PRELIMINARY STUDY OF THE BEPCII IMPEDANCE*

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Abstract

This paper summarizes the preliminary results on the impedance study of BEPCII, which is the upgrade of Beijing Electron Positron Collider (BEPC). Focus is on the longitudinal broadband impedance, which may lead to bunch lengthening and microwave instability. With the impedance of its main generating vacuum components being investigated, a primary impedance budget is obtained. The estimated impedance is below the impedance threshold of microwave instability.

1 INTRODUCTION

An upgrade project of BEPC to achieve the luminosity of $1\times10^{33}cm^{-2}s^{-1}$ at J/ψ energy range, namely BEPCII [1], is being studied in IHEP by adopting a 2 ring scheme with positron and electron circulating in each separate storage ring while colliding at the common interaction point. The two rings are accommodated in the existing BEPC tunnel. The main parameters of BEPCII are listed in Table 1, in comparison with the BEPC parameters at 1.55GeV.

Table1: The main parameters of BEPCII and BEPCI

Parameters	BEPCII	BEPC
Circumference (m)	237.5	240.4
β_x^*/β_y^* (cm)	100/1.5	120/5.0
Bunch number	93	2×1
Bunch current (mA)	12	22
Impedance $(Z/n)_0$	<0.7	~4.0
Mom. compaction α_p	0.033	0.042
Crossing-angle (mrad)	2×11.0	0
Energy spread σ_{e0} (10^{-4})	4.23	4.37
Bunch length σ_{l0}/σ_l (cm)	1.1/~1.5	3.2/~5.0
Luminosity ($10^{31}cm^{-2}s^{-1}$)	100	0.5

To achieve the high luminosity, micro-β scheme is adopted, i.e. β_y^*=1.5cm. This requires the bunch length be well controlled to around 1.5cm. It is well known that bunch lengthens due to Potential Well Distortion (PWD) and microwave instability. The threshold of microwave instability is calculated with the formula

$$I_{th}=\frac{\sqrt{2\pi}\alpha_p\frac{E}{e}\sigma_{e0}{}^2\sigma_{l0}}{R\,|\frac{Z}{n}|_{eff}}$$

where α_p is the momentum compaction factor, E the energy of the beam, σ_{e0} and σ_{l0} the natural rms energy spread and bunch length respectively, R the average radius of the ring, $|Z/n|_{eff}$ the longitudinal effective coupling impedance. It predicts for the design current of 12mA an instability threshold of $|Z/n|_{eff}$ =0.69Ω at the bunch length of 1.5cm.

Below the threshold of microwave instability, bunch lengthens due to PWD. The bunch length σ_l with PWD can be obtained by solving the following equation,

$$\left(\frac{\sigma_l}{\sigma_{l0}}\right)^3-\left(\frac{\sigma_l}{\sigma_{l0}}\right)+I_b\frac{e\alpha_p}{4\pi E\nu_{s0}{}^2}\left(\frac{R}{\sigma_{l0}}\right)^3\frac{Z}{n}\bigg|_0=0$$

where ν_{s0} is the synchrotron tune， $|Z/n|_0$ the inductive impedance at low frequency. So if $|Z/n|_0$ <0.7Ω, the bunch lengthening is within 10%.

Calculation and beam measurement show that $|Z/n|_0$ of the present BEPC storage ring is about 4Ω [2], so the vacuum chamber of BEPC should be rebuilt conscientiously in order to reduce $|Z/n|_0$ to less than 0.7Ω. In addition to reduce impedance, serious efforts have to be made to eliminate those structures that can trap HOMs, which may lead to an enormous heat deposition due to the short bunch.

As the preliminary study of BEPCII impedance, we calculate the impedance of axis symmetrical structures analytically or numerically with ABCI [3] code, and some estimated impedance is directly obtained by scaling from KEKB [4] and PEPII [5]. Calculating the impedance of non-axial symmetry structures using MAFIA [6] is also being done. As comparison, some typical structure in the present BEPC chamber with significant contribution to the impedance is also studied to demonstrate the necessity of renovation. Then a primary impedance budget is given.

2 IMPEDANCE OF COMPONENTS

The main impedance generating elements in the BEPCII storage ring are RF cavities, BPMs, bellows, masks, ports of vacuum pumps, feedback kickers, tapers, Y-shapes etc. The difference of the two rings is only in a few aspects, while the positron ring will adopt ante-chamber to minimize the photo-electron yielding. The impedance of typical elements is studied either numerically or analytically as follows

2.1 RF Cavities

RF cavities are important sources of impedance. Superconducting Cavities (SC) is chosen to provide the high RF voltage needed for compressing bunch length meanwhile to reduce the number of cavities so that the impedance can be minimized. Either KEKB style or

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CESR [7] style cavity is feasible. The beam hole of the SC can be fairly large, so the high order modes (HOM) can propagate along the beam pipe. Absorber made of ferrite is installed in the section of beam pipe so that the quality factor of HOMs can be damped to less than 100 to ease the coupled bunch instability. Taking the KEKB style cavity as an example to estimate the impedance, we use ABCI to calculate the loss factor k_l. At σ_l=1.5cm, k_l=0.40V/pC. The HOM power can be calculated as

$$P_{HOM} = k_l I_b^{\,2} n_b / f_{rev}$$

where I_b is the bunch current, n_b the bunch number, f_{rev} the revolution frequency. So P_{HOM}=5.6kW, which should be absorbed by the ferrite HOM loads. The loss factor due to the ferrite HOM load can be scaled from KEKB result [3], k_l=0.12V/pC. The total loss factor of one SC is thus 0.52V/pC, corresponding to P_{HOM} =5.5 kW.

2.2 Resistive wall

The impedance from resistive wall (RW) can be calculated analytically [5]. In BEPC, the aluminium beam pipe occupies about 70% in total length of the ring, whose cross section is of racetrack shape with horizontal and vertical diameter of 120mm and 58mm, respectively. The other 30% of the vacuum chamber is made of stainless steel with circular shape whose radius is of 55mm. So the longitudinal impedance is

$$Z_l = 0.66 \times 10^{-3}(1-i)\sqrt{\omega}$$

The loss factor is calculated for a Gaussian bunch by assuming a cylindrical beam pipe, k_l =0.18V/pC.

The transverse RW impedance for a circular pipe is got from the Panofsky-Wenzel theorem. For racetrack shape, it can be estimated from the impedance of two parallel planes, so

$$Z_{\perp x} = 0.53\times 10^{8}(1-i)/\sqrt{\omega},\ Z_{\perp y} = 1.1\times 10^{8}(1-i)/\sqrt{\omega}.$$

RW impedance causes transverse coupled bunch instability that should be overcome by feedback system[8].

2.3 BPMs

The total inductance of the 36 BPMs on BEPC is about 5.12nH. This is not small. In BEPCII case, the number of BPM may increase about 1 times. Due to short bunch length, attention should be paid not only to sensitivity but also to heating and power output to the cables. We may consider to adopt the design similar to KEKB and PEPII's. In this case, the inductance and loss factor of 72 BPMs can be estimated as L=2.6nH, k_l=0.15V/pC, respectively. The radius of the button and the cut width should be optimised to avoid the HOM modes trapped.

2.4 Bellows

There are 67 bellows in BEPC. Assuming the number is the same in BEPCII, we use the ABCI code to calculate the impedance and the loss factor of the present bellows in the case of 1cm long bunch, finding that both the inductance and loss factor are quite large. So the sliding finger structure design should be adopted. Since the pipe in the arc is elliptical, the impedance and loss factor are calculated using ABCI with equivalent radius. The total inductance and loss factor for 67 bellows are: L=0.46nH, k_l=0.0157V/pC.

As R&D, a 1:1 prototype of shielded bellows may be made and then tested on BEPC storage ring.

2.5 Masks

Each bellows in the arc has one mask located on its upstream so that it can be shielded from the synchrotron radiation by the beams from the nearby bending magnet. Additional masks are needed for protecting injection kicker, SC, IR etc. About 70 masks are needed in total. The impedance and loss factor can be estimated using ABCI results times the ratio of the opening angle of the mask regarding to the beam axis. For 70 masks, the impedance is L=6.3nH, k_l=0.14V/pC. This result is being checked with 3D calculation. The impedance depends on the height and open angle of mask, which are being optimised. The cooling of the mask is being studied too.

2.6 Pumping ports

On present BEPC there are 40 Distributed Ion Pumps (DIP) which are located in each dipole magnets of the storage ring, and about 48 Lumped vacuum Pumps (LP). The ports of them are screened with a grid of small holes. For the DIP, the hole is of elliptic shape with the major and minor axis of 27mm and 7mm respectively. The impedance of one hole can be estimated analytically. There are 3480 holes on the screens of DIPs in total, so the inductance due to them is 2.3nH. The total inductance due to LP ports is 9.3nH. To reduce the impedance, the DIP screen should be changed to be narrow longitudinal grooves as PEPII. With the 3mm width slot assumed, the total inductance can be reduced to about 0.1nH. LP screens will adopt the similar design.

2.7 Tapers

At least 4 tapers are needed to connect between circular vacuum chamber and the racetrack one. The 2D modelling of the taper with 15° tapering connection between two circular beam pipes with radii of 2.9cm and 5 cm respectively gives a conservative estimate of k_l=0.018V/pC, and L=0.3nH.

2.8 Injection port and kicker ceramic

Besides the transition between the vacuum chamber in the LSM and the kicker should be made as smooth as possible, kicker will be changed to the style with ceramic chambers to reduce the impedance. Here, the estimation of impedance is based on the PEPII configuration. For BEPCII, there are two kickers in each ring consisting of 2 0.75m-long ceramic sections. The average pipe radius can be estimated as b=4.2cm. With the surface resistivity of the coating material chosen as 0.6Ω/sq, the loss factor of one ceramic section is k_l=0.0144V/pC, and inductance $L=2\times10^{-4}$nH. The total inductance and loss factor due to kickers are $L=0.8\times10^{-3}$ nH, k_l=0.06V/pC.

2.9 Antechamber

To reduce the photo-electron cloud effect, antechamber is chosen for positron storage ring. Study shows that the broad-band impedance is generated mostly by the discontinuity of the antechamber at the ends and mainly inductive. This has been confirmed by MAFIA calculation by varying length of the slot. The slot with height of 1.5cm contributes impedance of $L=2.4\times10^{-4}$nH, $k_l=1.3\times10^{-5}$V/pC, which is negligible.

2.10 Y-Shape

Electron and positron rings are combined into one a single beam chamber on both sides of the IP, so there are two Y-shape. On the north site the two rings are crossed, which can be considered as an X-cross. The wake potential of the 1.5cm bunch appears most resistive, with k_l=0.085V/pC and parasitic loss of ~900W. Absorption of this power should be studied. The inductance is small.

2.11 Interaction region

Since the loss factor and impedance of the present BEPC IR is too large, modification should be made to make the k_l as small as possible. A feasible estimation of impedance can refer to the BTCF[9], then L=3.8nH, k_l=0.047V/pC. On both sides of the IP, there are masks to protect the detector. Besides the masks may introduce impedance, which is quite small, more concern should be paid on the modes that may be trapped between them.

2.12 Collimators

To reduce the background of the detector， two collimators corresponding to two straight sections around IP are needed. A simple model of a collimator as a pair of tapers with a height of 4.5cm and a taper angle of 10° gives k_l=0.02V/pC. The wake potential appears inductive and corresponds to L=1.27nH per collimator.

2.13 Feedback kickers

Transverse and longitudinal feedback systems are needed in BEPCII to cure the coupled bunch instabilities. Feedback kickers will introduce impedance. We may refer to either ALS [5] or DAΦNE [10] design. The longitudinal ALS kicker has inductance of about 20nH, but the cavity style adopted in DAΦNE has much smaller inductance. So the latter is preferred.

2.14 SR crotch

BEPC also serves as synchrotron radiation (SR) source. There are 4 beam lines around the storage ring. If the slot on the beam pipe for SR extraction is narrow and long, the wakefield is inductive and small. The impedance due to the SR crotch will be studied with MAFIA code later.

2.15 Impedance budget of BEPCII storage ring

Table 2: Impedance and loss factor of each component

Component	No.	L (nH)	k_l (V/pC)	HOM (kW)
SRF	1	1	0.52	5.5
Resist. Wall			0.18	1.9
BPMs	72	2.6	0.15	1.6
Bellows	67	0.46	0.01	0.1
Mask	70	4.9	0.14	1.4
Pump. ports		0.2		
Taper	4	1.2	0.05	0.5
Injection port	1	0.17	0.005	0.05
Inj. kicker	2	0.001	0.06	0.6
X-cross	1	1.12	0.025	0.26
Y-shape	2	2.24	0.17	1.77
IR	1	3.8	0.03	0.3
Collimator	2	2.54	0.03	0.3
Total		20.2	1.37	14.1

Note: the impedance of longitudinal feedback kicker is not included. If it is of ALS style, the total inductance will be 1 times higher.

3 CONCLUSION AND DISCUSSION

According to the above impedance budget, the total inductance is about 20nH, corresponding to $(Z/n)_0$~0.2Ω. Therefore, if the BEPCII vacuum chamber is rebuilt by adopting the state of art technology, it is possible to control the impedance under the threshold impedance of longitudinal microwave instability. However, since the engineering design has not yet started out and the number of items as well as the structure of components has not yet been fixed, so Table 2 does not list the full impedance budget of the storage ring and the actual impedance may be higher than 0.2Ω. On the other hand, sufficient margin between the impedance budget and the threshold of microwave instability is always needed [11]. So the impedance of each component has to be strictly controlled. Further study to get the wake function of the storage ring to simulate bunch lengthening is under way.

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