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CLIC – Note – 1188

WAKEFIELD SUPPRESSION IN THE MAIN LINAC OF THE KLYSTRON-BASED FIRST STAGE OF CLIC AT 380 GeV

J.Y. Liu[2,3], J. Shi[2,3], H. Zha[2,3], H.B. Chen[2,3] and A. Grudiev[1]

[1]CERN, Geneva, Switzerland
[2]Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[3]Key Laboratory of Particle and Radiation Imaging, Tsinghua University, Ministry of Education, Beijing 100084, China

Abstract

An alternative klystron-based scenario for the first stage of Compact Linear Collider (CLIC) at 380 GeV centre-of-mass energy was proposed. To preserve the beam stability and luminosity of CLIC, the beam-induced transverse long-range wakefield in main linac must be suppressed to an acceptable value. The design of klystron-based accelerating structure is based on waveguide damping structure (WDS). The high-order modes (HOMs) propagating into four waveguides are absorbed by HOM damping loads. In this paper, the wakefield suppression in CLIC-K based on GdfidL code simulations are presented.

Presented at the 10th International Particle Accelerator Conference, Melbourne, Australia, 19-24 May 2019

Geneva, Switzerland
May 2019

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB043

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J.Y. Liu[1], J. Shi[1], H. Zha[†1], H.B. Chen[1], Department of Engineering Physics, Tsinghua University, Beijing 100084, China
A. Grudiev, CERN, 1211 Geneva, Switzerland
[1]also at Key Laboratory of Particle and Radiation Imaging, Tsinghua University, Ministry of Education, Beijing 100084, China

Abstract

An alternative klystron-based scenario for the first stage of Compact Linear Collider (CLIC) at 380 GeV centre-of-mass energy was proposed. To preserve the beam stability and luminosity of CLIC, the beam-induced transverse long-range wakefield in main linac must be suppressed to an acceptable value. The design of klystron-based accelerating structure is based on waveguide damping structure (WDS). The high-order modes (HOMs) propagating into four waveguides are absorbed by HOM damping loads. In this paper, the wakefield suppression in CLIC-K based on GdfidL code simulations are presented.

INTRODUCTION

CLIC [1] is one of the candidates of the future lepton colliders. The baseline for a staged CLIC was updated in 2016 [2]. An alternative scenario for the first stage CLIC at 380 GeV using X-band high-efficiency klystrons was proposed.

The suppression of the transverse long-range wakefield excited by multi-bunches must be taken into account in the design of high-gradient accelerating structures to preserve the luminosity and stability of the colliding beams [3]. The beam dynamics study requires that the transverse long-range wakefield potential at the second following bunch must be lower than 4.75 V/pC/m/mm [4-6].

The RF design of the klystron-based accelerating structure named CLIC-K [7] uses the waveguide damping-scheme, which is same as the baseline design of the CLIC main linac [8, 9]. Fig. 1 shows the internal volume of the full tapered structure including 26 regular cells and 2 coupler cells. Four waveguides are strongly coupled to the accelerating cell to damp the HOMs. HOM damping loads have been designed to absorb HOMs propagating into the damping waveguides.

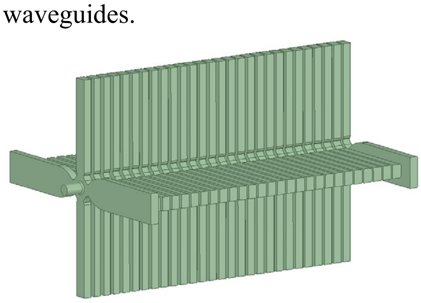

Figure 1: Internal vacuum volume of CLIC-K.

† zha_hao@mail.tsinghua.edu.com

In this paper, the wakefield suppressions in CLIC-K with prefect matching layer (PML) boundary condition and nominal geometry are described in the following parts, respectively. The dependences of wakefield suppression on the material properties and the tapering length of the HOM loads are also presented.

WAKEFIELD SUPPRESSION WITH PML BOUNDARY CONDITION

The wakefield suppression is depended on the coupling of damping waveguides and material properties of HOM loads. Therefore, the results of the transverse wake-field potential for the geometry shown in Fig. 1 where all damping and main waveguides are terminated with the PML boundary condition can give a reference to the design of HOM loads.

The simulations of transverse long-range wakefield were carried out by using GdifidL code [10]. The results of the wakefield suppression with PML boundary condition are shown in Fig. 2. The small differences between the wake-field potential on the X plane and the Y plane are due to the coupler cells. The results indicate that the wakefield potential at the second bunch is far better than the requirement, as presented in Fig. 3.

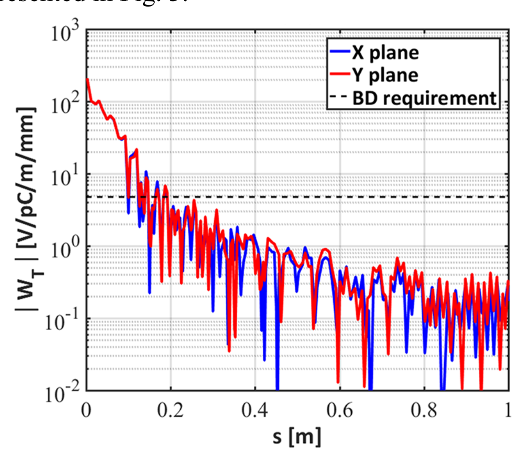

Figure 2: The envelope of the transverse long-range wake-field potential of CLIC-K with PML boundary condition.

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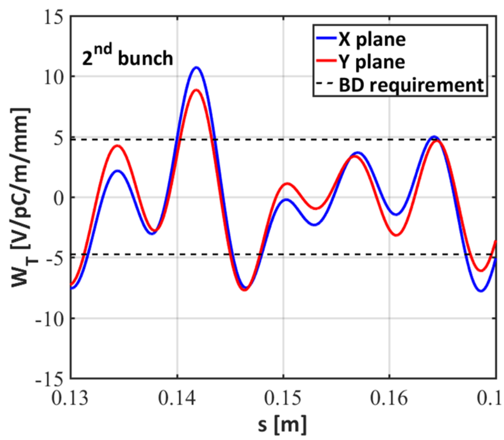

Figure 3: Transverse wakefield potential around the position of the second bunch at 0.15 m.

The beam instability caused by transverse long-range wakefield can be described with three transverse beam jitter amplification factors: F_c, F_{rms} and F_{worst} [4]. The beam dynamics study proposed that the F_{rms} should be below 2 and the F_{worst} should be below 5 in order to prevent a significant emittance growth along the linac. Moreover, the distribution of the transverse wakefield is depended on the frequency of the wakefield dipole modes, which might be affected by the fabrication errors of cell disks. These three transverse beam jitter amplification factors for CLIC-K calculated by the envelope of transverse wakefield with the PML boundary condition are presented in Table 1, which meets beam dynamics requirement even if the frequency of the wakefield dipole mode shifts within the range of ±1%.

Table 1: The Results of Transverse Beam Jitter Amplification Factors in CLIC-K with the PML Boundary Condition

	Ideally	Frequency errors within ±1%	Beam dynamics requirements
F_c	1.02	1.06	
F_{rms}	1.03	1.26	< 2
F_{worst}	1.10	3.12	< 5

HOM LOADS

The wakefield HOMs excited in the accelerating cells propagate into the damping waveguides are absorbed by HOM damping loads. The material of HOM loads is a silicon carbide named “EkaSiC-P”. The properties of this material have been measured in [11].

The geometry of HOM loads designed for the updated baseline structure CLIC-G* [9] is presented in Fig. 4. The tapering part from 1 × 1 mm cross-section to 5 × 5 mm is designed for broad-band absorption and low reflection from the tip. The same geometry is applied for the CLIC-K as the nominal geometry.

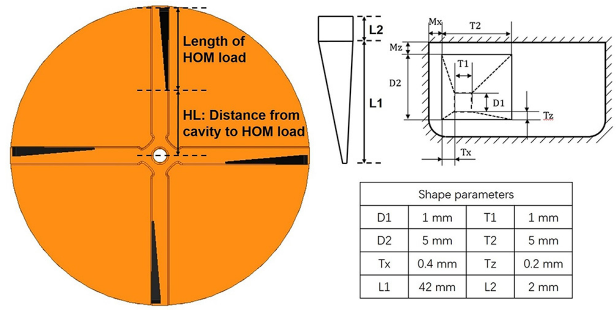

Figure 4: Nominal geometry of HOM loads.

Although the fundamental mode is cut off in the damped waveguides, a small portion of the power will be penetrated in the waveguide and reach HOM loads. A distance from accelerating cell to the HOM loads (marked as “*HL*” in Fig. 4) is preserved in order to reduce the power dissipation in the loads. The position of HOM loads in the damping waveguides was optimized to decrease the impact on the fundamental 12 GHz accelerating mode in the cells. The power dissipation of fundamental mode in HOM loads is lower when HOM loads are closer to the wall of damping waveguides. The clearances, “*Mx*” and “*Mz*”, between the HOM loads and waveguide wall are necessary for mechanical assembly. The final designs of “*Mx*” and “*Mz*” were both selected at 0.4 mm. The safe distance “HL”, the distance between the centre of the cells and the tip of the HOM load, is optimized to 35 mm.

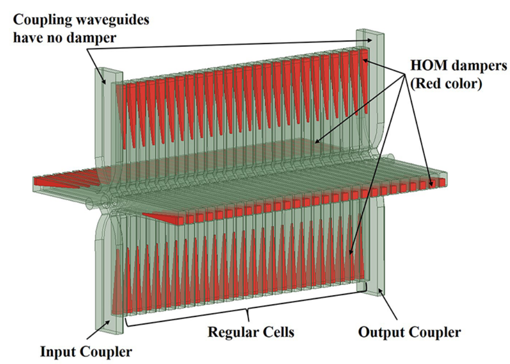

Figure 5: The view of the accelerating structure CLIC-K with HOM loads.

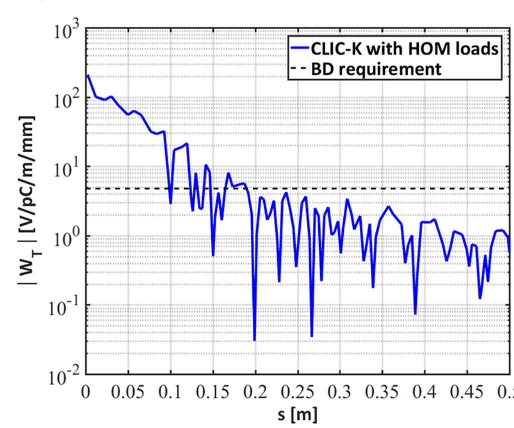

Figure 6: The envelope of the transverse long-range wakefield potential of CLIC-K with HOM loads.

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The final design of the accelerating structure CLIC-K with HOM damping loads are shown in Fig. 5. The results of wakefield suppression for the nominal geometry are described in Fig. 6 and Table 2, which are close to the results with PML boundary condition.

Table 2: The Results of Transverse Beam Jitter Amplification Factors in CLIC-K with HOM Loads

	Ideally	Frequency errors within ±1%	Beam dynamics requirements
F_c	1.02	1.06	
F_{rms}	1.05	1.34	< 2
F_{worst}	2.19	3.77	< 5

DEPENDENCE ANALYSIS

Material Properties

The properties of SiC material may vary from production batch to batch and depend on the supplier. This may result in the variation of the wakefield suppression. The sensitivity of the wakefield suppression and the SiC material properties was conducted in the research. The measured frequency dependence of the SiC material is expressed with a dispersive N-th order Lorentz medium in GdfidL code. For the properties, ε' is the real part of permittivity and ε'' is the imaginary part of permittivity. The calculated transverse beam jitter amplification factors always meet the beam dynamics requirements when material properties vary within ±20%, as shown in Fig. 7 and Fig. 8.

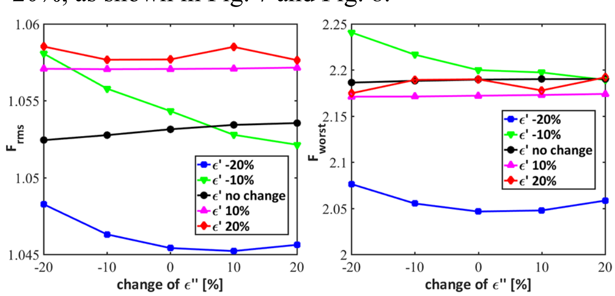

Figure 7: Wakefield suppression versus material properties of HOM loads.

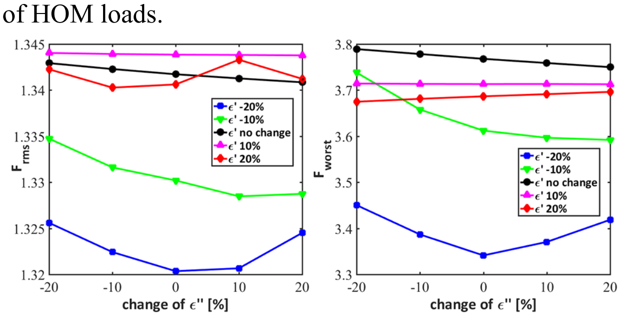

Figure 8: Wakefield suppression versus material properties of HOM loads including effect of the dipole mode frequency shift of ±1%.

Length of Tapering

Furthermore, an attempt to optimize the length of HOM loads was carried out. The dependence of the wakefield on the tapered length of HOM loads is illustrated in Fig. 9. The envelope of the wakefield at the third bunch (0.3 m) is very sensitive with the tapered length of HOM loads, which results in a larger F_{worst} with shorter HOM loads that does not meet the beam dynamics requirement.

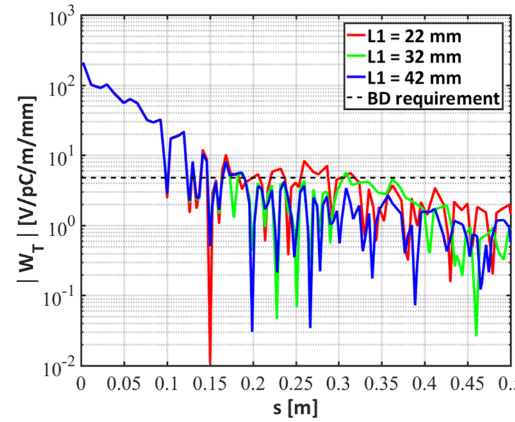

Figure 9: The envelope of transverse wakefield in CLIC-K with different tapered lengths of HOM loads.

CONCLUSION

The wakefield suppression in the main linac of the klystron-based first stage of CLIC at 380 GeV has been conducted to meet the beam dynamics requirements. The transverse long-range wakefield potential at the second bunch (0.15 m) was far better than the beam dynamics requirement. The results of HOM damping loads design showed good agreement with the results with PML boundary condition. The tolerance study of the material properties indicated that the wakefield suppression meets beam dynamics requirements even if the material proper-ties changed within ±20% and the frequency of the wake-field dipole mode shifts within ±1%. Moreover, the wake-field suppression is sensitive to the tapered length of HOM loads. Consequently, the geometry of the HOM loads in CLIC-K is kept same as the one optimized for 3 TeV accelerating structure CLIC-G*.

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ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB043

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