THE RF DISTRIBUTION SYSTEM FOR THE ESS

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Abstract

The RF distribution system for the super-conducting cavities of the European Spallation Source will be one of the largest systems ever built. It will distribute the power from 146 power sources to the two types of ESS cavity at two different frequencies and will use one line per cavity for resilience. It will consist of a total of around 3.5 km of waveguide and coaxial line and over 1500 hundred bends. It is designed to transport this RF power over a distance of up to 40m per line, while minimising losses, avoiding reflections and allowing the monitoring of performance.

INTRODUCTION

The European Spallation Source [1] (see Fig. 1) will be a high brightness source of spallation neutrons for materials and other studies. It is currently under construction in Lund, Sweden and is scheduled to produce its first neutrons in 2019. It is planned to build the facility in two stages, with the first accelerating protons to 1.3 GeV and 3 MW beam power. The second stage will extend this to 2 GeV and 5 MW. It will then deliver a peak neutron flux seven times more powerful than any existing accelerator based spallation source and a peak flux 30 times greater than any reactor based neutron source.

Figure 1: Artists impression of the ESS after completion.

The ESS will employ a linear accelerator for proton acceleration [2]. The front-end of this, up to 90 MeV, will use normally conducting cavities, while the rest will use two types of super-conducting cavities (see Fig. 2). There will be 26 spoke cavities running at 352 MHz, 36 medium beta (MB) elliptical cavities at 704 MHz and 84 high beta (HB) elliptical cavities at 704 MHz. Note that for the first stage of the ESS, 40 of the HB cavities will not be used. The RF pulse width will be 3.5 ms and the pulse repetition frequency will be 14 Hz.

RF DISTRIBUTION FOR THE SUPER-CONDUCTING CAVITIES

The purpose of the RF distribution system (RFDS) is to transport the RF power from the power sources, located above ground in the gallery building, through chicanes called stubs, to the RF cavities below ground in the accelerator tunnel, mainly through waveguides. The ESS requirement for high reliability, 95%, has resulted in a design with one power source per cavity and hence one waveguide run per cavity. As each stub has space for 8 waveguide runs, the RFDS mainly comes in units of 8 (see Fig. 3). The parameters of the RFDS are shown in Table 1.

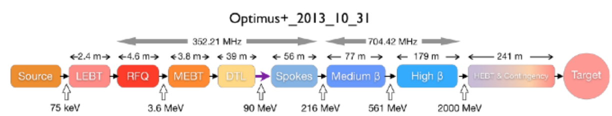

Figure 2: Schematic of the ESS linac.

Requirements

The requirements for the RFDS are:

- It must deliver power reliably to the cavities (a mean time between failures of 500000 hours), with minimal reflections: return loss (S11) > 30 dB, insertion loss (S21) < 0.05 dB.
- RF average power leakage at 704 MHz must not exceed 0.35 mW/cm^2 and at 352 MHz must not exceed 0.2 mW/cm^2.
- It must be possible to measure the forward and reflected power at various locations.
- The power sources must be protected against reflected power.
- Arcs must be detected and suppressed with a minimal rate of false trips.

The system designed to meet all of these requirements is shown in Fig. 3.

Table 1: RFDS Parameters for 5 MW Operation

Linac module	Frequency (MHz)	Power (kW) Peak	Power (kW) Average	Number of systems
Spoke	352.21	400	20	26
MB	704.42	1200	60	36
HB	704.42	1500	75	84

RFDS Design

Due to the low average power, the spoke systems will employ 6-1/8 coxial cables up to the circulator as this was determined to be cheaper than using waveguides for this section [3]. The rest of the system will use WR2300 half-height (HH) waveguides. The MB and HB systems will use WR1150 waveguides for the entire length. The circulators are three port devices for transporting power from one port to the next. At the ESS, power arriving at port 1 will be transported onto port 2 and from there to the cavities. Reflected power arriving at port 2 will be transported to port 3 and from there to a load, where it will be absorbed. This protects the power sources from reflections due to impedance mis-matches, etc. Directional couplers will be installed between the power source and the circulator, between the circulator and the load and in the gallery waveguide system. These are used to measure the forward and reflected power to monitor that the system is working correctly.

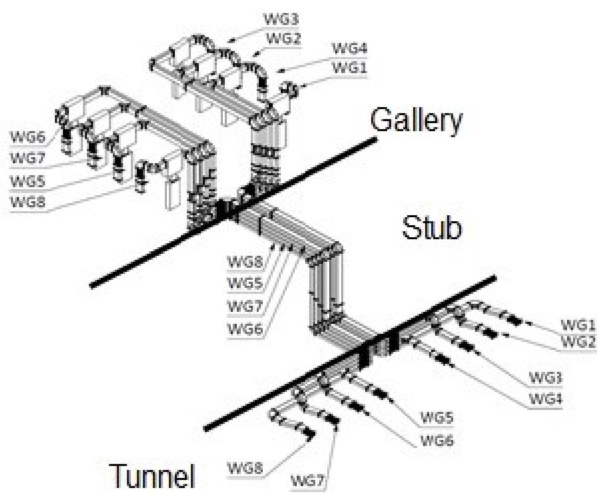

Figure 3: The layout of a group of 8 MB/HB wave guide runs.

Each waveguide run will contain up to 5 flexible waveguides (bellows) to allow for thermal expansion and small misalignments. There will also be so-called shutter switches to allow the testing of the power sources, without delivering power to the cavities. When open, these pass the power as normal. When close, the power is reflected back to the load via the circulator. Finally, each spoke waveguide run will have 3 arc detectors in the gallery and 2 on the cavity coupler and each MB/HB run will have 4 arc detectors in the gallery and 2 on each cavity coupler. These are used to prevent breakdown in the RFDS. The function of each of these components is described in more detail in the next section.

RFDS COMPONENTS

Waveguides

The waveguide system will consist of standard 6-1/8 inch coaxial straight cable and bends, WR2300 HH straight waveguides and bends and WR1150 straight waveguides and bends. The standard waveguide will be broken into nearly 90 different lengths, ranging from 72 to 4000 mm, with the minimum number of each length required being 1 and the maximum 120. The ESS will also be using a number of non-standard waveguides. As the stubs will be closed at the bottom and top with shielding walls for radio-protection purposes, the air circulation around the waveguides in this region will be limited. As a result, the heating of the waveguides will be sufficient to raise their temperature to approaching 90^{O}C. Although this is fine for the waveguides, it is too hot from the cables that will be above and below them. As a result, the waveguides need to be cooled. This will be done by blowing tunnel air through the waveguides. As this can be activated, it is not permitted to discharge this into the gallery. As a result, the air will be returned down a neighbouring waveguide and expelled back in to the tunnel. Vents will be included in special "air cooling" waveguides to allow sufficient air flow, while maintaining RF leakage below the legal limits. RF windows will also be installed upstream of the vents to prevent activated air entering the gallery through the waveguide.

In addition, a number of waveguide runs will use angled waveguides, to reduce the number of bends required. Each waveguide run will also have one section of "removable" waveguide. This will used as an additional protection, along with the shutter switches, to avoid power being delivered to the cavities while personnel are in the tunnel. They will be equiped with special flanges that will provide a signal to show that the flange is in place.

The total lengths and numbers of waveguides and bends required are shown in Table 2. Mechanical tolerances have been specified for each of these components to ensure they meet the return loss and insertion loss requirements. Further, each must have an internal surface roughness that is better than N6 to minimise reflections. The waveguide system will be supplied by Mega Industries LLC [4].

Circulators

The aim of the circulators is to pass the power onto the next port, with minimal power entering any other port or being reflected. They are included to ensure the reflected power is diverted to the load. The ESS circulators will be three port devices supplied by AFT Microwave GmbH [5] and will use the non-reciprocal nature of ferrite material to function as required. A prototype circulator has been built and observed to meet the requirements of return loss < 30 dB, insertion loss < 0.1 dB and isolation > 26 dB. Each circulator will have an active feedback unit to optimise performance based on the measured temperature and reflected power and an arc detector to avoid sparking.

Loads

The aim of the loads is to absorb any power reflected through the system via impedance mis-matches, the shutter switches, etc. Due to the energy recovery policy of the ESS, some of the components will be cooled with a water inlet temperature of 50°C or more. Further, the ESS will install the RF loads for MB/HB in series with a klystron collector with an inlet water temperature of 50°C. The water may also be recirculated to improve the heat recovery further. This means that the maximum outlet temperature for the load can be 80°C and they have been designed to work at this temperature. They will again be supplied by AFT Microwave GmbH and a prototype device has been built and tested up to this temperature, though at a low input power.

Table 2: Total Lengths and Numbers of Waveguides and Bends Required to the ESS

Linac module	**Component**	**Length (mm)**	**Total length or number required**
Spoke	Standard waveguide		497m
	Angled waveguides	733.0	37
	Air cooling waveguides var. A	733.0	7
	Air cooling waveguides var. B	539.1	45
	Removable waveguide	500	26
	H-bends		130
	E-bends		78
	Coax bends		52
	Coax straights		26
MB+HB	Standard waveguide		2583m
	Angled waveguides var. A	459.0	30
	Angled waveguides var. B	1009.0	60
	Air cooling waveguides var. A	305.4	60
	Air cooling waveguides var. B	457.2	180
	Removable waveguide	500	120
	H-bends		600
	E-bends		720

Directional Couplers

Three types of directional coupler are to be used for spoke and for MB/HB. For spoke, 2 directional couplers will be 6-1/8 inch coaxial type, one with 4 loops and one with 2 loops. The 4 loop types will provide forward and reflected power measurements for the low level RF (LLRF) and diagnostic systems. The remaining type will be WR2300 HH and in the waveguide system. This will again be 4 loop, but with a directivity > 40 dB for more accurate measurements. The MB/HB directional couplers will be the same, except that all will be WR1150.

Arc Detectors

Arc detectors are used to detector sparks within the waveguide system and inhibit the power amplifier before breakdown can occur. If this does occur, the discharge can travel in both directions along the waveguide, damaging this and amplifier and cavity at both ends of the system. The ESS will use at least two types of arc detector in up to 5 different locations. For the spoke waveguides, these will be on the circulator, close to the load and on a bend within the waveguide system. For MB/HB, there will also be a detector close to the power source. For both spoke and MB/HB, there will be arc detectors on the cavity couplers. As these are in a radiation environment, they are likely to be of a different technology from the other detectors.

Shutter Switches

The role of the shutter switch is to allow a waveguide run to be closed so that all the power is reflected back to the load through the circulator. Two types are being considered for the ESS. The first will use a switch which is moved via a level which can be locked in place, to prevent the position of the switch being changed. It will also have micro-switches to indicate what position the switch is in.

The second type is a new one in which the switch is closed by sliding a reflecting plate into the waveguide. A prototype of this has been built and will soon undergo rigorous testing.

CONCLUSIONS

A complete design of the RF distribution system for the super-conducting cavities of the ESS has been made. A number of prototypes for this system have been built and tested, though not all at high power. The system is now being procured, with deliveries due to start in October 2017 to meet the challenging ESS schedule.

REFERENCES

[1] M. Lindroos *et al.*, "The European Spallation Source", *Nucl. Inst. Meth. B*, vol. 269, no. 24, pp 3258-3260, 2011.

[2] H. Danared *et al.*, "Status of the ESS Accelerator Construction Project", in *Proc. IPAC'15*, Richmond, USA, 2010, paper THPF080, pp. 3870-2872.

[3] R.A. Yogi *et al.*, "Design of the RF Distribution System for the ESS Spoke Linac", FREIA Report 2013/02, Uppsala University, Sweden, 2013.

[4] Mega Industries LLC, `http://www.megaind.com/`

[5] AFT Microwave GmbH, `http://www.aft-microwave.com/`