EUROPEAN SPALLATION SOURCE (ESS) NORMAL CONDUCTING FRONT END STATUS REPORT

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Abstract

The European Spallation Source (ESS) will deliver first protons on target by mid 2019. Civil construction of the accelerator tunnel has made good progress and will allow starting installation of the normal conducting frond end (NCFE) by end of 2017. To achieve these milestones the design of all major beam line components have been completed and the construction of the subsystems begun. We report on the advancement of the subsystems and the commissioning progress of the microwave discharge Proton Source (PS-ESS).

ION SOURCE AND LEBT

A 2.45 GHz – 0.1 T PS-ESS has been designed and assembled at INFN-LNS in order to produce pulsed beams of protons up to 74 mA nominal current, at 75 keV of energy, with a transverse emittance containing 99 % of the nominal proton current below 2.25 π mm mrad. The specified beam stability between pulses during normal operation (in terms of current and emittance) shall be within ± 3.5 % variation and ± 2 % with respect to beam current, when averaged over a period of 50 µs.

The reliability goal for the overall accelerator is set to be better than 95 %. To meet this requirement the source's reliability has to be in excess of 99 %. This was a major design driver optimizing both MTBF and MTTR. The main disassembly procedure, as described in [1], can be performed without removing cooling pipes, sensor cables and all 500 A cables of the magnetic system as shown in Fig. 1. This allows venting and replacing of both extraction system and plasma chamber within the required time as specified in the contract between ESS and INFN.

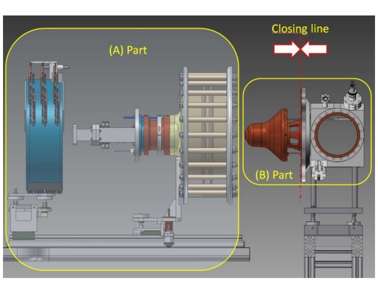

Figure 1: PS-ESS assembly schema. The solenoid and plasma chamber with extraction electrode chamber can be slided to gain fast access to all parts of this area.

Status and Initial Results

All major components of the source and LEBT have either been completed or are in their final stage of manufacturing. The source has been fully assembled in the test area in Catania as shown in Fig. 2, while only the first part of the LEBT, as needed during the initial stage of the commissioning, is assembled and ready for testing. This setup will house, once all devices have been delivered, a Faraday cup (FC), a Doppler shift monitor (DSM), an emittance measurement unit (EMU), and a beam stop.

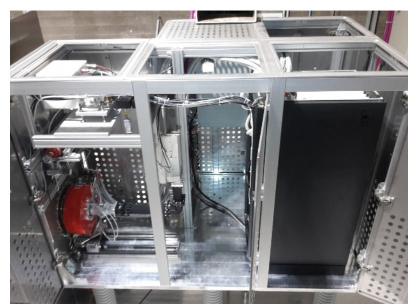

Figure 2: Picture of PS-ESS high voltage platform.

In June first plasma was achieved and thereafter plasma conditioning of the chamber performed. The obtained stability of the microwave power adsorbed by the plasma [2] is a first promising result to achieve the beam stability requested by ESS.

Next Steps

The first commissioning phase will focus on the characterization of the beam current generated by the source utilizing the FC and DSM. The EMU is scheduled to be delivered and installed in November. This will be followed by the second phase during which the main objective is to characterize the source's emittance as a function of different source parameter configurations. The plasma chamber conditioning is ongoing and the tests under thermal load have so far shown satisfactory results. Results of initial tests have been very promising and both INFN and ESS teams are confident for PS-ESS to reach the performance needed by the ESS.

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RFQ

The ESS Radio-Frequency Quadrupole (RFQ) [3] is a 4-vane resonant cavity designed at the frequency of 352.21 MHz, bunching and accelerating a 70 mA proton beam from 75 keV to 3.62 MeV with a 4 % duty cycle. The RFQ design has already been completed, and we present in the following the technical solutions chosen and the present status of the RFQ manufacturing.

Design Choices

The main parts of the RFQ are manufactured of pure copper (Cu-OFE, 99.99 % Cu). It has been chosen for its high electrical and thermal conductivity as well as for its brazing characteristics. A High Isostatic Pressing (HIP) treatment has been added to the manufacturing process of the RFQ to avoid any microscopic shrinkage defect or porosity in the copper (as was seen in IPHI RFQ). Flanges are manufactured of stainless steel.

The vanes are machined with a precision of 20 µm and then positioned and brazed with a 30 µm precision, according to beam dynamics and RF studies and design. The brazing of these vanes and ports are performed in two steps under vacuum. The first step is a bi-metal brazing between the copper tube and the stainless steel flange, at high temperature, to obtain a "port" (vacuum, tuner, pick up or coupler port). The second step is a copper-copper brazing, at 1000 °C, to finalize the assembly of the four vanes and the ports on the poles into one section.

The exact machining of every vacuum port before brazing can be individually adapted, allowing to change the local geometry to correct for fabrication errors and their effect on the RF properties. This will be used in addition to the adjustable tuners to obtain an optimized voltage profile.

Tuners are used to adapt the cavity volume in order to re-adjust the voltage profile along the beam axis and allow correcting fabrication errors (machining, positioning, brazing). The RFQ for ESS is composed of 60 tuners, 12 per section. The final depth position of each tuner will be set during the RF tuning phase performed at the final location in the accelerator tunnel in Lund. For higher efficiency and time saving during the RF tuning, the new design of this tuner includes a depth adjustable function in situ. A first prototype (Fig. 3) utilizing a bellow with a screw/nut system has already been manufactured and tested showing a few manufacturing issues. A second prototype using a studded connection instead of a bellow has been designed and ordered. This second prototype is more cost efficient and easier to produce.

Figure 3: Prototype version A of adjustable tuner for RFQ for in-situ field flatness correction without machining.

A Test Cavity was designed to validate the new RFQ components design as well as manufacturing and assembly processes for the RFQ, such as: tuner and coupler, large brazing of the exit section flange, mechanical assembly.

Manufacturing Status

Most of the major contracts for the RFQ manufacturing were signed last spring or summer. The main RFQ manufacturing contract was signed last July and the manufacturer has received the HIP treated copper. The first step includes the production of 2D manufacturing drawings including manufacturer's tooling modifications. This process is ongoing and in parallel, the definition of several mock-ups, in order to validate the manufacturer's processes, is progressing. The contract for the test cavity and the RFQ ports was signed last May with the machining of the test cavity in progress. The contract for the RF couplers was signed last June. Process qualification is ongoing with several mock-ups planned for ceramic TiN coating and loop machining. Currently the tender for the RFQ cooling system is being processed.

The current work is focused on the design of the support and tooling (section transport chassis, tuning tools…) of the RFQ as well as assembly of required documentation (test plan improvement, assembly specifications…). The ESS RFQ schedule is very challenging and demands a rigorous follow up (weekly) of the work ongoing at the vendors to guarantee performance and timely execution.

MEDIUM ENERGY BEAM TRANSPORT

The ESS MEBT [4] matches the RFQ output beam characteristics to the DTL input both transversally and longitudinally. Additional functions include beam diagnostic and beam collimation, both transverse and longitudinal. The latter will employ a fast kicker and beam dump.

The design parameters of the pulser and deflector are challenging as shown in Table 1 and no commercial available product fulfilled them. An R&D program was initiated by ESS-Bilbao and kicked off with a workshop in early 2015. As design choice a stripline deflector was chosen and designed. The components are in the final stage of production, with assembly and testing planned before the end of this

Table 1: Partial List of MEBT Kicker Specifications

Parameter	Value
Rise / fall time	$\leqslant$ 10 ns (10-90)%
Amplitude	$\geqslant$ 2.5 kV
Nominal pulse duration	1 - 20 µs
MPS pulse duration	200 µs
Repetition rate	1-14 Hz
Puls separation	5 µs–2.86 ms

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year. An industrial partner, FID Technology, was chosen to develop and build a pulser according to specifications. First prototype tests with a load started beginning of 2016 and after several improvements a second set of tests was carried out beginning of last July. During the latter all requirements where reached. The measured fall time of ~4 ns into the load is shown in Fig. 4. This device will be used as the first

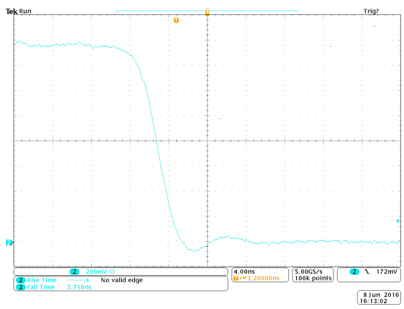

Figure 4: Measured fall time of the pulser as measured into a 50 Ω load. The horiz. scale is 4 ns the vert. 400 V per division.

production device. The test of the full system is scheduled for the end of 2016 and if successful a second pulser ordered.

These results are very encouraging as the prototype pulser is fulfilling all requirements as shown in Table 1, which are very challenging. The next important step will be the qualification of the full system. The overall progress of the work for the MEBT is within the planned time line and installation in the accelerator tunnel in Lund is planned June 2018.

DRIFT TUBE LINAC

The ESS DTL [5] is designed to operate at 352.2 MHz with a duty cycle of 4 % (3 ms pulse length, 14 Hz repetition period) and will accelerate a proton beam of 62.5 mA pulse peak current from 3.62 to 89.91 MeV.

The beam physics and EM design of the tanks has been complete. Some minor changes to the design include the redesign of the stainless steel section flanges, optimization of corrector and BPM location as well as number per tank and the use of pulsed corrector magnets (EMD). The latter change from CW to pulsed mode allowed changing from water-cooled to air-cooled coils allowing the use of one stem design for different types of drift tubes (empty, housing BPM, PMQ or EMD). Also the number of windings used has been increased from 4 to 40 allowing to use more efficient and smaller power supplies.

The mechanical design is in its final phase with a completed 3D model, focusing on 2D production drawings for drift tubes. Prototypes [6] of drift tubes empty, with BPM, and permanent magnet quadrupoles have been fabricated and tested or are in the process as shown in Fig. 5. The processes of plating stainless steel with copper, brazing and e-beam welding have been qualified by prototyping with industrial partners. The process of locating a PMQ within the required specifications inside the drift tube has been

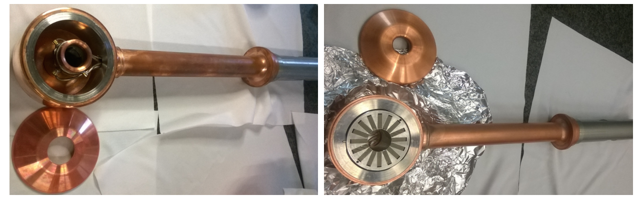

Figure 5: The left picture shows the drift tube prototype with cu-coated stem and BPM installed, the right with PMQ. Both assemblies are awaiting e-beam welding.

successfully tested verifying the machining of placeholders technique.

The tendering process has been started for all major components, e.g. raw material for tank sections, copper, PMQ's and machining of sections three and four of tank 4. The latter will be used as prototypes to qualify the related design choices and to allow time for design adjustments should these necessary.

CONCLUSION

The construction of the proton source in the test area in Catania has been concluded and commissioning started. First results are promising with full testing planned until the transport and installation in Lund November 2017. The main contract for the RFQ has been awarded with start of manufacturing set in October. First results of prototyping for both MEBT and DTL have been successful and the production of the main components are scheduled to start before the end of this year. The focus of the activities have shifted from design to construction.

ACKNOWLEDGMENT

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