I-7. Properties and Applications of the TM_{11} Mode in Cylindrical Disk-Loaded Waveguide

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Several laboratories in Europe and the United States have recently become interested in the TM_{11} mode in cylindrical disk-loaded waveguide. This interest has been stimulated by the realization that the TM_{11} mode exhibits interesting and useful properties when made to interact with charged particle beams. Whereas the TM_{01} mode in cylindrical disk-loaded waveguide has been used for years to give cumulative *longitudinal* interaction with an electron beam, as, for example, in traveling-wave tubes or linear accelerators, the TM_{11} mode is found to exert a *transverse* force on particles traveling along the direction of propagation.

This paper will review the studies undertaken at Stanford University to examine the properties of the TM_{11} mode, to design traveling-wave structures with prescribed parameters, and to make use of these structures for specific applications. Because these applications deal with highly relativistic beams, the frequency and dimensions (See Fig. 1) have been selected in all cases to yield a phase velocity v_p equal to the velocity of light c. The number of disks per wavelength has been chosen to be 3 ($d = \lambda/3$).

The field equations for the general case are quite complicated but when $v_p = c$, they simplify to the following approximate expressions:

$$\begin{aligned}
E_z &= E_o kr \cos\theta, \\
E_r &= E_o\left[(kr/2)^2 + (ka/2)^2\right]\cos\theta, \\
E_\theta &= E_o\left[(kr/2)^2 - (ka/2)^2\right]\sin\theta, \\
Z_oH_z &= -E_o kr \sin\theta, \\
Z_oH_r &= -E_o\left[(kr/2)^2 - (ka/2)^2 + 1\right]\sin\theta, \\
Z_oH_\theta &= E_o\left[(kr/2)^2 + (ka/2)^2 - 1\right]\cos\theta.
\end{aligned}$$

These fields produce a Lorentz force on a particle of charge q, given in rectangular coordinates by

$$F_x = qE_o, \qquad F_y = 0.$$

Hence, the transverse deflecting field is uniform in magnitude and direction over the aperture. This property is desirable since it implies that one can expect an aberration-free deflection from this mode. Integrating the Poynting vector over the aperture, one obtains for the power in the z-direction:

$$P_z = \frac{E_o^2}{Z_o}\frac{\pi a^2}{2}\left(\frac{ka}{2}\right)^2\left[\frac{4}{3}\left(\frac{ka}{2}\right)^2 - 1\right].$$

One observes that depending on whether $ka > \sqrt{3}$ or $< \sqrt{3}$, the deflecting mode is a forward or a backward wave.

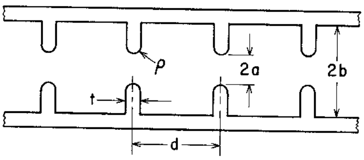

Fig. 1 Schematic of disk-loaded wave-guide showing input coupler and mode stabilizer holes in disks.

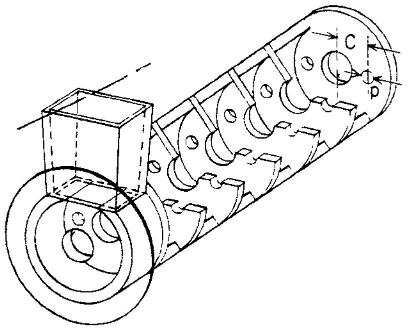

Fig. 2 Schematic of disk-loaded wave-guide showing input coupler and mode stabilizer holes in disks.

Figure 2 shows a cutaway view of a practical disk-loaded structure with a matched coupler. The holes in the disks are used to prevent θ-rotation of the mode as it propagates in the structure. In practice, by removing the degeneracy, they cause the Brillouin diagram to separate into two diagrams depending on the coupler orientation. The paper will include the pertinent Brillouin diagrams, a discussion of all design parameters such as the shunt impedance, the phase and group velocities, the attenuation and space harmonic amplitudes, and the microwave measurements.

This paper will describe four practical applications of this type of mode: a) A multi-Bev particle separator; b) A bunch analyzer; c) A beam position monitor; d) An explanation for the phenomenon of beam break-up encountered in linear electron accelerators.

The particle separator is illustrated in Fig. 3. A bunched primary beam hits a target and produces a bunched secondary beam. From the transport system emerge particles of equal momenta but different masses and hence different velocities. The distance L is chosen so that the transit time difference for two particles of different velocity is one half an *rf* period. As they enter the *rf* separator, the angle of deflection depends on their entrance

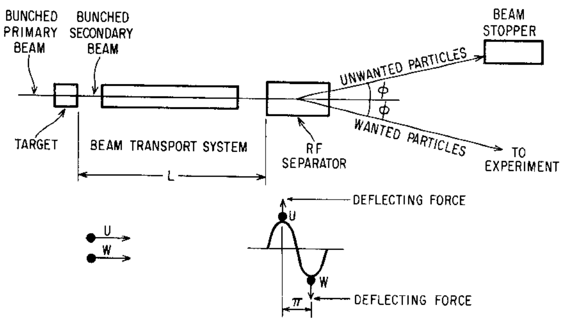

Fig. 3 Proposed experimental layout of an rf separator for a bunched beam. Wanted particles (W) and unwanted particles (U) are shifted in phase by π with respect to each other over distance L.

phase. Hence, by proper adjustment of the phase of the *rf* source powering the separator, the wanted particles can be separated from the unwanted ones.

The bunch analyzer uses the same general layout, except that in this case one sweeps the primary beam and obtains its *rf* structure by measuring the number of particles contained in discrete phase intervals.

The beam position monitor illustrated in Fig. 4 makes use of the fact that a bunched beam induces in the structure an *rf* wave, whose phase and amplitude are determined by the beam position.

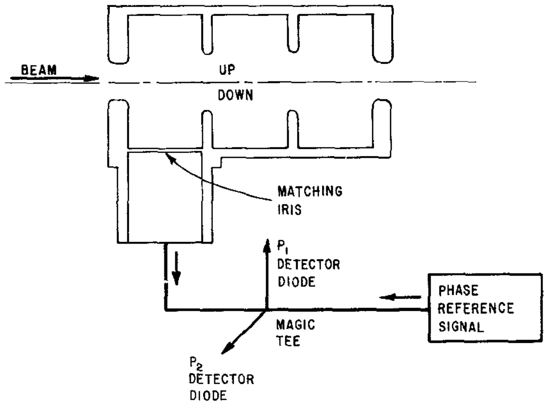

Fig. 4 Beam position monitor using TM_{11} mode structure and magic tee for phase comparison. For example, a maximum for P_1 indicates that the beam is up, a maximum for P_2 that the beam is down.

Finally, it will be shown how an intense electron beam in a uniform linear accelerator operating in the TM_{01} mode can in a finite time excite a TM_{11} wave which, in turn, defocuses the beam and deflects it into the accelerator walls.

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