ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO027

SERIES PRODUCTION OF THE SPECIFIC WAVEGUIDE DISTRIBUTION FOR THE EUROPEAN XFEL AT DESY

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Abstract

The European XFEL uses 100 accelerating cryomodules. One RF station with 10 MW klystron supplies, through a waveguide distribution, four cryomodules with eight cavities each. The RF station operates at 1.3 GHz, 1.37 ms pulse width and 10 Hz repetition rate. The results of the cryomodule test have shown however different maximum gradients for each cavity. The maximum gradient has been measured between 11 MV/m and 31 MV/m, which requires cavity power of 29 kW to 230 kW. To operate with the maximum energy for every cryomodule, it is necessary to supply individual power to the cavity. In this case the weakest cavity problem can be avoided. For this goal, a specific waveguide distribution has been developed. 100 waveguide distributions have been successfully tailored, produced, and tested at the Waveguide Assembly Test Facility (WATF) at DESY and finally assembled to the cryomodules.

We present the series production of the specific waveguide distributions at the WATF.

REQUIREMENTS FOR WAVEGUIDE DISTRIBUTION PRODUCTION

To meet the requirements for measuring such complex waveguide distribution, basically three different test stands have been created for special procedures of measurements at the Waveguide Assembly Test Facility (WATF), binary cell test stand, LLRF test stand and HPRF test. The installation of all test stands had taken a lot of time due to the mechanical control and RF control. In addition, the custom-built test stands needed special equipment to avoid mistakes during measurements.

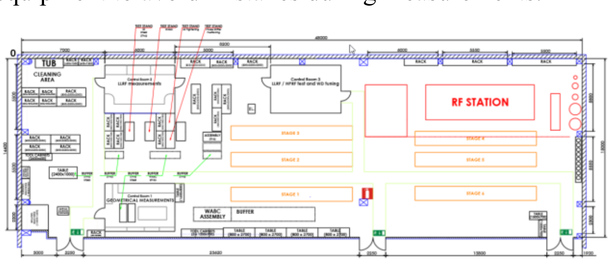

Figure 1: Layout of the WATF.

Fig. 1 shows the 670 m^2 area of the WATF. The WATF includes two RF laboratory for LLRF and HPRF tests of the waveguide distributions. In addition the WATF area has a laboraty for the waveguide components referring to the geometric parameter control. An assembly area with five movable platforms for installation of the waveguide distributions is also part of the WATF. Many auxiliarities systems such as waveguide distribution support hangers, water cooling systems and cable trays are available at the WATF. Furthermore there is a test area for reliability position tests of the movable phase shifters and for pneumatic components. The WATF includes test areas for cooling water leakage, for pressure hydraulic tests and for checking of isolators cooling water flow sensors. In addition there is an area for cleaning, drying and dust hermetically covering of the waveguide components. To avoid problems with logistic time from main store, there is a small area for storing six waveguide distributions.

The working process at the WATF provides a parallel installation of different systems such as waveguide distribution supporting structures, water cooling systems, and flexibility in the assembly activities organization.

More than 150 complex mounting, adjustment, measurement and control operations are performed at the WATF for each waveguide distribution.

The waveguide distribution is based on the tunable binary cells and the tunable asymmetric shunt tees [1]. It consists of several specific waveguide components, which were created precisely to operate with the maximum energy for every cryomodule. On the one hand, the waveguide distribution should have a compact size, on the other hand it should supply high pulse RF power to the individual cryomodule cavities with high flexibility by only one power klystron.

Each RF station of the test facility consists of a 5 MW RF station, with a waveguide distribution. Each waveguide distribution supplies RF power to eight cavities, four pair of cavities as shown in Fig. 2.

In order to satisfy these conditions, specific waveguide components have been developed and integrated in the waveguide distribution for the series production of the specific waveguide distribution.

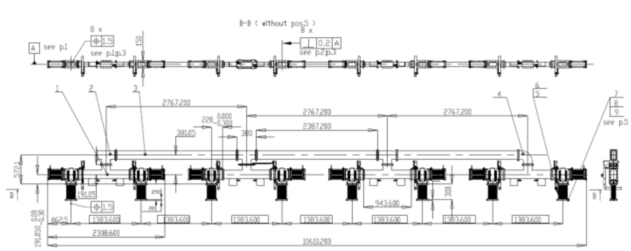

Figure 2: Layout of the XFEL waveguide distribution.

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FROM SHUNT TEE TO BINARY CELL

In order for the XFEL to work with the maximum energy for every cryomodule, each cavity has to be fed with power individually. Therefore the power distribution for each cavity has to be calculated. The first step is to define the long shunt tee for a pair of cavities. To obtain specific components from standard components, eight types of long shunt tees have been developed. Four each for right waveguide distribution and four each for left waveguide distribution. All waveguide distributions are based exactly on the tunable binary cells. The main reason for these eight types of binary cells is the acceleration of the production rate for the waveguide distributions. The schematic below shows the dynamic range of a right type binary cell (see Fig. 3).

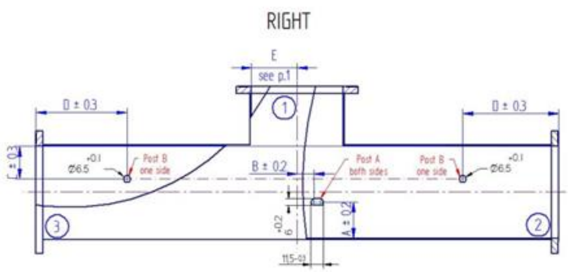

Figure 3: Layout of a right type shunt tee.

Each output port is supplied through the shunt tee which divides the RF power individually to the two cavities. The dimension of B is changing from 0 mm to 15 mm depending on the type of the binary cell [1]. Furthermore, two phase shifters as shown in Fig. 4 are integrated into the shunt tee to compensate the phase difference during tuning. Depending on the phase shifter position, the RF power is distributed between the two output ports. A piston is driven by a linear positioning system with stepping motors. The linear positional accuracy is better than 0.1 mm. By moving the phase shifter up to 25 mm the phase is changing up to 90 degrees. To achieve maximum energy efficiency, the phase has to be 0 degrees between both outputs of the shunt tee. Due to the positions of the phase shifters the coupling ratio and the standing wave ratio (SWR) can be tuned in a very reliable way. This delivers an error rate of only ±0.1 dB coupling ratio and a SWR of maximum 1.20 related to the binary cells [1]. In addition, two isolators are assembled to the two arms of the shunt tee as shown in Fig 4. The isolators consist of a circulator with ferrites and a dummy load, which is used directly after the power source to protect it from high reflected power.

400 binary cells with completely different coupler ratios and SWR have been produced, tuned and tested for the European XFEL at the WATF.

Figure 4: Measuring of a binary cell with all components at the binary cell test stand.

FROM BINARY CELL TO WAVEGUIDE DISTRIBUTION

After the tuning of each waveguide component, the binary cells have been combined with three asymmetric shunt tees, three fixed phase shifters, and one H-bend. One asymmetric shunt tee is shown in Fig. 5. The waveguide distribution enables a flexible division of the power for each cavity to ensure that the cavities can work with their maximal individual power. 300 fixed phase shifters, 100 H-bends and 300 completely individual asymmetric shunt tees with the dynamic range of 0.89 dB to 7.27 dB have been produced, tested and assembled to the waveguide distributions as shown in Fig. 6.

The installation of the 10.6 m long system has completed with a special setup, which provides an accuracy level of ±1 mm and ±0.15 degrees. This allows for the installation of the waveguide distribution to the cryomodule without any stress on the main coupler of the cryomodule.

Figure 5: Asymmetric shunt tee of a waveguide distribution.

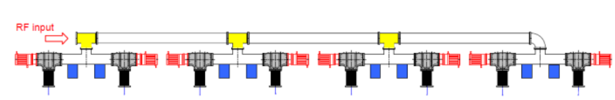

Figure 6: Waveguide distribution for the European XFEL.

29th Linear Accelerator Conf. LINAC2018, Beijing, China JACoW Publishing
ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO027

LLRF MEASUREMENTS AND HPRF TEST OF WAVEGUIDE DISTRIBUTION

For LLRF measurements SWR, the coupling ratio and the phase of each output and the forward and reflected pickups have been measured by using a special measurement setup. In addition the waveguide distribution has been measured with open and short planes for each output. After fine-tuning at LLRF test stand, final measurements at HPRF test stand have been done as shown in Fig. 7. By using special software, as demonstrated in Fig. 8, the waveguide distribution has been measured under high power. The special software allows for a dramatic decrease of nearly ten times the tuning and test times. To increase the reliability of the waveguide distribution and avoid problems in the XFEL tunnel, a stress test has been done with 20 to 30 percent more power than the specification of the cryomodule allows. Figure 9 shows the temperature for each isolator at HPRF test stand.

Figure 7: Measuring a waveguide distribution at HPRF.

Figure 8: Measuring results of coupling ratio and phase for each output at HPRF test stand.

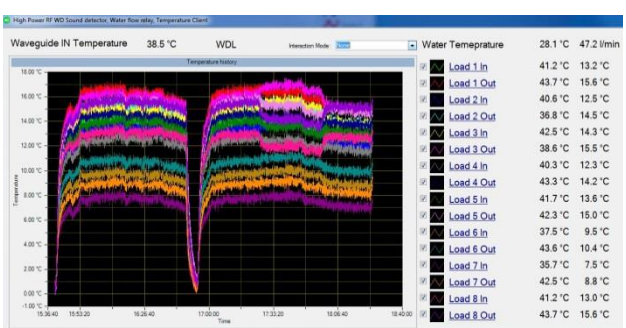

Figure 9: Measuring results of temperature for each isolator at HPRF test stand.

From the Accelerator Module Test Facility measurements (AMTF measurements) cavity accelerating gradient measurement error for the pulsed RF power measurement on the module test stand is evaluated as 8.9 %. For example, measured Eacc of 25.0 MV/m must be treated as Eacc = (25.0 ± 2.2) MV/m.

The WATF production error rate for all one hundred measured waveguide distributions is not more than ±0.2 dB. In this way, all waveguide distributions meet the AMTF requirements.

INSTALLATION OF WAVEGUIDE DISTRIBUTION TO THE CRYOMODULE

In order to save a lot of time and increase reliability, the waveguide distributions have been produced, tuned and tested at the WATF, and finally installed to the cryomodule at the AMTF (see Fig.10). The installation in the XFEL tunnel would have taken much more time. The first waveguide distributions have taken more time for completion (approximately three weeks for one and a half system.) But due to quality management, improvements of measurement and installation procedures, the time for completion has been reduced by one week.

Figure 10: Transportation of the waveguide distribution from WATF to AMTF for installation to the cyromodule.

SUMMARY

25 RF stations, which consist of 5304 waveguide components, have been successfully installed at AMTF and finally in the XFEL tunnel. The waveguide distributions for each station have been tuned and tested up to full power.

ACKNOWLEDGEMENTS

The authors are grateful to all the members of the DESY MHF-p teams for the successful tailoring, producing, tuning and testing of the WATF waveguide distributions.

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