DESIGN OF AN E-H TUNER AND AN ADJUSTABLE DIRECTIONAL COUPLER FOR HIGH-POWER WAVEGUIDE SYSTEMS

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Abstract

The calculation and experimental results for a 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 are presented. The investigations were carried out at 2.797 GHz and 1.3 GHz. The so-called E-H tuner shall provide the possibility of independent adjustment of external Q-factor and RF phase for the TESLA cavity structures. 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. A hybrid coupler with a coupling factor of 3.0 dB and an adjustable range of ±1 dB at more than 25 dB directivity was calculated. The adjustment elements of this coupler are variable choke plungers in two additional H-arms opposite the coupling-slot.

1 INTRODUCTION

The high power RF distribution system of the electron-positron collider TESLA [1] is designed to ensure independent external Q-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 it is planned to use E-H-tuners. An E-H-tuner is a Magic-T with a variable shorting plunger in each of the E- and H-arms. Such a tuner allows arbitrary transformation of load impedance within the whole Smith-chart area. In practice it is possible to transform a reflection factor > 0.9 (VSWR > 20) to a reflection factor of 0 (VSWR =1) and to shift the RF phase over a $\pm 180^0$ range. The transmission S_{21} can be adjusted between 1.0 and 0.03

For matching the RF power distribution system to cavities with different quench thresholds, the investigation of adjustable hybrid couplers is underway. For the TESLA machine it is planned to feed 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 ±20% (±1 dB) are necessary. The directivity should not be less than 25 dB. In a first step an adjustable 3-dB hybrid coupler is investigated because this type has the strictest requirements in terms of adjusting-range.

2 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 the calculated values of scattering matrix element S11 for variable short position in arm 4 and different short positions in arm 3. The calculations were carried by the program HFSS [2]. The HFSS calculation agrees well with results from formula (1), which was obtained using matrix formalism. An experimentally measured S11 matrix element vs. plungers' position (Fig. 3) agrees with calculations.

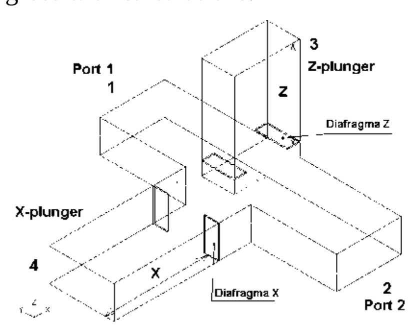

Fig.1: Magic tee, matched using inductive irises

$$S11 = \frac{b_1}{a_1} = S_{11} + \frac{-S_{13}^2 e^{-2i\varphi_e}(1+S_{44}e^{-2i\varphi_h}) - S_{14}^2 e^{-2i\varphi_h}(1+S_{33}e^{-2i\varphi_e}) + 2S_{13}S_{14}S_{34}e^{-2i(\varphi_e+\varphi_h)}}{(1+S_{33}e^{-2i\varphi_e})(1+S_{44}e^{-2i\varphi_h}) - S_{34}^2 e^{-2i(\varphi_e+\varphi_h)}}, \quad (1)$$

where $\varphi_e = \frac{2\pi}{\lambda_e}(z - z_0)$ and $\varphi_h = \frac{2\pi}{\lambda_e}(x - x_0)$, a_1 and b_1 are the incident and reflected waves at port 1.

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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.

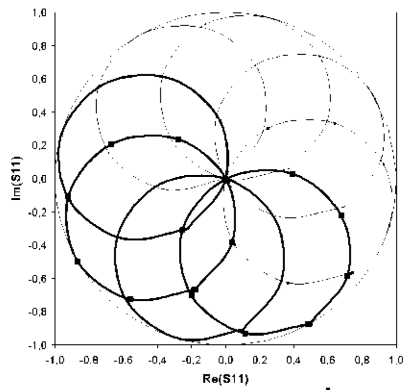

Fig.2: Calculated S11

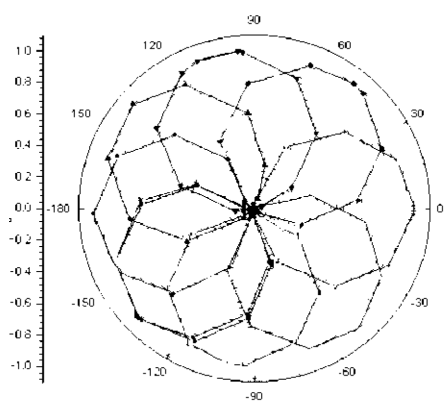

Fig.3: Measured S11

The first design variant of the choke plunger was a traditional construction (see Fig.4).

Despite several variations of the choke shape, the field in the gap between the first quarter of the ½ wavelength labyrinth and the waveguide wall could not be sufficiently reduced. The transmission ratio RF leak / RF input was –53.6 dB. The maximum field strength inside all gaps does not exceed 50% of the incident wave.

In the second design variant of the choke plunger (see Fig.5) the choke part and the body of the plunger are connected via two plastic bars of 8 mm diameter. Thus a common short-circuit plane on the back-side of the plunger results for the upper and the lower 1/2 wavelength labyrinth. This essentially reduces the intensity of the field strength in the choke. The maximum field strength inside all gaps does not exceed 35% of the incident wave. Inside the waveguide the entire choke plunger is constrained in the transverse direction by means of plastic distance pieces and has no electrical contact with the waveguide surface. The transmission ratio RF leak / RF input is –65 dB in this design.

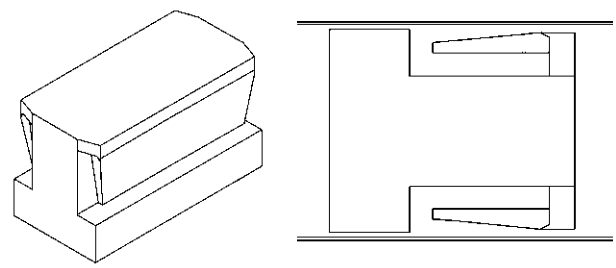

Fig.4: First design variant of the choke plunger

The choke plungers are motorized by stepping motors. In Fig.5 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.

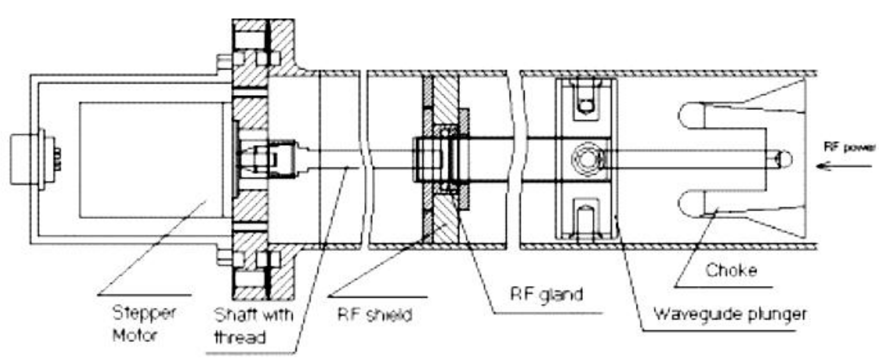

Fig.5: Second design variant of the choke plunger, motorized by a stepping motor

3 ADJUSTABLE HYBRID COUPLERS

Adjustable directional couplers for independent adjustment of RF input power for the TESLA cavity structures are investigated. Two different constructions are considered. Firstly hybrid-coupler, adjustable via capacitive plungers inside the coupling gap (see Fig.6) and secondly hybrid-coupler, adjustable via inductive plungers in two additional H-arms opposite the coupling-slot (see Fig.7).

The meanings of the abbreviations are:

L: plunger width

h: coupling aperture width

s, sh: bevelling

d: plunger position

Some results of computations for this type are presented in Fig.8 and 9.

Figs.8 shows the coupling factor C versus plunger position d for different bevelling sh.

Fig.9 shows directivity D versus plunger position d for different bevelling sh.

The calculations were made for L=276mm, h=322mm, s=19mm.

The calculations show that the described principle allows the design of a hybrid coupler with an adjustable coupling factor over a range of 2 dB with a directivity >26dB. Further investigations and the production of prototypes

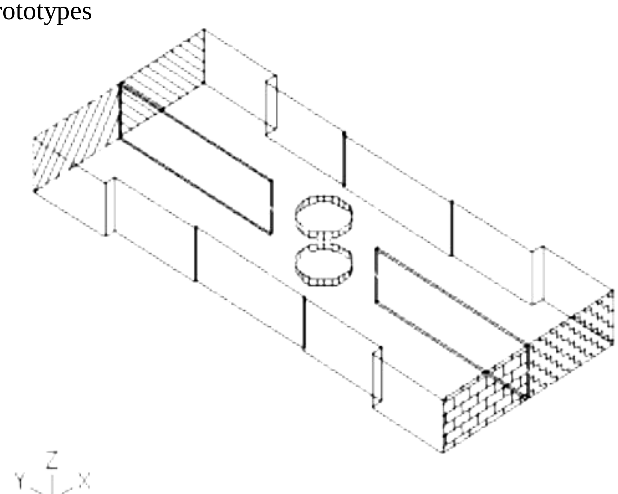

Fig.6: Hybrid-coupler, adjustable via capacitive plungers inside the coupling gap are underway.

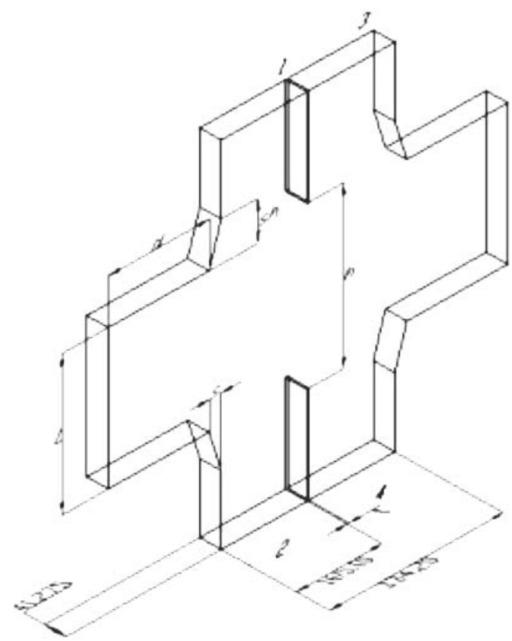

Fig.7: Hybrid-coupler, adjustable via inductive plungers

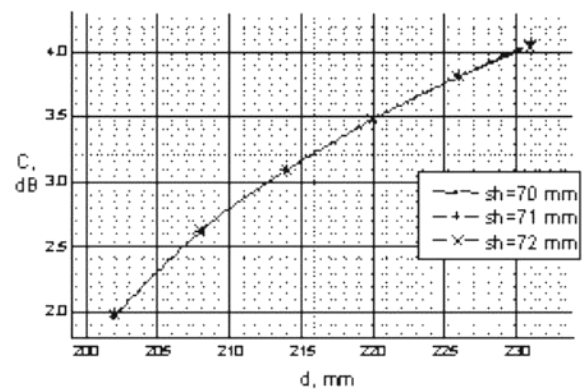

Fig.8: Coupling factor vs. plunger position

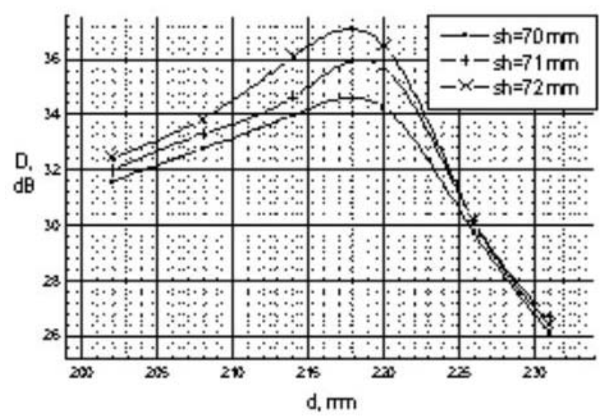

Fig.9: Directivity vs. plunger position

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[1] R. Brinkmann, G. Materlik, J. Rossbach, A. Wagner, Conceptual Design of a 500 GeV e^+e^- Linear Collider with Integrated X-ray Laser Facility, DESY 1997-048, ECFA 1997-182, vol.1

[2] ANSOFT HFSS 3D EM simulation software for RF