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HEAT LOAD AND RADIATION PULSE OF CORRUGATED STRUCTURE AT SHINE FACILITY

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Abstract

Corrugated structure modules are being proposed for installation after the end of the linac and before the undulator regions of SHINE facility, where it has been used for energy chirp control and as a fast kicker for two color operation of the FEL.When ultra-relativistic bunch of electrons passing through corrugated structure will generate strong wakefield, we find most of the wake power lost by the beam is radiated out to the sides of the corrugated structure in the form of THz waves, and the remaining part casue Joule heating load on the corrugated structure wall. In this paper, we estimate the Joule power loss and radiation pulse power of the corrugated structure in SHINE facility.

INTRODUCTION

In order to eliminate residual energy chirps in superconducting linear accelerator (linac)-driven X-ray FEL facilities, there are currently two traditional ways: one involves exploiting the resistive-wall wakefield induced by the beam pipe; another option, which involves running the beam 'off-crest,' is inefficient and costly, especially for ultrashort bunches in FEL facilities [1]. As far as SHINE linac [2, 3] is concerned, the electron bunch length is less than 10 lm after passing through the second bunch compressor. Therefore, the beam energy spread cannot be effectively compensated by chirping the RF phase of the main linac. The SHINE linac adopts the corrugated structure (Fig. 2) to dechirp the energy spread [4].

When an ultra-short electron bunch passing through very small gap corrugated structure, strong wake effect be generated to manipulate the phase space of the electron bunch. Most of the power radiates out along the opening of the corrugated structure, and only a small amount of power causes a heat load on the metal wall of the corrugated structure. The paper is organized as follows. In the 2nd section, the main parameters of corrugated structure in Shine Facility are introduced briefly, and the distribution wake power lost by the beam through the corrugated structure is also described. In the 3rd section total wake power lost by beam are investigated, and the heat load and distribution of the corrugated structure are calculated by numerical simulation. The 4th section introduces a radiation pulse generated by corrugated structure, and calculate the centre frequency and length of the pulse at the outlet of the corrugated structure, as well as the length of the required cooling water pipe. The final section summarizes the results and significance of this paper.

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THE DISTRIBUTION OF WAKE POWER LOST BY THE BEAM THROUGH THE CORRUGATED STRUCTURE

Schematic diagram of the corrugated structure is shown in the Fig. 1, the red ellipse indicates the on-axis bunch. The transverse directions are denoted x and y, with x pointing into the page, and z represents the longitudinal direction. The corrugated structure parameters are the radius a, the depth h, the period p and the gap width t. The parameters for the corrugated structure and for the exciting bunch to be used in simulations presented below are given in Table 1

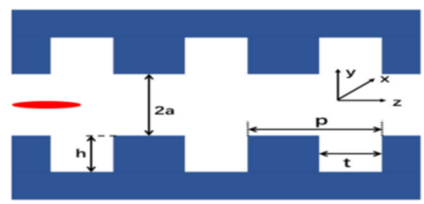

Figure 1: Schematic diagram of the corrugated structure.

Table 1: Parameters for the corrugated structure and for the exciting bunch.

Parameter	Value
Plate length, L (m)	2
Gap, a (mm)	0.7
Depth, h (mm)	0.5
Period, p (mm)	0.5
Longitudinal gap, t (mm)	0.25
Width, w(mm)	12.7
W/2a	9.07
Energy, E (GeV)	8
Charge per bunch, Q (pC)	100
Beam current, I (kA)	1.5
Bunch length (RMS), σ (μm)	5

According to the previous work by K. Bane [5–7], in a flat corrugated structure of a finite length, the wakefield energy loss experienced by a relativistic beam of charged particles is partly absorbed in the walls as Joule heat and partly generates a THz pulse that leaves the structure just behind the driving particle. The energy per unit length lost by the beam to the wake is then given by the sum:

$$P_w = P_h + (P_{\text{rad}})_z + (P_{\text{rad}})_x \tag{1}$$

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with P_h the energy generating Joule heating in the metal walls, $(P_{\rm rad})_z$ the energy in the THz pulse that leaves the end of the structure following the driving particle, and $(P_{\rm rad})_x$ the energy radiating out the sides of the structure.

Through the comparison of analytical estimate and numerical simulation [5], P_h/P_w ~10%, $(P_{\rm rad})_z/P_w$ ~ 80 % , $(P_{\rm rad})_x/P_w$ ~ 10%, when the beam pass through the two-plate flat corrugated structure on the axis and w/2a = 8.5.

HEAT LOAD OF CORRUGATED STRUCTURE

We firstly need to calculate the total wake power lost by beam $Pw = Q^2 * K_{loss} * f_{rep}$, where K_{loss} is loss factor. For a bunch with Gaussian distribution, the loss factor [8–10] is given by

$$K_{loss} = \int \lambda(s) w_z(s) ds \tag{2}$$

Where $w_z(s)$ is short-range, point charge wake of a beam on the axis of a flat corrugated structure:

$$w_z(s) = \frac{\pi^2}{4a^2} e^{-\sqrt{s/s_0}} \tag{3}$$

with $s_0 = 9a^2 t / \left[8\pi\alpha(t/p)^2 p^2\right]$ and $\alpha(x) \approx 1 - 0.465\sqrt{x} - 0.07x$. For the parameters of table 1, the loss factor and wake power lost by beam is obtained : K_{loss} = 20.44 (KV/pC/m), P_w = 204.4073 W/m, P_h = 20.4 W/m.

When the beam passes close to the side of the corrugated structure, the short-range, point charge wake of a beam passing by a single plate of a flat dechirper at offset b is

$$w_z(s) = \frac{1}{b^2} e^{-\sqrt{s/s_{0l}}}, \tag{4}$$

with $s_{0l} = 2b^2 t / \left(\pi\alpha^2 p^2\right)$ and $\alpha \approx 1 - 0.465\sqrt{(t/p)} - 0.07(t/p))$. According to Ref. [5], P_h/P_w ~5.5% when the beam passes close to the side of the corrugated structure. For the parameters of table 1, the loss factor and wake power lost by beam at offset b = 0.25 mm is obtained : K_{loss} = 58.067 (KV/pC/m), P_w = 580.67 W/m, P_h = 31.93 W/m.

THE DISTRIBUTION OF HEAT LOAD IN CORRUGATED STRUCTURE

Although the heat load of the corrugated structure accounts for only 10 % of the total wake power, for the 2 m corrugated structure of shine, the heat load has reached 40 W. With such a high heat load, a water cooling system on the corrugated structure is required. Considering the layout of the water cooling system on the surface of the corrugated structure, we need to know the heat load distribution of the corrugated structure. Simulations were carried out using the numerical simulation software CST [11] to simulate the power of each section by dividing the corrugated structure into n sections of the same length and material along the Z-direction. The 2-metre long corrugated structure is divided into six pieces of the same length and material, and the simulation results show that the Joule power of each piece is the same, as shown in Fig. 2, which implies that the heat load inside the corrugated structure is uniformly distributed.

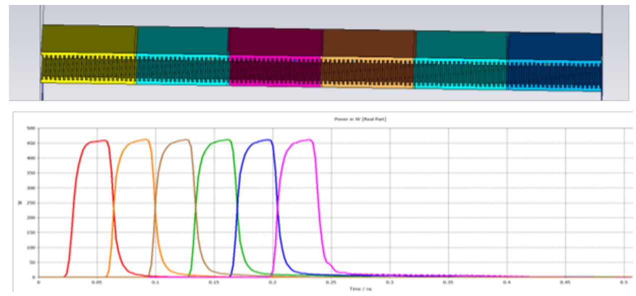

Figure 2: The 2-metre long corrugated structure is divided into six pieces of the same length and material with different colours(Top plot), Joule power of six piece (Bottom plot).

A RADIATION PULSE GENERATED BY CORRUGATED STRUCTURE

When the beam pass through the corrugated structure, most of the power will be in the form of radiated pulse that continue to propagate forward along the Z-axis with the direction of the beam. Outside the corrugated structure is a beam pipe with a radius of 35 mm, into which the radiation pulses generated by the beam after the exit of the pleated structure are spread. Now we need to know how far the radiation pulse spreads to this beam pipe and how long the cooling water pipe needs to be arranged. Therefore, a corrugated structure with Table 1 parameters was modelled with a 35 mm diameter beam pipe using CST simulation, as shown in Fig. 3(a).

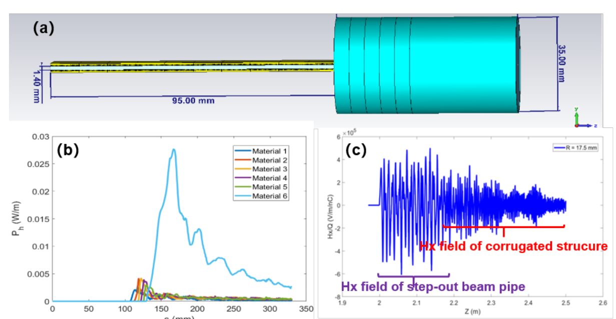

Figure 3: (a): the geometry of corrugated Structure and step-out 35 mm diameter beam pipe which created by CST; (b):Joule power calculations of 35 mm diameter beam pipe obtained by CST time-domain simulation; (c):Hx field calculation 35 mm diameter geometry by ECHO simulation [12].

Figure 3(b) shows the simulation results of Joule heating for a 35 mm diameter beam pipe where the beam pipe is divided into six sections, the first five being of the same 10 mm length and material. It can be noticed that the Joule heating of the first five sections shows the heat load of the first section rising first, the heat load of the middle three sections is uniform, and the heat load of the fifth section begins to decay. Figure 3(c) shows the Hx field distribution on the wall

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of the beam pipe simulated with ECHO [12], and it is clear that the Hx field consists of the Hx field due to the corrugated structure immediately following the beam and the Hx field due to the step-out structure of the beam pipe. Combining the results of Fig. 3, we can conclude that the pulses radiated by the beam through the corrugated structure to the step-out structure of the beam pipe spread over a distance of roughly 30-50 cm, and thus require cooling-water system of about 50 cm.

Next, a Fourier analysis of the radiation pulse caused by the folded structure was done, yielding a pulse with a frequency around 100 GHz, as shown in Fig. 4. According to $f = kc/\sqrt(ah)$, the parameter a or h can be reduced to obtain 1 THz.

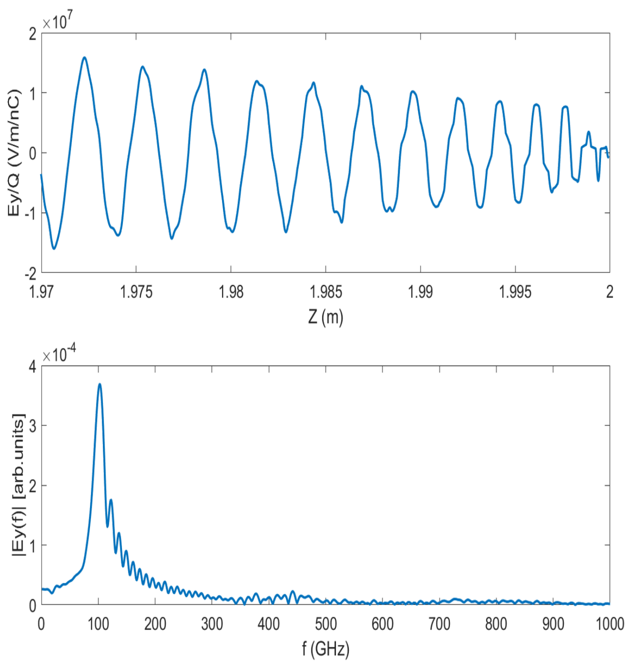

Figure 4: The radial electric field Ey at y = 0.7 mm at a monitor located at the downstream end of corrugated strucure as function of time t (Top plot);The absolute value of the Fourier transform of this function, Ey, as function of frequency (Bottom plot) .

CONCLUSION

We have performed heat load calculations and radiation pulse for the SHINE corrugated structure in this paper. We find that 204 W/m (80%) most of the wake power lost by the beam is radiated out to the sides of SHINE corrugated structure, and only 20.4 W/m (10%) a small part of the power caused heat load of metal wall. Most of the wake power is radiated downstream along the Z-axis of corrugated structure in the form of pulse, which can cause severe downstream heat load effect. Calculations and analyses show that the radiation pulses generated by the corrugated structure will spread on the walls of the 35 mm radius circular beam pipe 30 ~50 cm from the exit of the pleated structure, so additional cooling water pipes are required. At the same time, in order to avoid damage to downstream components from radiation pulses, the photon absorber might be considered to be mounted to the downstream.

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