

WAVEGUIDE DISTRIBUTION SYSTEMS FOR THE EUROPEAN XFEL

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Abstract

In the European X-ray FEL 32 superconducting cavities are connected to a 10 MW multibeam klystron through a waveguide distribution system. The basic waveguide system is a linear system. The XFEL tunnel has limited space for the waveguide system and therefore some new compact high power waveguide components like a motor driven phasemitter, an iris tuner and an asymmetric shunt tee have been developed. Also alternative layouts of the waveguide distribution system which may have certain advantages have been designed. In this report we will present the different layouts and report on the status of the development of the different new waveguide components.

INTRODUCTION

The linac for the XFEL has 116 cryomodules with 8 cavities each [1]. The linac is operated at an RF pulse length of 1.38 ms, a repetition rate of 10 Hz and an RF frequency of 1.3 GHz. One 10 MW klystron feeds 4 cryomodules with 32 cavities. The superconducting cavity has a loaded quality factor of about 4.6×10^6 .

In order to achieve 23.4 MV/m accelerating gradient for 5 mA beam current it is necessary to supply 122 kW RF power to each cavity. 5.2 MW RF power from the klystron is required including 10% losses in the waveguide distribution system and a regulation reserve of 15% for phase and amplitude control. When operated at 10 MW the klystrons supplies 280 kW to each cavity.

WAVEGUIDE COMPONENTS

All waveguide components are based on WR650 type waveguide and PDR14 flange. Since the distribution system is not gas tight, we are planning to fill the waveguide distribution with a small flow of dry air to increase the reliability of system.

The waveguide losses have been measured to 0.0075-0.008 dB/m at a frequency of 1.3 GHz. For 5 MW, 1.38 ms RF pulse and 10 Hz repetition rate the waveguide temperature reaches 35-40 °C.

The theoretical power capability of a straight WR650 is about 55 MW RF power. Experience shows that in reality it is a factor 5-7 times lower.

Phase Shifter

The basic idea of phase shifter is variation of the waveguide width and thus a change of the phase constant. In order to vary the width a removable special form piston can be inserted in a 400 mm long straight waveguide. The piston has no sliding contacts and is isolated from the inner surface of waveguide by kapton foil of 0.15 mm thickness. By moving in the piston up to 25 mm the phase is changed by 100 degree for $SWR \leq 1.2$. In this position the wall losses increase by about 50%.

There is a strong resonance in the kapton gap when the piston is near the narrow waveguide wall (see Fig.1). In this case the gap voltage increases several times and a gap spark can occur. The dimensions of the piston have been computed, and the piston has been designed to minimize the gap voltage.

The phase shifter has been tested successfully up to 4 MW limited by the available power.

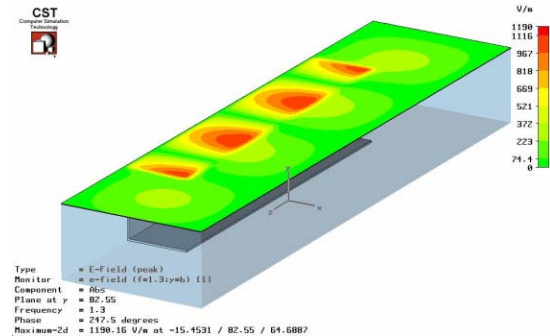


Figure 1: The resonance in the kapton gap.

Moving in the piston up to 65-70 mm the isolation between two ports of phase shifter becomes 30-35 dB. And therefore the phase shifter can be used as an RF switch too.

Iris Tuner

An equivalent circuit of iris tuner is shown in Fig.2. The superconducting cavity with impedance $Z_c = R_s / (1 + j\xi)$ is powered through a circulator with a fixed obstacle between two phase shifters. Where R_s and ξ are the shunt impedance and the detuning of the superconducting cavity.

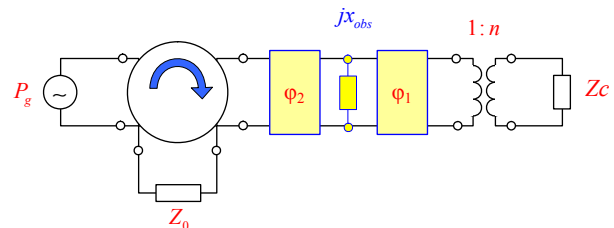


Figure 2: The equivalent circuit of the iris tuner.

It can be shown that the loaded quality factor Q_t with tuner changes like

$$\frac{Q_t}{Q} = \frac{1 + 2x_{obs}^2 - \cos(2\phi_1) + 2x_{obs}^2 \sin(2\phi_1)}{2x_{obs}}$$

where Q is the loaded quality factor without tuner and x_{obs} is the normalized impedance of the obstacle.

An inductive iris has been chosen as the obstacle, because it has more power capability than a capacitive obstacle. The iris with the window width of 88 mm will change the loaded quality factor by a factor of 17 (see Fig. 3). By tuning the loaded quality factor also the cavity frequency is changing by 250 Hz. To compensate this frequency shift the blade tuner of the superconducting cavity can be used [4].

A second phase shifter ϕ_2 is necessary for changing the phase of the incident power.

The iris tuner has higher power capability in comparison with a 3-stub tuner and smaller dimensions than an E-H tuner. The advantage of the iris tuner is that loaded Q depends only on one parameter ϕ_1 whereas it depends on 3 or 2 parameters in a 3 stub tuner or an E-H-tuner respectively. [3].

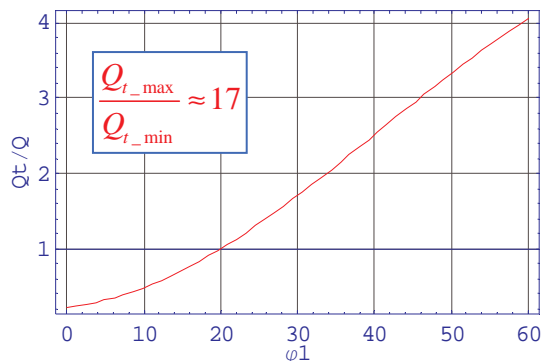


Figure 3: The load quality factor depending on phase shift ϕ_1 .

It is possible to modify the range of the quality factor by changing the iris window width only.

Asymmetric Shunt Tee

The asymmetric shunt tee uses two posts to match the side port and to get the required coupling ratio. Three kind of asymmetric shunt tee 3.0, 4.77, 6.0 dB have been computed by Microwave Studio (see Fig. 4) and manufactured.

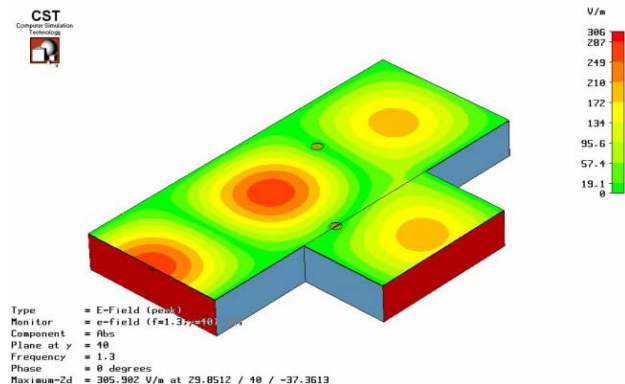


Figure 4: The 3 dB asymmetric shunt tee.

Low level RF measurements of the asymmetric shunt tee have shown a good agreement with the calculations.

The asymmetric shunt tee can be used instead of a hybrid with dummy load. It allows a reduction of space required for the waveguide distribution in the XFEL tunnel.

Directional Coupler

A 150 mm length directional coupler has been developed at DESY and manufactured by industry (see Fig. 5).



Figure 5: The directional coupler and stripline head.

The directional coupler measures the forward and reflected RF power in the waveguide system. It is gas tight with an Al_2O_3 ceramic window. The directional coupler has a head with a stripline made with the dielectric RO4003 ($\epsilon \approx 3.4$) and is matched to a 50 Ω load with a capacitor variable stub. Each head can be tuned with an accuracy of ± 0.1 dB for a coupling ratio range of 55 ÷ 65 dB with a directivity not less than 40 dB.

WAVEGUIDE LAYOUTS

The XFEL linac tunnel has a diameter of 5.2 m [5]. The waveguide distribution system will be placed behind the cryomodule in area with has a cross section of 1.45x0.95 m only (see Fig. 6).

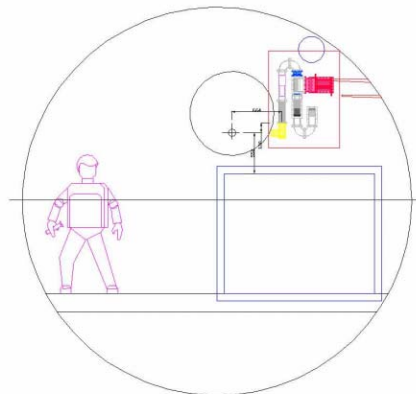


Figure 6: The cross section of the XFEL tunnel.

The waveguide distribution uses as basic unit a phase shifter, a 350 kW circulator and a bellow between cavity coupler and the waveguide distribution to avoid mechanical stress on the coupler.

Linear Waveguide Distribution

The baseline waveguide system is a linear system. The linear system branches off identical amounts of RF power for each individual cavity from a single line by means of directional couplers. The waveguide distribution for one cryomodule is shown in Fig. 7.

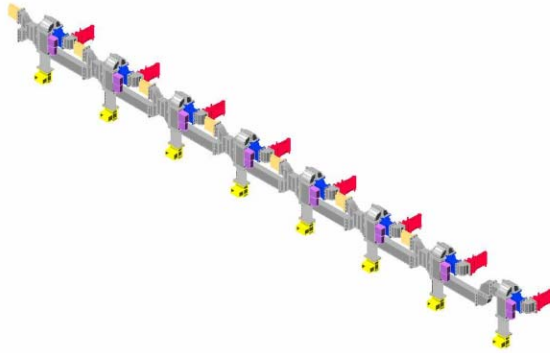


Figure 7: The linear distribution system.

A similar system is used now in the VUV-FEL [6]. The system is capable of about 300 kW RF power per cavity. The linear system uses 7 different hybrid coupling ratio and needs the additional dummy loads for hybrid matching. The advantage of the system is the long experience from TTF/VUV-FEL operation and the good decoupling of the cavities. A disadvantage is that it is difficult to phase and that it requires more space than alternative layouts.

Waveguide Distribution With Asymmetric Shunt Tee

One of alternative layouts of the waveguide distribution system is a waveguide system with a binary cell and asymmetric shunt tee (see Fig. 8).

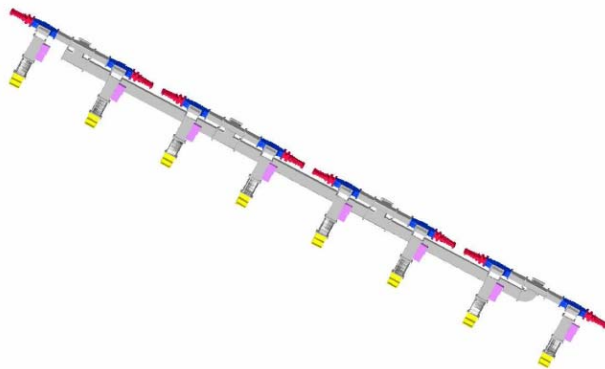


Figure 8: The distribution system with binary cell and asymmetric shunt tee.

The binary cell consists of two circulators which are fed through a symmetric shunt tee. An advantage is that the cell is phased for the beam already and therefore it is necessary to tune 4 binary cells only. Another advantage is that by using the asymmetric shunt for connecting the binary cells it is possible to save space and to avoid 7 dummy loads. In addition the system has much better access to all waveguide components and couplers and uses only three types of the shunt tees - 3.0 dB, 4.77 dB, 6.0 dB. Disadvantages are that this system needs about 25% more straight waveguides and no long term experience from operation is available.

CONCLUSION

Many new components for the waveguide distribution system for the XFEL were investigated and tested successfully with high power RF power. We are still continuing this work for further improvement of waveguide components. One of basic goals is to increase the reliability of each waveguide component.

Two types of waveguide systems were developed and assembled. While experience exists only with the linear systems it is planned to test and compare both of the waveguide distributions, the linear system and the alternative, at full operating power from a klystron on a test stand.

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