A NEW OPTION TO INCREASE ACCELERATING RATE BY 30 % FOR ILC UPGRADE

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Abstract

The proposed way to increase the accelerating rate of a cavity consists in adding the third harmonic to the fundamental accelerating field. For this purpose, the shape of the cells is changed so that the frequency of one of the higher order modes is shifted to become the multiple of the fundamental mode. Preliminary calculations show that the accelerating gradient can be increased by several tens percent with the same or lower surface electric and magnetic fields as for the TESLA cavity geometry.

INTRODUCTION

The shape of the TESLA cavity cells is carefully optimized to obtain maximal accelerating rate for a given magnetic and electric fields on the surface. Some improvements of the shape have been proposed [1]. Such approaches yield 10 – 15 % improvement in gradient potential depending on the features that are compromised, such as aperture or surface electric field. Another possibility to increase the accelerating rate is the "sliding phase structure" when the length of the cell is several percent longer and the lost of acceleration due to the "wrong" cell length is compensated for a few percent gain by better optimized shape of these cells [2]. The investment level in the present cavities is so big that it is doubtful that the shape of the present cells will be changed for small gains. Only an appreciable increase of accelerating rate in several tens percents can make possible to change the mature scheme of acceleration. Here a new approach to increase the accelerating rate is proposed. However it requires considerable development and so would only be suitable option for 1 TeV upgrade.

INFLUENCE OF TRANSIT TIME FACTOR

The transit time factor decreases the effect of applied RF voltage on the accelerated beam. To obtain maximal acceleration, the maximum of the sinusoidal field is usually applied to the bunch of particles when it appears in the middle of the cell. We consider the case of the π-mode that is used for the standing wave structure of TESLA. When the bunch goes to the end of the cell (or enters the cell) the field decreases (increases) sinusoidally with time. Moreover, even at the moment of its maximum the field is going to zero at the both ends of the cell. It would be helpful if the field is big enough even when the bunch is close to the cell ends. This can be accomplished by admixture of modes with multiple frequencies to the fundamental mode.

MODES OF THE ACCELERATING CELL

The frequencies of eigenmodes of the cavity are not multiple numbers in a general case. As an example, frequencies of the first axially symmetric TM-modes of the regular TESLA cell are shown in Table 1, the force lines of these modes are shown in Fig. 1. Because of symmetry, only halves of the cells are shown. The fundamental π-mode with a frequency f = 1300 MHz has a "magnetic wall" boundary condition on the iris end. For our purpose to find the best mode to admix we can include in consideration modes with an "electric wall" on the iris plane alike the 0-mode. Modes with the magnetic wall at the iris plane are shown in the upper row; modes with the electric wall are in the lower row of Fig. 1. We can try to shift the frequency of some mode to obtain an odd multiple of the fundamental mode frequency so that it can be admixed to the fundamental mode giving additional acceleration.

Table 1: Frequencies of the TESLA regular cells lowest TM axially symmetric modes, MHz

Modes with magnetic wall in the middle iris plane	Modes with electric wall in the middle iris plane
1300.0 (fundamental, π-mode)	1275.7 (0-mode)
2774.4	2672.0
3857.8	3757.3
4237.7	3919.0
4892.9	4723.4

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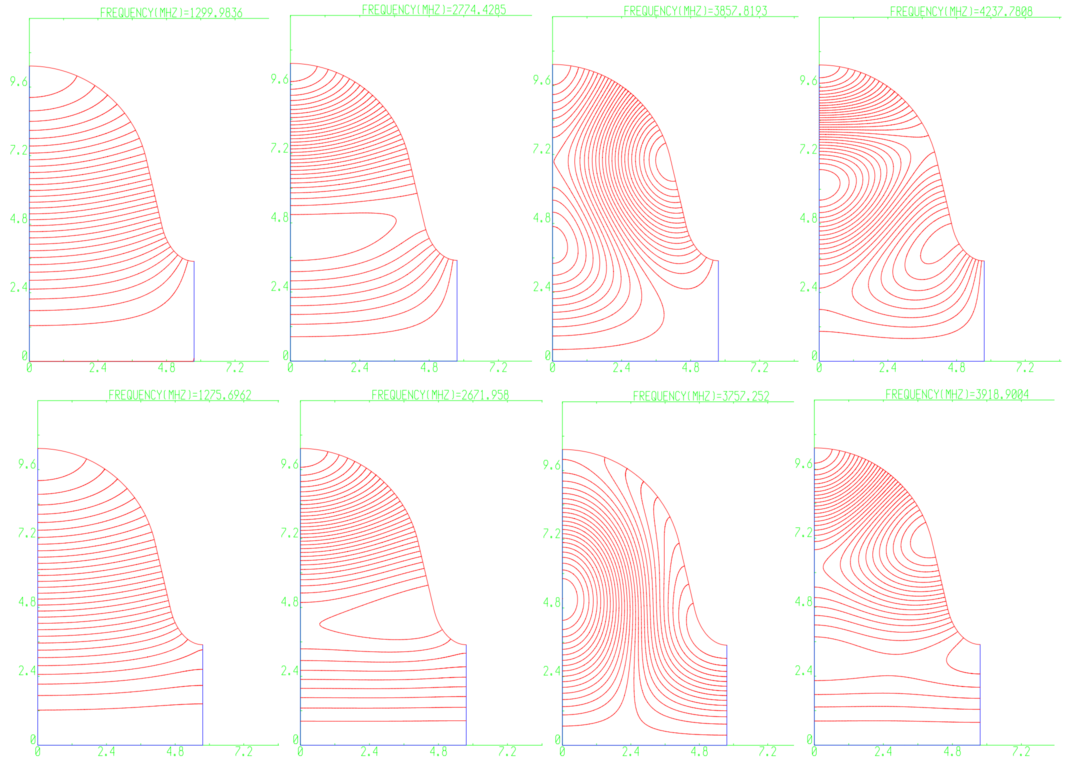

Fig. 1: Lowest axially symmetric TM modes of the TESLA regular cells.

The goal of adding the higher mode for acceleration is to decrease the values of E_{pk}/E_{acc} and H_{pk}/E_{acc} when the averaged accelerating field on the axis E_{acc} and peak electric and magnetic fields on the surface E_{pk} and H_{pk} are obtained as a combination of two different modes. We will consider the combination of the fundamental and the mode with three times higher frequency. No one mode in Fig. 1 has frequency of 3900 MHz. However, we can try to tune any one of these modes to this frequency changing the geometric parameters of the cell.

Certainly, it can be a hard task or impossible to tune the mode if its frequency is too far from the desired one. Usage of the modes from the upper row will not change the decreasing electric fields near the cell margins. So, it appears preferable to tune modes with frequencies 3757 or 3919 MHz for our purpose. The last one is the nearest mode to the desired frequency but the mode with two variations along the *z*-axis (3757) can be phased so that it has no deceleration field.

THE MODE WITH A VARIATION ON THE *Z*-AXIS

The mode with f = 3757 MHz can accelerate the beam on both parts of the shown axis line: when the bunch comes to the point near z = 2.4 cm (see the third mode in the lower row, Fig. 1) the electric field of this mode changes its sign and becomes accelerating again. The shape of the cell and electric force lines of this mode after tuning to the triple frequency of 3900 MHz are shown in Fig. 2. The field that acts on the bunch on the cavity axis is shown in Fig. 3. Because of symmetry, the fields are presented on the interval from the middle plane of the cell to its end. The phases of the fields are taken those that both electric fields (fundamental and harmonic) have their maxima at the same moment of time; magnetic fields will be shifted by phase $\pi/2$ relative to corresponding electric fields and by phase π between each other at the moment when the fundamental magnetic field is maximal:

$$E_a = E_{a1}\cos\theta + M\cdot E_{a3}\cos 3\theta,$$
$$E_s = E_{s1}\cos\theta + M\cdot E_{s3}\cos 3\theta,$$
$$H_a = H_{a1}\sin\theta + M\cdot H_{a3}\sin 3\theta,$$
$$H_s = H_{s1}\sin\theta + M\cdot H_{s3}\sin 3\theta.$$

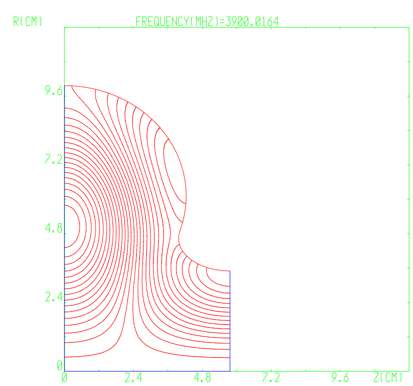

Fig. 2: The shape of the cell and electric force lines after tuning.

Here indices a and s correspond to fields on the axis and on the surface, respectively, 1 and 3 correspond to frequencies, and M is a relative amplitude of the admixed mode. Functions $E_{a1}(z), E_{a3}(z), E_{s1}(L), E_{s3}(L)$ and same for the magnetic field were found with SLANS code [3]. The values of them correspond to energy of 1mJ in each mode. z is a distance from the middle plane along the axis; L is distance from the cell equator along the profile line. The value of M was fitted so that the value of H_{pk}/E_{acc} was minimal. It appeared that the value of E_{pk}/E_{acc} was also improved in comparison to TESLA cells. For the surface fields, it was taken into account that functions of the form

$$f(\theta) = A\cos\theta + B\cos 3\theta,$$

$$g(\theta) = C\sin\theta + D\sin 3\theta$$

can have their extrema not only at the ends of the interval $[0, \pi/2]$ of values θ but also at the phases

$$\theta_c = 0.5\arccos\sqrt{1-\frac{A}{3B}} \text{ or } \theta_s = 0.5\arccos\sqrt{3-\frac{C}{3D}},$$

respectively. This correction, however, didn't change substantially the shape of the surface field graphs. Maximal electric and magnetic fields for the whole period of oscillations are shown in Fig. 4. The peak surface magnetic field is achieved at phase of $\pi/2$ when the component $M \cdot H_{s3}$ is multiplied by $\sin(3\pi/2) = -1$ and should be *subtracted* from the component H_{s1}. The peak surface electric field is achieved at phase 0 on the curve that is *the sum* of both components: E_{s1} and $M \cdot E_{s3}$.

The task of optimization is to decrease the value H_{pk}/E_{acc} as much as possible changing 4 geometric parameters of the cell: half-axes of ellipses that define the cell, keeping the frequencies of two modes equal to 1300 and 3900 MHz, and fitting the relative amplitude M minimizing this value. It is not a fast procedure so we can not say now that the best possible value is obtained. However, for the presented shape, Fig. 2, the ratio H_{pk}/E_{acc} was obtained equal to 32.2 Oe/MV/m *i.e.* 1.30 times smaller than TESLA cells have. The value of E_{pk}/E_{acc} was also improved by 1.3 (as nearly as good as a pill-box cavity with no beam holes!). For this shape, $M = 0.65$. Results of presented optimization are not final and there is a possibility to improve the declared value. The shape shown in Fig.2 consists of two conjugated elliptic arcs whereas the TESLA cell consists of two arcs,

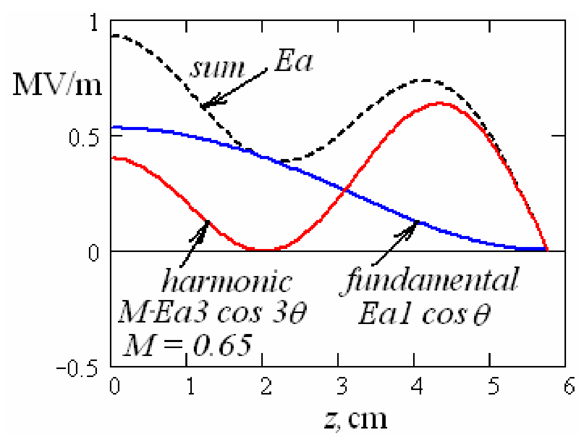

Fig. 3: Acting electric fields on the axis.

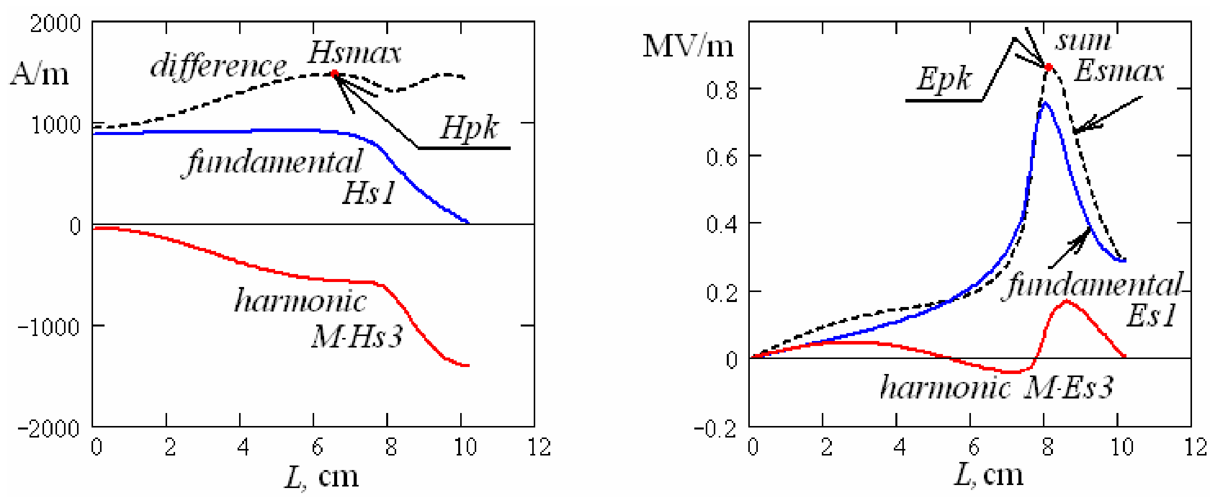

Fig. 4: Maximal fields on the surface along the profile line.

circular and elliptic, and a straight segment between them. Dependence of obtainable increase in the two-elliptic geometry on the ellipse parameters is shown in Fig. 5. A stands for the bigger and a for the smaller ellipse horizontal half-axis. The coordinate $4A + a$ is chosen for the graph axis to make the graph more compact.

CHALLENGES OF 2*f*-CAVITY

The cavity with 2 working modes with different frequencies (or 2*f*-cavity) calls for solving several problems. Fortunately there is time as this an option to be developed for the 1 GeV upgrade. First of all both frequencies should be strictly phased. This can be achieved by obtaining the higher order mode by frequency multiplication of the fundamental one. Good mode separation must be achieved. Fig. 5 shows very narrow limits for the cavity dimensions. So, high accuracy and independent tuning of two modes is needed. To obtain the non-propagating regime in the beampipes, the chokes on both sides of the cavity must be used. There are no programs for calculations of multipacting in a cavity with 2 frequencies. It is known that grouping the multipacting electrons in a complex geometry is difficult; however we need to check the analogous statement about composition of 2 harmonics. On the other hand, there are no visible problems to expand the existing multipactor codes for calculations with 2 frequencies. We have to calculate dissipated power which is going to be higher because 3rd harmonic losses increase like f^2, but losses are not just a sum of losses of each harmonic. The impact of mode-mixing on emittance growth and energy spread is to be evaluated. The flatness of field in the cells of a cavity is a limiting factor for maximal number of cells. However, cell-to-cell coupling of the third harmonic is much better than of the fundamental mode and should not be an additional obstacle. The shape of 2*f*-cavity is reentrant. Such a shape is more intricate in fabrication and treatment, now the work on fabrication of a reentrant SC cavity is in progress in our laboratory [4] and these problems are being solved.

CONCLUSIONS

A new type of accelerating cavity is proposed: the cavity with two accelerating modes having multiple frequencies. It is shown that the shape of cavity cells can be found such that this approach can be realized. There are some problems to be solved for realization of this proposal. It is believed that further optimization is possible and the declared value of 30 % increase of the acceleration rate in comparison with the TESLA existing cells is not a limit. Realization of this proposal can significantly decrease the length of the future linear collider or substantially increase its final energy.

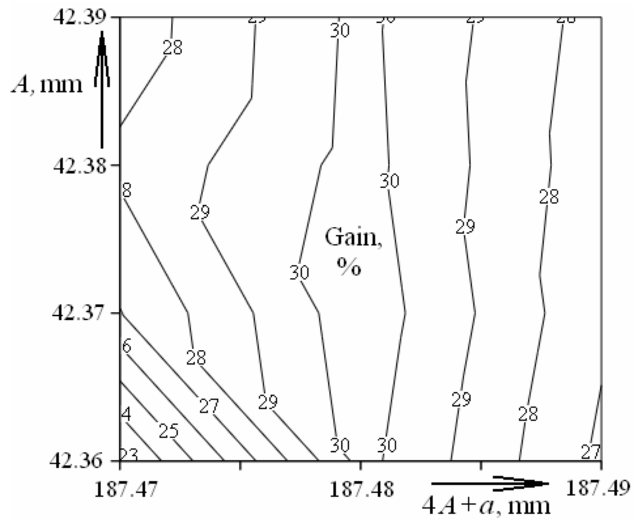

Fig. 5. Achievable increase in accelerating rate with two working modes for geometry of two conjugated elliptic arcs.

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