FLASH2020+ UPGRADE – MODIFICATION OF RF POWER WAVEGUIDE DISTRIBUTION FOR THE FREE-ELECTRON LASER FLASH AT DESY

B. Yildirim*, S. Choroba*, V. Katalev*, P. Morozov*, Y. Nachtigal*

*Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany

Abstract

One goal of the FLASH2020+ upgrade is to increase the energy of the FLASH accelerator, which allows to generate even shorter wavelengths, which, in turn, will allow new fields of research. For this purpose, during the shutdown in 2022, two superconducting accelerator cryomodules for ACC2 and ACC3 will be replaced by new ones. To fully realize the potential of these cryomodules, European XFEL type optimized waveguide distributions will be installed on them [1]. In addition, the existing ACC4 and ACC5 cryomodules will also be equipped with new waveguide distributions, similar to the XFEL type. These waveguide distributions will be modified and improved so that the accelerator can operate with maximum energy due to individual power supply for each cavity. Furthermore, three RF stations will receive a new klystron waveguide distribution, which will improve the reliability of all systems. The new specific waveguide distributions have been developed, produced and tested at the Waveguide Assembly and Test Facility (WATF) at DESY. All together will lead to increasing the electron beam energy from 1.25 to 1.35 GeV.

This paper presents data on the production and tuning of waveguide distribution systems for the FLASH2020+ upgrade at DESY.

INTRODUCTION

The Free-Electron Laser FLASH consists of a 1.3 GHz RF gun and seven 12 m long TESLA type superconducting accelerating cryomodules (ACC) with eight cavities each. Five RF stations with 5 MW or 10 MW klystrons supply cryomodules through a specific waveguide distribution system with RF power.

One goal of FLASH2020+ upgrade is to achieve high energies of the accelerator with high reliability. Due to different cavity power requirements individual waveguide distribution systems for accelerator cryomodules were produced, tested and tuned. To create the entire waveguide distribution as reliable as possible all sub-systems such as klystron-, connecting- and cryomodule waveguide distributions have been customized to the module gradients and also to the space conditions in the tunnel.

An additional air flow system for each RF station will decrease the breakdown level in the waveguide distributions.

Figure 1 shows an overview of RF station 1 with its klystron-, connecting- and cryomodule waveguide distribution for ACC2 and ACC3. These cryomodules are European XFEL type modules with 0-degree phase advance between the cavities. This allows easier final measurements for the phase tuning.

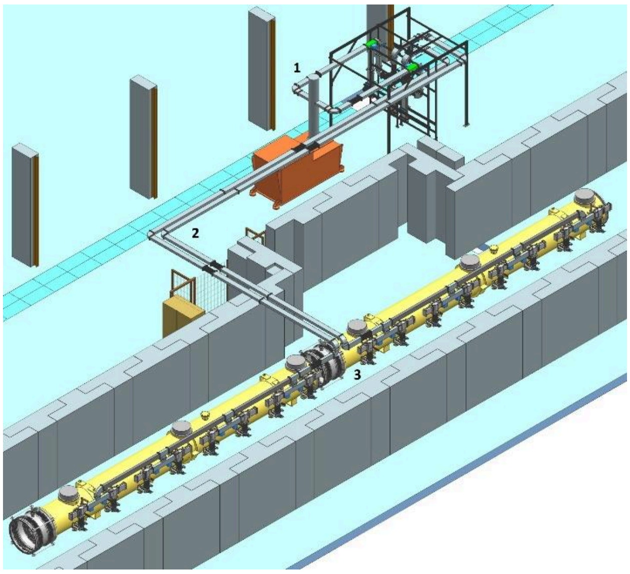

Figure 1: Overview of klystron- (1), connecting- (2) and cryomodule waveguide distribution (3) for ACC2 and ACC3.

The layout of RF station 5 is shown in Figure 2. The cryomodule waveguide distributions for ACC4 and ACC5 are different to the ones of ACC2 and ACC3. The reason for that is both the module type and the insufficient space. Although these cryomodules have not been exchanged, new and optimized waveguide distributions were constructed and installed. The phase difference between the cavities of ACC4 and ACC5 has been compensated due to the final LLRF measurements [2].

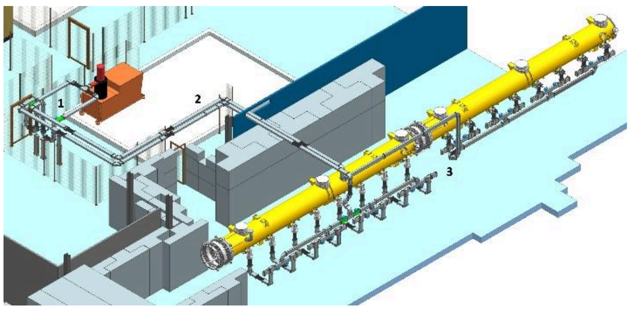

Figure 2: Overview of klystron- (1), connecting- (2) and cryomodule waveguide distribution (3) for ACC4 and ACC5.

In contrast to the previous modules the cryomodules as well as the waveguide distribution systems for ACC6 and ACC7 stay unchanged. The tuning for this station will be done within the final phase measurements of the complete accelerator.

WAVEGUIDE DISTRIBUTION SYSTEM FOR ACC2 AND ACC3

The 10 MW multibeam klystron supplies power for the cryomodules ACC2 and ACC3 through their specific waveguide distribution system. Both distributions are designed like the former XFEL type distributions with a 0-degree phase difference between the cavities [3]. The given gradients vary between 28.7 MV/m and 32.2 MV/m for ACC2 and 24.3 MV/m and 33.0 MV/m for ACC3. The total power for each cryomodule is approximately 2.6 MW.

Even though the LLRF measurements show a SWR of 1.3 and 1.2, it must be considered that the components with a significant influence on the SWR, especially the 450 kW isolators, show their optimum behavior at operation conditions, which leads to a substantial decrease of the total SWR (see Fig. 3).

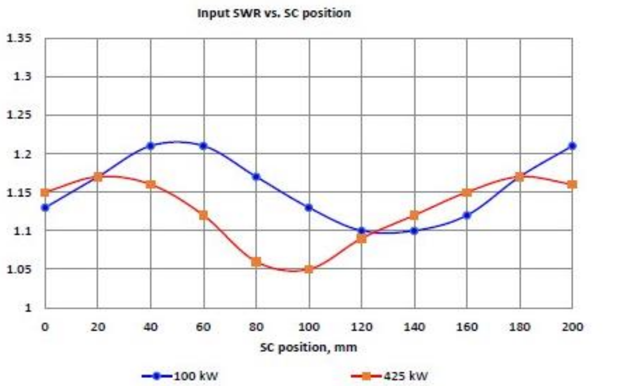

Figure 3: SWR vs. short circuit position of an isolator at different power levels.

The coupling ratios of both distribution systems are comparatively balanced due to the similarity of the gradients. These are totaled in the range of 8.7 dB and 10.2 dB. The FLASH2020+ upgrade includes the complete replacement of all components for RF station 1 such as klystron, modulator, cryomodules and all their waveguide components.

WAVEGUIDE DISTRIBUTION SYSTEM FOR ACC4 AND ACC5

The waveguide distribution systems for the cryomodules ACC4 and ACC5 transmit the RF power from a 5 MW single beam klystron to the cryomodules.

In contrast to RF station 1, the cryomodules of RF station 5 have not been exchanged, so these are still the previous ones with a phase difference of 7 degree between cavities for ACC4. Both cryomodule waveguide systems are unique and differ from each other due to the small amount of available space in the tunnel and a different type of main couplers for cavities.

The distribution for ACC4 has a symmetrical design with its RF power input in the center of the system, shown in figure 4. In addition to the 7-degree phase difference, the total phase tuning of this distribution requires more effort as the phase tuning of the cryomodules ACC2 and ACC3. The gradients vary from 22.6 MV/m to 31.5 MV/m. The power is approximately 181 kW to 352 kW, accordingly.

In contrast ACC5 has nearly the same structure such as ACC2 and ACC3. The main difference is, that the waveguide distribution is installed upside down due to the old orientation of main couplers of the cavities (see figure 5). The parameters such as gradients and equivalent power are in a similar range of 22.9 MV/m to 30.9 MV/m and 187 kW to 340 kW.

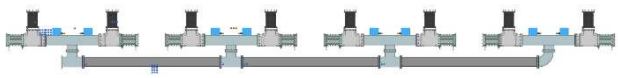

Figure 5: Design of the cryomodule waveguide distribution for ACC5.

Especially the phase tuning between the waveguide distribution systems for ACC4 and ACC5 needs a high level of accuracy since different main couplers are used. Those have a specific phase difference, which needs to be considered carefully. The power distribution between the cryomodules will be realized with a tunable 3 dB shunt tee. The total power for each waveguide distribution system is approximately 2.1 MW.

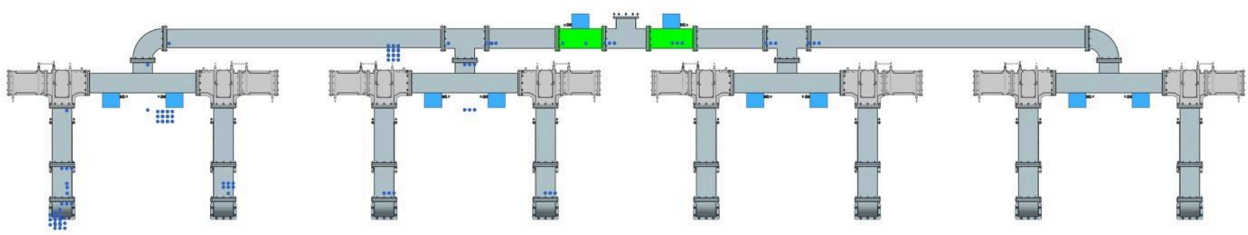

Figure 4: Layout of the cryomodule waveguide distribution for ACC4.

WAVEGUIDE DISTRIBUTION SYSTEM FOR ACC6 AND ACC7

The upgrade for ACC6 and ACC7 includes the klystron waveguide distribution system and the connecting waveguide distribution as well as the phase tuning for RF station 4 only, see figure 6. The given gradients vary between 20.6 MV/m and 35.9 MV/m with 151 kW to 458 kW accordingly for ACC6 and 13.0 MV/m to 38.4 MV/m with 60 kW to 524 kW for ACC7.

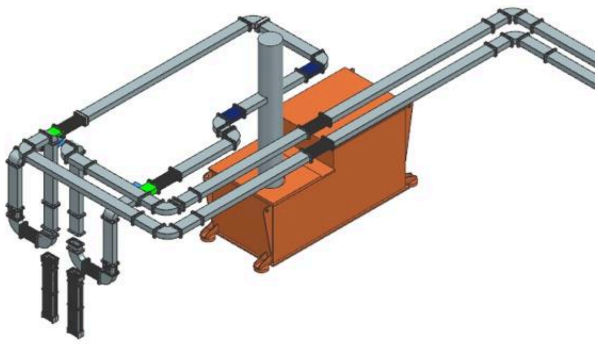

Figure 6: Design of the klystron waveguide distribution of RF station 4 for ACC6 and ACC7.

Both module distributions have already been adjusted and fine-tuned beforehand in 2019. To optimize the input power distribution of the cavities, three additional attenuators have been installed between the cavity and the isolator. Two of the them have been installed for ACC6 (0.8 dB for cavity 2, 1.2 dB for cavity 8), the third one with 5.1 dB has been used at ACC7 for cavity 8. Figure 7 shows the attenuator position for cavity 8 of ACC7. The reduction of power to these limiting cavities allowed to increase the power to the other cavities and thus the total power to the modules. This improvement resulted in a total beam energy gain of about 20 MeV, which is equivalent to one additional cavity.

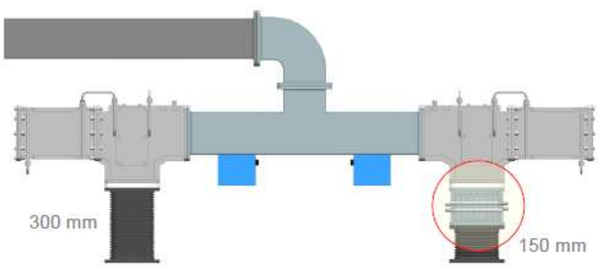

Figure 7: Position of the inserted attenuator for cavity 8 of ACC7.

AIR FLOW MACHINES FOR THE WAVEGUIDE DISTRIBUTIONS FOR FLASH

The air flow system for the waveguide distribution for the FLASH accelerator consists of two air flow machines for the RF gun as well as one machine for every RF station.

These air flow systems have been developed to decrease the probability of breakdown and for phase tuning. By changing the air pressure in the waveguides, the size of the waveguide changes and therefore the RF phase advance [4].

The air flow machine for the RF gun supplies an air pressure of maximum 1.5 bar inside two branches of the waveguides. Each waveguide branch is followed by a 2.5 MW isolator. The main reason of using two isolators is to reduce the RF power in each isolator and by this to ensure a highly reliable system. In order to reach only one waveguide path and thus to supply the maximum RF power to the RF gun with the same phase, both branches have been combined by a 3-dB asymmetric shunt tee.

A Programmable Logic Controller (PLC) is used to control the air flow machines.

The control of the airflow system is integrated in the control system of FLASH. Thus, operators can modify desired parameters quickly and directly.

CONCLUSION

The waveguide distribution for the FLASH2020+ upgrade, which consists of a large number of waveguide components, has been successfully installed in the FLASH tunnel. The waveguide distribution system for the RF stations 1, 4 and 5 as well as the cryomodules ACC2&3, ACC4&5 and ACC6&7 have been tuned and tested up to full power. High reliability is expected from previous experience with other RF waveguide distributions designed in a similar way.

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