CONCEPTUAL DESIGN OF AN L-BAND RECIRCULATING SUPERCONDUCTING TRAVELING WAVE ACCELERATING STRUCTURE FOR ILC*

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Abstract

With this paper, we propose the conceptual design of a traveling wave accelerating structure for a superconducting accelerator. The overall goal is to study a traveling wave (TW) superconducting (SC) accelerating structure for ILC that allows an increased accelerating gradient and, therefore reduction of the length of the collider. The conceptual studies were performed in order to optimize the acceleration structure design by minimizing the surface fields inside the cavity of the structure, to make the design compatible with existing technology, and to determine the maximum achievable gain in the accelerating gradient.

The proposed solution considers RF feedback system redirecting the accelerating wave that passed through the superconducting traveling wave acceleration (STWA) section back to the input of the accelerating structure. The STWA structure has more cells per unit length than a TESLA structure but provides an accelerating gradient higher than a TESLA structure, consequently reducing the cost. In this paper, the STWA cell shape optimization, coupler cell design and feedback waveguide solution are considered. We also discuss the field flatness in the superconducting TW structure, the HOM modes and multipactor performance have been studied as well. The proposed TW structure design gives an overall 46% gain over the SW ILC structure if the 10 m long TW structure is employed.

INTRODUCTION

We have developed an accelerating structure for the ILC based on a high gradient STWA cavity that will allow higher acceleration gradients, a main goal of the superconducting accelerating community.

The STWA structure concept is described in [1-3]. In the present work, the results of further optimization of the TW structure geometry are discussed. The optimization was performed in order to achieve the maximum available accelerating gradient for the maximum cavity surface fields.

Although the basic idea of a superconducting TW resonant ring accelerator structure is in itself not new [4-7], there have not been any known and published attempts to apply this design to the ILC. A number of innovative ideas were required in the details of the technology in order to develop the TW design with parameters competitive with the current SW TESLA solution for ILC.

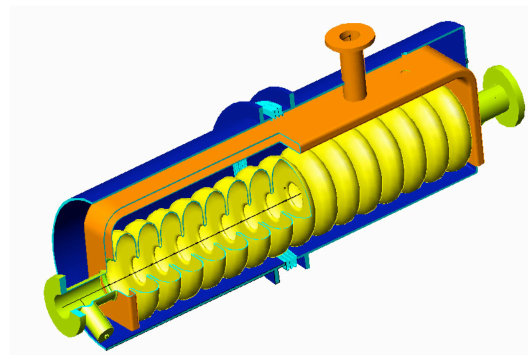

Figure 1: 15-cell SC TW structure with a waveguide inserted into the liquid helium volume.

Because of the limitations imposed by the critical magnetic field of a superconductor, SC accelerator technology is inherently "gradient challenged". Although the use of SC technology in linear collider applications has many attractive features, the average accelerating gradient obtainable in structures mass-produced by industry leads to a collider length and cost which is only marginally acceptable. If successful, the proposed STWA accelerating structure will have a strong impact in reducing the length and cost of the ILC.

CONCEPTUAL DESIGN

Shape Optimization

The cell shape in the SC traveling wave accelerating (STWA) structure presented in Fig. 1 has been optimized to reach the maximum accelerating gradient while keeping the magnitude of surface magnetic and electric fields less than the experimentally verified limits for superconductors. The magnitudes of the electric and magnetic fields demonstrated experimentally in the Re-Entrant shape cavity design for ILC [8] have been chosen as a reference. A STWA cavity with a 80 - 120 phase advance per cell has been studied, Taking into account the technological limitations on diaphragm thickness as well.

As mentioned above, the main limitation on the accelerating gradient is determined by the maximum magnitude of the surface magnetic field. Thus, the goal of accelerator structure optimization is in maximizing the accelerating gradient at a given surface magnetic field as a parameter. Two immediate and obvious conclusions may be obtained: (1) if the phase advance is not equal to 180 , a traveling wave should be used for acceleration, because

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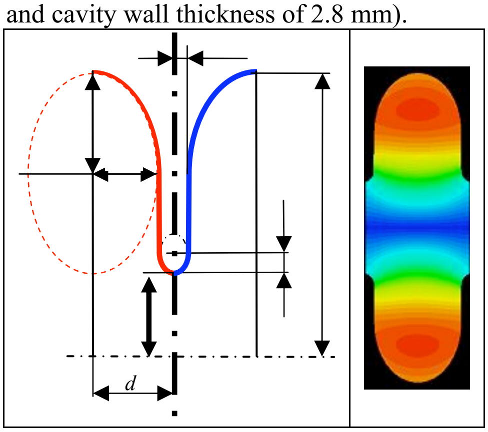
if the accelerating gradient is fixed the surface field of the standing wave is twice as high as those of the traveling wave propagating in the structure; (2) the phase advance per cell should be small enough to achieve the maximal gradient, because for small phase advances the transit time factor *T* is close to 1. From the point of view of the stability of the structure the most favorable phase advance should be about 90 . However, for a real structure the gain would be limited for two main reasons: (1) the aperture is 60 mm; (2) the coupling diaphragm thickness is 10.5 mm (thaning into account the welding by electron beams and cavity wall thickness of 2.8 mm).



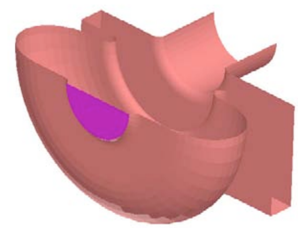
a b

Figure 2: Cell geometry of the superconducting TW accelerating (STWA) structure: (a) STWA structure cavity shape; (b) magnetic field distribution in the STWA cell.

In order to understand the maximum increase in the accelerating gradient, we compared the optimized traveling wave structure with the standing wave Re-Entrant structure, in which the previous record values of gradient have been achieved [9]. We considered the version of Re-Entrant structure having an aperture of 70 mm, where the gradient achieved was 54 MeV/m. Note that the Re-Entrant cavity with a 60 mm aperture demonstrated an even higher gradient of 59 MeV/m .

While optimizing the SC TW structure, we used the following evident constraints: (1) the structure should have the same surface magnetic rf fields as those of the 70 mm Re-Entrant structure; (2) the structure should exhibit a maximal surface RF electric field that does not exceed the field in the 70 mm Re-Entrant structure; (3) the diaphragm thickness should not be less than 10.5 mm.

Numerical simulations of the cell showed that with the limitations mentioned above, an optimal value of the phase advance per cell was found that provided the maximum accelerating gradient. The STWA cavity cell shape is presented in Fig.2. The maximal gain in accelerating gradient is of about 24% for a phase advance per cell in the range of 100-105 . A phase advance of 105 is preferable to 100 because of its smaller number of cells [3]. This advantage is an increased accelerating gradient to up to a factor 1.24 while maintaining the same Re-Entrant surface field enhancement parameters.



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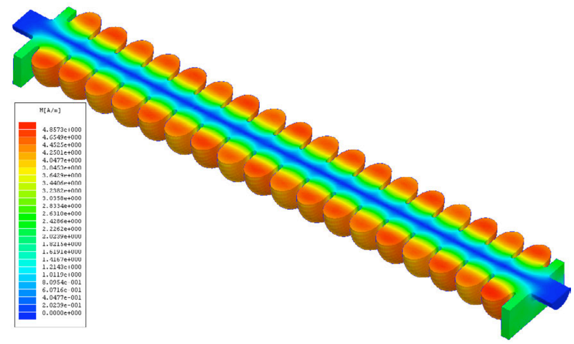

b)

Figure 3: a) Transverse cuts through the rectangular waveguide coupling section for the L-band SCTW accelerating structure, side view; b) Magnetic field of the 18-cell SCTW cavity with the optimized coupling section.

Rectangular Feedback Waveguide

The bends of the feedback waveguide have been studied with respect to additional field enhancements that could be developed by STWA structure feedback. A reasonable choice of waveguide parameters has been proposed: a waveguide height of 20 mm and internal bend radius of 40 mm have been chosen. This gives a field in the waveguide of about 65% of the maximal field in the structure and also allows the transverse size to satisfy the cryomodule dimension requirements. The reflection does not exceed -50 dB for the 40 mm bend radius.

Coupling Section Development

The design of the L-band coupling section for the SCTW accelerating cavity with a feedback waveguide is presented in Fig. 3. A rectangular waveguide type of coupling section has been chosen and the method of impedance boundary conditions has been used for the coupling section parameter optimization. Single cell, four-cell and 18-cell configurations have been considered. The optimized coupling section provides no field enhancement at the coupling cells and the feedback waveguide is 20 mm in width.

Field Flatness Studies

The field flatness parameters for SC SW and TW (105 and 90) 1-16 m long accelerating structures have been simulated. We have found that any SC traveling wave structure with length < 15 m will have a flatness better than the TESLA 1meter long cavity.

We define the flatness parameter as flatness= (max(E_s) - <E_s>)/<E_s>), where max(E_s) and <E_s> are the maximum and average values of the accelerating gradient in cavity cells. For the TESLA nine-cell cavity it is required that this parameter should be better than 5%. Frequency errors in each cell result in gradient variations along the structure. Flatness depends on cell-by-cell frequency errors, the coupling between cells k, and the number of cells in the structure.

After production the cell-to-cell frequency errors are typically too large to provide the required field flatness and the cavity is tuned to get the correct frequency and good field flatness (on the order of few %). But after the final chemistry, HPR, welding to the helium vessel, cool-down and frequency tuning in the cryostat we will also have uncontrolled changes in cell frequencies which will disturb the flatness.

The results of the flatness simulations are shown in Table 1. The flatness even in the 16 m long TW structure is better than in the 1 m long standing wave TESLA structure.

Table 1: Field flatness comparison for accelerating structures. N is the number of cells per unit length. The coupling coefficient *k* and relative frequency spread $\delta f/f$ are assumed to be the same in all cases.

	TESLA(180⁰)	STWA(105⁰)
Coupling (%)	1.88	3.344
N per 1 m	9	15
flatness(N, k, $\delta f/f$)	$1.05 \cdot N^{3/2} \cdot \left(\frac{\delta f / f}{k}\right)$	$1.3 \cdot N^{06} \cdot \left(\frac{\delta f / f}{k}\right)$
flatness(L_{cavity}= 1m)	5 %	0.65 %
flatness(L_{cavity}= 2m)	15.8 %	1.0 %
flatness(L_{cavity}= 4m)	30.5 %	1.5 %
flatness(L_{cavity}= 8m)	> 50 %	2.26 %
flatness(L_{cavity}= 16m)	-	3.42 %

Thus, the SC TW structure gives the possibility of considering a long STWA section that is limited only by the cryomodule length. This means that the effective accelerating gradient if a TW structure is employed can be increased by an additional 22% excluding the gaps between the short 9-cell cavities [3] and giving an overall 46% gain over the SW ILC structure (see *Shape Optimization* section above).

Modeling of the Traveling Wave Regime

A theoretical model [10] of the STWA structure including feedback and input couplers is being developed and tested. The model includes beam loading effects, and allows analysis of tuning, tolerance requirements and beam loading. It was found that the most flexible and stable scheme of the structure excitation is the two-coupler scheme [11], where the input couplers excite independently the two orthogonal standing waves that comprise the resulting traveling wave.

Multipactoring Performance

Multipactoring performance for the SC traveling wave accelerating (STWA) structure has been studied. For 90° and 105° phase advance per cell modes, no multipacting was found at least for peak surface electric field magnitudes up to 100 MV/m, i.e., E_{acc}=52.8 MV/m (90°) and 51.6 MV/m (105°). Some resonant trajectories have been found around the equatorial region. Those trajectories do not correspond to multipacting as long as the impact energy is too low or too high for it development. There is no secondary electron yield generated at these impact energy levels.

High Order Modes (HOM)

High Order Modes of the SC traveling wave accelerating structure (STWA) have been considered. In SW cavities some modes are "trapped" inside the structure: the fields in the end cavities are too small to provide a good coupling of these modes to an external load. This coupler is a wide-band device that provides small reflections for higher-order dipole modes. This means that there are no trapped modes in this pass band, and one can damp HOMs using external dampers coupled to the structure. The dispersion curves of the six lowest transverse (dipole) modes have been simulated. No trapped modes were found in the frequency domain up to 3.5 GHz.

CONCLUSION

A conceptual design of the SC TW accelerating structure was discussed. This structure allows an increased accelerating gradient by a factor 1.24 while maintaining the same the Re-Entrant cavity surface field ratios. The proposed TW structure does not have field flatness limitations as do the SW designs. The STWA structure gives the possibility of considering a long TW section limited by the cryomodule length. The effective accelerating gradient can be increased then by 22%, giving an overall 46% gain over the SW ILC structure.

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