STUDIES OF A FREQUENCY SCALED MODEL TRANSFER STRUCTURE FOR A TWO-STAGE LINEAR COLLIDER

T. Garvey, G. Geschonke, W. Schnell and I. Wilson
CERN, Geneva, Switzerland

ABSTRACT

Results are reported of bench-top measurements of the RF and electromagnetic properties of a travelling waveguide structure. These measurements are performed with the aim of assessing the suitability of this device for playing the role of a transfer structure in a two-stage RF linear collider.

1. INTRODUCTION

In the two-stage RF linear collider proposal of Schnell [1] it is envisaged that the extraction of energy from the low-energy (≤ 5 GeV), low-frequency drive beam will be by direct deceleration in an RF structure. This "transfer structure" would essentially consist of small sections of travelling waveguide linking alternate drive beam accelerating structures and would be coupled to the high energy (1 TeV) high frequency (29 GHz) linac by short runs of waveguide. Results are presented here of a dimensionally scaled-up model of a structure which may be suitable for this purpose. The results presented here were obtained with a 12-cell model and represent an extension of work previously carried out on a four-cell device. A preliminary account of this work is given in Ref. [2].

2. THE TRANSFER STRUCTURE

Although the structure will be required to be resonant at the same frequency as the main linac the model structure was machined for 2 GHz nominal operation. This obviated the need for machining and working with small structures and allowed us to operate within the frequency range of available sources and detectors. The device consists of a comb-like structure in rectangular waveguide rather like a linear magnetron (Fig. 1). The teeth of the comb however do not extend across the full height of the guide so allowing adjacent cells to couple through both electric and magnetic fields. As the device is desired to operate in the $\pi/2$ mode the cell spacing was set at $\lambda/4$ (where λ is the free space wavelength) resulting in an overall length of 450 mm. A complete geometrical description of the structure can be found in Ref. [2].

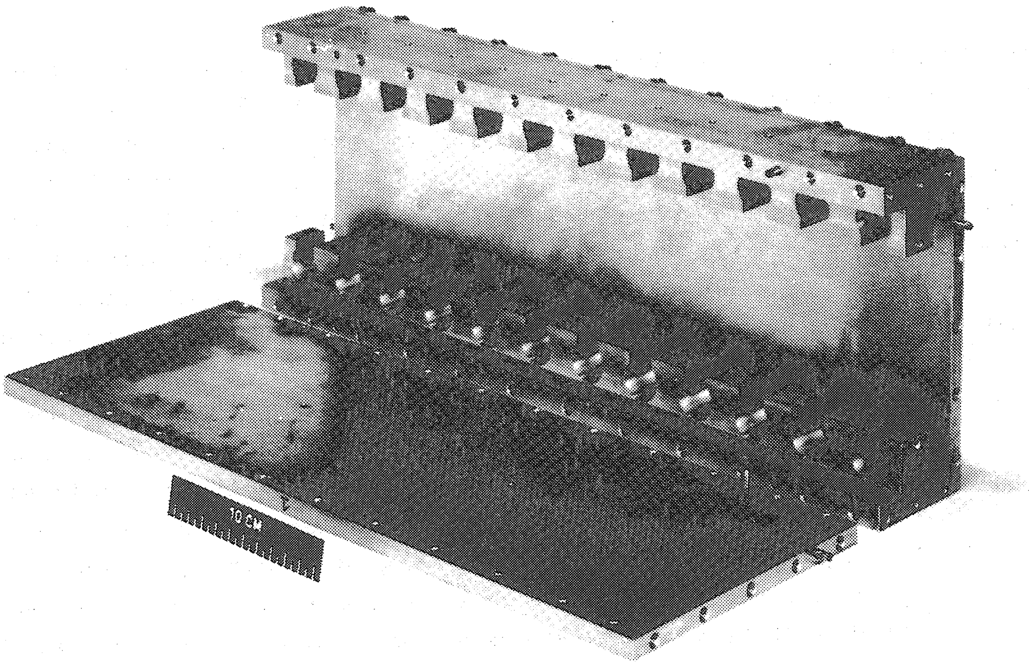

Fig. 1 The transfer structure

3. MEASUREMENTS

The properties of the transfer structure were investigated using two existing automated and computer-controlled test arrangements originally constructed for testing LEP components.

The first allowed low-power CW measurements to reveal the frequency response of the structure (terminated in electric walls) up to frequencies of 3 GHz. Having determined the resonant response of the device the distribution of longitudinal electric field on axis was obtained by the Muller-Slater perturbation technique [3,4]. The shunt impedance per unit length (R') was calculated from the perturbation data for the $\pi/2$ mode and the cavity quality factor (Q) was calculated from the half power (3 dB) points. Identification of the normal modes of the structure was confirmed by measuring the relative RF phases of adjacent cells in standing-wave mode. Modal identification permitted construction of the dispersion relation of the structure.

The second arrangement consisted of a time domain co-axial wire measurement of the structure which gives information on the longitudinal wake potential [5,6]. A comparison between data obtained on the two test arrangements yields a value for the beam-loading enhancement factor of the structure.

4. RESULTS

4.1 CW measurements

The 12-cell structure would normally be expected to exhibit 11 eigen-modes corresponding to travelling-wave phase shifts of $m\pi/12$ ($m = 1, 2, 3, \ldots .11$) from cell to cell. Transmission tests, however, revealed a much richer spectrum. Subsequent perturbation analysis of each resonance in turn indicated that the resonances could be grouped in pairs which exhibited identical field distributions along the faces of the combs, despite having distinctly different distributions on axis. These resonance pairs were believed to be due to the normal modes but with each pair corresponding to a situation in which the opposite combs, considered as coupled oscillators, resonated either in anti-phase or in phase with respect to each other. In contrast to the in-phase modes the anti-phase modes have non-zero magnetic fields on axis and these fields considerably complicate the signals obtained during perturbation runs with a metal bead (sensitive to contributions, of opposing sign, from electric and magnetic fields). In order to avoid the effects of magnetic fields the perturbation runs were repeated with a dielectric bead (sensitive only to electric fields) for the perturbing object. For the in-phase modes the field distribution of the m^{th} mode has m nulls while the anti-phase mode has m-1 nulls and all modes were duly identified from the observed distributions.

Another consequence of anti-phase modes is that the on-axis fields are purely transverse in contrast to the in-phase modes where the on-axis fields are always longitudinal. This situation was verified by performing perturbation measurements with disc- and needle-shaped objects which are sensitive to field polarity.

For some modes coupling to and from the cavity appeared weak and the resulting perturbation signals were not clean enough to unequivocally identify a mode. In this case the variation in phase between adjacent cells confirmed the identity of the resonance. The resulting dispersion diagram of the transfer structure is shown in Fig. 2.

Frequency tuning of the structure was carried out by altering the length of the teeth of the combs. The correct length was obtained empirically on the four-cell structure and interpolation of the data resulted in the 12-cell device having an in-phase $\pi/2$ mode resonant at 1.992 GHz.

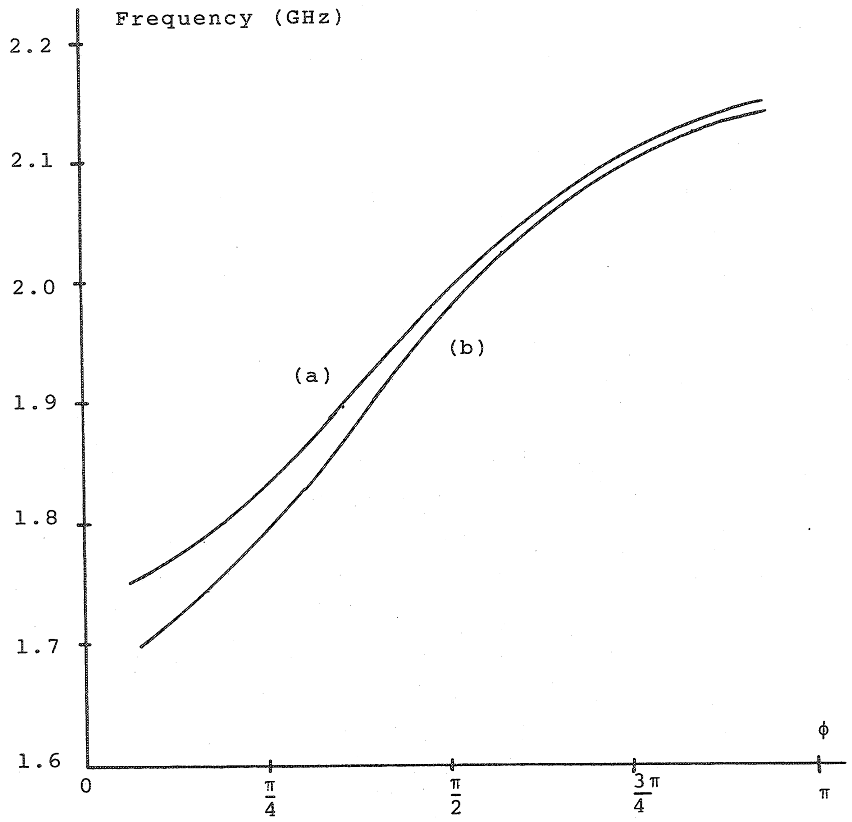

Fig. 2 Dispersion of 12-cell transfer structure
(a) in-phase mode, (b) anti-phase mode

In the usual theory of perturbation a metal bead of radius r located at a point in the cavity where the local electric field is E and the magnetic field is zero causes a frequency shift, Δf, from the unperturbed resonant frequency, f, where

$$\frac{\Delta f}{f} = \frac{\pi r^3 \varepsilon_0 E^2}{W} \qquad (1)$$

where ε_0 is the permittivity of free space and W is the average cavity stored energy.

This results in a phase shift between generator and cavity, $\Delta\phi$, given by

$$\tan \Delta\phi = 2Q \, \Delta f/f \qquad (2)$$

where Q is the resonator quality factor for the mode in question.

The automated equipment used to make the perturbation runs incorporates a computer program which performs a point-wise integration over the measured phase shifts [7]. This integral is then used to compute the standing-wave impedance of the resonator (suitably corrected for transit time effects).

The standing-wave shunt impedance of the $\pi/2$ mode was found to be 94 kΩm^{-1} (±5%) and the measured Q was 2860. The latter was obtained by varying the excitation frequency until the 3 dB points were found.

4.2 Pulsed measurements

These measurements were made by sending a short (~ 110 ps FWHH) electromagnetic pulse down a coaxial wire threaded through the transfer structure so simulating the passage of a relativistic bunch. This is done for both the structure and for a reference line which is essentially a length of unloaded waveguide whose dimensions are equal to those of the structure in the absence of combs. Tapered waveguide is used to match into and out of the structure and to provide connections for the cable carrying the fast pulse. In principle the change in pulse deformation between the structure and the reference yields the value of the total longitudinal loss factor, k [5,6]. The transmitted current pulses are fed to a fast rising sampling scope, analog-to-digital converted and the data then stored in a desktop computer which contains a program for computing the loss factor [6].

Repeated measurements of the loss factor indicate that it has a value of $\leq$ 0.055 V/pC. This corresponds to a loss factor per unit length, k', where

$$k' \leq 0.122 \text{ V/pCm.}$$

Following the definition of the fundamental loss factor, k_0, we have [8],

$$k_0' = \frac{\omega}{4}\frac{R'}{Q} \tag{3}$$

where $\omega = 2\pi f$. This yields (using the perturbation data) a value of 0.1 V/pCm for the transfer structure which, when suitably corrected for a pulse of 110 ps FWHH, gives

$$k_0' = 0.071 \text{ V/pCm.}$$

The longitudinal beam loading enhancement factor B is then given by

$$B = \frac{k'}{k_0'} \leq 1.72.$$

5. DISCUSSION

An immediate consequence of the large transverse aperture of the structure is the wide bandwidth ($\simeq$ 20%) and corresponding high group velocity of the structure

(Fig. 2). As the fill time of the structure must equal the period of the low-frequency drive linac (2.86 ns) a high group velocity is required to prevent the structure being inconveniently short [1]. This large transverse aperture is also beneficial in terms of reducing the effects of transverse wakes.

The measured value of r'/Q is 32 Ωm^{-1} which scales to give 900 Ωm^{-1} for a travelling wave at 29 GHz. This value although small is not less than that required for the transfer structure. Interpolating between the data points of Fig. 2 one can easily estimate the group velocity of the forward wave structure using the relation

$$\frac{V_g}{c} = \frac{1}{c}\frac{d\omega}{dk} = \frac{\pi}{2f}\left(\frac{\Delta f}{\Delta\phi}\right)_{\phi = \frac{\pi}{2}} . \qquad (4)$$

For the structure under investigation we have $V_g/c = 0.14$.

The value obtained for B can be taken to be a measure of the efficiency of energy transfer to the fundamental mode relative to all other possible longitudinal modes. The fact that this ratio is not too far from unity must be considered to be encouraging although one has to bear in mind the possible errors which typify coaxial wire measurements.

6. CONCLUSIONS

Preliminary measurements on the device discussed in this paper indicate that it may be a solution to the geometry required of a transfer structure for the linear collider proposal of Ref. [1]. Further studies are necessary however before proceeding with a more formal design. In particular, computational studies of the model would provide complementary information to that obtained by the measurements. Indeed three-dimensional codes are now available for computing such geometries and runs to calculate the normal mode frequencies of the structure are in excellent agreement (better than 3%) with the values obtained experimentally [9].

ACKNOWLEDGEMENTS

We are indebted to H. Henke for providing the means to perform the coaxial wire tests and for his advice on the measurement techniques. He is the author of the computer code for the evaluation of the loss factor.

* * *

REFERENCES

[1] W. Schnell, CERN-LEP-RF/86-27 (1986)

[2] T. Garvey et al., CERN-LEP-RF/86-35 (1986)*

[3] J. Muller, Hochfrequenz-technik und Elektroakustik, 54, part II (1939) 157

[4] J.C. Slater, Microwave Electronics (D. Von Nostrand Company Inc., Princeton, N.J.) (1950)

[5] M. Sands and J. Rees, Stanford Linear Accelerator note, PEP-95 (1974)

[6] H. Henke, CERN-LEP-RF/86-21 (1986)

[7] J.P. Boiteux and G. Geschonke, CERN-LEP-RF/86-33 (1986)

[8] P.B. Wilson, SLAC-PUB-2884 (1982)

[9] T. Weiland and A. Khursheed, private communication.

* N.B. The top figure of page 5 from this reference should have the dimension 150 mm replaced by 142 mm.