OPERATION EXPERIENCE WITH THE FLASH RF WAVEGUIDE DISTRIBUTION SYSTEM AT DESY

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Abstract

The RF stations for the FLASH linear accelerator at DESY provide RF up to 10MW for 1.3ms and 10Hz at 1.3GHz for forty-eight superconducting cavities grouped into six cryogenic modules and for one normal conducting RF gun. A WR650 waveguide distribution system distributes the power generated by five RF stations using 5MW single beam and a 10MW multibeam klystron to the cavities and the gun. Since FLASH is based on the Tesla Test Facility, TTF, a number of different distribution layouts for the different modules and the gun have been developed and used over the years in terms of type of components and distribution scheme. This paper presents the layout and summarizes the experience with the existing waveguide distribution system.

INTRODUCTION

FLASH bases upon the TESLA Test Facility at DESY which has been constructed since the early 1990 in order to test all components required to construct a linear collider using superconducting cavity technology. Over the years the test facility has undergone many changes in order to meet the demands of different test options and operation conditions. Today FLASH serves as a user facility for synchrotron radiation research as well as a test facility for the European XFEL and for ILC studies.

FLASH accelerates an electron beam of 1nC bunches up to 1GeV which is used to generate laser light in the VUV regime. The electrons are produced in a RF gun and are accelerated in forty-eight superconducting nine-cell niobium cavities which are grouped in six cryogenic modules. The cavities are operated in a range between 12MV/m and 32MV/m. The RF power required by the RF gun and the cavities is generated by three 5MW klystrons and one 10MW multibeam klystron. The RF power distribution based on WR650 type waveguide distributes the power between the RF sources and the RF gun or the superconducting cavities. Due to different requirements and state of the art at a certain point of time a number of waveguide components and layouts have been developed, installed and operated over the years.

RF STATION LAYOUT

Each FLASH RF station consists of a HV pulse modulator with pulse transformer, a high power klystron, which generates the power required by the RF gun and the cavities, and a number of additional components. The HV pulses modulator converts AC line voltage to pulsed high voltage up to 130kV at a pulse duration of 1.5ms and 10Hz repetition rate. The klystrons convert pulsed power into pulsed RF power by amplifying an input RF drive power of 200W to the 5MW or 10MW output level with pulse durations up to 1.3ms of which 500µs required to fill the cavities with RF power and 800µs to accelerate the beam. More detailed information of the RF station layout can be found in [1].

RF DISTRIBUTION LAYOUTS

General Distribution Layout

Six RF stations have been installed at TTF and are labelled by #1 to #6. Station #1 is not in regular use for FLASH. It serves as power source for superconducting cavity tests but could be used as spare for FLASH which has not been required during the years. Station #3 provides RF power to the RF gun of FLASH, #2 to the first cryogenic module ACC1 with eight cavities, #5 supplies RF power for the modules ACC2 and ACC3 with sixteen cavities in total. Station #4 supplies power to the three modules ACC4, 5 and 6 with twenty-four cavities in total. Station #6 serves as spare for the other stations and, in case this is not required, is used for experiments and tests of waveguide elements. Figure 1 shows the actual RF distribution.

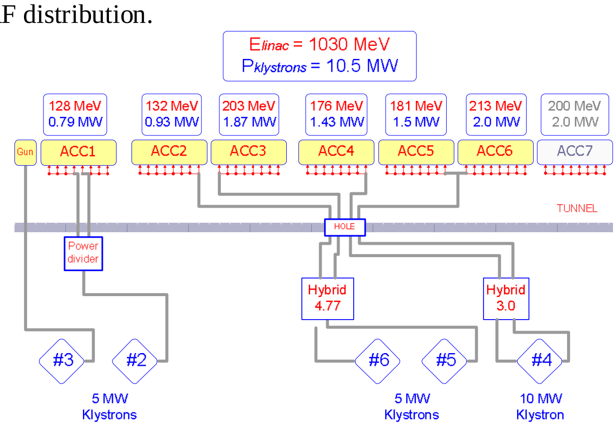

Figure 1: FLASH RF System.

All waveguide distributions between the klystrons and the superconducting cavities comprise the following sections. A section of typical 2m between the klystron window and an additional window with circulator in between filled with SF6 of typical 1.2bar, a module distribution for eight cavities at the cryogenic module either of linear or of combined (tree like and linear) type, and several meters of WR650 waveguide filled with air between these two sections. The module distributions with the exception of the distribution for ACC6 are of linear type. Equal amounts of power are branched off by hybrids. Therefore the operation gradient of these modules is limited by the maximum gradient of the weakest cavity in the module. Optimization is only possible in coarse steps by insertion of hybrids of completely other coupling ratio than for equal power branching ratio or by insertion of an attenuator in front of the weak cavity. The module distribution for ACC6 is of combined type. The power for a pair of cavities is branched off by asymmetric shunt tees. By adjusting the position of the tuning posts in the shunt tees the coupling ratio can be adjusted so that each pair of cavities is operated at its maximum possible gradient. Waveguide isolators (circulators with load) capable of 400kW in front of each cavity are used to absorb the power reflected from the cavities during the filling time of 500µs or in case of arcing or quenching. In case of the linear module distributions three-stub tuners between circulator and cavity are used to adjust the phase and Q_{ext}. In case of the combined system piston phase shifters which are integrated in the shunt tees which divide the power for a pair of cavities are used to adjust the phase. Adjustment of Q_{ext} is done by adjustable cavity couplers of ACC6. The Q_{ext} in all cases is $3 \cdot 10^6$. The module distribution in front of each module is filled with normal air at atmospheric pressure. The typical power loss in the circulators and long waveguides between the klystron and the cavity is of the order of 25%. Total length of the FLASH waveguides is about 300m. More detailed information about the different module distributions can be found in [2-4].

Distribution for the Cryogenic Modules

The 5MW THALES TH2104C klystron of station #2 provides about 1MW of power for the eight superconducting cavities of the cryogenic module ACC1. This module distribution of ACC1 has a specific feature. The first four cavities are operated at a gradient of 12MV/m and the second four at 20MV/m, with the exception of one at 14MV/m, thus 50kW, 140kW and 70kW, respectively of input power per cavity are required. Therefore the power between the first and second four cavities is split unequally and then branched off by a linear type system. The total accelerating voltage is 128MV.

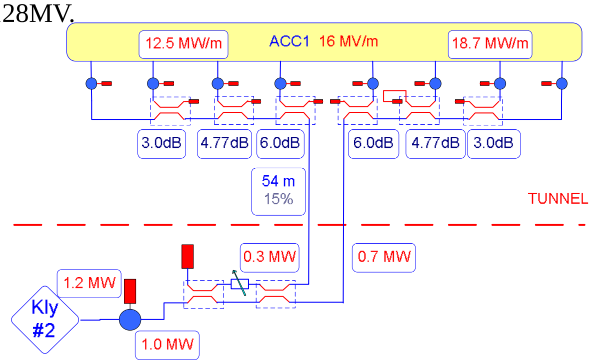

Figure 2: Distribution for ACC1.

The 5MW THALES TH2104C klystron of station #5 provides about 4MW of power for the sixteen superconducting cavities of the cryogenic modules ACC2 and 3. The cavities of ACC2 are operated an average gradient of 16MV/m, the cavities of ACC3 at 24MV/m, thus the average power per cavity is 90kW and 210kW, respectively. Two cavities in ACC2 are operated with an attenuator in front of the cavity because their maximum possible gradient is only 15MV/m and 17MV/m. Since the klystron has only one output arm, the power is split in a 4.77dB hybrid and transmitted in two 65m long waveguides to the two module distributions. The total accelerating voltage of the two modules is 132MV and 203MV.

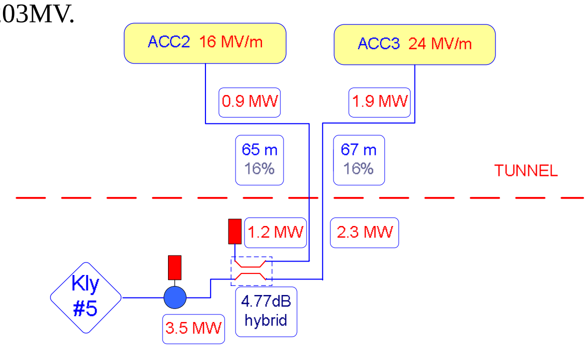

Figure 3: Distribution for ACC2 and ACC3.

The 10MW THALES TH1801 multibeam klystron of station #4 provides up to 7MW of power for the twenty-four superconducting cavities of the cryogenic modules ACC4, 5 and 6. The cavities of ACC4, 5 and 6 are operated at an average gradient of 21MV/m, 22MV/m and 26MV/m, thus an average input power of 160kW, 169kW and 241kW per cavity is required. Since ACC6 uses a combined waveguide distribution with asymmetric shunt tees the coupling ratio could be optimized for maximum possible gradient in each cavity. Four of the cavities receive 350kW which is sufficient for 32MV/m. Since the klystron has two output arms, the power is combined in a section of two 3dB hybrids with phase shifter.

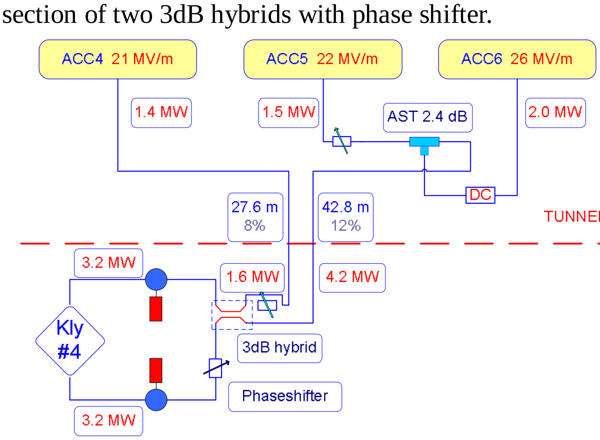

Figure 4: Distribution for ACC4, ACC5 and ACC6.

This allows adjustment of the power for two arms. Power for ACC4 is transmitted in a 27m long section between the output port of the hybrid to the module distribution, whereas the other output arm is connected to another 42m long waveguide which is connected via a shunt tee to the distributions of ACC5 and 6. The total accelerating voltage of the three modules is 176MV, 181MV, 213MV.

RF Gun Distribution

The 5MW THALES TH2104C of station #3 generates RF power of 5MW for the one-and-a-half-cell normal conducting RF gun. Since this cavity is normal conducting the filling time is some microseconds only and the total RF pulse duration is 800µs at 10Hz repetition rate. The electrons for the accelerator beam are produced in the RF gun by firing a laser onto the photocathode located at the position of maximum electrical field of some 40MV/m. Since the klystron requires SF6 at the klystron window a section of about 2m length between the klystron window and an additional window is filled with SF6 of typical 1.2bar. A four-port circulator is located in the tunnel in front of the input window in order to protect the klystron from reflected power from the RF gun. This section of ca. 2m between the RF gun window and an additional window is filled with SF6 at 1.2bar, too, in order to protect the RF gun window and to enhance the power capability of the circulator. The waveguide length between the klystron and the RF gun is about 40m. Because of losses in the waveguides and the circulator only 3.5MW of power are reaching the RF gun.

MAIN COMPONENTS

Many waveguide components have been developed at DESY and in cooperation with or by industrial companies. Some of them are described in the following briefly. The 5MW four-port circulators which protect the klystrons from reflected power have been manufactured by Ferrite SPA, St. Petersburg, Russia. They must be filled with SF6 at typical 1.2bar in order to enhance the breakdown level, just filled with air at atmospheric pressure this level is only 800kW. In order to decrease losses in the ferrite material the magnetic field must be carefully adjusted. No active tuning circuit either by cooling water or electromagnetic adjustment of the magnet field exists. The insertion losses depend on the temperature of the ferrite material, thus losses depend on operation conditions. The 400kW isolators in front of each cavity are required to absorb power reflected from the cavities during filling time. They can be operated in air. Some of the circulators are only capable of 350kW whereas others are capable of 450kW. The specification is 400kW at full reflection and any phase for 1.5ms and 10Hz repetition rate.

The asymmetric shunt tees of the combined distribution have two posts inside. By adjusting the position of the posts the coupling ration can be adjusted in order to optimize the power distribution for a given maximum gradient distribution in a cryomodule. This is not possible in the linear distribution because the hybrids used there can not be tuned to a specific coupling ratio. The integrated phase shifters of the new combined distribution are capable of 4MW and allow the adjustment of phase by 90 degree. The three-stub tuners in the linear distribution have similar tuning range and in addition allow the tuning of Q_{ext}. The three-stub tuners limit the maximum power which can be transmitted to a cavity. This is due to the reduced breakdown capability in case a stub reaches too far inside the waveguide. Under normal operation condition this usually is not a problem but during conditioning of the cavity couplers it might be.

Although the theoretical power limit of WR650 waveguides in air is 58MW the practical limit is much lower. It is near the 5MW operation level of some of the waveguides and even less in some of the components in the module distributions. This limitation is mainly due to limited size inside some of the components, due to higher order modes, which are generated in the klystrons and built up to high electrical field strength in the waveguides because they are not well terminated for these frequencies, and also due to imperfect VSWR of waveguide components at the fundamental frequency, thus leading to high electrical field in the standing wave parts. Most critical are three-stub tuners, hybrids, circulators and windows. The use of the new combined module distribution has improved the situation.

OUTLOOK AND SUMMARY

During the next FLASH shutdown another module will be installed. Module ACC7 will be supplied together with ACC6 by one klystron. The use of the new combined module distribution has improved the operation conditions with respect to power limitation and to optimization for maximum gradient. This type of distribution will be used in the XFEL too.

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