

# DESIGN OF AN S-BAND CHOKE-MODE TRAVELLING-WAVE ACCELERATING STRUCTURE

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## Abstract

Charged particle bunches excite wakefields in accelerating cavities, and the transverse components of these wakefields can degrade beam stability. Since these effects are mainly driven by higher-order modes (HOMs), effective HOM suppression is essential for accelerator operation. The choke-mode structure is one of the approaches used for HOM damping.

This study presents the design of a 2856 MHz S-band choke-mode travelling-wave accelerating structure. The fundamental-mode parameters of the single cell and cavity chain are optimized using electromagnetic simulations. HOM characteristics and wakefields are analyzed using HFSS and CST simulations, and a two-step optimization of the choke geometry is performed. The results show a clear reduction in transverse wake impedance, demonstrating effective HOM suppression.

## INTRODUCTION

In accelerator structures, wakefield effects arise when a charged bunch travels through the cavity and induces image currents on the cavity wall. The transient currents subsequently excite electromagnetic fields inside the structure, which in turn interact with both the driving bunch itself and the following bunches.

When the wakefield acts on subsequent bunches, it is referred to as the long-range wakefield. In general, long-range wakefields form resonant modes inside the accelerating structure. Among them, dipole modes produce transverse kicks to the beam, leading to beam offset variation and degradation of transverse beam quality. Since the frequencies of dipole modes are always higher than that of the fundamental accelerating mode, accelerating structures with higher-order-mode (HOM) damping capability are essential for suppressing transverse long-range wakefields.

A choke-mode structure introduces a radial choke branch that reflects the accelerating mode back into the cavity, while most HOMs propagate along the radial line and are absorbed by loads located at the end of the branch. The choke-mode structure also provides advantages such as relatively simple fabrication and lower surface magnetic field.

This paper presents the design of an S-band choke-mode accelerating structure, including simulations of the fundamental mode for both single-cell and cavity chain configurations, as well as optimization studies for HOM suppression.

## CAVITY CHAIN DESIGN

A choke-mode travelling-wave linear accelerator operating at 2856 MHz was designed using Ansys [1] softwares. The structure operates in the  $3\pi/4$  mode and consists of 20 cells. The detailed design parameters are listed in Table 1. Based on the design specifications, the RF input power was minimized as much as possible.

Table 1: Design Specifications of the Choke-Mode Accelerating Structure

Parameter	Value
Working Frequency	2856MHz
Operating mode	$3\pi/4$
Number of cells	20
Length of the linac	78.6cm
Input RF power	$\leq 18\text{MW}$
Output beam energy	$\geq 9\text{MeV}$
Filling time	$\leq 300\text{ns}$

The typical single-cell geometry of the choke-mode structure used in simulations is shown in Fig. 1. To reduce the computational cost of simulations, only a  $5^\circ$  azimuthal section of the axisymmetric cavity was modeled.

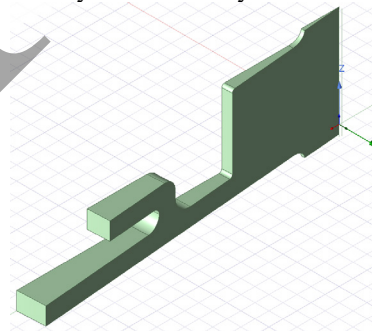


Figure 1: A typical single-cell geometry of the choke-mode structure.

In the simulations, the relationship between the cavity radius ( $b$ ) and the iris aperture radius ( $a$ ) was first determined to maintain a constant operating frequency for different iris apertures. Based on these results, the variations of the quality factor ( $Q$ ), the group velocity ( $v_g$ ), and  $(R/Q)$ , as functions of the iris aperture radius were subsequently obtained from the single-cell simulations.

Numerical simulations were performed under the discrete-cell approximation. Assuming that the input power of the  $n$ -th cell is  $P_n$ , the following recursive relation can be obtained.

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$$P_{n+1} = P_n \left( 1 - \frac{\omega L}{Q_n v_{g,n}} \right) - I_b V_n \quad (1)$$

Here,  $I_b$  denotes the beam current, which was assumed to be 1 A in this study, and  $V_n$  represents the effective accelerating voltage of the  $n$ -th cell, which satisfies

$$V_n = \sqrt{\frac{P_n \omega L}{v_{g,n}}} \quad (2)$$

where  $L$  is the cell length.

To achieve field flatness along the accelerating structure, the parameters of each cell were adjusted according to its position in the cavity chain. In the present design, a linearly tapered iris aperture ( $a$ ) was adopted, while the disk thickness ( $d$ ) was fixed at 6 mm and the ellipticity parameter of the disk profile ( $e$ ) was fixed at 1.5. In general, the upstream cells require a higher group velocity, which can be most directly realized by increasing the iris aperture radius. In contrast, the downstream cells require a lower group velocity and therefore a smaller aperture radius.

Under the constraints of the design specifications in Table 1, and through further optimization based on the simulation results, the parameters of the complete choke-mode accelerating structure were determined, as listed in Table 2. In this design, the RF input power was optimized to 15.65 MW.

Table 2: Parameters of the Choke-Mode Accelerating Structure from Simulation

Parameter	Value
Input RF power	15.65MW
Output beam energy	9.01MeV
Filling time	264ns

The fundamental design parameters of the input cell, middle cell (the 10<sup>th</sup> cell), and output cell in the accelerating structure are listed in Table 3, where  $c$  denotes the speed of light.

Table 3: Fundamental Design Parameters of Typical Cells in the Choke-Mode Accelerating Structure

Parameter	Input cell	Middle cell	Output cell
Iris radius, $a$ [mm]	13.85	12.12	10.20
Group velocity, $v_g$	1.7% $c$	1.1% $c$	0.6% $c$
Shunt Impedance, $R_s$ [M $\Omega$ /m]	33.7	36.8	40.4
Quality Factor, $Q$	11680	11659	11652

## HOM OPTIMIZATION

In a choke-mode structure, the frequencies of wakefield modes are primarily determined by the main cavity geometry. However, by modifying the choke configuration, the damping of these wakefield modes can be significantly enhanced.

## Absorption Curve Analysis

To evaluate the full reflection frequency of the designed choke structure, a radial transmission-line model, as shown in Fig. 2, was employed for simulations. In this figure, the near and far ends are defined as Port 2 and Port 1, respectively. Perfect magnetic boundary conditions were applied on the two cut planes. The transmission coefficient  $S_{12}$  was then used to characterize the level of power absorbed by the choke structure. The result of simulation is shown in Fig. 3.

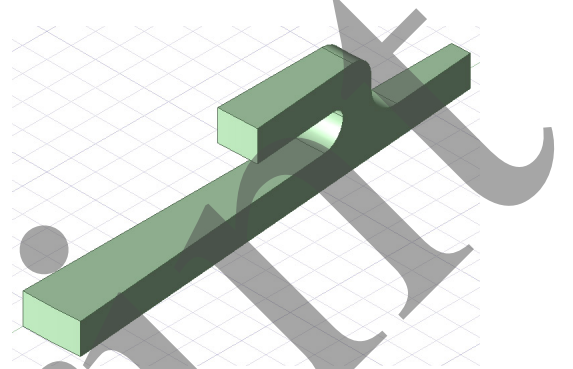


Figure 2: The geometry used in the analysis of the full reflection frequencies.

As can be seen, the first full-reflection point on the left side of the figure occurs at approximately 2.86 GHz, corresponding to the accelerating mode. Furthermore, additional full-reflection modes appear within the 0–15 GHz range, located at approximately 7.3 GHz and 12.2 GHz.

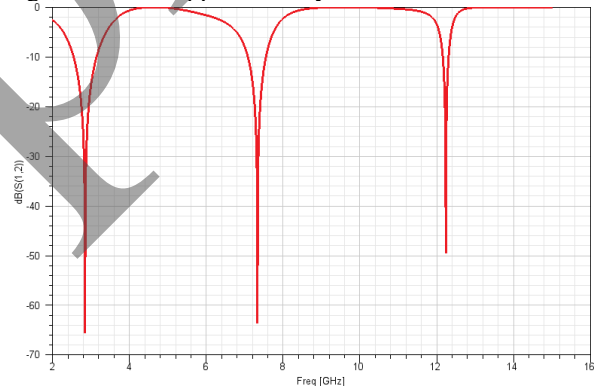


Figure 3: Absorption curve simulation result of the geometry in Fig. 2.

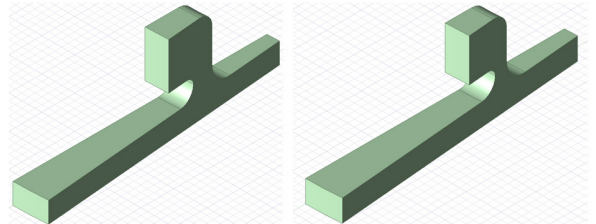


Figure 4: Geometries after the first (left) and second (right) optimization steps.

Next, the damping performance of the choke structure for HOMs was optimized through a two-step procedure. The modified choke geometries are shown in Fig. 4, and the absorption curve simulation results are shown in Fig. 5.

- In the first step, the choke length was reduced while its width was increased, with the fundamental mode frequency kept unchanged. The corresponding absorption response of the choke structure is represented by the blue curve in Fig. 5.
- In the second step, the “neck” region of the choke was narrowed, and the choke width was further fine-tuned to maintain the same fundamental frequency. The resulting absorption response is shown by the red curve in Fig. 5.

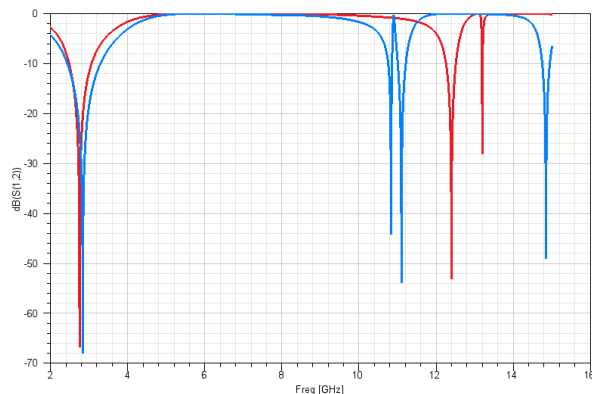


Figure 5: Absorption curve simulation results after the first (left) and second (right) optimization steps.

The results show a clear increase in the full-reflection frequencies, especially in comparison with Fig. 3.

### Wakefield Analysis

The wakefield simulation of this structure was further carried out using CST [2], from which the frequency-domain distribution of the transverse wake impedance can be obtained, as shown in Fig. 6 below. The unit of the transverse wake impedance is  $\Omega/\text{mm}/\text{m}$ , which represents the impedance per unit beam offset and per unit length of the accelerating structure.

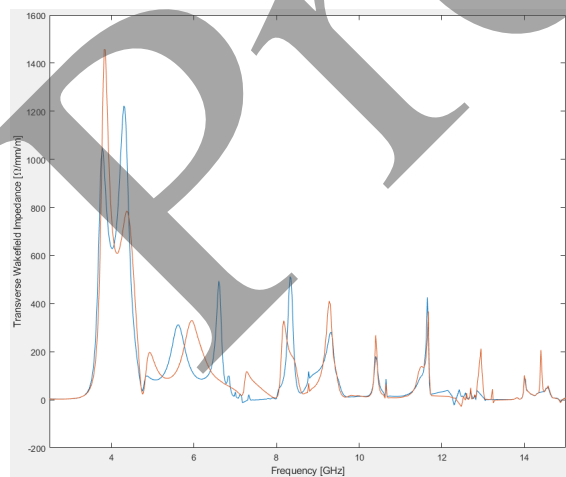


Figure 6: Transverse wake impedance before (blue) and after (orange) optimization obtained from wakefield simulations.

As shown in Fig. 6, the peaks in the impedance spectrum are significantly reduced within the 0–15 GHz range after

optimization. The peaks in the absorption curve do not necessarily correspond exactly to those in the impedance spectrum, which may be attributed to the fact that the absorption-curve simulation cannot fully reproduce all higher-order modes accurately.

It is evident that the present design still has considerable room for further optimization. For example, the first peak on the left side of the spectrum remains relatively high. In future work, higher-order modes may be further suppressed through approaches such as impedance matching.

## CONCLUSION

In this work, an S-band choke-mode traveling-wave accelerating structure operating at 2856 MHz was designed and analyzed. The fundamental-mode performance of the cavity chain was optimized using electromagnetic simulations, leading to a reduced input power of 15.65 MW under the required operating conditions.

For higher-order modes, a combined HFSS–CST simulation approach was used to study the wakefield characteristics. A two-step optimization of the choke geometry was then carried out, which effectively reduced the transverse wake impedance peaks and improved HOM damping performance.

Although the present design already shows clear suppression of higher-order modes, further optimization based on impedance matching and geometric refinement is still expected to provide additional improvement.

## REFERENCES

- [1] ANSYS, <https://www.ansys.com>
- [2] CST, <https://www.3ds.com/products/simulia/cststudio-suite>