DESIGN OF LONGITUDINAL FEEDBACK KICKER FOR HLS STORAGE RING

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Abstract
Hefei Light Source (HLS) is a dedicated synchrotron radiation research facility. It is now undergoing a major upgrade. To obtain a better performance of the light source, a longitudinal feedback system needs to be developed as part of the upgrade project to suppress the coupled bunch mode instabilities. In this work, we present a design of the LFB kicker, a waveguide overloaded cavity with two input and two output ports. The cavity design specifications include a central frequency of 969 MHz ($4.25 \cdot f_{RF}$), a bandwidth of more than 100 MHz, and a high shunt impedance of 1200 Ω. A study is carried out to find the dependence of the cavity performance on a few critical geometric parameters of the cavity. Since the cross-section of the vacuum chamber of the HLS storage ring is an octagon, a transition from a circular beam pipe to an octagonal one is built into the end pieces of the cavity to minimize the total cavity length. To lower the required amplifier power, the structure is optimized to obtain a high shunt impedance. The higher order modes of the kicker cavity are also considered during the design.

INTRODUCTION

Hefei Light source (HLS) is now undergoing an upgrade project which is called HLS II. As part of the project, a longitudinal feedback system (LFB) is being built. As the key component of the LFB system, a kicker cavity will be installed into the storage ring during the construction. The performance of the kicker cavity depends on parameters of the storage ring; some of the parameters are shown in Table 1 [1].

Table 1: Main Parameters of HLS II Storage Ring.

Parameter	Value
Operation energy (MeV)	800
RF frequency (MHz)	204
Harmonic number	45
Synchrotron frequency (kHz)	30.7
Bunch length σ_τ (ps)	150

According to the coupled bunch mode instabilities (CBMIs) theory, a complete set of frequencies of all coupled-bunch modes are located within $p \cdot f_{RF}$ and $(p+1/2) \cdot f_{RF}$, where p is any integer and f_{RF} is the RF frequency of the storage ring. So we can set the central frequency of the kicker cavity at $(p+1/4) \cdot f_{RF}$. The required minimum bandwidth of the cavity should be $\frac{1}{2} f_{RF}$. For the Hefei light source storage ring, the RF frequency is 204 MHz. To determine the central frequency of the kicker, we only need to choose p. For practical reasons, they choose 969 MHz as the central frequency which is $4.25 \cdot f_{RF}$ i.e. $p = 4$. The bandwidth of the kicker should be 102 MHz ($\frac{1}{2} f_{RF}$) or wider.

HLS is a second generation light source which has only 8 short straight sections. To reserve space for insertion devices (IDs) and other equipment, the LFB kicker will be installed in the injection section of the storage ring. The total length of the available space is 800 mm. The transverse radius for the cavity should be smaller than 160 mm otherwise it will hit the transport line. The estimated dimensions for the whole kicker cavity are shown in Fig. 1. Scaling the space occupied by the Duke LFB kicker [2] which has the similar performance, the space is sufficient for the HLS kicker.

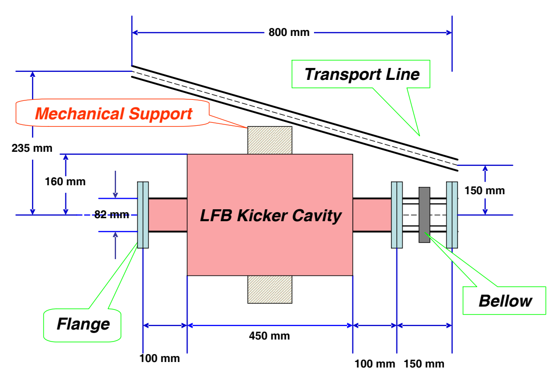

Figure 1: Estimated dimensions of the HLS kicker.

An octagonal vacuum chamber is adopted for the HLS II storage ring. The dimension of the vacuum chamber can be found in Fig. 3 (a). The electron beam enters and exits the kicker via a beam pipe. Because the vacuum chamber is not a circular one, we have two choices for the kicker beam pipe. One is to keep the cross-section of the beam pipe the same as the vacuum chamber, like Swiss

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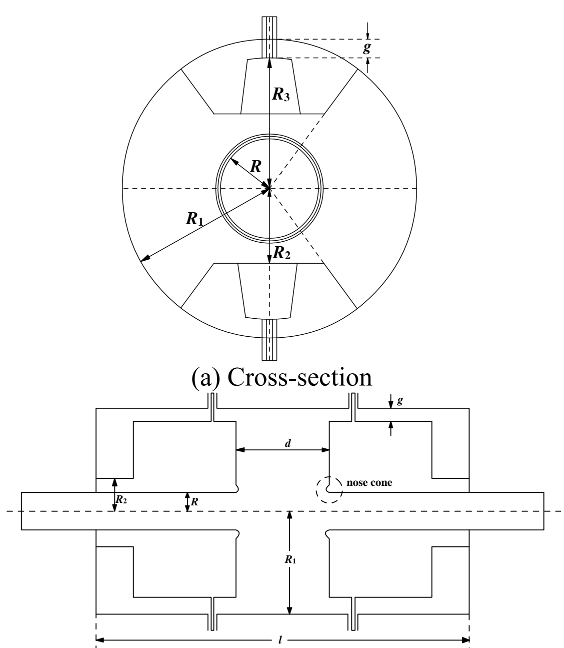
Light Source (SLS) [3]. This kind of design is simple and direct in mechanical design but somewhat more difficult to machine. More importantly the kicker cavity has to be designed and optimized using whole cavity model instead of a quarter cavity model with a round beam pipe, significantly increasing the computing time for the design process. The other choice is to design and optimize the kicker cavity with round beam pipes, and then build in a tapered section to transit from the round beam pipe to the octagonal vacuum chamber. We decide to use the second method. The design is divided into two steps. First, we design a kicker cavity with round beam pipes to satisfy the design requirements. Then a transition part is built into the kicker, followed by minor tuning of the cavity design to bring back its performance to specifications.

PRELIMINARY DESIGN

The Duke LFB kicker cavity model is used as the starting point for the HLS kicker [2]. Fig. 2 shows the schematic of the kicker which is a waveguide overloaded pillbox cavity with two input and two output ports and two round beam pipes. The cavity works at its fundamental mode TM_{010}. The radius of the beam pipe R is set at 38 mm, which is half the width of the octagonal vacuum chamber. Its lowest cutoff frequency of TM mode is 3.02 GHz. R_1 is the radius of the pillbox cavity. For an ideal pillbox cavity, the radius should be 118.5 mm to produce a fundamental resonant frequency 969 MHz. The back cavity height R_2 and the waveguide gap g are the two main geometric parameters of the waveguide, which determine the coupling between the ports and the pillbox. d is the pillbox gap. For the TM_{010} mode, the resonant frequency of an ideal pillbox does not



(a) Cross-section

(b) Profile

Figure 2:The LFB kicker cavity with round beam pipe.

depend on this length. But a small gap may result in a low shunt impedance. Due to the space limitation for the LFB kicker, the pillbox gap is fixed at 94 mm. Nose cones are optimized in order to get a higher shunt impedance [4]. During the design, HFSS is used as the simulation code.

To optimize the LFB kicker, we need to know the dependency between the geometric parameters and the performance of the cavity. Three geometric parameters are selected to calculate the dependency, which are R_1, R_2 and g. After calculating several sets of (R_1, R_2, g), we obtain the dependency. A set of kicker performance, which matches our design goal best, is listed in Table. 3 as the preliminary result. The shunt impedance is as high as 1740 Ω. The related (R_1, R_2, g) is (115 mm, 74 mm, 9 mm). The final design of the HLS LFB kicker is based on this result.

Some high order modes may be excited by the wakefield of the electron beam. These modes need to be investigated because they may cause beam instabilities. Some obvious HOMs are listed in Table 2. The shunt impedances of all these HOMs are reasonably small so they are not going to be a serious problem.

Table 2: Calculated HOMs of HLS Kicker Cavity.

Mode	**Frequency (GHz)**	**Bandwidth (MHz)**	**Shunt Impedance (Ω)**
TM_{110}	1.541	52.3	12.6
TE_{111}	1.687	30.2	10.4
TE_{311}	2.243	40	13.8
TM_{311} *like*	2.478	11.1	9.9

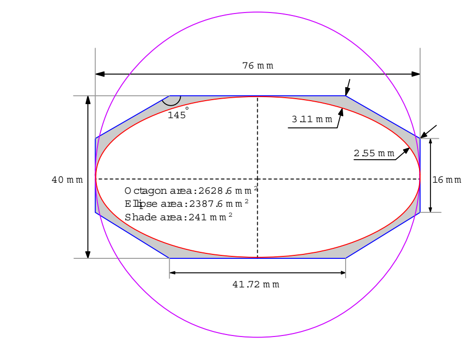
LFB KICKER WITH TRANSITION PART

To minimize the total length of the LFB kicker cavity, the transition part is built into the end pieces of the kicker cavity, shown in Fig. 3. It tapers from a circle to an ellipse and then joins the vacuum chamber of the storage ring. The length of the major axis of the ellipse equals the diameter of the round beam pipe. The minor axis of the ellipse equals the height of the vacuum chamber. To reduce the impact upon the performance of the original kicker design, the round beam pipe is remained for a certain length l_1, which is 20 mm. Given the space limitation, the transition ratio is chosen as 1/5 i.e. the transition length l_2 is 90 mm. This length is appropriate and acceptable.

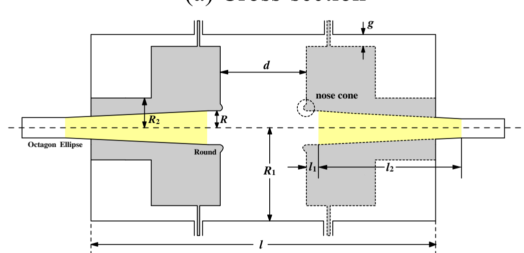
After the transition part is built into the kicker cavity, the performance is changed slightly, shown in Table. 3. The central frequency is 2.2 MHz higher than the design goal while the bandwidth is 1.9 MHz narrower. Although the performance already satisfies the design specifications well, the kicker is finally modified using the dependency obtained from the original design to demonstrate its correctness. The shunt impedance is not considered as it is already very high. Because the central frequency and the bandwidth are not linear functions of R_1, R_2 and g, quadratic functions are used for the fitting. The model function has the following form:

$$f(x,y,z) = a_0 + a_1 x + a_2 y + a_3 z + a_4 x^2 + a_5 y^2 + a_6 z^2 + a_7 xy + a_8 xz + a_9 yz, \quad (1)$$

where x, y, and z represent R_1, R_2 and g. The method of least squares is adopted to fit the data set obtained from dependency calculation which consists of 36 points. The result shows that the fitting is a good one. The relative rms error is 0.00088 and 0.014 for central frequency and bandwidth fitting, respectively. Next we need to solve these fitted equations related to our design goal. For practical reason, the waveguide gap is fixed at 9 mm. So we have two equations and two variables. We use Newton's method to find the solutions. After several



(a) Cross-section



(b) Profile

Figure 3: HLS LFB kicker cavity with transition part.

Table 3: Calculated Performance of HLS Kicker Cavity

Parameter	Preliminary Design	After Building Transition Part	Final Design
Central frequency (MHz)	971.7	971.2	969.2
Bandwidth (MHz)	106.1	100.1	102.8
Shunt impedance (Ω)	1740	1806	1744
Quality factor	9.16	9.7	9.43

iterations, one solution that fits our design goal very well is found : $R_1 = 115.8$ mm and $R_2 = 71.6$ mm. The performance is shown in Table. 3 as the final design. Both the central frequency and the bandwidth are very close to our design specifications. We've also obtained a high shunt impedance.

Another thing needs to be considered is the filling time. For the HLS storage ring, the bunch separation is 4.9 ns. To avoid leakage of kicks to adjacent bunches, the filling time of the LFB kicker must be shorter than the bunch separation. The theoretical filling time of a kicker is $\tau = 1/(\pi \cdot BW)$. For our case, the bandwidth is 102.8 MHz so the filling time is 3.1 ns, which is adequate for the HLS LFB.

We have completed the design of the LFB kicker for the HLS storage ring. The main geometric parameters of the kicker cavity are shown in Table 4.

Table 4: HLS Kicker Cavity Geometric Parameters.

Geometric Parameter	Value (mm)
Radius of pillbox	115.8
Radius of beam pipe	38
Ridge height	106.8
Waveguide gap	9
Back cavity height	71.6
Pillbox length	94
Cavity length	314
Nosecone radius	6
Transition start length	20
Transition length	90

SUMMARY

This design of the longitudinal feedback kicker cavity for the Hefei Light Source storage ring has been presented. The design performance of the kicker has met or surpassed the design specifications. The design also satisfies the space limitation for the HLS kicker.

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