FERMILAB-CONF-07-253-TD

PROGRESS TOWARDS OF A SUPERCONDUCTING TRAVELING WAVE ACCELERATING STRUCTURE*

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Abstract

In the ILC project the required accelerating gradient is higher than 30 MeV/m. For current technology the maximum acceleration gradient in SC structures is determined mainly by the value of the surface RF magnetic field. In order to increase the gradient, the RF magnetic field is distributed homogeneously over the cavity surface (low-loss structure), and coupling to the beam is improved by introducing aperture "noses" (re-entrant structure). These features allow gradients in excess of 50 MeV/m to be obtained for a singe-cell cavity. Further improvement of the coupling to the beam may be achieved by using a TW SC structure with small phase advance per cell. We have demonstrated that an additional gradient increase by up to 46% may be possible if a π/2 TW SC structure is employed. However, a TW SC structure requires a SC feedback waveguide to return the few GW of circulating RF power from the structure output back to the structure input. The test cavity with the feedback is designed to demonstrate the possibility of achieving a significantly higher gradient than existing SC structures.

INTRODUCTION

The most serious problem of ILC is its high cost, resulting in part from the enormous length of the collider. This length is determined mainly by the achievable accelerating gradient in the RF system of the ILC. In turn, the accelerating gradient in a SC structure is limited mainly by quench, i.e, by the maximum surface RF magnetic field [1]. The following techniques have been developed to increase the gradient: (1) development of surface processing in order to avoid the field enhancement caused by surface microstructure. A recently developed electro-polishing technique [2] permits micro-tips only less than 0.1 micrometers [2]; (2) Improvement of niobium material. For example, large grain and mono-crystal materials are currently considered [3]; (3) improvement of the structure shape in order to decrease the surface magnetic field for a given accelerating gradient. There are two ways to decrease the magnetic field: (1) develop a homogeneous magnetic field distribution over the cavity surface (Low-Loss structure [4], Ichiro structure [4], and Re-Entrant structure [5,7]); (2) improvement of the beam interaction with the structure like increasing the transient time factor (Re-Entrant structure [5,7]). The maximum gradient achieved in the one-cell cavity is 54 MeV/m for an aperture of 70 mm [5] and 59 MeV/m for 60 mm [6].

SW and TW Designs for ILC, Pros and Cons.

Standing Wave (SW) SC 9-cell RF cavities are planned to be used in the ILC Main Linac. The phase advance per cell in this design is π, but a SW π-structure has the following limitations:

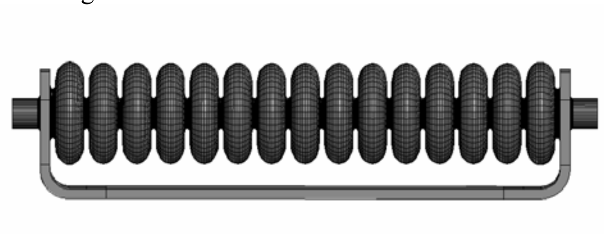

Figure 1. Schematic of an example of a traveling wave structure with a feedback waveguide and feedback couplers. The input coupler is not shown.

(a) *Transit Time*. is the SW structure has a quite small transit time factor T ($T=E_{accel}/E_{average}$, E_{accel} – acceleration gradient, $E_{average}$ – average field over the cell gap). Note that if the acceleration gradient is limited by the maximum surface RF magnetic field, $E_{accel} \sim T$. The higher T is, the higher is the acceleration gradient. For the SW π-type structure $T \sim 0.7$;

(b) *Stability.* Poor SW structure stability of the field distribution to small geometrical perturbations: $\delta E \sim \delta f/k \times N^2$, where δE is the maximal field perturbation, δf is the cell resonance frequency perturbation, k is the coupling coefficient, and N is the number of cells. Note the strong (quadratic) increase of the field perturbation with the number of cells. Therefore, the filed perturbation gives the field enhancement in the structure and limits the acceleration gradient; the field perturbation limits the number of the cells in the structure leading in turn to a small structure length (9 cells for ILC); the SW structure requires a great number of input couplers and HOM dampers; a large number of gaps between the structures resulting in a significant decrease in the effective acceleration gradient.

(c) *Trapped modes.* If all the cells of the structure have the same length, the field at the end cells is the same as in the regular cells for the operating mode only. For all other modes the maximum field can appear not at the end cells of the structure, but at the interior cells. This causes the field magnitude in the end cells to be rather small, preventing high-order mode (HOM) extraction – the so-called trapped modes.

*Work supported by US Department of Energy

(d) *Input coupling transverse kick.* Recently the significant beam-coupler transverse kick problem in the input couplers of the current SW structure design has been identified. Note the great number of input couplers that are required for the SW TESLA-like concept implementation.

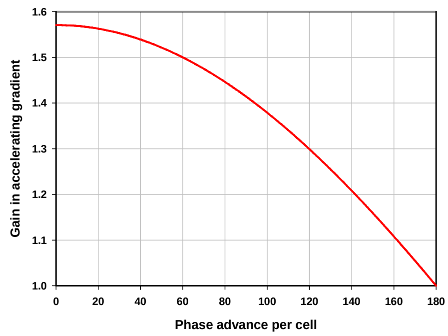

Figure 2. The gain in the accelerating gradient of the traveling wave accelerating structure compared to a standing wave π-structure versus the phase advance per cell for the ideal case. For π/2 the gain is √2, or 42%.

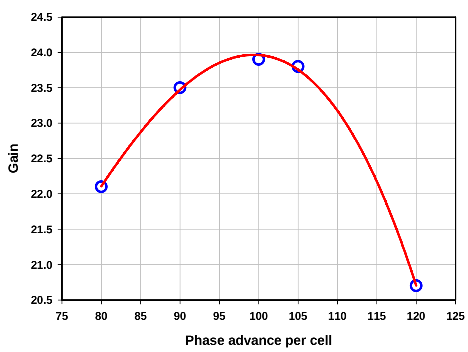

Figure 3. The gain in accelerating gradient versus phase advance per cell. The aperture is 60 mm, and the diaphragm thickness is chosen to be not less than 11.5 mm.

An alternative approach is a superconducting traveling wave acceleration structure (STWA). Recently a SC Traveling Wave Accelerating structure with feedback waveguide intended for ILC applications has been suggested [8,9]. The STWA structure schematic is presented in Fig. 1.

GRADIENT IN A SC TW ACCELERATING STRUCTURE.

The original idea of using feedback in conjunction with a traveling-wave linear accelerator was proposed by R.-Shersby-Harvie and Mullett [10] in 1949. Recent research developments on a "warm" TW accelerator with an rf feedback waveguide system are presented in the paper by Dr. J. Haimson [11], Initially the superconducting traveling-wave accelerator with feedback was considered in [12], where the advantages of the TW accelerating scheme with feedback over the conventional SW SC systems were noted and discussed.

The proposed SCTW structure possesses the following benefits in comparison with the standing wave design:
a) Higher transit time factor (T~1), higher acceleration gradient at the same surface RF magnetic field magnitude in comparison with SW designs. For an ideal structure with a small aperture $T \sim \sin(\varphi/2)/(\varphi/2)$ (φ is the phase advance per cell) the acceleration gradient increase compared to the SW π -structure is then

$$Gain = E\varphi/E\pi = (2/\varphi)\times\sin(\varphi/2) \quad (1) \quad ;$$

The gain in the accelerating gradient of the *ideal* π/2 traveling wave accelerating structure is 42% in comparison with the SW design, Fig. 2.
b) High stability of the field distribution along the structure with respect to geometrical perturbations. This allows (1) a much longer structure length up to the length of a cryostat (~10 m); (2) much fewer input couplers, up to two couplers per cryostat; (3) no gaps between short cavities, giving an additional effective gradient;
c) the TW structure has no trapped modes for the lower dipole mode pass band. Only two HOM dampers per a long TW structure are required.
d) the transverse kick caused by the input and HOM couplers is not an issue for a long TW structure, because the number of the couplers is small. In addition, the couplers may be optimized in order to minimize the transverse kick.

Note, in the case of breakdown the SC TW structure with feedback demonstrates the same behavior as the SW structure i.e., while at breakdown the power from the source is reflected back from the structure, it is not dissipated in the structure destroying the niobium walls [13].

Meanwhile, employing the SC TW design has some significant pay-offs: (1) a STWA has negligibly small RF field attenuation, and thus, use of high power feedback is necessary. The corresponding technology to fabricate and process the longer SC structure with a feedback waveguide needs to be developed; (2) a high-power coupler should be designed to feed a long SC TW structure.

The most favorable phase advance per cell from the point of view of stability is about 90°. However, for a real structure the gain would be limited for two main reasons: (1) the aperture needs to be large enough in order to provide an acceptably low magnitude of the transverse wake field. For ILC applications the aperture diameter is 60 mm; (2) the coupling diaphragm thickness is limited to satisfy the requirements of diaphragm welding by electron beams. The distance between the cavity walls should not be less than 5 mm wide. Taking into account the thickness of the cavity wall (2.8 mm), one can conclude that the diaphragm thickness should not be less than ~10.5 mm. This gives the optimal phase advance of 105°.

The SC TW structure is a result of compromise between electrodynamic properties and technological feasibility, and has a phase advance per cell of 105°, Fig. 3. It allows an increased transit time factor and finally, a maximum gradient that is 24% higher than those of the Re-Entrant structure, Fig. 4. The proposed superconducting TW cell is about half the length of the SW cavities currently being developed for the ILC.

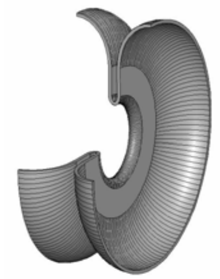

Figure 4. Optimized shape of the SC traveling wave accelerating structure with a phase advance of 105° per cell.

The STWA structure has an additional benefit in that it can be much longer than the SW structure. In the SW structure the length is limited by the strong sensitivity of the field flatness along the structure to dimension errors. The errors lead to a field distribution deviation from cell to cell and thus cause surface field enhancements. In the current TESLA and ILC designs the length of SW structure is limited to 1 m. As a result, there is an unavoidable space (gap) between 1 m long structures of about 280 mm [1] that reduces the effective gradient by about 22 %. The TW structure has no such fundamental limitation and the length of STWA structure can be up to the length of cryomodule (10 m) if the technology of the SC cavity fabrication and surface processing allows it. This means that the effective accelerating gradient if a TW structure is employed can be increased by up to 22%, giving an overall 46% gain over the SW ILC structure. Note that if the technology allows a length of 10 m, the total length of both accelerators will be 46% less in comparison with the currently accepted design, i.e. 15 km instead of 22 km. The number of structures will be ~14 times less than for SW ILC structures, the number of input couplers will be reduced 7-14 times as well depending on the excitation scheme, and the power distribution system will be much simpler than that in the current ILC design. That in turn will give significant overall cost reduction for the International Linear Collider.

Our collaboration has completed the following studies of the proposed SC traveling wave structure [8,14,15]: (1) optimization of the STWA structure cell in order to minimize surface magnetic field without sacrificing surface RF field on the aperture [14]; (2) optimization of the end coupler that couples the structure to the feedback waveguide [14]; (3) optimization of the feedback waveguide parameters [14]; (4) investigation of stability of the structure to geometrical perturbations and determination of the maximal structure length [14,15]; (5) TW regime studies and backward wave reduction, tuning ranges [15]; (6) investigation of possible dipole mode trapping in the structure; (7) multipactoring performance studies; (8) preliminary engineering design of the structure [14]. We have developed a strategy for structure development and proposed a single-cell cavity design with a feedback waveguide for preliminary high gradient tests.

CONCLUSION

A Superconducting Traveling Wave Accelerating (STWA) structure is suggested for the Main Linac of the ILC. The STWA structure has crucial advantages in comparison with the standing wave designs (SW) like the recently developed Re-Entrant cavity that in turn has significant advantages over the 9-cell TESLA cavity. This advantage is an increased accelerating gradient to up to a factor 1.24 while maintaining the same magnetic and electrical surface field ratios E_{peac}/E_{acc} and B_{peak}/E_{acc} as the Re-Entrant cavity. Furthermore, the proposed SC TW acceleration method will provide accelerating parameters that allow much longer accelerating structures to be built, also critical for the effective gradient enhancement. The length of the SW accelerating structure is limited by the strong sensitivity of the field flatness along the structure to dimension errors. The proposed TW structure does not have this limitation. If manufacturing and surface processing technology allow, the STWA structure is a strong candidate technology for a 10 m 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 22%, giving an overall 46% gain over the SW ILC structure. The proposed modification will result in a total accelerating structure length reduction by a factor of 1.46.

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