PROPOSAL FOR A HIGH-GRADIENT AND HIGH-EFFICIENCY LINAC

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Abstract A proposal for a linac with traveling-wave resonant ring is introduced. The proposed linac would have both a high accelerating field strength and a high efficiency. The accelerating field strength would be more than 100 MV/m. The length of the 1 TeV linac would be 10 km.

1. INTRODUCTION

Experimental results regarding RF breakdown for a disk-loaded accelerating structure have already been reported by SLAC. 1,2,3 In the SLAC experiments an S-band traveling-wave linear accelerator section was excited in a standing-wave mode and an equivalent traveling-wave accelerating field of 146.7 MV/m was attained. The theory and experimental results regarding linear accelerators with traveling-wave resonant rings have been reported.4-9 It has a high accelerating field strength and high efficiency. Both are important for the design of a TeV linac. It is necessary to use very high RF power in order to use ordinary linac technology to obtain an accelerating field as high as 100 MV/m. For example, in the electron-positron linear collider R&D program at KEK a test accelerator facility will be built.10 The main part of the facility would be a 1-GeV S-band linac. It would comprise three sections of a 3.3m structure unit. Hence, the required peak RF power per unit section would be 840 MW for the average accelerating gradient 100 MV/m. According to this scale, a 1-TeV linac would require 2,400,000 MW of RF power.
In our proposal we adopt every accelerator guide with a traveling-wave resonant ring in which RF power can repeatedly go through the guide in the same direction so that the accelerating field strength can reach more than 100 MV/m. The length of a 1-TeV linac would be 10 km and it would only require 1,800,000 MW of RF power.

2. DESCRIPTION OF THE LINAC

A part of the 1-TeV linear accelerator is shown in Fig. 1. The linac design comprises 30,000 accelerator guides, each of which has a traveling wave resonant ring of its own, being fed by a 60 MW klystron. There are two types of accelerator structures: one is the \( 2\pi/3 \) mode; the other is the \( \pi/2 \) mode. They would be arranged alternatively. The parameters of the accelerator structures are given in Table 1.
**TABLE 1** Parameters of the two types of accelerator structures

<table>
<thead>
<tr>
<th></th>
<th>type 1</th>
<th>type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating frequency (MHz)</td>
<td>2856</td>
<td>2856</td>
</tr>
<tr>
<td>Phase shift per cavity</td>
<td>$2\pi/3$</td>
<td>$\pi/2$</td>
</tr>
<tr>
<td>Length of a guide (m)</td>
<td>0.35</td>
<td>0.34</td>
</tr>
<tr>
<td>Number of cavities</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Shunt impedance $R$ (MΩ/m)</td>
<td>71.89</td>
<td>65.06</td>
</tr>
<tr>
<td>Attenuation $\alpha$ (nepers/m)</td>
<td>0.4128</td>
<td>0.434</td>
</tr>
<tr>
<td>Factor of merit $Q$</td>
<td>14230</td>
<td>11640</td>
</tr>
<tr>
<td>Group velocity $V_g/C$</td>
<td>0.005092</td>
<td>0.00506</td>
</tr>
<tr>
<td>Diameter of disk hole 2a (cm)</td>
<td>1.65</td>
<td>1.65</td>
</tr>
<tr>
<td>Disk thickness t (mm)</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

An accelerator guide with a traveling-wave resonant ring is shown in Fig. 2.

Fig. 2 An accelerating guide with a traveling-wave resonant ring
3. PHASING SYSTEM

In the proposed linac with traveling-wave resonant rings the phasing system would have two parts. One of them would be used to adjust the phase of each klystron so as to make the beam bunch be in suitable phase with the wave in the accelerating guide. The other would be used to adjust the phase of each resonant ring so as to meet resonance conditions. If one uses a phase shifter in every traveling-wave resonant ring to adjust the phase, it would not only increase the investment but would also increase the loss which causes the field multiplication factor to decrease. For increasing the accelerating field strength we would rather use two spacers than one phase shifter to adjust the phase in the ring.

4. DESIGN OF A LINAC WITH TRAVELING-WAVE RESONANT RINGS

For the design of a linac with traveling-wave resonant rings under optimal coupling we can use the following formulae:

\[ V_i = \frac{M E_o L}{\tau} \left( 1 - e^{-\tau} \right) - \frac{IR}{E_o} (1 - e^{-\tau}) - \frac{1}{2} \left( \tau + \tau' \right) \]  

(1)

\[ \frac{\sqrt{\frac{I^2 R^2}{E_o^2} (1 - e^{-\tau}) e^{-\tau'} (1 - e^{-2(\tau + \tau')}) - \frac{1}{2} \left( \tau + \tau' \right)}}{1 - e^{-2(\tau + \tau')}} \]  

(2)

\[ C = \frac{1}{M} \]  

(3)

\[ E_o = \sqrt{2P_o \alpha R} \]  

(4)

where \( V_i \) is the energy gain for every accelerating guide, \( M \) the field multiplication factor in the traveling-wave resonant ring, \( C \) the voltage coupling coefficient, \( E_o \) the accelerating field strength in the beginning of the accelerator guide (actually, \( E = ME_o \)), \( P_o \) the input power, \( \alpha \) the attenuation of the accelerator guide per unit length in nepers, \( R \) the shunt impedance of the accelerator guide per unit length, \( L \) the length of one accelerator guide, \( \tau \) the attenuation constant of the one accelerator guide, \( \tau = \alpha L \), \( \tau' \) the attenuation constant of the waveguide of the traveling wave resonant ring except accelerator guide and \( I \) the beam pulse current.

To prevent BBU appearance the accelerator guide is designed to be as short as possible and to use two types guides arranged alternatively.
SLAC's 5045 klystrons were selected as RF power source. The output power of one klystron is 67 MW and pulse width is 3.5 μs. The power build-up in the ring is a step-wise process with intervals between steps equal to the filling time. In the ring the power builds up to 95% of the steady state value after ten transits through the ring. Thus, the beam pulse width is about 1.5 μs (Fig. 3).

Fig. 3 Pulse shapes of the RF envelope and beam

For short pulses in the accelerator guide with the traveling-wave resonant ring, the stored energy can be written as

\[ W = \frac{m^2 P_0 T_f}{2} \left( 1 - \frac{e^{-2\tau}}{2\tau} \right) \]  

(5)

In each guide \( W = 24 \) J; thus, a 20 A, 3ns (10 bunchs) beam current takes only 10% of the stored energy away.

The total energy gain \( V \) equals \( NV_i \), where \( N \) is the number of accelerator guides. The parameters of the design are listed in table 2.
Table 2 The results of the design

<table>
<thead>
<tr>
<th>Operating frequency (MHz)</th>
<th>2856</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the linac (km)</td>
<td>10.4</td>
</tr>
<tr>
<td>Beam energy (TeV) for 20A 3ns for 0.2A 1.5μs for 0.4A 1.5μs</td>
<td>1.10 1.08 1.02</td>
</tr>
<tr>
<td>Total RF power (MW)</td>
<td>1,800.000</td>
</tr>
<tr>
<td>Number of accelerator guides</td>
<td>30,000</td>
</tr>
<tr>
<td>Number of klystrons</td>
<td>30,000</td>
</tr>
<tr>
<td>Power of one klystron (MW)</td>
<td>60</td>
</tr>
</tbody>
</table>

REFERENCES