MICROWAVE FEEDING SYSTEM DEVICES OF LINEAR COLLIDER

B. Yu. Bogdanovich, V.I. Kaminsky, M.V. Lalayan, N.P. Sobenin, D.A. Zavadtsev, Moscow Engineering Physics Institute (State University), Russia
M. Ebert, DESY, Germany

Abstract

The simulations, manufacturing and experimental results for two devices of linear collider RF power distribution system are presented. One of these devices is magic tee with movable choke plungers in E- and H-arms for the tuning the coupling-factor and RF phase of high-power accelerating cavities. The Q_{EXT} of the cavity structures must be tuneable in the range from $0.9*10^6$ to $9*10^6$ to match the RF system under different beam conditions. For matching the waveguide power distribution system to cavities with different quench thresholds, adjustable directional couplers are necessary. These directional couplers with a coupling factor of 3.0 dB and 12.5dB with adjusting range of ±1 dB and directivity better than 30dB in were designed and produced. The adjustment elements of these couplers are movable membrane based plungers in two additional 90^0-bended H-arms opposite the coupling slot. All devices were designed for operation at 1.3 GHz and pulse power 1-5 MW.

INTRODUCTION

The high power RF distribution system of the electron-positron collider TESLA [1] is designed to ensure external Q independent adjustment of each superconducting cavity by a factor of 10 and also independent adjustment of the cavity RF phases. A further demand is the individual adjustment possibility of the cavity power feed. For this item adjustable waveguide couplers are foreseen. For Q and phase adjustment E-H-tuners were constructed [2]. For matching the RF power distribution system to cavities with different quench thresholds, the investigation of adjustable direction couplers is underway. The TESLA machine is feeded 18 cavities with one 5-MW klystron-output. Therefore waveguide couplers having different coupling factors between 1/18 (12.6dB) and 1/2 (3.0 dB) with an adjustment range of ±1 dB are necessary. The directivity D should not be less than 25 dB. At first step adjustable 3dB and 12.5dB hybrid couplers are investigated. Another requirement to adjustable direction coupler is to fit the given space limiting the dimensions: length less than 500 mm and width less than 400 mm.

E-H TUNER

Fig.1 shows a magic tee, matched to reflection factor of 0.001, using inductive irises in the E- and H-arms (3 and 4 respectively). Removable sliding shorting plungers with a range of half a wavelength are connected to these arms. Fig. 2 shows an experimentally measured S11 matrix element vs. plungers' position

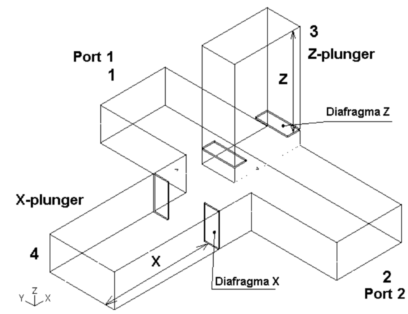

Fig.1: Magic tee, matched using inductive irises

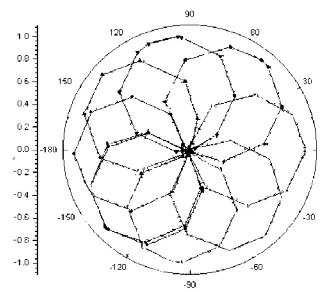

Fig.2: Measured S11

The necessary power capability for the E-H tuner is 280 kW pulse power in a totally reflecting load. This corresponds to 1100 kW to a matched load. Therefore it is important to provide optimum conditions for the short circuit current at the sliding shorts and minimum field strength at sparking endangered locations. Two different variants of choke plungers were considered. Both for 1300 MHz and the waveguide type WR-650 with dimensions 165.1 x 82.55mm^2.[2]

The choke plungers are motorized by stepping motors. In Fig.3 a sketch of the assembly is shown. Positioning the plungers is made by a computer with RS-232 or RS-422 interface. In a calibration mode the computer moves both plungers successively over the full sliding range defined by limit sensors and measures the S-matrix via a network-analyzer. Plunger positions and associated S-parameters are stored in a computer table. In the normal operating mode the user can define desired S-parameters, coupling factors or phases, which are then adjusted automatically by the computer-controlled plungers.

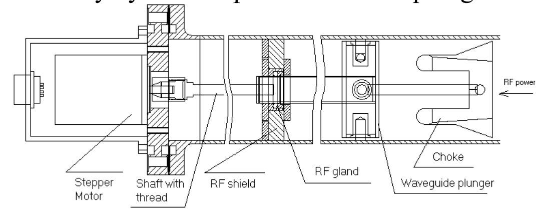

Fig.3.Second design variant of the choke plunger, motorized by a stepping motor

12.5 dB ADJUSTABLE DIRECTIONAL COUPLER

The coupler model is presented in Fig.4. In order to comply the device dimension limitations the 90 grad turn of side waveguides with movable plungers was used.

The side waveguides broad walls length was chosen 276 mm. The simulations show that the side waveguides of reduced width result in dramatic directivity degradation at the plungers displacement from the initial position corresponding to the coupling of C=12.5dB. Enlarged waveguide makes the directivity degradation on the adjustment band sides lesser but moves the entire D vs. C curve down, i.e. decreasing the directivity. So, there is optimal waveguide width value ensures the maximal directivity at adjustment range frontiers (at 11.5dB and 13.5dB coupling)

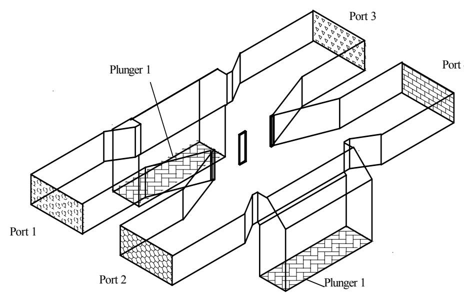

Figure4: 12.5dB directional coupler model

The D vs. C dependence "centering", i.e. directivity maximum shift to the middle of adjustment range C=12.5dB was done by protrusions at the sides of adjusting waveguides dimensions variation. Input waveguide ports matching was done by wedge between 1st / 2nd and 3rd / 4th ports angle variation. Coupling window dimensions define the coupling.

The adjusting waveguide segments at 45 grad allowed matching the bends. The minor segment reduces the electric field overvoltage on the bend edge thus ensuring the coupler electric strength. The model is symmetric and two plungers are displaced simultaneously during the simulation. The results obtained for the coupler with optimized geometry are the following: D exceeding 29dB, reflection R less than –32dB within the full coupling adjustment range 11.5dB to 13.5dB.

Based on the simulation results the coupler design was developed suitable for manufacturing. According to the technological guidelines the coupler has straight waveguide sections just before flanges, latter being of standard shape. The flanges for adjusting waveguides were chosen of increased width keeping the other parameters unchanged.

The coupler parameters computation and its geometry was done by Gradient descent back-propagation method involving 10 dimensions, using HFSS 8.0 code. The main results for optimized device are presented in Fig.5, a. The data show that D is better than 28dB in the coupling adjustment range 11.5dB to 13.5dB. Along with equal plungers positioning the case of independent one was considered. Fig.5, b. shows the surfaces representing the parameters D change with two independent parameters (plunger positions d1 and d2) variation.

The electric strength is one of the most important issues presented by the coupler development. The electric field distribution in the coupler volume was studied for different plunger positions and the field peak values were

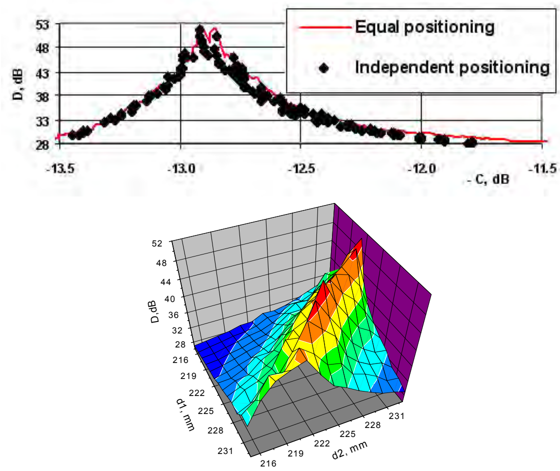

Figure 5: Directivity for 12.5dB coupler vs. coupling dependences (a) and plunger positions (b)

obtained. The adjusting waveguide H-bend corner area being possibly discharge-dangerous is free from overvoltage. Also the field strength in adjusting waveguides is less than one in input waveguides, thus the movable plungers will operate in less strict conditions. The movable plungers design relies on electric time-dependant field distribution in the plunger vicinity. The field distributions are different for two plungers with respect to both time and space. In one waveguide the TE_{10} mode predominantly propagates whereas in the other one TE_{20} mode is distinctive. This means that in case of choke-type plungers they are to be different thus making the coupler design more complicated. The maximum overvoltage factor K, determined as the maximal electric field strength in directional coupler to the traveling wave field strength in attached waveguide, was K=13% at d=233mm corresponding to coupling to C=13.5dB.

3dB ADJUSTABLE DIRECTIONAL COUPLER

The directional coupler with 3dB coupling was designed according to the algorithm used for 12.5dB coupler (see Fig.6.). The main difference in device geometry is in coupling window design. The adjusting waveguides have the same dimensions as for 12.5db device for plunger unification. The optimization was done by gradient descent back-propagation on 7 geometry parameters. The model is symmetric and the plungers' positions are equal for both adjusting waveguides. The directional coupler main parameters after the model optimization are the following: D exceeds 31dB, R less than –35dB inside coupling adjustment range 2db to 4dB. The directional coupler parameters with frequency change in (1300±5) MHz band were determined for three fixed plunger positions of 211mm, 226mm and 246mm, corresponding to the 2dB, 3dB and 4dB coupling respectively. The data obtained show that the coupler parameters in this frequency band: directivity exceeds 32dB, reflection is less than –32dB and the coupling change is less than 0.15dB.

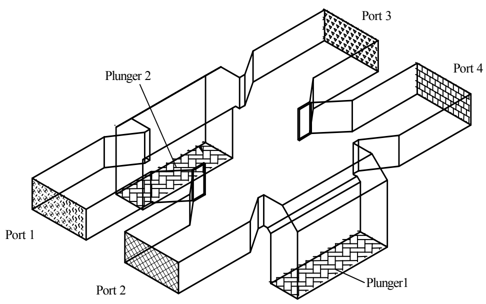

Figure6: 3dB directional coupler model

MOVABLE PLUNGERS

In order to achieve better directivity of the device at the coupling variation within ±1 dB range wide waveguides of 276×82.55 mm^2 cross-sections were chosen. The plunger development was done taking into account two concerns – effective short-circuiting in whole travel range and keeping the fields on the plunger surface below the waveguide fields value.

All the reasons mentioned led to the design of the fits-all-cases plunger based on flexible membrane element. In this design the thin bronze alloy film permanently attached to the waveguide wall and to the plunger body is used to have conductive plane (see Fig.7).

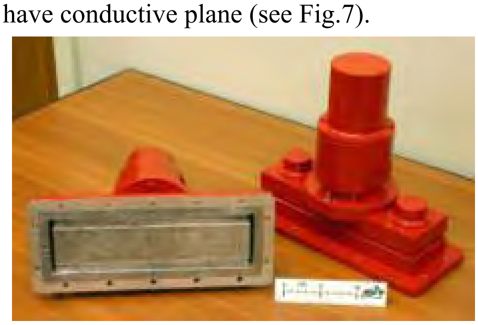

Figure 7:Membrane plunger

This plunger design has the following advantages. High-frequency currents in narrow walls of TE_{10} and TE_{20} modes are perpendicular to the waveguide axis so there will be no high electric field arise between plunger and waveguide (in 9mm slots). Electromagnetic properties of this plunger were determined by HFSS simulation. Electric field maximum was detected at plunger is 20mm displaced from its middle plane towards the coupler. Electric field at 1mm away from membrane edge is 0.07 of the coupler input waveguide field.

Actuating mechanics powered by step motor moves the plungers. Each plunger is equipped with two optical sensors limiting the traveling range.

EXPERIMENTAL RESEARCH

The measurements were done using test stand based on Agilent Network Analyzer 8753ET. Fig.8 presents the directional coupler photo with Network Analyzer connected using waveguide to coaxial transitions.

The controlling, save and recall of the data obtained during measurements are performed by PC. Two controllers by Integrated Motion Systems power the step motors. Network Analyzer connected to PC via GPIB interface measures directional coupler parameters. The computer code is developed using LabView.

Figure 8: Directional couplers measurement setup

Fig.9 presents the experimentally obtained and simulated by HFSS code parameters comparison. The data include coupling, directivity vs. plungers position. For the same cases directivity vs. coupling dependences are presented.

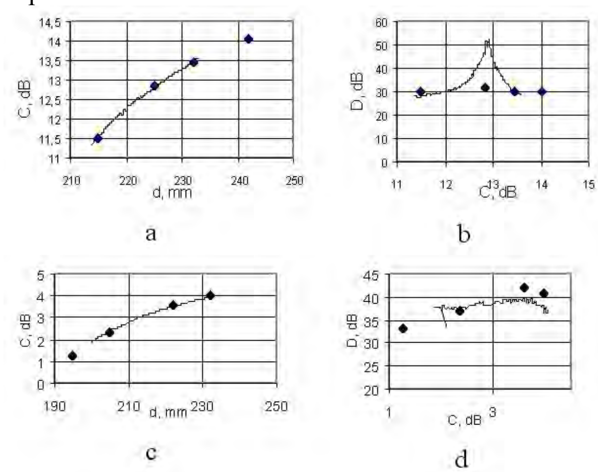

Figure 9: Experimental and calculated using HFSS code data comparison12.5dB (a, b) and 3 dB coupler (c, d): ♦ experiment, – calculation

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