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Optimisation of the new low surface field accelerating structure for the ILC

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ABSTRACT

The main superconducting radio frequency (SRF) linacs of the international linear collider (ILC) operate at a frequency of 1.3 GHz with a π phase advance per cell in the standing wave mode. An option being considered to reduce the overall footprint and project cost is to enhance the cavity gradient. The present baseline design for the main linacs of ILC demands the cavities to be able to reach a gradient of 35 MV/m—although during commissioning and operation the gradient will be 31.5 MV/m. This research concerns itself with the new cavity design with a view to reaching higher gradients. This design is focussed on minimising the surface electromagnetic fields and maximising the bandwidth of the accelerating mode. This new shape, which is referred to as the New Low Surface Field (NLSF) design. A design of a complete nine-cell cavity, including power couplers and higher order mode damping couplers is presented.

1. Introduction

The ILC is designed to collide electrons and their antiparticle, positrons, at an initial centre of mass energy of 500 GeV with an option to upgrade to 1 TeV [1]. In contrast to the LHC where collision between protons at a centre of mass energy of 14 TeV, the ILC will provide good signal to background ratio, which will allow precision measurement of the physics of the interaction. The ILC accelerator is based on 1.3 GHz SRF accelerating cavities. More than 17,000 of these cavities are needed for the ILC. The use of SRF technology was recommended by the International Technology Recommendation Panel (ITRP) in August 2004 [2]. The ILC SRF linac technology was pioneered by the TESLA collaboration in a proposal for a 500 GeV centre of mass energy linear collider in 2001 [3]. The current baseline assumes an average accelerating gradient of 31.5 MV/m—requiring a minimum of 35 MV/m gradient during mass production vertical testing. The TESLA cavity has been chosen as the baseline design for the ILC project. This is illustrated in Fig. 1 [4]. However, other new cavity shapes have recently also been designed.

Alternative cavity shapes and materials are being studied in order to reduce the cost of fabrication and to achieve higher gradients. Higher gradients can be reached by changing the shape of cavity cell walls in such a way that the magnetic flux on the wall is reduced and the electric field is also reduced to acceptable levels. The enhanced surface electric field gives rise to field emission of electrons and can lead to electron capture in the field of the accelerating cavities. The magnetic field causes heat dissipation on the surface of the cavity, which can lead to a quench—a rapid change in state from superconducting (SC) to resistive. The maximum achievable accelerating gradient (E_a) of SC cavity is limited by the maximum magnetic (B_s) and surface electric (E_s) fields which can be sustained on the walls. These maximum surface fields are dependent on the cavity geometry, detailed surface morphology, and vacuum conditions. In designing a new shape, the ratios: E_s/E_a and B_s/E_a are important parameters. Another criterion is the fractional bandwidth of the accelerating mode, $\kappa_c \approx (\omega_\pi - \omega_0)/\omega_{\pi/2}$ (where $\omega_\pi/2\pi$ is the π mode frequency). This represents the sensitivity of the cavity mode frequency to cell fabrication errors and also controls the frequency separation of other modes with respect to the accelerating mode. So far only a single cell of the new alternative cavity designs have been tested and achieved high gradients up to 50 MV/m. At Cornell University this has been experimentally tested with a Reentrant (RE) shape [5]. At DESY it has been achieved with a Low loss (LL) shape, and at KEK with a Ichiro shape [6]. However, it still remains a challenge to mass produce cavities which will achieve the desired yield for nine-cell cavities of 35 MV/m gradient.

The intrinsic rf critical magnetic field (B_c) is the limit of B_s. It is at the point the material loses its superconductivity. The limit of E_s is determined from the field emission within the cavity. For a niobium cavity B_c lies in the range 180 mT to 230 mT [7] and the E_s restricted to ~100 MV/m [8–11]. Single cell cavities have achieved larger surface fields than the current multi-cell cavity values.

The paper is structured such that the next section presents an optimisation to obtain the new low surface field structure, which has both the surface fields minimise whilst maintaining the

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fundamental mode bandwidth. This is followed by and wakefields study and a design of fundamental power coupler. The final sections provide details on a means to couple out the higher order modes and some concluding remarks.

2. NLSF cavity optimisation

The NLSF cavity is designed to optimise the surface fields and has a slightly larger bandwidth compared to the existing cavity designs for the ILC. This section provides detailed optimisation of this cavity. SuperFish [12] was used as the main field solver, to facilitate rapid cavity design, for calculating the accelerating frequency and the surface fields. The 3 D finite element code HFSS [13] was subsequently used to validate these optimised designs. To expedite the simulation procedure, a Mathematica [14] code was written to provide a front-end to the SuperFish simulations. A Mathematica front-end controls SuperFish to obtain the cell geometry and figures of merit. These geometries were also simulated in HFSS in order to validate the results. The simulation results obtained using SuperFish are within $\pm 1.5\%$ of the HFSS simulation results. The rms of the error in κ_c is less than 0.5%, and 7% and 1.5% for E_s/E_a and B_s/E_a, respectively. A comparison of the HFSS and SuperFish results for several cavity shapes is presented in Table 1.

A generic geometrical cavity shape is displayed in Fig. 2. Optimisation of this shape is based on the criteria that the surface fields are minimised and the accelerating bandwidth is maintained: $\kappa_c > 1.5\%$, $E_s/E_a \sim 2.00$, and $B_s/E_a < 3.80$. Eight parameters are varied: L, θ, R_{eq}, R_i, A, B, a, and b. In the TM_{010} cavity case, for the π mode operating at a frequency of 1.3 GHz, the cavity gap length is fixed at $L = 115.304$ mm. The optimisation was conducted on the Low loss-like shape with a wall angle $\theta = 0$ and equator radius $R_{eq} = 98.58$ mm. There are two reasons behind this; (i) the properties of the Low loss shape, which was previously optimised based on minimising the surface magnetic field, whilst relaxing the minimal allowed surface electric field and (ii) setting the wall to be vertical ($\theta = 0$) allows the cavity to be easily cleaned and water rinsed. Later on, the optimisation was also extended for both positive and negative wall angles. With a fixed wall angle, the equator parameter A depends on the iris parameter a: $A = (L/2) - a$ for $\theta = 0$. If the iris radius is fixed there are two parameters: a, and b, free to use in the optimisation process, since the equator parameter B is used for tuning the frequency. This can be conceived as a series of parameter regions as illustrated in Fig. 3.

In Fig. 3 for any given iris radius there will be two parameters that are free to be varied in order to obtain the optimal design. The results of this procedure can be compared with those for other iris radii to find the best design, which satisfies all criteria.

The iris radius R_i, determines the concentration of the accelerating field along the cavity axis and hence the efficiency of the cavity. The present Low loss and Ichiro shape is designed with a 30 mm iris radius whereas the iris radius of the TESLA shape is

Fig. 1. TESLA nine-cell SRF cavity (Courtesy DESY [4]).

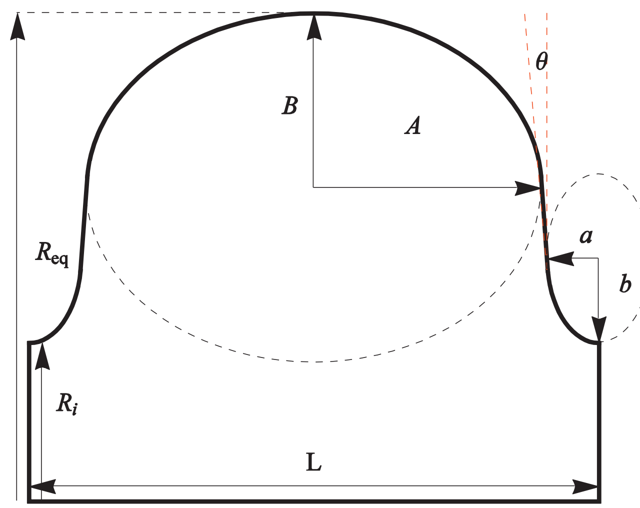

Fig. 2. A generic SRF cavity's geometry.

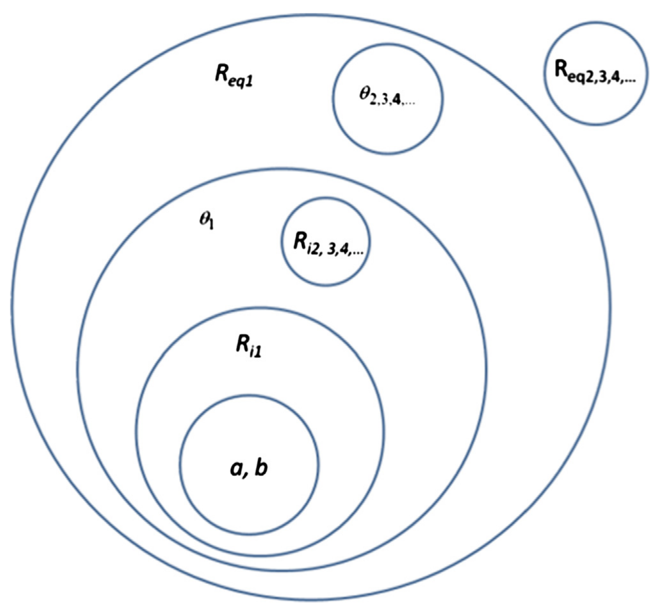

Fig. 3. Optimisation parameter regions for the NLSF cavity.

Table 1
Three figures of merit for proposed high gradient ILC cavities.

Parameters	TESLA		LL		Ichiro	
	HFSS	SF	HFSS	SF	HFSS	SF
κ_c [%]	1.89	1.89	1.53	1.53	1.54	1.54
E_s/E_a	2.18	2.02	2.42	2.30	2.37	2.29
B_s/E_a [mT/(Mv/m)]	4.18	4.17	3.64	3.61	3.62	3.61
f_π [MHz]	1301.16	1301.06	1300.08	1299.97	1300.40	1300.31