frequency of the cavity operating mode frequency by changing the coolant fluid temperature.

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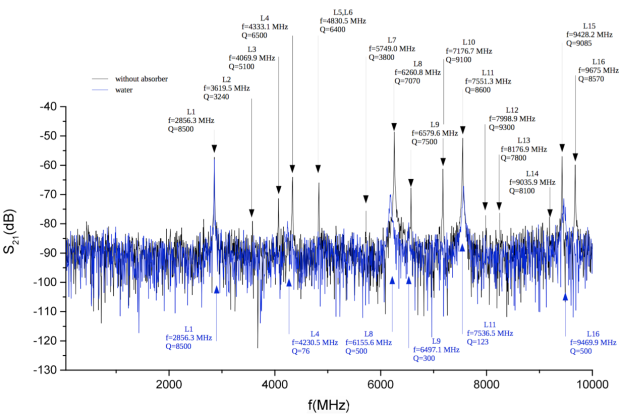
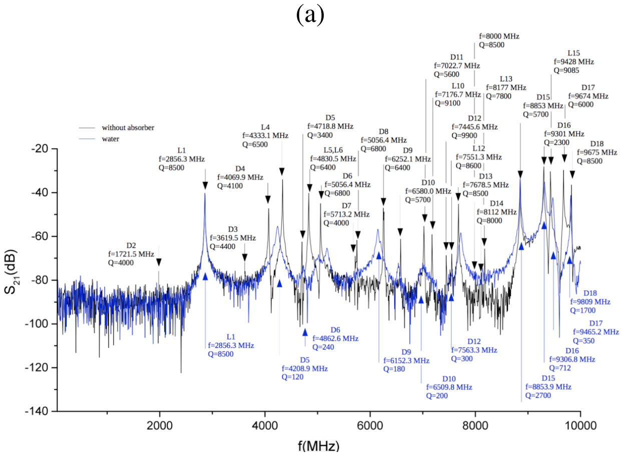
MEASUREMENT OF THE HIGH-ORDER MODES CHARACTERISTICS

To test the operability of the method for lowering the quality factor of high-order modes, we made an aluminum prototype of the RF cavity. Identification of longitudinal modes was carried out based on the measured field distribution on the axis; identification of dipole modes was done by measuring the number of angular field variations. After identification, the electrodynamic characteristics of each mode with and without the absorber were measured. Water was used as an absorber. Figure 7 shows the spectra of (a) longitudinal modes, (b) transverse modes; the black curve reflects measurements without an absorber, the blue curve — with an absorber.



(a)



(b)

Figure 7: Measured spectra of (a) longitudinal modes, (b) dipole modes. Black curve — measurements without an absorber, blue curve — with an absorber.

An important indicator of the operability of the cavity is the influence of the absorber on the characteristics of the operating mode. For the tested aluminum prototype, the calculated values of the frequency and quality factor of the operating mode without an absorber and with water as an absorber are 2856 MHz, 8482 and 2855.9 MHz, 8482. Measured values, respectively, are 2856.3 MHz, 7630 ± 100 and 2856.3 MHz, 8500 ± 100.

Table 1: Change in the Characteristics of Higher Order Modes Due to the Absorber

Type	W/o absorber		With absorber	
	f, MHz	Q_0	f, MHz	Q_0
L_4	4333.1	6500	4230.5	76
L_8	6260.8	7070	6155.6	500
L_9	6679.6	7500	6497.1	300
L_{11}	7551.3	8600	7536.5	123
L_{16}	9675.0	8570	9469.9	500
D_5	4718.8	3400	4208.9	120
D_6	5056.4	6800	4862.6	240
D_9	6252.1	6400	6152.3	180
D_{10}	6580.0	5700	6509.8	200
D_{12}	7445.6	9900	7563.3	300

The measured frequencies and quality factors of a number of higher order modes, which are potentially dangerous in terms of beam dynamics in the storage ring, without an absorber and with an absorber, are summarized in Table 1. As can be seen the ratio of quality factors with the absorber and without absorber for different modes is in the range 0.01–0.1.

CONCLUSION

In this paper we propose the design of a RF resonator for a storage ring, which consists of two cavities fed through a 3-dB coupler, and makes it possible to use a single RF source without a ferrite isolator. The results of optimization of a 3-dB coupler and of RF energy input are presented as well as the results of thermal condition calculations, which showed the possibility of adjusting the operating mode frequency by means of the coolant fluid temperature, which makes it possible not to complicate the design by the presence of a tuning plunger. The results of measurements of characteristics of higher order modes are given. It is shown that the chosen design of the RF cavity provides an effective reduction in the quality factor of the potentially dangerous modes.

ACKNOWLEDGEMENTS

The authors express their gratitude to N.V. Shvedunov for developing the design and issuing the drawings of the prototype.

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