Study of Linear Collider Coupler Parameters and Accelerating Section Impedance Characteristics

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Abstract

The linear collider accelerating section coupler with small dimensions and symmetric electromagnetic field in the vicinity of the beamline is considered. The principles basic for the coupler matching and a method of experimental determination of the coupler parameters are described. Requirements for the coupler and accelerating section impedance characteristic are determined.

1 MODELLING AND MAIN EXPRESSIONS

The input (output) coupler represents the first (the last) cell of the disk-loaded circular waveguide (DLW) wich is connected to two rectangular waveguides (RW). The rectangular waveguides are parallel and have the coupling slots in their narrow walls for connection with coupler. One end of each RW is short-circuited and another one is connected to a port of the T-junction (three-port power devider). (fig.1).

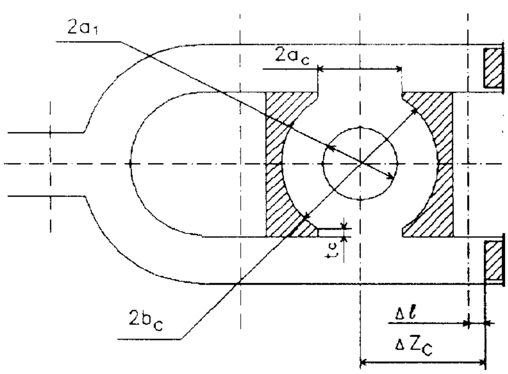

Figure 1: Symmetrical coupler with two waveguides and power devider

To obtain expression needed for development of the matching method and impedance characteristics calculation we use the resonant model of the DLW and coupler [1]. DLW cells are characterized by the resonance frequency f_r and coupling coefficients with adjacent cells $k_0/2$. The coupler itself is characterized by the resonance frequency f_c, coupling coefficient with adjaccent DLW cell $k_c/2$, coupling coefficients with of RW χ and own Q-factor Q_c. In general $k_c/2$ is not equal to $k_0/2$. The T-junction is characterized by the scattering matrix with the following elements: $S_{11} = 0, S_{22} = S_{33} = 1/2, S_{12} = S_{21} = S_{13} = S_{31} = 1/\sqrt{2}, S_{23} = S_{32} = -1/2$ (if the reference planes of the T-junction are chosen in an appropriate way). The position of short-circuited plungers in the rectangular waveguides are characterized by $\psi = \pi - 4\pi \Delta l/\Lambda$, where Λ - is the wavelength in the RW, Δl - is the distance between the short-circuited plunger and the reference plane chosen in an appropriate way, Δl being negative if the plungers are displaced from the coupler and Δl being positive if they are displaced to the coupler.

To provide the travelling wave regime in the infinite uniform lossless DLW with operating mode φ_0 at the frequency f_0 it is necessary that

$$f_r = \frac{f_0}{\sqrt{1 - k_0 \cos\varphi_0}} \tag{1}$$

The reflection coefficient at the input of the T-junction (when the coupler is connected with an infinite uniform lossless DLW) is defined by

$$\Gamma = \frac{2\chi - (2\chi - 1 - \chi_{DLW} - }{2\chi + 1 + \chi_{DLW} + }$$

$$\frac{-jQ_c\left[\frac{f}{f_c} - \frac{f_c}{f} + \frac{f_c}{f}\frac{k_0}{2}\left(\frac{k_c}{k_0}\right)^2\cos\varphi\right])\exp(j\psi)}{+jQ_c\left[\frac{f}{f_c} - \frac{f_c}{f} + \frac{f_c}{f}\frac{k_0}{2}\left(\frac{k_c}{k_0}\right)^2\cos\varphi\right] - 2\chi\exp(j\psi)} \tag{2}$$

where j - is the imaginary unit. f and φ are corelated by the dispersion characteristics of the infinit uniform lossless DLW $f = f_r\sqrt{1 - k_0\cos\varphi}$, $\chi_{DLW} = Q_c\frac{k_0}{2}\left(\frac{k_c}{k_0}\right)^2\frac{f_c}{f}\sin\varphi$. The reflection coefficient equals zero at the operational frequency f_0 if

$$f_c = \frac{f_0}{\sqrt{1 - \frac{k_0}{2}\left(\frac{k_c}{k_0}\right)^2\cos\varphi_0}},$$

$$\psi = \pi \quad (or \, \Delta l = 0), \tag{3}$$

$$4\chi = 1 + Q_c\frac{k_0}{2}\left(\frac{k_c}{k_0}\right)^2 \frac{\sin\varphi_0}{\sqrt{1 - \frac{k_0}{2}\left(\frac{k_c}{k_0}\right)^2\cos\varphi_0}}$$

Because of $4\chi \gg 1$ (Q_c is usually large) we can assume that the coupler loaded Q - factor is

$$Q_{CL} = \frac{Q_c}{4\chi} = \frac{2}{k_0}\left(\frac{k_0}{k_c}\right)^2 \frac{\sqrt{1 - \frac{k_0}{2}\left(\frac{k_c}{k_0}\right)^2\cos\varphi_0}}{\sin\varphi_0} \tag{4}$$

Thus, to match the coupler it is necessary to have a possibility to determine experimentally positions of the short-circuiting plungers in the RW at wich $\psi = \pi$, as well as the coupler parameters: f_c, $k_c/2$ $(or k_c/k_0)$ and Q_{CL}. The DLW cells parameters are assumed to be known (φ_0, f_0, k_0, f_r). If the first DLW cell (adjacent to the coupler) is strogly detuned by inserting a thick ring into this cell (see fig.2) reflection coefficient can be rewritten as

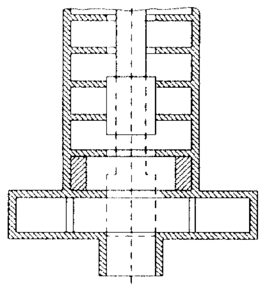

Figure 2: Schematic drawing of experimental model for measurement of the coupler parameters (f_c, Q_{CL})

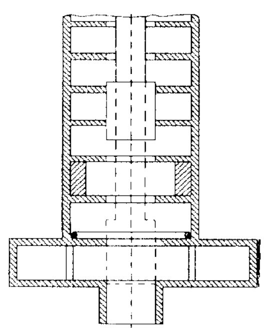

Figure 3: Schematic drawing of experimental model for measurement of the first DLW cell parameters (f_{r1}, $\frac{k_c}{2}$)

$$\Gamma_1 = \frac{2\chi - (2\chi - jQ_c\left[\frac{f}{f_c} - \frac{f_c}{f}\right])\exp(j\psi)}{2\chi + jQ_c\left[\frac{f}{f_c} - \frac{f_c}{f}\right] - 2\chi\exp(j\psi)} \tag{5}$$

and if the coupler is strongly detuned by inserting a moving cylindrical plunger into the coupler (see fig.2, dashed lines).

$$\Gamma_0 = \exp(j\psi) \tag{6}$$

From (5) and (6) we have $\Gamma_1(f = f_c) = 1$ and $\Gamma_0(f = f_c) = \exp(j\psi)$. Moreover, if $\psi = \pi$ then $\Gamma_1(f = f_c \pm \Delta f) = \exp(\pm j\alpha)$, where $\alpha = 2atan\left(\frac{Q_c}{2\chi}\frac{\Delta f}{f_c}\right)$ and $\Delta f \ll f_c$.

So by means of measurement the reflection coefficients Γ_1 and Γ_0 arguments we can experimentally determine the coupler resonant frequency f_c as well as the loaded Q-factor $Q_c/4\chi$.

If the second DLW cell is strongly detuned by inserting a thick ring into this cell (see fig.3) and resonant frequency of the first DLW cell is made equal to f_c (by inserting a thin ring into the first cell) there are two frequencies f_1 and f_2 at which $arg\Gamma_2(f = f_{1,2}) - arg\Gamma_0(f = f_{1,2}) = \pm\pi$, where Γ_2 - is the reflection coefficient value when the second cell is strongly detuned. The coupling coefficient between the coupler and the first DLW cell can be determined as

$$\frac{k_c}{2} = \frac{|f_1^2 - f_2^2|}{f_1^2 + f_2^2} \tag{7}$$

Notice that if the first cell frequency is equal to f_c we have $arg\Gamma_2(f = f_c) = arg\Gamma_0(f = f_c)$.

The expression (2) represents the impedance characteristic of the infinite uniform lossless section with input coupler. If the section is not uniform and consists of N cells (including input and output couplers) the impedance characteristic can be written as

$$\Gamma = \frac{2\chi - (2\chi - 1-}{2\chi + 1+}$$

$$\frac{-jQ_c\frac{f_c}{f}\left[\frac{f^2}{f_c^2} - 1 + \frac{k_c}{2}\frac{\chi_2}{\chi_1}\right])\exp(j\psi)}{+jQ_c\frac{f_c}{f}\left[\frac{f^2}{f_c^2} - 1 + \frac{k_c}{2}\frac{\chi_2}{\chi_1}\right] - 2\chi\exp(j\psi)} \tag{8}$$

where

χ_1, χ_2, χ_3,...,χ_N - are the complex values, which can be calculated as

$$\chi_{n-1} = -\frac{k_n}{k_{n-1}}\chi_{n+1} - \frac{2}{k_{n-1}}\left(\frac{f^2}{f_n^2} - 1 - j\frac{f}{f_n}\frac{1}{Q_n}\right)\chi_n \tag{9}$$

Here $\frac{k_n}{2}$ is the coupling coefficient between n-th and (n+1)-th cells, f_n, Q_n are the resonance frequency and own Q-factor of n-th cell,
Q_N is the loaded Q-factor of the output coupler cell.
$f_1 = f_c$, $Q_1 = Q_c$, $\frac{k_1}{2} = \frac{k_c}{2}$, $\chi_N = 1$,
$k_N = 0$, $\chi_{N+1} = 0$, $n = N, N-1, N-2, ..., 2$.
f is the frequency.
The physical meaning of the value $\chi_n = |\chi_n|\exp(j\varphi_n)$ is as follows: $|\chi_n| = \sqrt{2W_n}$, where W_n is the electrical field energy stored in n-th cell,
φ_n is the electrical field phase in the middle of this cell.

In this case the reflection coefficient equals zero at the operational frequency f_0 if

$$\psi = \pi \quad (or \,\Delta\, l = 0),$$

$$f_1 = f_c = \frac{f_0}{\sqrt{1 - \frac{k_c}{2}Re\left(\frac{\chi_2}{\chi_1}\right)}}, \tag{10}$$

$$Q_{CL} = \frac{Q_c}{4\chi} = -\frac{2}{k_c}\frac{\sqrt{1 - \frac{k_c}{2}Re\left(\frac{\chi_2}{\chi_1}\right)}}{Jm\left(\frac{\chi_2}{\chi_1}\right)}$$

where $Re\left(\frac{\chi_2}{\chi_1}\right)$ and $Jm\left(\frac{\chi_2}{\chi_1}\right)$ are the real and imaginary parts of $\left(\frac{\chi_2}{\chi_1}\right)$ which is calculated at the operational frequency. If $\psi = 0$ or $\psi = 2\pi$ then $\Gamma = 1$ and the coupler couldn't be matched. When $\psi = \pi$ the coupling slots width are minimal. If $0 < \psi < \pi$ the coupler could be matched but the coupling slots width should be made larger.

Table 1:

		k_c	f_c, MHz	Q_{CL}	k_0	f_{r1}, MHz	$\|\Gamma\|$
Input	calculated	–	2981,19	51,3	0,04525	2964,65	0,0
coupler	experimental	0,0455	2981,05	52,5	–	2963,63	0,047
Output	calculated	–	2992,68	170,4	0,01423	2987,39	0,0
coupler	experimental	0,0139	2992,70	173,5	–	2987,4	0,035

2 EXPERIMENTAL RESULTS AND IMPEDANCE CHARACTERISTICS

The experimental study of the input and outrput coupler for DESY collider was curried out. For this purpose two DLW section with 11 cells were fabricated. The first section had the cells similar to the initial cell of the collider section with the period of DLW 33,33 mm, the ratio $a/\lambda = 0,10885$, $t/\lambda = 0,05$, $k_0 = 0,01423$, where a and t are the radius and thickness of disks correspondingly. The second section consisted of cells which are identical to the last cell ($a/\lambda = 0,155$, $k_0 = 0,04525$). The operational frequency $f_0 = 2998 MHz$, the operational mode is $\varphi_0 = \frac{2\pi}{3}$.

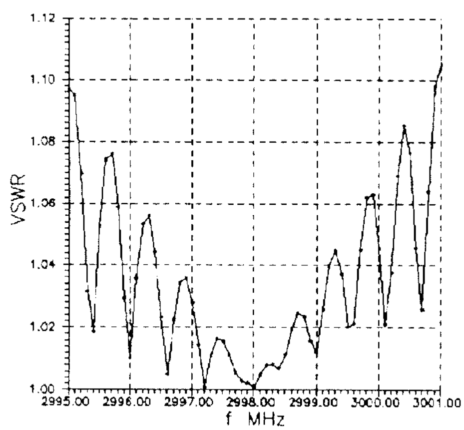

Figure 4: The impedance characteristic of 6m length accelerating section with ideal tuned cells and matched couplers

Experimentally determined and calculated parameters of the input and output cells are presented in Table 1, the experimentally determined parameters being related to matched couplers. Where f_{r1} is the resonance frequency of the cell adjacent to the coupler.

The experimental values of the reflection coefficient Γ were obtained by means of movable absorbing load technicque [2]. The matching was achieved by changing the inner coupler diameter ($2b_c$) and the coupling slots width ($2a_c$).

The impedance characteristics of the 6m length accelerating section with variable dimentions are shown in fig.4 and fig.5. The first characteristic (fig.4) corresponds to the idially matched and tuned couplers and cells, and the second one was calculated when cells frequencies (including couplers frequencies) and coupling coefficients ($\frac{k_n}{2}$) had random homogeneous dispersion in the range ($f_n \pm 0,5) MHz$ and $\frac{k_n}{2}$ $(1 \pm 0,01)$ correspondingly.

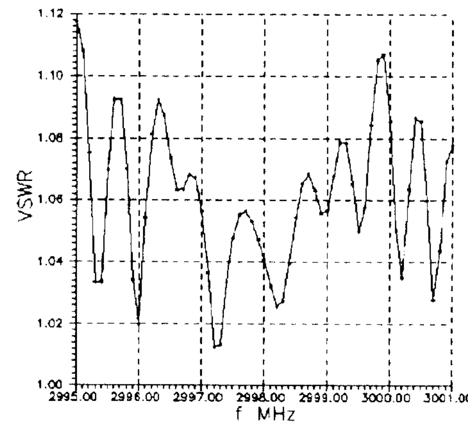

Figure 5: The impedance characteristic of 6m length accelerating section when the cells frequencies and couplinq coefficients have homogeneous dispersion

3 CONCLUSION

The analytical expressions obtained in this work are in a good correspondence with the experimental results, and can be used as the basis for the coupler matching and experimental determination of the coupler parameters. The method of matching described here can be used for matching of other types of couplers.

4 REFERENCES

[1] V.E.Kaluzhny, V.F.Vikulov, "Investigation of Travelling Wave Accelerating Section High Frequency Characteristics on the Basics of Resonant Models", Journal of Technical Physics, V52, No11, pp.2168-2176, 1988.

[2] O.A.Valdner, N.P.Sobenin et. all., Handbook of Disk Loaded Waveguide, Moscow: Energoatomizdat, 1977, pp.342-348.