Design Study on Quasi-Constant Gradient Accelerator Structure*

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1. INTRODUCTION

In order to obtain high luminosity, the Next Linear Collider will operate in multibunch mode with ten or more bunches per bunch train. This leads to the need for detuning and/or damping of higher modes to control multibunch beam breakup [1]. Continued studies of wake fields for a detuned structure with a Gaussian distribution of dipole modes showed encouraging results [2], and a detuned structure model has been tested experimentally [3]. It is desirable to study the design method for this type of structure, which has a quasi-constant accelerating gradient. This note gives a brief summary of the design procedure. Also, the RF parameters of the structure are evaluated to compare with conventional constant gradient and constant impedance structures.

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2. FEASIBILITY OF DESIGN

It has been shown by using computer codes (TRANSVRS [4], URMEL [5]) that increasing the cavity diameter $2b$ causes both the accelerating mode frequency f_0 and the first dipole mode frequency f_1 to increase, while increasing the iris diameter $2a$ leads to a decreased accelerating mode frequency and an increased first dipole mode frequency. This contradictory behavior is summarized in a three-dimensional plot shown in Fig. 1. It can be clearly seen that keeping the frequency of the accelerating mode constant yields one set of a, b pairs. Each of these a, b pairs corresponds to a different dipole mode frequency. Joining them gives a curve with the steepest slope, which means the highest detuning gradient. If a certain detuning range of the dipole modes is given, clearly the two end pairs of a, b for the accelerator section can be found. It is always possible to find a unique a, b pair to let the dipole mode frequency be any value between the frequencies of the first and last cavities, and also to keep the frequency of the accelerating mode constant.

3. DESIGN PROCEDURE

Following is a summary of the design steps. Notice that the numbers given in brackets are the design values actually used.

1. For a given operating frequency ($f_0 = 11.424$ GHz) and phase shift ($\phi = 2\pi/3$) of the accelerating mode, the a, b pairs can be found by using computer codes, e.g., KN7C [6]. The result is shown in Fig. 2.
2. By using the code TRANSVRS, the resonant frequency of the dipole mode f_1 for a distinct a, b pair can be calculated. The dependence of f_1 on a is plotted in Fig. 3 (notice that the cavity radii b can be deduced from step 1).

3. The group velocities v_g of the accelerating mode for the first cavity and last cavity are calculated according to the design parameters of the accelerator section (length L , quality factor Q , attenuation constant τ). These velocities uniquely determine the a, b pairs and thereby, the overall dipole mode frequency spread F_1 and the mean frequency $\bar{f}_1$.
4. Recent studies on the behavior of long-range wake fields for detuned structures show that the most effective dipole mode scrambling is a Gaussian distribution of dipole mode frequencies. Choosing the appropriate error function or a Gaussian stepping, the frequency of the dipole mode for each cavity can be calculated. Notice that the frequencies refer to the synchronous modes with the phase velocities equal to the speed of light for a uniform structure.

In the actual calculation, the frequency stepping of dipole modes was chosen according to the following formula [7]:

$$df_1 = \frac{\sqrt{2\pi} \sigma_f}{N} \frac{k_1}{\bar{k}_1} \frac{\bar{f}_1}{f_1} \frac{\bar{a}^2}{a^2} \exp \left[\frac{(f_1 - \bar{f}_1)^2}{2\sigma_f^2} \right], \quad (1)$$

where

N is the number of cavities used (205),

σ_f is the Gaussian standard deviation (2.5%),

$\bar{f}_1$ is the mean dipole mode frequency (15.30 GHz),

$k_1/\bar{k}_1$ is the weighting factor for nonconstant loss factors (0.9, ..., 1.05),

$\bar{k}_1$ is the mean loss factor (2.452 V/pC/cell).

The weighting factor $k_1/\bar{k}_1$ takes into account the fact that the loss factors k_1 are not constant with the frequency. The calculation was performed for $N=205$ cavities with a period of $d=0.875$ cm, adding up to a section length of $L=1.8$ m.

4. EVALUATION OF RF PARAMETERS

Once the dimensions of the cavities are determined, the RF parameters for the section can be calculated using the codes TRANSVRS, KN7C, and SUPERFISH [8]. Although these codes only calculate RF parameters for uniform structures with constant a, b, d , and g , the calculations are still valid for our detuned structure with slowly changing a 's and b 's. The calculated quality factor $Q(z)$ along the structure is displayed in Fig. 4. Figure 5 shows the calculated group velocity $v_g(z)$ along the structure.

The power flow in the accelerator section can be expressed:

$$P(z) = P_{in} e^{-\tau(z)}, \quad (2)$$

where P_{in} is the input power and $\tau(z)$ is the attenuation along the section, which can be calculated by using the following formula:

$$\tau(z) = \int_0^z \frac{\omega dz}{Q(z) v_g(z)}. \quad (3)$$

Then the accelerating electric field $E_z(z)$ can be calculated:

$$E_z(z) = \sqrt{\frac{\tau(z) dP(z)}{dz}}. \quad (4)$$

$E_z(z)$ is illustrated in Fig. 6. Finally, by integrating the electric field $E_z(z)$, we can calculate the energy gain $U(z)$ along the accelerator section, which is shown in Fig. 7. The energy gain for a conventional constant gradient and constant impedance section with the same input power is also plotted in Fig. 7. The behaviors of both the detuned and the constant gradient structure are very similar; therefore, the detuned structure was named the quasi-constant gradient structure. We note that the quasi-constant gradient structure is seen to have a slightly higher energy gain.

The dispersion curves for accelerating and dipole modes are displayed in Figs. 8 and 9, respectively. For the accelerating mode, all curves cross at the frequency $f_o = 11.424$ GHz with a phase advance of $\phi = 2\pi/3$. The slopes of those curves are the group velocities, which were already shown in Fig. 5. The dispersion curves for the dipole modes are very shallow, with positive group velocities in the front end of the section and negative ones at the back end (see Fig. 10).

5. CONCLUSION

A design procedure for detuned quasi-constant gradient structures has been developed. Computer simulations showed a slightly improved behavior of this structure in comparison with a conventional constant gradient and constant impedance structure. It seems clear that a detuned structure is feasible and easy to build. In order to prevent a large fraction of the dipole wakes from recoupling within the length of a bunch train, a combination of both damping and detuning techniques will perhaps be used. For this type of structure, the design method that is presented in this note can still be used.

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FIGURE CAPTIONS

Fig. 1. Three dimensional plot of the accelerating (TM_{01}) and dipole (TM_{11}) mode

frequencies with dependence on cavity aperture $2a$ and cavity diameter $2b$,
frequencies a, b pairs with the accelerating mode frequency $f_0 = 11.424$ GHz and phase
advance $\phi = 2\pi/3$.

Fig. 3. Dipole mode frequency dependence on cavity aperture a .

Fig. 4. Quality factor Q along the structure.

Fig. 5. Group velocity v_g for the accelerating mode along the structure.

Fig. 6. Accelerating electric field E_z along the axis of the structure.

Fig. 7. Accelerating voltage $U(z)$ on the axis.

Fig. 8. Dispersion curves of TM_{01} modes.

Fig. 9. Dispersion curves of dipole modes.

Fig. 10. Group velocity v_g of the first dipole mode along the structure.

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