

# PRELIMINARY FUNCTIONAL ANALYSIS AND OPERATING MODES OF THE ESS 704 MHz SUPERCONDUCTING RADIO-FREQUENCY LINAC

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## Abstract

The European Spallation Source (ESS) is one of Europe’s largest planned research infrastructures. The project is funded by a collaboration of 17 European countries and is under design and construction in Lund, Sweden. Three families of Superconducting Radio-Frequency (SRF) cavities are being prototyped, counting the spoke resonators with a geometric beta of 0.5, medium-beta elliptical cavities ( $\beta=0.67$ ) and high beta elliptical cavities ( $\beta=0.86$ ). The ESS linac will produce 2.86 ms long proton pulses with a repetition rate of 14 Hz (4 % duty cycle), a beam current of 62.5 mA and an average beam power of 5 MW. A control system is being developed to operate the different accelerator systems. All operating modes of the superconducting linac shall ensure a safe operation of the accelerator. This paper presents the preliminary functional analysis and the operating modes of the 704 MHz SRF linac.

## INTRODUCTION

The ESS will use a 2 GeV superconducting linac to produce the worlds most powerful neutron source by spallation process with a beam power of 5 MW [1].

Protons are produced in the ion source, followed by the Low Energy Beam Transport (LEBT) section and Radio Frequency Quadrupole for bunching and acceleration.

The beam is then transported and matched to the normal conducting drift tube linac (DTL) through the Medium Energy Beam Transport section.

Afterwards the beam enters the superconducting portion of the linac, where acceleration is accomplished via SRF cavities made of niobium and cooled by a superfluid helium bath operating at 2 K and housed inside cryomodules (CM).

The first SRF section contains the double spoke cavities [2] followed by two sections of elliptical cavities, medium- $\beta$  and high- $\beta$  [3], which operate at 704.42 MHz.

## OPERATING MODES AND FUNCTIONAL ANALYSIS

Each operational mode of the ESS linac is a combination of one machine mode and one beam mode.

The operation of the 704 MHz SRF linac is governed by the Integrated Control System (ICS) [1] based on Experimental Physics and Industrial Control System [4] (EPICS).

High-level operating modes have been identified describing the required sequences to operate the CM. The state diagram of the system for normal operation is shown in Figure 1.

### The ESS Linac Operational Modes

Machine modes refers to a specific configuration defining the intended destination of the proton beam, whilst beam modes are defined through the specific sets of beam properties and describe the envelope of operating ranges of beam parameters such as peak current, pulse length, pulse repetition rate, etc.

In total 6 different destinations of the proton beam have been defined: one Faraday Cup downstream the LEBT chopper, one Faraday Cup before the first DTL tank, one after the last DTL tank (separating the warm from the cold linac section), a possible beam stop in the medium beta section, the tuning dump line and as main destination the target station.

At least four different beam modes are required to commission and operate the linac including: probe beam modes, production beam modes and setup beam modes.

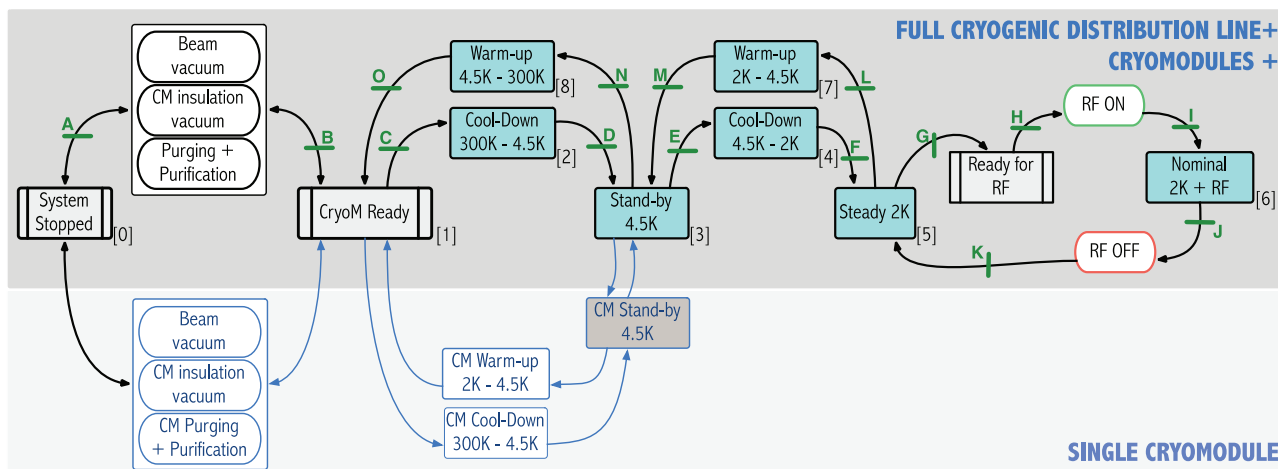


Figure 1: State diagram for the cryomodule normal operating modes.

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## The Operating Modes of the 704 MHz SRF Linac

Figure 1 shows the processes required to operate the cryomodules, such as cool-down from ambient temperature to 4.5 K, stand-by at 4.5 K, cool-down to 2 K, stand-by at 2 K and nominal operation at 2 K with RF and beam being turned on.

Similarly there is a series of operating modes to warm-up the SRF linac back to ambient temperature (e.g. during scheduled maintenance periods), to warm up and cool down a single cryomodule and also to bring a cryomodule into a “ready” state after interventions.

Detailed definition of the control process for each mode is currently underway, together with the required conditions for transition between states, warnings, alarms and interlocks.

## The 704 MHz Cryomodules

The medium- $\beta$  cavities use a five-cell elliptical geometry and are constructed from niobium, while the high- $\beta$  use a six-cell construction. The cavities are housed inside CM, each housing 4 cavities.

Every complete section is composed respectively of 9 medium and 21 high beta cryomodules. Each cryomodule is connected to the Cryogenic Distribution Line (CDL) that runs alongside the linac. The CDL distributes the cryogenic cooling power from the Cryogenic Plant allowing each of the cavities to be operated at 2 K.

The operating frequency of each cavity can be adjusted by means of a Cold Tuning System (CTS), also housed in the cryomodule, consisting of a stepper motor and piezo tuner actuators. Fundamental power couplers allow for the radio-frequency (RF) power to be delivered to each cavity. Figure. 2 shows the main components of the cryomodule.

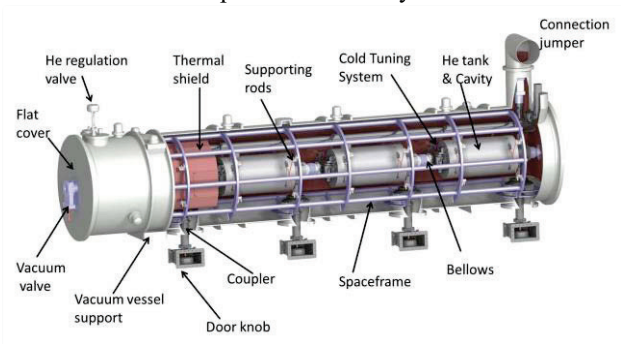


Figure 2: Elliptical cryomodule overview.

## THE ARCHITECTURE OF THE CONTROL SYSTEM

ICS is in charge of the controls for all parts of the machine, including the accelerator, target, neutron-scattering systems and conventional facilities [1].

ICS will work as a single entity connecting all the parts of the ESS facility and providing operation, control and monitoring capabilities.

The proposed controls architecture for the cryomodule (Fig. 3) is based on a Programmable Logic Controller (PLC), which is integrated into EPICS through the Controls Network and takes care of the process functions.

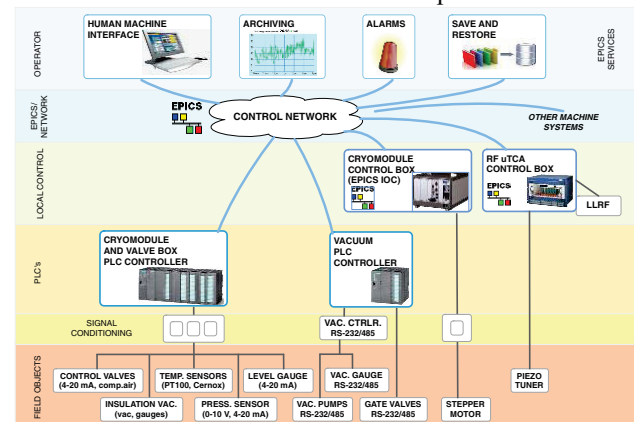


Figure 3: The Cryomodule Controls Architecture

This type of integration allows for the remote operation of the cryomodule from the control room and the necessary interaction of the cryomodule control system with other related systems (e.g. RF system, Vacuum System, Control Room and EPICS services like archiving, alarms and save-and-restore).

The logic contained on the cryomodule PLC is the implementation of the states diagram, complementary to the process diagram (shown in Fig. 4), where for each operating mode, steady state and transition state of the process a corresponding state in the control system is present. Each state is characterized by a set of process variables that are inputs or outputs to the PLC IO.

Most of the stationary states of the process need Proportional-Integral-Derivative (PID) regulation of the helium flow, temperature and level. The general procedure to implement these control functions consists of the following steps:

- Derive a controls state diagram for the list of instrumentation and signals and the process diagram.
- Design the PID regulation for the valves according to the relevant process variables.
- Translate the controls state diagram into GRAFCET [5] representation.
- Translate the GRAFCET representation in PLC code.

The cold tuning system of the cavities has two different controllers: the slow tuning (based on a motion controller) works on an EPICS controller while the fast tuning system works on an RF controller from the Low Level RF system (LLRF). This is the controller of the RF system feeding the cryomodule and will be located in a MicroTCA [6] chassis, as the ESS LLRF system is being designed with this specification. Some signals from the cryomodule will be also read by the RF control system through this controller. Finally, systems will be connected to the controls network in order to provide the necessary EPICS services (Human-Machine Interfaces, Alarms, Archiving system for different process variables and save-and-restore service).

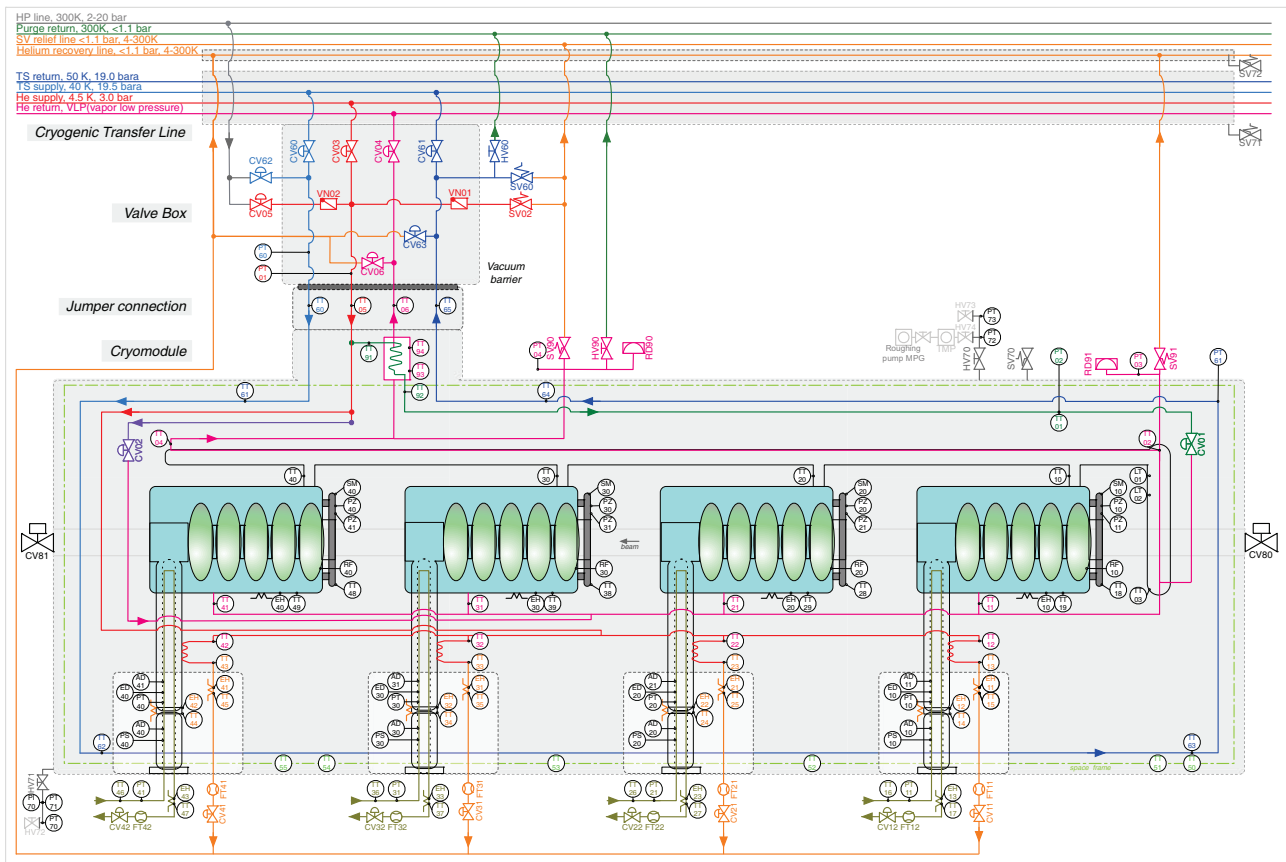


Figure 4: Process and Instrumentation diagram of the medium-b cryomodule. Diagram depicts the different cryomodule sub-systems (beam vacuum, cryostat vacuum, cavity cooling, power coupler cooling, cold tuning system, etc).

## THE CRYOMODULE INSTRUMENTATION

The piping and instrumentation diagram shown in Fig. 4, shows the equipment and instrumentation required to control, monitor and safely operate the cryomodule, that also serve as sensors and actuators for the PLC IO.

A list summarizing the necessary instrumentation has been produced where each instrument is classified by location and type, such as: temperature sensors (64), heaters (16), pressure sensors (9), vacuum gauges (8), level gauges (2), flow meters (8), control valves (18), gate valves (2), step motors (2), piezo actuators (8), arc detectors (8), electron charge detector (4), RF pick-up coils (4), pumps, etc. The instrumentation list allows the assessment of the type and quantity of each instrument, but also the signal types, cable types, space allocation and interfaces with other systems.

Process abstract and function tables were created to allow for a more detailed description of each operating mode. Here the status of each controlled object is defined for each moment during the operating sequence, along with the necessary interlocks and process variables thresholds to allow for a safe operation.

## CONCLUSIONS

The preliminary operating modes and functional analysis of the ESS 704 MHz SRF linac are shown, as well as the architecture and main features of the control system to allow for the safe operation of the 704 MHz SRF linac. A synopsis of the cryomodule instrumentation, equipment and circuitry was presented, serving as basis for the detailed definition of signals and processes.

Due to the maturity of the present assessment, the project will move into the detailed phase, where the comprehensive definition of the process variables, sequences, regulation routines and interlocks will be defined further for all the operating modes.

## REFERENCES

- [1] S. Peggs et al., ESS Technical Design Report, released 2.63, March 23, 2013.
- [2] S. Bousson et al., The ESS Spoke Cavity Cryomodules, proceeding of CEC2013.
- [3] C. Darve et al., The ESS Elliptical Cavity Cryomodules, proceeding of CEC2013.
- [4] EPICS website: <http://www.aps.anl.gov/epics/>.
- [5] Lewis, R. W., Programming Industrial control systems using IEC1131-3.
- [6] MicroTCA is a trademark of PICMG, specifications source: <http://www.picmg.org>