CALCULATION AND SIMULATION OF THE STRIPLINE KICKER USED IN HLS*

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Abstract

A bunch-by-bunch analogue transverse feedback system at the Hefei Light Source (HLS) is to cure the resistive wall instability and the transverse coupled bunch instabilities. The kicker of the feedback system has four 21-cm-long electrodes of stripline type mounted in a skew 45°. Calculation and Simulation of the transverse kicker are shown.

INTRODUCTION

The feedback kicker is an important part in the transverse feedback system. It will give a net electromagnetic force to correct instabilities. For the HLS, with a 204MHz RF system and every buckets filled, the bandwidth of the kicker should be 102MHz so that each coupled-bunch mode can be damped.

The transverse kicker of feedback system at the Hefei Light Source (HLS) is of strip line design, operating in a baseband, and of a 102MHz bandwidth. Since the circumference of HLS storage ring is merely 66 meters. Only a 31.5 cm straight segment can be provided for designing a kicker of about 21cm long, referring to the design of SPring8 short stripline kicker [1]. It's designed and manufactured by the Institute of High Energy Physics.

However, there's less information about calculating the shunt impedance of the transverse kicker, whose electrodes are mounted in dip angle of 45°. In practical terms, the geometric coverage factor is required. In this paper, the derivation process of calculation and the result of calculation and simulation will be shown.

A PROFILE OF SHUNT IMPEDANCE

Shunt impedance R_s, used to define the efficiency of stripline type kicker, is always the focal point of designers and users. It is defined as follow[2, 3, 4, 5]:

$$R_s = \frac{V_\perp^{\,2}}{2P} \tag{1.1}$$

Here, $V_\perp$ is the integration of the transverse Lorentz force received by the unit charge along z-axis.

$$V_\perp = \int_0^l [\vec{E} + \vec{v} \times \vec{B}]_\perp dz \tag{1.2}$$

For strip line, the shunt impedance can be calculated by this formula:

$$R_s = 2Z_c \left(g_\perp \frac{l}{a} \frac{\sin(kl)}{kl}\right)^2 \tag{1.3}$$

Where Z_c (50Ohm) is the characteristic impedance of transmission line. $g_\perp$ is the geometric coverage factor.

For particles at relativistic velocity the electric field may be calculated as the electrostatic potential supplied on the boundary.

GEOMETRIC COVERAGE FACTOR FOR A Y-KICKER

In case of a *y*-kicker, the electrodes are excited with a voltage $\pm V_k$, while the power is P. And when passing at transverse position of coordination (x, y), beam particles receive a kick $-\frac{dV(x,y)}{dy}$. The coverage factor $g_\perp$ is defined as the following equation.

$$\frac{dV(x,y)}{dy} = -g_\perp \bullet \frac{V_k}{b} \tag{2.1}$$

Where, 2b is the separation of plane stripline pair. The configuration is shown in Fig.1.

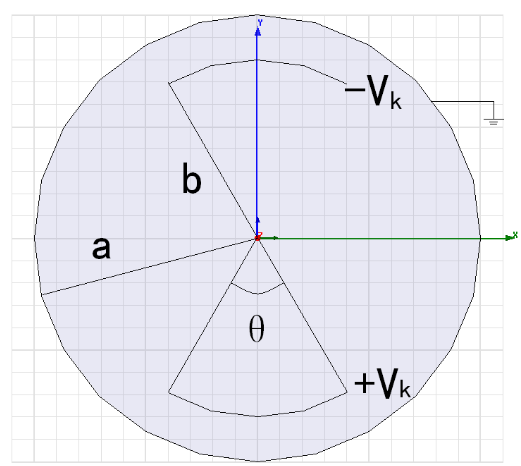

Figure 1: The configuration of y-kicker of two electrodes.

In the case of circular aperture and y-kicker, the coverage factor for this geometry:

$$g_\perp = \frac{4}{\pi} \sin\frac{\theta}{2} \tag{2.2}$$

Where θ is the cover arc of the upper and the lower stripline.

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GEOMETRIC COVERAGE FACTOR FOR KICKER OF HLS

In HLS's case, the transverse kicker works for both x and y planes. Four 21-cm-long electrodes of stripline type are mounted in a skew 45° , seen in table.1. The geometric coverage factor should be calculated. In a circular aperture of radius b , four stripline electrodes cover arcs of θ on the upper right and left, the lower right and left boundary. Used as a y-kicker, these electrodes are at voltages U on the upper ($y>0$) sides and $-U$ on lower sides. The configuration is shown in Fig.2.

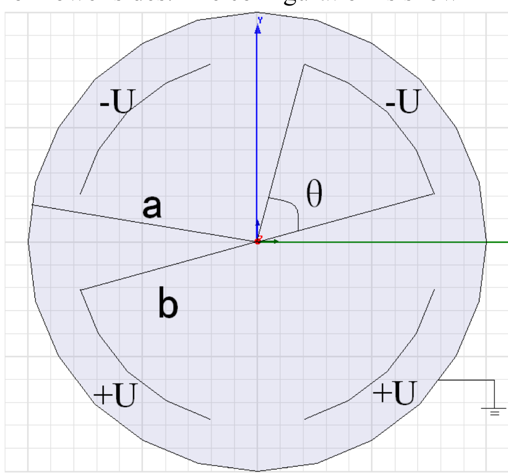

Figure 2: The configuration of kicker. It has four electrodes mounted in a skew 45°.

This is a common electrostatic boundary value problem. In order to simplify the calculation, the metallic strip is considered to be infinite long. Any point on the cylinder axis is chosen to be the cylindrical coordinate system origin. Boundaries of the electrode are at $r = b$ and $\phi=-\frac{\theta}{2}$, $\phi=+\frac{\theta}{2}$, $\phi=\frac{\pi}{2}-\frac{\theta}{2}$, $\phi=\frac{\pi}{2}+\frac{\theta}{2}$, $\phi=\pi-\frac{\theta}{2}$, $\phi=\pi+\frac{\theta}{2}$, $\phi=\frac{3\pi}{2}-\frac{\theta}{2}$, and $\phi=\frac{3\pi}{2}+\frac{\theta}{2}$. According to symmetric structure, the potential is independent of the z coordinate. Because no free charge inside, the potential satisfies the Laplace equation:

$$\nabla^2\varphi=\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\varphi}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2\varphi}{\partial\phi^2}=0 \tag{3.1}$$

In order to find an analytic solution, Boundary conditions are set as follows:

$$\varphi(b,\phi)=\begin{cases}-U,\frac{\pi}{4}-\frac{\theta}{2}<\phi=<\frac{\pi}{4}+\frac{\theta}{2}\\ -U,\frac{3\pi}{4}-\frac{\theta}{2}<\phi<\frac{3\pi}{4}+\frac{\theta}{2}\\ +U,\frac{5\pi}{4}-\frac{\theta}{2}<\phi<\frac{5\pi}{4}+\frac{\theta}{2}\\ +U,\frac{7\pi}{4}-\frac{\theta}{2}<\phi<\frac{7\pi}{4}+\frac{\theta}{2}\end{cases} \tag{3.2}$$

φ needs to satisfy: being limited in the axis, and $\varphi(r,2\pi+\phi)=\varphi(r,\phi)$. The general solution satisfying the above requirements is:

$$\varphi(r,\phi)=\sum_{n=0}^{\infty}r^n(A_n\cos n\phi+B_n\sin n\phi) \tag{3.3}$$

Use boundary conditions and the orthogonality of trigonometric functions, so:

$$A_n=\frac{\int_0^{2\pi}\varphi(a,\phi)\cos n\phi d\phi}{b^n\int_0^{\infty}\cos^2 n\phi d\phi}=0 \tag{3.4}$$

$$B_n=\frac{\int_0^{2\pi}\varphi(a,\phi)\sin n\phi d\phi}{b^n\int_0^{\infty}\sin^2 n\phi d\phi}$$
$$=-\frac{16U}{n\pi b^n}\sin\frac{n\theta}{2}\sin\frac{n\pi}{4}\cos^2\frac{n\pi}{4}\cos(n\pi)$$
$$n=0,1,2,\ldots \tag{3.5}$$

Thus :

$$\varphi(r,\phi)=-\sum_{n=0}^{\infty}[(\frac{r}{b})^n\frac{16U}{n\pi}\sin\frac{n\theta}{2}\sin\frac{n\pi}{4},$$
$$\bullet\cos^2\frac{n\pi}{4}\cos(n\pi)\sin(n\phi)]$$
$$n=0,1,2,\ldots \tag{3.6}$$

Then:

$$\left.\frac{dV(x,y)}{dy}\right|_{(0,0)}=-\frac{4\sqrt{2}U}{\pi b}\sin\frac{\theta}{2} \tag{3.7}$$

Note that, here the kicker has to four stripline electrodes, and it's different from the case mentioned before.

$$V_k=\sqrt{2R_0/R_0}U=\sqrt{2}U \tag{3.8}$$

Synthesizing equation (2.1), equation (3.7), and (3.8), the same result as the y-kicker of two electrodes:

$$g_\perp=\frac{4}{\pi}\sin(\frac{\theta}{2}) \tag{3.9}$$

Table 1 shows the configuration of the feedback kicker of the HLS. Taking the datum in the Table 1 into the formula (1.3) and (3.9), the formular result is obtained, shown in fig.3.

Table 1: Configuration of the feedback kicker.

Bandwidth	102MHz
Length	210 mm
Opening angle	60 deg
Thickness	2 mm
Radius of stripline	33 mm
Radius of pipe	44 mm

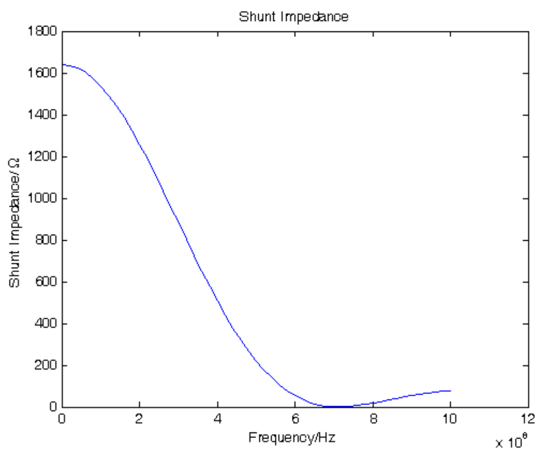

Figure 3: Shunt impedance obtained by calculation.

SIMULATION AND CORRECTION

The shunt impedance may be acquired by the way of integrating the Lorenz force along the z-axis, as formula (1.2). In HFSS code, the way in [4, 5] is taken to get the electromagnetic data at any specified frequency. The result is shown in Fig.4, contrastively with the calculation result.

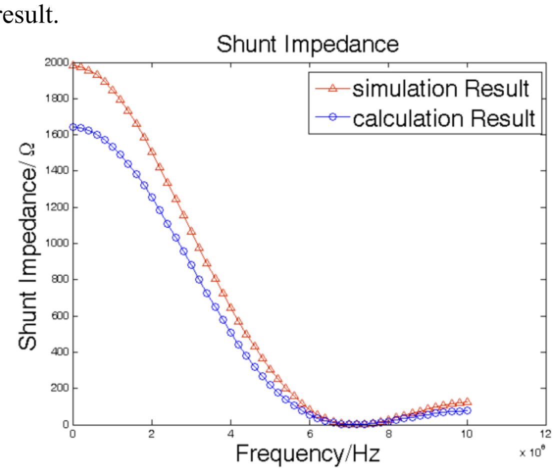

Figure 4: shunt impedance: simulation and calculation results.

Intuitively, there is about 10% difference between the simulation result and the calculation result. The thickness of the electrodes can make it seems to be wider. Hammerstadt, E.o. gave a formula to count it [6]:

$$W_e = \frac{W}{h} + \frac{t}{\pi h}\left(1 + \ln\frac{2h}{t}\right) \qquad (4.1)$$

Computing with the datum in Table.1, the corrected opening angle is obtained, and then, the shunt impedance. Fig.5 shows the result.

As described in the former section, in order to simplify the deriving and get analytic result, many approximations are used. Actually, the potential does not change acutely from +U to zero in infinitesimal distance. These factors of influence cause the shunt impedance larger than the calculation result and corrected result. Calculation with realistic and suitable approximations is to lead to a result closer to the simulation result. It will be studied as future work.

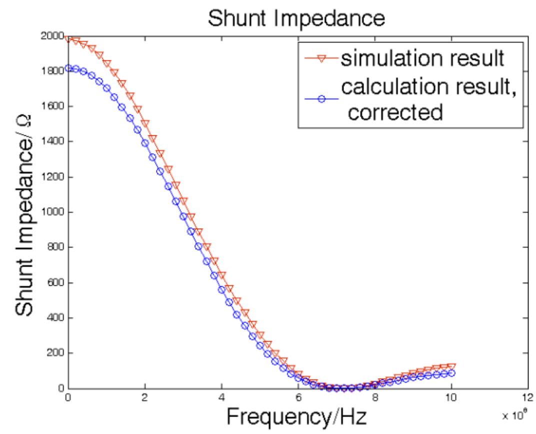

Figure 5: The corrected calculation shunt impedance curve and the simulation result.

CONCLUSION

This kicker is for bunch-by-bunch feedback of the HLS. The geometric coverage factor is derived. The derivation process of calculation and the result of calculation and simulation are shown. The future work is looking for realistic and suitable approximations to get better form of geometric coverage factor and more accurate calculation result.

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