ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPR23

PRELIMINARY DESIGN OF A 500 MHZ NORMAL-CONDUCTING CAVITY FOR MAIN RINGS OF SUPER TAU-CHARM FACILITY*

Y. Wei†, Z. Huang, Z. Cao, L. Sun, Y. Zhang, C. Wang, Y. Xie,
National Synchrotron Radiation Laboratory, University of Science and Technology of China, China

Abstract

A 500 MHz normal-conducting (NC) cavity is being developed for Super Tau-Charm Main Rings which have a current of 2 A and a synchronous radiation energy loss of 410 keV per turn. This NC cavity operates in a higher order mode of TM_{020}. Through optimizations, it results in a high quality factor and a low R/Q. This feature is beneficial to reduce the required detuning frequency so that the coupled bunch instabilities (CBIs) driven by the accelerating mode are greatly suppressed. It employs ferrite absorbers inside coaxial slots located at the node of the TM_{020} mode to heavily damp all of dangerous parasitic modes except from the TM_{020} mode.

INTRODUCTION

The Super Tau-Charm facility (STCF) [1] is an electron-positron collider proposed by the Chinese particle physics community. It is designed to operate in a center-of-mass energy range from 2 to 7 GeV with a peak luminosity of 0.5×10^{35} cm^{-2}s^{-1} or higher. For the electron and positron main rings, the designed current is 2 A and synchrotron radiation energy loss per turn is 410 keV. In order to compensate the energy loss for both rings, a RF system is required to provide an accelerating voltage of 3 MV and a beam power of 820 kW for each main ring.

Table 1: Different RF Schemes for Each Main Ring

Parameters	KEKB SC	ARES NC	PEP-II NC	Bessy-II NC
Number of cavities	3	5	4	10
Each cavity voltage [kV]	1000	600	750	300
Each cavity beam power [kW]	273.3	164	205	82
Characteristic impedance [Ω]	93	15	234	230
Each cavity total power [kW]	273.3	373	285.4	95
Each cavity detuning frequency [kHz]	46	12	155	380

* Work supported by the "Hundred Talents Program" of the Chinese Academy of Sciences and by the Fundamental Research Funds for the Central Universities.
† wylong@ustc.edu.cn

Such a RF system can be superconducting (SC) cavities or normal-conducting (NC) cavities. A SC cavity can sustain an accelerating voltage (≥1.5 MV) much higher than that of a NC cavity (0.3 ~ 0.85 MV). However, it is much easier and cheaper for maintenance on a NC cavity than a SC cavity during operation. Four kinds of RF schemes are assumed for each main ring of STCF including a SC scheme (KEKB [2]) and three NC schemes (PEP-II [3], Bessy-II [4], ARES [5]). All of these RF schemes are heavily-damped cavities by employing HOM absorbers in the beam pipe, in the waveguide or in the coupler [6-7]. After calculations, the ARES NC cavity has a lowest detuning frequency of 12 kHz while the Bessy-II NC cavity has a highest detuning frequency of 380 kHz, as shown in Table 1. The RF system works at a frequency of 499.7 MHz and the harmonic number for main rings is 1360, so the revolutionary frequency is calculated to be 367.4 kHz. When the detuning frequency of RF cavity is close to the revolutionary frequency, longitudinal coupled-bunch instabilities (CBIs) caused by the accelerating mode prevent storing a large beam current. In this case, a feedback system using comb filters is required to suppress these instabilities. The ARES cavity is a three-cavity system [5] developed for KEKB in order to suppress these CBIs due to large detuning of the accelerating mode from the RF frequency for beam-loading compensation. The RF system based on the ARES cavities doesn't require any feedback systems.

The TM_{020}-type RF cavity [8-9] was first proposed as a heavily-damped accelerating cavity for the SPring-8-II upgrade project. Such a cavity has several advantages: it has a very high quality factor and a low R/Q which greatly reduces the CBIs driven by the accelerating mode; it adopts a simple and compact HOM-damping scheme by attaching absorbers into the slots of cavity body. It should be noted that HOMs are all of harmful parasitic modes which cause CBIs in this paper. Taking these advantages into account, a new 500 MHz NC cavity working at a mode of TM_{020} is designed for main rings of STCF in this paper including optimizations on the cavity geometry and HOMs analysis.

RF DESIGN

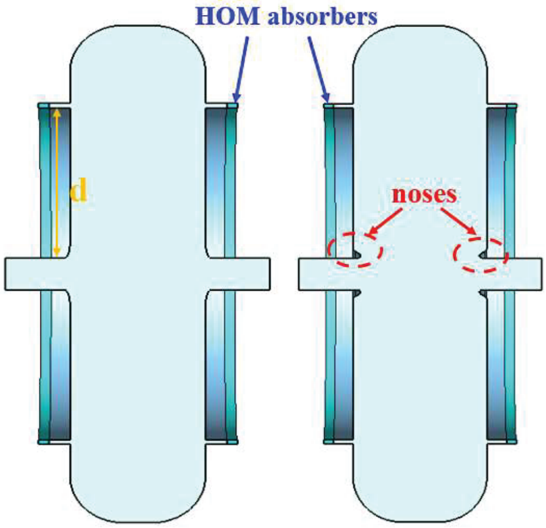
A new 500 MHz NC cavity is designed for main rings of STCF with the aim to provide an accelerating voltage of ≥0.5 MV.

Geometrical Optimizations

The TM_{020}-type RF cavity in SPring-8-II project employs a cavity geometry with noses in order to achieve a high shunt impedance. However, these noses impose a poor $E_{\rm p}/E_{\rm acc} \geq 2.8$ [8-9], which is an issue for achieving a high

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPR23

accelerating voltage in high-power tests. In order to improve E_p/E_{acc}, a geometry without noses is chosen for our new cavity. CST Microwave Studio [10] is used for the modelling which can be seen in Fig. 1.



(a) (b)

Figure 1: Modelling of geometry (a) without noses and (b) with noses for the new NC cavity.

Through the tracking simulations, it was found that a RF cavity with a R/Q < 100 Ω greatly reduces the CBIs driven by the accelerating mode for main rings of STCF. So the optimizations are performed to generate a R/Q < 100 Ω. Two symmetrical slots are used to transport all of HOMs into them and then HOMs are damped by the absorbers inside slots. It should be noted that the HOM slots are located at the nodes of the magnetic field for TM_{020} mode. In this case, the electromagnetic fields are absent from slots. The absorbers inside the slots do not have any effect on the electromagnetic fields of the TM_{020} mode, but only absorbs the other modes which are HOMs in this paper. Through sweeping the radial position of slots, it is found that maximum unloaded quality factor is obtained at a position of $d = 362.5$ mm, as shown in Fig. 2. Figure 3 shows the corresponding electric and magnetic fields for the TM_{020} mode inside the cavity with slots. It can be clearly seen that slots are located in the radial position which has the weakest electric and magnetic fields.

Through optimizations, RF parameters for this new NC cavity are listed in Table 2. It can be found that this new NC cavity generates an $E_p/E_{acc} = 1.92$ which is much better than that of previous TM_{020}-type cavities. This new NC cavity has a low $R/Q = 84.4\ \Omega$, which is beneficial to greatly reduce the CBIs driven by the accelerating mode.

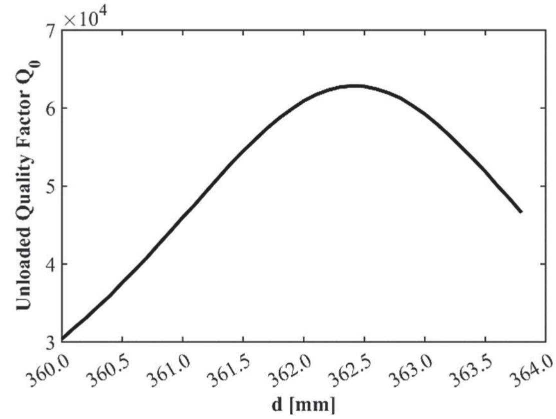
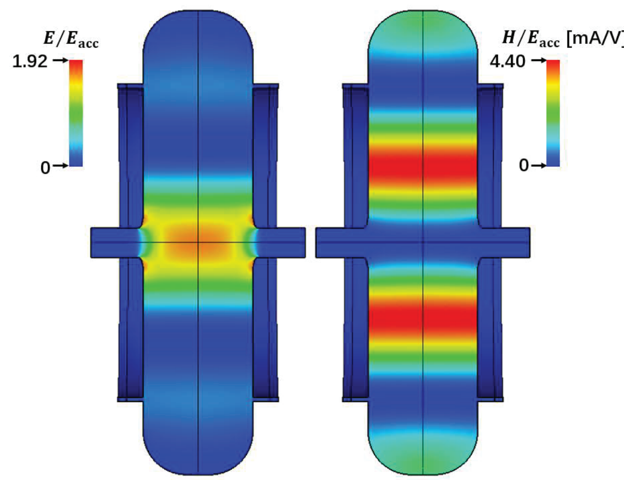


Figure 2: Unloaded quality factor Q_0 as a function of slots radial position d.



(a) (b)

Figure 3: (a) Electric and (b) magnetic fields for the TM_{020} mode.

Table 2: Optimized RF Parameters for New NC Cavity

RF parameters	
Working mode	TM_{020}
frequency f [MHz]	499.7
Unloaded quality factor Q_0	62828
R/Q [Ω]	84.4
E_p/E_{acc}	1.92
	2.64

Considering each cavity provides an accelerating voltage of 0.5 MV, the RF system for each STCF main ring adopts 6 cavities using such a TM_{020}-based cavity to meet the requirement, as shown in Table 3. The corresponding detuning frequency is calculated to be 84 kHz. This means that RF system does not require any feedback doesn't require any feedback systems for the accelerating mode.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPR23

Table 3: New NC Cavities for Each Main Ring

Parameters	TM_{020} NC cavity
Number of cavities	6
Each cavity accelerating voltage [MV]	0.5
Each cavity beam power [kW]	137
Each cavity total power [kW]	184
Each cavity detuning frequency [kHz]	84

HOMs Analysis

After geometrical optimizations, we need to perform simulations in order to see whether all of harmful modes are strongly damped. RF absorbers mainly include magnetical ferrite and electrical silicon carbide (SiC). In our simulations, the ferrite absorbers are fitted into the slots to damp all of harmful parasitic modes except from the accelerating mode of TM_{020}.

By comparing the simulation results with and without ferrite absorbers, the simulated frequencies and unloaded Q_0 for the principal parasitic modes are summarized in Table 4. These simulations are performed by using the Eigenmode Solver of CST Microwave Studio while omitting the input coupler and frequency tuners.

Table 4: RF Properties (Frequency / Unloaded Quality Factor Q_0) of Harmful HOMs for the New NC Cavity

HOMs	Without any absorbers]	With ferrite absorbers]
TM_{010}	217.114 MHz / 34823	218.477 MHz / 18
TM_{110}	345.888 MHz / 49557	346.758 MHz / 64
TM_{210}	464.209 MHz / 58812	464.527 MHz / 251
TE_{111}	611.072 MHz / 43710	615.133 MHz / 67
TM_{120}	630.273 MHz / 68652	631.276 MHz / 237
TM_{011}	637.855 MHz / 32348	648.850 MHz / 24
TE_{011}	677.895 MHz / 62211	677.895 MHz / 62210
TM_{111}	697.953 MHz / 37300	706.044 MHz / 34
TM_{030}	773.740 MHz / 57691	779.391 MHz / 75
TM_{021}	798.816 MHz / 45790	800.320 MHz / 264

It can be found that all of harmful parasitic modes are heavily damped for our new 500 MHz NC cavity except the TE011 mode. However, $R/Q = 9.9 \times 10^{-8}$ is obtained for the TE011 mode, so the shunt impedance is calculated to be 0.006 Ω, which has a negligible effect on the beam instabilities. This means that CBIs due to harmful parasitic modes can be greatly suppressed for main rings of STCF. Wakefield Solver will be used to simulate the impedance for all of harmful parasitic modes in a large frequency range (800 MHz~5 GHz) in the next step.

CONCLUSION

A new 500 MHz NC cavity has been preliminarily designed for the main rings of STCF including geometrical optimizations and HOMs analysis. Through optimizations, a very high quality factor of 62828 and a low $R/Q = 84.4$ Ω has been obtained for this new cavity. By fitting a pair of ferrite absorbers into the slots which are located at the inner wall of cavity body, preliminary simulations show that all of harmful parasitic modes except from the TM_{020} mode are significantly damped. Further studies are undergoing including the input power coupler, frequency tuner and low level RF control system development.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Tianlong He, Dr. Linhao Zhang and Dr. Zeran Zhou for the fruitful discussions. The authors also would like to thank the Hefei Comprehensive National Science Center for their strong support on the STCF key technology research project.

REFERENCES

[1] M. Achasov *et al.*, “STCF Conceptual Design Report: Volume 1 -- Physics & Detector”, arXiv:2303.15790v3, Oct. 2023. doi:10.48550/arXiv.2303.15790

[2] T. Tajima *et al.*, “The superconducting cavity system for KEKB”, in *Proc. PAC’99*, New York, NY, USA, 1999, pp. 440-444. doi:10.1109/PAC.1999.795727

[3] R. A. Rimmer *et al.*, “Comparison of calculated, measured, and beam sampled impedances of a higher-order-mode-damped rf cavity”, *Phys. Rev. ST Accel. Beams*, vol. 3, p. 102001, Oct. 2000. doi: 10.1103/PhysRevSTAB.3.102001

[4] I. Agapov *et al.*, “Status of the PETRA IV project”, in *Proc. IPAC’19*, Melboune, Australia, May 2019, pp. 1404–1407. doi:10.18429/JACoW-IPAC2019-TUPGW011

[5] T. Kageyama *et al.*, “The ARES cavity for the KEK B-Factory”, in *Proc. EPAC'96*, Sitges, Spain, Jun. 1996, paper WEP054L, pp. 2008-2010.

[6] M. Nishiwaki *et al.*, “Developments of HOM dampers for SuperKEKB superconducting cavity”, in *Proc. SRF’13*, Paris, France, Sep. 2013, paper THP061, pp. 1058-1060.

[7] V. Serriere *et al.*, “352.2 MHz HOM damped normal conducting ESRF cavity: design and fabrication”, in *Proc. IPAC’11*, San Sebastian, Spain, Sep. 2011, paper MOPC004, pp. 68-70.

[8] H. Ego *et al.*, “Design of a HOM-damped RF cavity for the SPring-8-II storage ring”, in *Proc. the 11th Annual Meeting of Particle Accelerator Society of Japan*, pp. 237-241, 2014. http://www.pasj.jp/dai11kainenkai/

[9] T. Inagaki *et al.*, “High-power tests of the compactly HOM-damped TM020 cavities for a next generation light source”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 2635–2638. doi:10.18429/JACoW-IPAC2023-WEODC3

[10] CST Microwave Studio®, Ver. 2020, CST AG, Germany.