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FUNCTIONAL INTEGRATION OF THE RFQ IN THE ESS SYSTEMS

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Abstract

The 352 MHz Radio Frequency Quadrupole (RFQ) for the European Spallation Source ERIC (ESS) will be delivered during 2018. After delivery, installation and tuning of the cavity, the high power RF conditioning will be performed. At this point all the different systems that are needed to condition and operate the RFQ have to be in place and operational. This paper will give an overview of the system analysis that has been performed for the RFQ. The RFQ requirements for the RF system, including the RF distribution system (RFDS), the Low Level RF (LLRF) and the local RF protection system (RFLPS) will be presented. In addition, the paper covers the system integration of the structure in the ESS control and vacuum systems as well as the outcome of a machine protection analysis.

INTRODUCTION

The linear accelerator of the European Spallation Source ERIC (ESS), which is currently under construction in Lund/Sweden, consists of a normal conducting front end and three sections of superconducting cavity types. The schematic of the linac is shown in Fig. 1, an overview of the project is given in [1]. The resonators in the normal conducting front end (radio frequency quadrupole, bunchers and drift tube linac) as well as the spokes cavities are operated with 14 Hz repetition rate and an RF pulse flattop of 2.86 msec at 352.21 MHz; medium- and high-beta structures at 704.42 MHz.

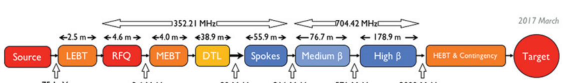

Figure 1: The architecture of the ESS linac. Normal conducting sections are represented in warm colours, superconducting parts in blue.

The first accelerating structure, following the ion source and the low energy beam transport, is a 4-vane radio frequency quadrupole (RFQ). The RFQ is provided by CEA, IRFU, Saclay/France and will be delivered to ESS this year. Fig. 2 gives an impression of the cavity with its support, cooling manifold and waveguide interface. It consists of five sections with a total length of 4.6 m and accelerates the proton beam from 75 keV up to 3.6 MeV. The RFQ design was optimised for a high transmission (> 97%) with an intervane voltage between 80 kV at the beginning of the RFQ and 120 kV at its end, keeping a low Kilpatrick factor (< 2). This design is based on an 70 mA input beam with a transverse emittance of 0.25 π mm mrad (normalised RMS) [2]. The max. total power coupled into the RFQ is expected to be 1.6 MW [3].

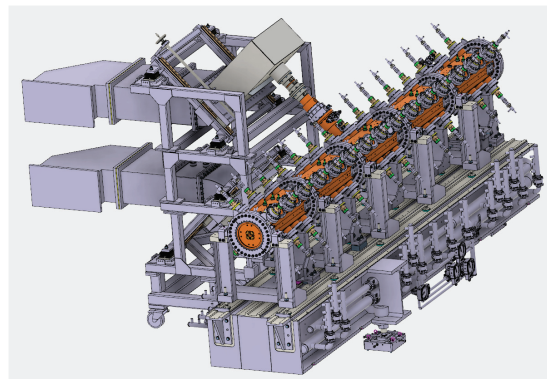

Figure 2: A view of the RFQ 3D model.

During the installation, alignment and leak tests, but also for RF tuning, the RFQ will be handled as a stand-alone system. Only the ESS vacuum system will be connected to the cavity already during installation and local tests. In the next step the RFQ will be connected to the permanent systems for water cooling, RF power distribution and controls. Fig. 3 shows an overview of the installation, test and conditioning workflow on the RFQ at ESS.

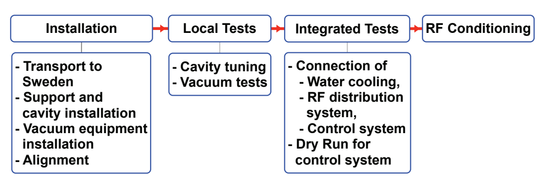

Figure 3: The workflow of the RFQ project in Lund until it is ready for beam commissioning.

THE COOLING SYSTEM

The RFQ water cooling skid regulates the operating temperature of the RFQ via four separate cooling loops - one for the vanes and three for the cavity body, tuners and power couplers. Thermo-mechanical simulations are presented in [4].

Several pressure, flow and temperature sensors are installed inside the skid to monitor the settings. On the cavity and the power couplers in total 32 temperature sensors are

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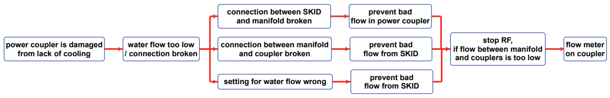

Figure 4: Part of the machine protection analysis for the RFQ power couplers. This scheme shows the analysed events and hazards that lead to the decision to integrate water flow meters on the cooling circuits on the couplers.

distributed. Following the outcome of the machine protection analysis, additional flow meters have been added on cooling circuits on the power couplers. The part of the machine protection analysis leading to the flow meters on the couplers is shown in Fig. 4.

The control system on the skid evaluates the status of the skid components like pumps, valves, etc. as well as the collector valve positions in the tunnel and the flow meters on the power couplers. Based on this input, an interlock signal is generated and sent to the RFQ local protection PLC.

The same PLC acquires also the signals from the temperature sensors to publish them in the ESS control system, which is based on EPICS [5]. Common thresholds will be used for groups of temperature sensors, for example on the body, power couplers or the end plates of the RFQ. These location groups of the sensors will be treated differently in the assessment of their status - an interlock signal will be triggered in case one temperature sensor fails on the power coupler, but more than one sensor on the cavity body needs to fail for an interlock, otherwise a warning signal is published by the PLC.

A single interlock signal (RFQ_CoolingStatus), including the state of all temperature measurements and the skid status, is sent via a hardwired connection to the slow module of the RF local protection system (RFLPS) in order to stop the RF power and prevent overheating of the cavity.

The temperature setting for the skid control system is given by the LLRF system. The LLRF publishes a process variable to define the detuning of the cavity compared to the operating frequency. This input is translated by the skid control into settings of pressure, flow, etc. Calibration measurements of the transfer function will be taken during the integrated hardware tests.

A schematic of the integrated cooling system is shown in Fig. 5.

THE RF SYSTEM

The description of the RF system can be split into three main parts: The RF power distribution system (RFDS), the RF local protection system (RFLPS) and the low level RF system (LLRF). The slow module of the RFLPS has been addressed in the previous section together with the cooling system, so this section will focus on the fast module.

The RF Distribution System

The RFQ is driven by a klystron, which is able to deliver up to 2.8 MW peak power [6]. Two power couplers in ad-

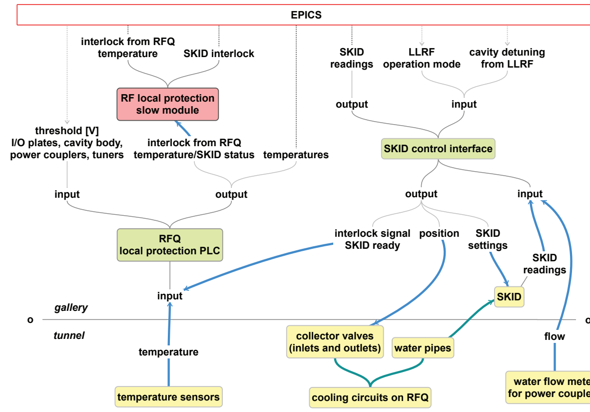

Figure 5: Schematic of the RFQ cooling system and its integration in the slow module of the RFLPS.

jacent quadrants of the RFQ transfer the operational power of 1.6 MW into the cavity. Both couplers (and one spare coupler) have been conditioned up to nominal power at a test stand at CEA [7]. In the gallery, following the klystron, the RF power passes a circulator before it is split for the two couplers by a magic-T [8]. The reference measurement of the forward and reflected power to the cavity is taken on bidirectional couplers following the magic-T. From here, the waveguides lead the RF into the accelerator tunnel, with a phase shifter for fine adjustments in one of the paths. The interface to the waveguide system is defined by a WR2300 (full height) waveguide flange. Between this interface and the power couplers another pair of bidirectional couplers is installed, so that also the forward and reflected power just before the couplers can be monitored. The sequence of elements is pictured in Fig. 6.

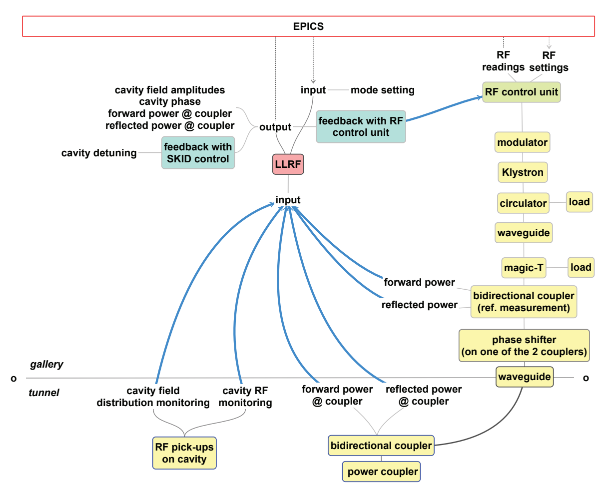

Figure 6: Overview of the RFQ interfaces with the RFDS and LLRF system.

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The LLRF System

The signals of all pick-ups on the RFQ cavity and on the bidirectional couplers are acquired and published by the LLRF as shown in Fig. 6. In total there are 22 pick-ups on the cavity. In each of the five sections one RF pick-up is installed per quadrant to monitor the field distribution in the RFQ. Two additional pick-ups (one, plus one spare) are located in section five to be used for the cavity reference measurement in the LLRF.

Several operation modes of the LLRF for the RFQ have been requested and are currently under evaluation. A general system description is given in [9].

In standard operation the LLRF will be used to regulate the cavity voltage by adjustment of the RF amplitude and phase. The requirements for stabilisation here are ±0.2 dB for the amplitude and ±0.2° for the phase. As mentioned in the section about the cooling system, the RFQ's resonance frequency is tuned in operation via the cavity temperature setting. In this mode, the LLRF computes the detuning ($\Delta\omega = \omega_{cavity} - \omega_{operation}$) at the end of each RF pulse based on measurements of the decaying cavity field. This information will be published and read by the cooling system controls, so that the temperature settings can be adjusted for the next pulse.

Two additional modes have been requested specially for the cavity conditioning process. One is an open loop operation of the RFQ with regulation of the forward power by the LLRF. The second mode is a closed loop with regulation of the RF frequency to follow the resonance frequency of the RFQ cavity. The boundary conditions for this mode are currently under investigation. This includes the maximal detuning of the cavity that could be followed by the RF system, as well as the closed loop bandwidth.

The maximum expected detuning of the cavity during the conditioning is < 100 kHz with a fixed temperature setting of 30 °C.

The RF Local Protection System and Arc Detection

The main task of the RFLPS is to prevent damage on the RF installations (klystron and modulator, waveguides, circulator loads, etc.) [10], but the system will also be used to stop the RF power in case of potential harm for the cavities.

The most critical part to get damaged during operation of the RFQ are the power couplers with the ceramic windows to separate the part under vacuum and air pressure. Both sides (air and vacuum) have separate cooling circuits and are equipped with viewports for arc detection. A pick-up to monitor electron currents is installed on the vacuum side of the couplers.

Fig. 7 shows the signals that are integrated from the RFQ in the fast module of the RFLPS. All arc events and analog signals are published either by the RFLPS or the arc detector controller. The arc detector system should include as well a testing option to verify the functionality of the system between the test port on the power coupler and the RFLPS.

In addition to the arc detectors and electron current monitors, also the vacuum pressure in the couplers is included in the fast module of the RFLPS. In addition, the reflected power from the cavity is interlocked. Other vacuum related signals (valve positions, cavity pressure, etc) are handled within the vacuum control system and either connected to the machine protection system or monitored as alarms.

For all interlocked parameters variable threshold settings can be applied. A threshold range from 1 to 5 Lux has been specified for the arc detectors on the power couplers with a measurement sensitivity on the coupler viewports of 0.1 Lux. The response time for the RFLPS to stop the RF power will be <18 μsec.

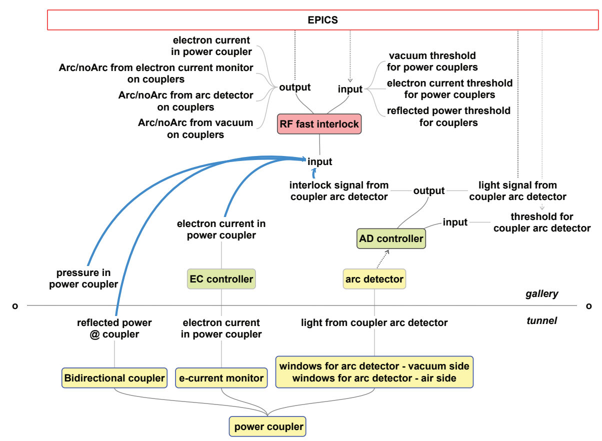

Figure 7: Overview of the RFQ interfaces with the RFLPS and arc detection system.

OUTLOOK

The main focus in the next months will be on implementation of the specifications in the different systems. On a following stage the high level control applications will be prepared. For example the RFQ conditioning procedure has been defined based on the experience during the power coupler conditioning. With this input, it is planned to prepare an application for an automatic ramping of the RF power following the behaviour of the vacuum level and arc detection in the power couplers. The RFQ is expected to arrive at ESS during this year and RF conditioning is planned for next year.

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