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THE FEASIBILITY STUDY ON BEPC-II RF SYSTEM

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Abstract

In up-coming BEPC luminosity upgrade plan, a new storage ring will be added to original BEPC tunnel, which is called as BEPCII double rings scheme. This paper described the preliminary design considerations of BEPCII RF system, in which the single cell super-conducting (SC) damped cavity will be chosen as the accelerating cavity in BEPCII.

1 INTRODUCTION

Beijing electron positron collider (BEPC) was constructed and operated successfully since 1989. The earlier RF system in BEPC consists of two 200MHz normal-conducting (NC) cavities providing total RF voltage of 1 MV. The RF power was supplied to two RF cavities by eight sets of tetrode transmitter of 25KW with coaxial wave-guide. Namely, combined four sets of transmitters power one cavity, respectively. For upgrade luminosity, the mini-β scheme on BEPC was performed in 1992-1995, in which RF system added two the retired cavities from CERN SPS ring to provide present total RF voltage of 2MV. The RF power stations for added two SPS cavities were reconstructed as combined two sets of transmitter power one cavity.

In up-coming further BEPC luminosity upgrade program, a new storage ring will be added to original BEPC tunnel, which is called as BEPCII double rings scheme. The present NC RF system will be replaced by new 500MHz SC RF system. The expected luminosity in BEPCII will reach 1 $\times 10^{33}$ /cm^{2}sec.

2 REQUIREMENTS AND PARAMETERS

The RF system design is mainly considered around the following requirements:

- Providing sufficient high RF voltage for a short bunch length and a longer beam lifetime;
- Providing sufficient high RF power compensate for synchrotron radiation power loss of the beam;
- Suppressing the instabilities related to RF system.;
- RF system stability and reliability.

The main parameters related to RF system in BEPCII are shown in Table1.

2.1 RF Voltage

The required RF voltage is given by

$$V_c \sin\phi_s = \frac{cC\,\alpha_p E\,\sigma_\varepsilon^2}{e\,\omega_{rf}\,\sigma_s^2} \qquad (2.1)$$

Where, V_c is the RF voltage, ϕ_s the synchrotron phase, ω_{rf} the RF fundamental frequency, c the velocity of light, C the circumference, α_p the momentum compaction, E the beam energy, σ_ε the relative energy spread, and σ_s the rms bunch length.

In general, a short bunch length requires a high RF voltage and high RF frequency. The RF frequency of 500MHz and voltage of 1.5MV per ring are chosen in order to obtain the bunch length around 1.5cm in BEPCII first stage, the second stage will increase the RF voltage to 3MV per ring.

2.2 RF Power

Because of the wiggler magnet hasn't been adopted in BEPCII. Therefore, the beam power is given by

$$P_b = P_{SR} + P_{HOM} \qquad (2.2)$$

Where, P_b is the beam power, P_{SR} the synchrotron radiation power loss of the beam, P_{HOM} the additional power loss is caused by wake fields due to the beam excited HOMs in the components of storage ring .

In BEPCII impedance evaluation, the total loss factor in one ring is about 3.1V/PC, which respond to power loss of 22.8kW at single bunch current of 10mA. Therefore the required beam power at 1.89GeV is about 137.8kW in BEPCII.

Table 1: Main parameters related to RF system

Beam Energy	GeV	1.55	1.89
Beam Current	MA	1116	930
RF Frequency	MHz	499.8	
RF Voltage	MV	1.5	
Revolution Frequency	MHz	1.262	
SR Energy Loss/Turn	KeV	55.8	123.4
SR Power Loss	KW	62.3	114.8
Bunch Number		93	
Single Bunch Current	mA	12	10
Bunch Length	cm	1.5	
Momentum Compaction		0.033	
Luminosity	cm^{-2}sec^{-1}	1.0E33	

2.3 Suppressing the Instabilities Related to RF System

To control broad band impedance and narrow band HOMs impedance are of overwhelming importance in the

RF system of the BEPCII. These key issues are mainly considered as follows:

(1) To directly reduce R/Q

To directly reduce R/Q can be realised essentially by optimum cavity shape design with a large aperture on both ends of the cavity cell. But, due to the large iris-opening shape, R/Q of the accelerating mode will be unavoidably decreased. For superconducting cavities, this is an affordable solution for its extremely large unloaded Q, but this is not the case for normal conducting cavities.

(2) To minimise the number of cavities

To keep the number of cavities small and adopt single-cell cavities to avoid some possible modes due to coupling between cells. This goes along with an increase of accelerating gradient and input power, which determine the minimum number of cavities.

(3) Deeply damping HOMs

Q_{ext} of HOM should be sufficiently damped typically below 100. In addition, the damping systems must be capable of dissipating HOM power on the order of kWs.

2.4 RF System Stability and Relibility

RF system is required for a long-term stable operation in BEPCII. Thus, the mature technology with successful operation experience in other machines should be adopted.

3 THE CHOICE OF RF CAVITY

The high beam current brings some of challenges to BEPCII RF system, due to the excited HOMs, which will interact with the successive bunches and make adverse effect on the beam. Thus, the choice of RF cavity is mainly considered to enable to deeply suppress the HOMs and reduce the number of cavities for reducing the coupling impedance.

3.1 The Comparison between SC Cavity an NC Cavity

For deeply damping HOMs arising from high beam current, both SC damped cavity and NC damped cavity are developed in several large laboratories in the world, such as ARES, PEP-II NC damped cavities and CESRIII, KEKB SC damped cavities, respectively. As compared with NC cavity, SC cavity has the following advantages:

(1) A larger accelerating voltage gradient (~10MV/m) can be provided, which is 3-5 times higher than NC cavity. Thus, for the given total voltage the number of cavities can be largely reduced, which results in lower machine impedance. The comparison between NC cavity and SC cavity for BEPCII are shown in Table 2.

Table 2: The comparison of NC cavity and SC cavity

Freq. MHz	Type	Voltage Per Cavity MV	Required Voltage MV	Number of cavity
500	NC	0.5	3	6
500	SC	1.5	3	2

(2) Because of the high Q, the SC-cavity can be shaped into a very smooth structure with a large beam port, which is unallowable for NC-cavity, thereby reducing the parasitic impedance of HOMs and improving the stability of high intensity bunch.

(3) In addition, the large beam tube on both ends of a SC cavity is specially designed to enable the transmission all of HOMs, and the HOMs power leaking out into the pipe will be absorbed by ferrite, the ferrite is bonded outside the cryostat at the room temperature beam pipe. Consequently, one obtains a nearly single mode cavity and gets rid of the HOM couplers at the cavity.

(4) Sharply reducing the AC power requirements because of very low RF cavity wall loss. This is particularly true for BEPCII where the high RF voltage is required.

Based on the above comparisons, the single-cell SC cavity is chosen as the accelerating cavities in BEPCII. Namely, using one single-cell SC cavities per ring to provide the RF voltage of 1.5MV for compressing the bunch length to about 1.5cm.

3.2 The choice of SC Cavity Shape

There are two single mode SC cavity-styles that have been successfully manufactured, tested and operated. They are the CESRIII SC cavity and the KEKB SC cavity (see Figure 1). As comparison, the main parameters of two cavities are listed in Table 3.

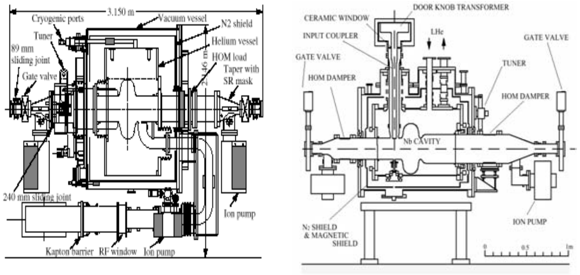

Figure 1: Two Shapes of Single-Cell SC Cavity

Table 3: Parameters of KEKB and CESRIII SC Cavity

SC cavity type		KEKB	CESRIII
Frequency	MHz	508.887	499.765
R/Q	Ω	93	89
Unloaded Q		1×10^9	1×10^9
Loaded Q		$6\text{-}8\times10^4$	2×10^5
Max. Voltage/ Cavity	MV	3	3
Opera. Voltage/Cavity	MV	1.5	1.8
Total Loss Factor at 1.5cm bunch length	V/PC	0.52	0.45
Input power coupler		400kW Coaxial	300kW Waveguide
HOM load (ferrite) Off line test		SBP5kW LBP7kW	7kW/load
Operating temperature	K	4.5	4.5

The parameters of the above two cavities show that either of them satisfies the requirement of BEPCII. We would choose one of those two type cavities with modified frequency required by BEPCII.

4 RF HIGH POWER SOURCE

For the optimized energy region of 1.89GeV operation, the maximum beam power of 137.8kW will be required to compensate the synchrotron radiation loss and HOMs loss in BEPCII. Considering the power reflection and the transmission loss, the RF power source of 180kW will be chosen, which is commercially available by Thomson and Toshiba electric company. Thus, two klystrons of 180kW will be employed to feed two SC cavities, respectively. Each klystron will equip with a circulator of 180kW CW power capability for matching the power source system.

As high power feed lines, the WR-1800 standard waveguide will be used.

5 LOW-LEVEL CONTROL SYSTEM

Low-level control system consists of signal generator, interlock protection and several control feedback loops (cavity voltage, phase, tuning loop, etc.)

The above feedback loops are usual controls for the stable magnitude and phase of the accelerating field. Besides, the direct RF feedback loop is required to increase Robinson current limit for reaching the required total stored beam current in BEPCII. The coupled bunch instabilities due to accelerating mode seem to be not a severe problem, because of a large revolution frequency of BEPCII ring, which is much larger than the detuning frequency caused by the beam loading.

In addition, the interlock protection system is very important for protecting the device and personnel safety when some of dangerous troubles suddenly appear. The main items which need to be monitored and protected include the LHe level, the He pressure, the cavity voltage, the input power, the reflecting power, the VSWR, the temperature, the vacuum pressure, the cooling water flow, the multipactor effect, and etc.

6 CRYOGENIC SYSTEM

Two SC cavities are required for delivering the RF voltage of 1.5MV per cavity to the beam. Thus, the cryogenic system is necessary for two SC cavities operation. For the choice of the refrigeration capability, the heat load of cryogenic system is estimated preliminarily as follows:

(1) Static heat loss of the cryostat

The static heat loss of the cryostat is caused mainly from the beampipe thermal transition on both ends of the cavity cell, the coupler thermal transition, the radiation from LN2 shield to LHe vessel. The total static heat loss of a cryostat is estimated as about 30W per cavity.

(2) Dynamic heat loss due to RF loss

Because of the existence of the surface resistor, SC cavity will dissipate a little microwave power, which is an important source of heat load. Taking CESRIII cavity parameters with unload Q of 5×10^8, the RF loss is estimated as 51W at 1.5MV per cavity.

(3) The waveguide cooling

In CESR SC cavity module design utilizing the LHe boil-off gas cools the waveguide, and this will cause the consumption of 28W cooling power with the flow of 268mg/s.

(4) Single channel transfer line is estimated with the power loss density of 1.5W/m.

(5) Multi-channel transfer line is estimated with the power loss density of 0.5W/m.

Except the above estimated heat loads, an important source of heat loading should be regarded, which is the radiation impinging from beamline apertures and wave-guide ducts, the radiation source will be considered by setting the margin factor of refrigeration capability. The estimated heat loads of cryogenic system are summarised in Table 4.

Table 4: The estimated heat loads for two SC cavities

Static heat load	30W×2
Single channel line 10m	15W×2
Multi channel line 50m	25W
Dynamic loss(RF loss)	51W×2
Waveguide cooling	28W×2
Total heat load	273W

It can be seen from Table 3, that the refrigeration capability of 300W is required for two SC cavities at the RF voltage of 1.5MV/cavity. Considering a sufficient margin, the refrigerator of 450W will be chosen in BEPCII.

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