NUMERICAL SIMULATION AND OPTIMIZATION OF A 3-GHZ CHOPPER/PREBUNCHER SYSTEM FOR THE S-DALINAC*

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Abstract

A new source of polarized electrons with energy of 100 keV is presently being developed at the superconducting Darmstadt electron linear accelerator S-DALINAC for future nuclear- and radiation-physics experiments. The pulsed electron beam emitted by the photocathode will be cut to 50 ps by a chopper operated at 3 GHz, and further bunch compression down to 5 ps will be achieved by a two-stage prebuncher section.

The chopper-prebuncher system is based on similar devices used at the Mainz Mikrotron (MAMI) where the accelerator frequency is slightly smaller (2.45 GHz). For the chopper, a cylindrical resonator operating at TM_{110} mode is selected to deflect the electron beam onto an ellipse, i.e., both horizontally and vertically. This is simply achieved by particular slits on both ends of the resonator. The prebunching system consists of two cavities. For increasing the longitudinal capture efficiency, the first cavity will be operated at the fundamental accelerator frequency of the S-DALINAC of 3 GHz, and the second cavity at 6 GHz. The cavities are designed to work at the TM_{010} mode and TM_{020} mode for the fundamental and first harmonic, respectively.

INTRODUCTION

At the S-DALINAC, chopper and prebuncher resonators are used to produce electron bunches that are short enough for further acceleration. With the installation of the new polarized-electron injector, new resonators need to be designed. The geometry of the devices is based on the systems employed at the University of Mainz with a different operating frequency. The selected geometries are simulated and optimized with CST MICROWAVE STUDIO®[1].

A cylindrical resonator operating at TM_{110} mode [2] is the suitable device for the chopper to deflect the electron beam elliptically so that the beam can be subsequently cut at a collimator. The two-stage harmonic bunching system is selected for increasing the longitudinal capture efficiency. The first cavity will be operated at the fundamental accelerator frequency of 3 GHz, and the second cavity at 6 GHz. The cavities are designed to work at the TM_{010} mode and TM_{020} mode, respectively.

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CHOPPER SYSTEM

The basic system is composed of a chopper cavity, a drift tube and a collimator. The electron beam traveling along the longitudinal axis of the cavity is elliptically deflected by the magnetic field according to the Lorentz force. At the collimator the beam is chopped to a bunch length of 50 ps.

Chopper Design

For the deflection of the beam, the magnetic field on the longitudinal axis of the cavity is maximum, on the other hand, the electric field vanishes. Figure 1 represents the optimized geometry of the cavity [3] designed to work at 3 GHz in order to match to the operating frequency of the S-DALINAC.

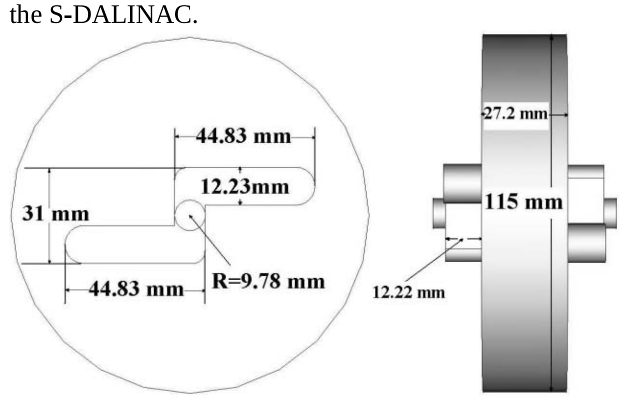


Figure 1: Optimum geometry of the chopping cavity.

Slits on both sides of the cavity have some advantages. Normally, if elliptical polarization of the magnetic field is required, it is necessary to have two cavities or to feed a cavity with two couplers located at 90° difference to each other which is complicated. Another disadvantage of these structures is the multiplicity of the parameters to be taken into account like amplitude and phase of the input power. Thus, employing slits reduces the complexity and in this case, only one input RF power is required.

Field Distribution of the Chopper

In the TM_{110} mode the electric field is zero on the cavity's axis and its direction changes sign across the plane of symmetry. The magnetic field is maximum on the axis and has reversal points defined by the polar co-ordinates r=0.481a, ϕ=0 and π which represent regions of maximum electric field with equal and opposite longitudinal vector. Figures 2 and 3 present the simulated magnetic and electric field distribution of the chopper operating at 3.00868 GHz, respectively.

Due to the slits, the magnetic field direction rotates along the beam direction shown in Fig. 2. The electric field has the minimum value along the travelling path of the electron beam presented in Fig. 3. Thus, it can be concluded that at the chopper cavity the electron beam is only deflected, not accelerated. After being deflected by the magnetic field, the electron beam is subsequently cut at the collimator to the bunch length of 50 ps.

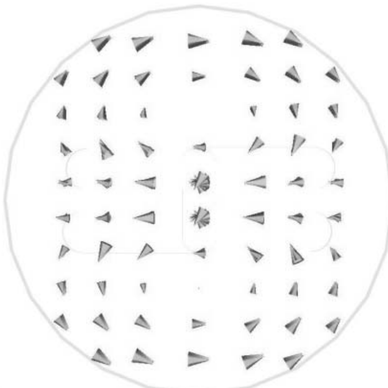


Figure 2: Magnetic field distribution of the cavity.

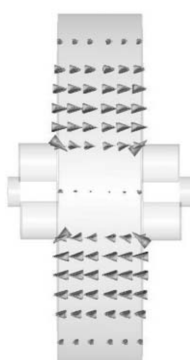


Figure 3: Electric field distribution of the cavity.

Some Parameters of the Chopper

The calculation of some important parameters can be found in [4] and [5]. The chopper cavity possesses the unloaded quality factor and the loss/W(peak) of 12,568 and $3.0096 \cdot 10^6$ W respectively, the parameters are normalized to 1 J stored energy. The shunt impedance is 3.124 MΩ (114.837 MΩ/m) and the transit time factor is 0.75.

PREBUNCHING SYSTEM

The function of the prebuncher is to compress the electron bunch to the required length of 5 ps for further acceleration in the S-DALINAC. Usual practice is to impart a small time-varying energy difference to the mono-energic beam followed by a drift of the beam until the faster electrons catch up with the slower electrons.

For the optimization, two objectives should be taken into account [6]: the nonlinear distortion of the beam has to be minimized in the longitudinal phase. Ideally a δ-function-like phase space distribution at the longitudinal focus should be obtained for zero initial beam energy spread. The electron bunch compressed by the prebunching system has to be matched to the longitudinal acceptance of the S-DALINAC.

Prebuncher Design

A larger phase acceptance can be obtained by linearization of the field distribution as suggested by single-cavity double-frequency or two-cavity harmonic prebunching systems found in [6, 7]. In comparison with the single-cavity double-frequency system, the two-cavity harmonic prebuncher has the better flexibility.

For the S-DALINAC, the first cavity is designed at the fundamental frequency of 3 GHz operating with TM_{010} mode. The 6-GHz cavity with TM_{020} mode located at the appropriate distance behind the fundamental cavity is chosen. The optimized geometries of the fundamental and first harmonic cavity are presented in Figures 4 and 5, respectively.

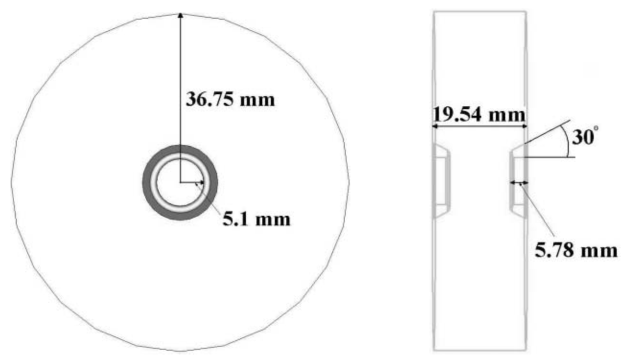


Figure 4: Optimized geometry of the 3 GHz cavity.

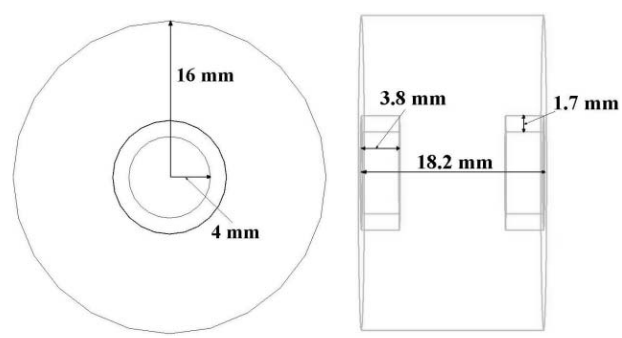


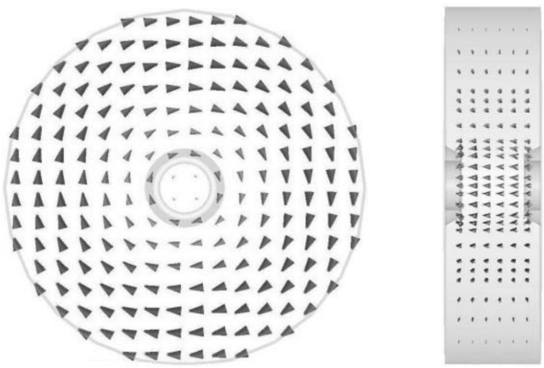
Figure 5: Optimized geometry of the 6 GHz cavity.

Field Distribution of the Prebuncher

The field distributions on or near the axis, which are seen by the beam, are essentially identical for the two modes. The ratio of the TM_{020} and TM_{010} mode frequencies in the right circular cylinder is approximately 2.3 [7]. Only small changes in the geometry should be required to make this ratio exactly two. However, for the buncher cavities to have reasonable high effective shunt impedance, ZT^2, and to be of the suitable length, the drift tube noses are required to be close to the beam axis.

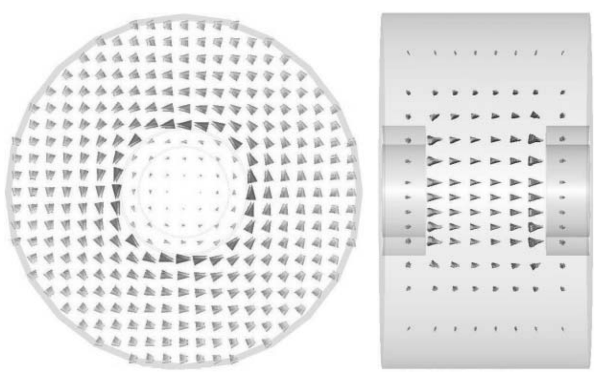
This method increases the capture efficiency to approximately 40-50% while preserving the high beam quality of the S-DALINAC, i.e., bunch lengths of more than 100 ps should be compressed sufficiently to be further accelerated in the superconducting cavities of the S-DALINAC. Figures 6 and 7 represent the magnetic and electric field distribution of the fundamental and first harmonic prebuncher cavity, respectively.

For the fundamental frequency cavity a 30° drift tube nose is selected to improve the RF efficiency as shown in Fig. 6(b). For the 6 GHz cavity a rectangular nose shape is chosen, Fig. 7(b).



(a) (b)

Figure 6: Field distributions of the 3-GHz prebuncher (a) magnetic field, (b) electric field



(a) (b)

Figure 7: Field distributions of the 6-GHz prebuncher (a) magnetic field, (b) electric field

Some Parameters of the Prebuncher

For the 3-GHz cavity the quality factor is 10,609. The normalized power loss/W(peak) is $3.5537 \cdot 10^6$ W and the operating frequency is 3.00017 GHz from simulation. Calculating from power loss and electric field intensity, the shunt impedance is 13.4 MΩ or per length 685.5 MΩ/m. Calculation of the transit time factor can be found in [5]. The fundamental mode cavity possesses the transit time factor of 0.84.

For the 6-GHz prebuncher, the quality factor and the normalized power loss are 7,966 and $9.4714 \cdot 10^6$ W respectively. The normalization is based on the energy stored in the cavities of 1 J. The operating frequency is designed to work at 6.00405 GHz. The first harmonic prebuncher possesses the shunt impedance and the transit time factor of 39.733 MΩ (per length 2,189 MΩ/m) and 0.88, respectively.

SUMMARY

The cylindrical chopper cavity is selected to work at 3 GHz in TM_{110} mode for chopping the electron beam to 50 ps. In order to deflect the electron beam elliptically, slits on both sides are included for forming an elliptical polarization of the magnetic field. This has the advantage of feeding the cavity with only one input RF power instead of two or employing two cavities. The electric field on the beam path axis is designed to be zero, but the magnetic field is designed to be maximal.

The prebunching system consists of two cavities operating at 3 and 6 GHz in TM_{010} and TM_{020} mode respectively, a so-called harmonic prebunching system. The drift tube noses are employed to increase the electric field intensity. After passing through the prebunching system the electron beam is compressed from 50 ps to 5 ps.

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