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Status update on the ESS Target systems development

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Abstract

The on-going project for construction of the European Spallation Source (ESS), the 5 MW long-pulsed neutron research facility in Lund, Sweden, has entered the phase in which design work and development are focused on realising solutions that shall satisfy well-defined requirements. The Target Station, which converts the pulsed proton beam delivered by the linear accelerator to cold and thermal neutron beams tailored for neutron science applications, consists of several systems. Each of these elements offers unique design challenges for the engineering teams both in terms of providing the necessary primary function and in satisfying complex requirements for physical and functional interfaces between systems.

The Target systems, consisting of the tungsten target wheel, the drive, and the associated helium cooling system, have undergone optimisation and development during the preliminary design phase. Issues that have been studied include the helium coolant pressure and temperature level, internal flow paths and patterns, seal leak rates, manufacturability, integration with moderator and reflector components, remote handling strategies and waste management.

This paper is a status update on the ESS Target systems development; presenting specified parameter values, discussing chosen design solutions and addressing upcoming engineering challenges.

1. General description Target Station [1]

The function of the target station is to convert the intense proton beam from the accelerator into a number of intense neutron beams. This conversion is achieved by the interplay of a number of basic functions. In the heavy metal target the impinging proton beam radiation from the accelerator is converted via the spallation process into fast neutrons as the useful product, while generating a large amount of heat, radioactive isotopes and prompt radiation as unavoidable by-products. The moderator-reflector assembly surrounding the target transforms the fast neutrons emitted by the target into slow neutrons, which are the final form of useful radiation provided by the neutron source, while further radioactive waste is produced by the absorption of neutrons by various target structures. (Here, “fast” means neutrons with velocities in the range of 10% of the velocity of light and “slow” means velocities comparable to the speed of sound.) These two neutronically active systems are surrounded by a radiation shielding system of approximately 7000 tons of steel, in order to contain the extreme level of highly penetrating gamma and fast neutron radiation created in the target and its vicinity. The beam extraction system provides intense slow neutron beams through beam guides, which traverse the target shielding. These neutron beam guides are accessible at the surface of the shielding, for delivery to and use at the neutron-scattering instruments facing the beam ports at variable distances. The proton beam window separates the high vacuum in the accelerator from the atmospheric-pressure inert helium gas inside a large container vessel, in which all of these systems are housed. They form, together with the tight container, the target monolith, which takes the shape of a 11 m diameter and 8 m high cylinder.

At ESS, the proton beam will deliver 5 MW power in the form of kinetic energy. About 10% of this energy is converted to mass through the nuclear reactions in the spallation process that produces neutrons, other nuclear fragments, isotopes and gamma radiation. The energy of these particles makes up the remaining 90% of the proton beam energy, and it is almost all deposited within a distance of 1 m from the site of proton beam impact in the target. Different cooling circuits in the target monolith remove this large amount of heat from the target itself (3 MW), from the moderator-reflector assembly (1.2 MW) and from the monolith shielding (0.3 MW). The proton beam window is directly heated by the traversing beam and requires cooling of about 6 kW, though this value is strongly dependent on window design details.

Radiation damage and fatigue limit the lifetime of the three most strongly affected systems: the target, the reflector-moderator assembly and the proton beam window. All of these systems will need to be changed multiple times during the lifetime of the facility, with frequencies ranging between 6 months and 5 years, as conservatively estimated on the basis of available experience at spallation sources. The removed used components represent a considerable amount of radioactive waste. The other part of the radioactive waste consists of gases, volatiles and airborne particles, which will be continuously captured by a variety of efficient filters and traps.

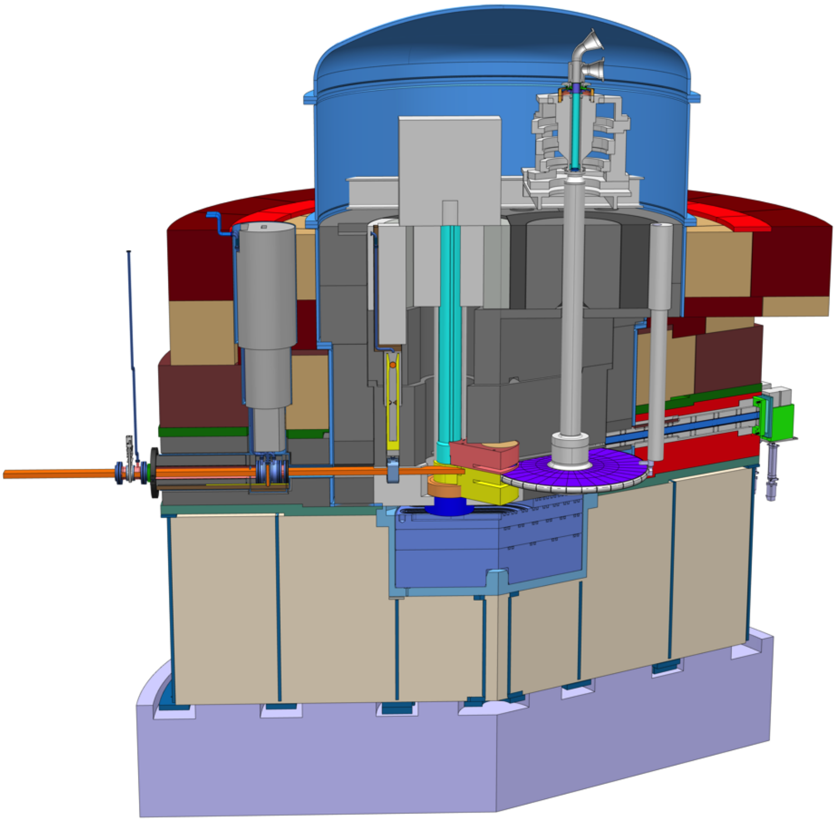

Figure 1 Monolith with target wheel and shaft inside

2. Improvements on Target Wheel, Target Shaft and Target Helium Cooling System

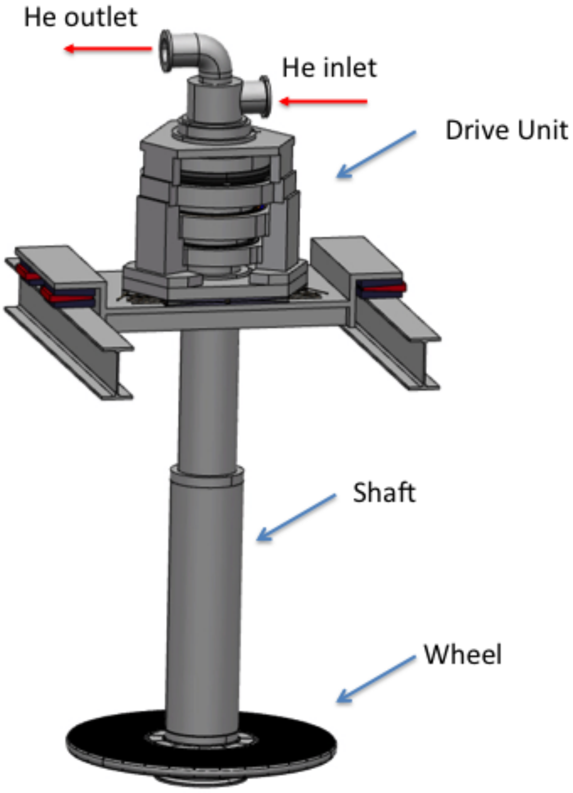

Figure 2 Target Wheel and Shaft

The Target consists of the Wheel, the Shaft, the Driving Unit and the Target Helium Cooling System. The design has been evolved since the original baseline, as described in the ESS Technical Design Report. The baseline target design calls for 33 target sectors, each made up of slabs of tungsten, the spallation material, held in place between two structural holder beams. The 33 beams delimit the target sectors and are connected to a massive central hub that makes the transition to the shaft, as shown in Figure 3

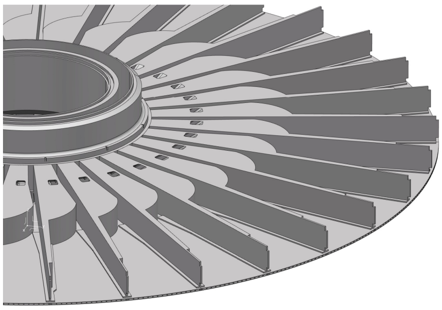

Figure 3 Central piece, beams and bottom shroud

The 33 sectors of spallation material and structural beams are contained between top and bottom ring-shaped lids welded to the periphery of the central hub, with a rim composed of the beam entrance windows and their frames. The target wheel rotates around a vertical axis. The shrouds and rim form the gas-tight target vessel, which, together with the structural beams to which it is welded, forms the target's pressure container.

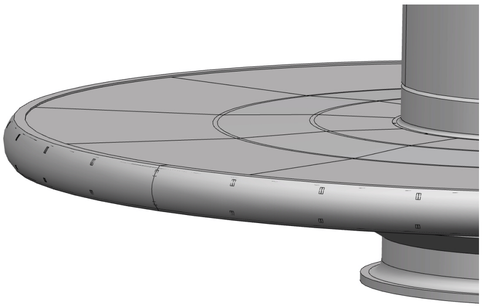

Figure 4 Target Wheel (pressure container)

To improve the cooling of the spallation material in the wheel the shroud has been redesigned. The Wheel Shroud is now built up with two plates with cooling channels in between where the helium flows from the center of the Shaft to the outer edge of the Wheel (figure 5) The helium flows both in the upper part of the shroud and the bottom.

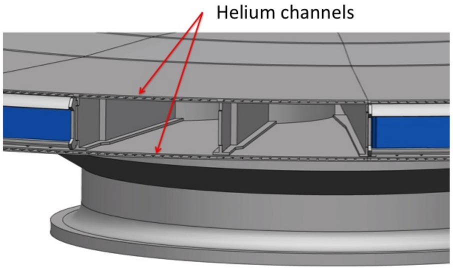

Figure 5 Target Wheel Shroud. The rim removed and the helium channels in both the upper and lower shroud plates shown.

The helium flows then back to the center of the shaft in a serpentine pattern, cooling the tungsten (figure 6).

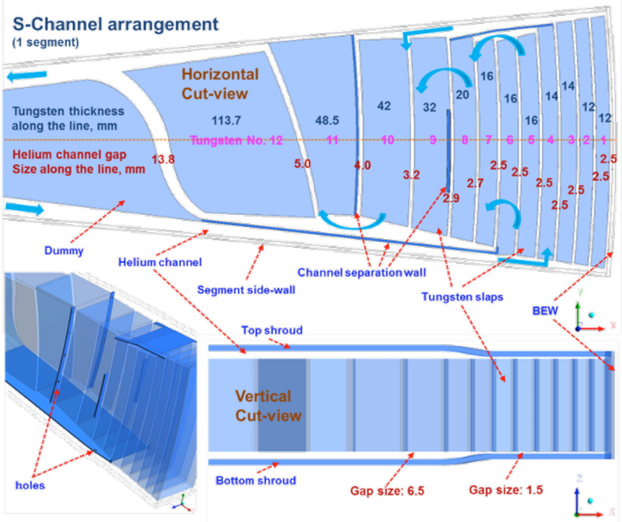

Figure 6 Spallation material arrangement. The helium flow follows in a serpentine pattern through the tungsten slabs, guided by the channel separation walls. Blue arrows indicate direction of helium flow.

A helium mass flow of 3 kg/s and an inlet temperature of 40 °C will keep the tungsten material below the critical temperature of 500°C and the Vessel including the internal structure below 400°C. These temperature limits will prevent the tungsten from oxidization in the event that air infiltrates the target vessel, and will also assure that creep behavior on the steel structure is avoided.

In the baseline design the helium operation pressure was decided to be 0,36MPa based om facts at the time. With a mass flow of 3 kg/s this pressure level leads to high helium volume flow, which puts extensive demands on the helium compressor. Critical design factors has been calculated and are compiled in a parameter diagram (figure 7)

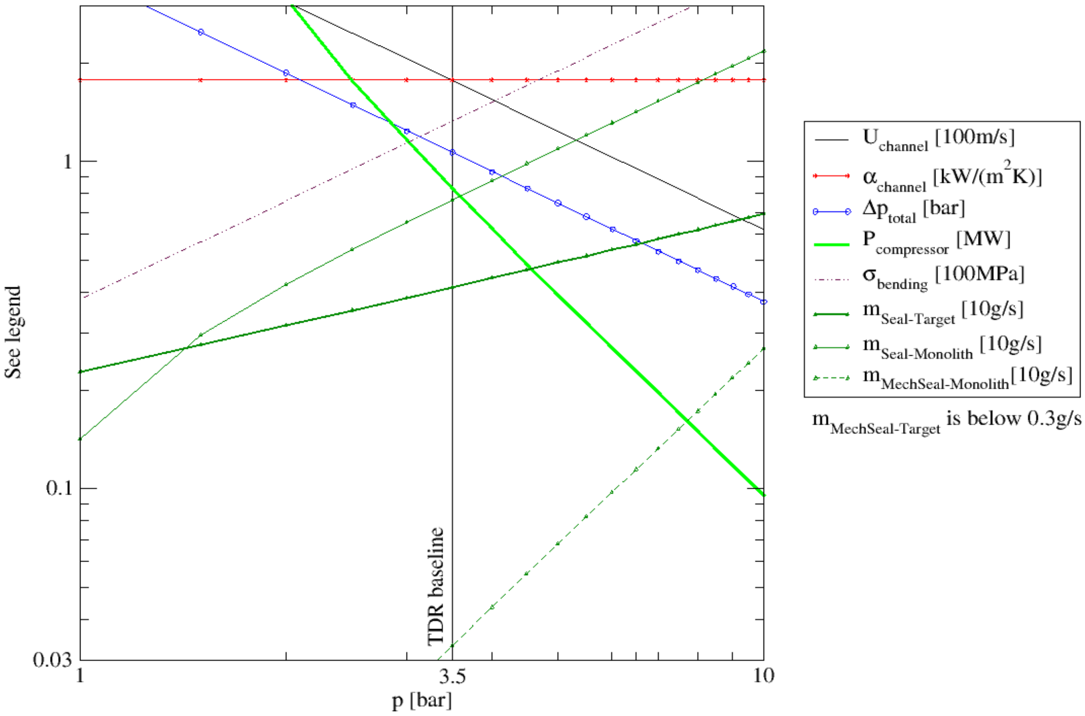

Figure 7 Critical Design Factors

The diagram shows the decreasing need of compressor power and also the reduced pressure drop, if the operation pressure is increased. Of course an increased pressure will on the other hand increase the helium leakage and also stress to the shroud.

To optimize the Target Helium Cooling System the critical design factors has been examined. The advantages to increase the operation pressure to some degree overrides drawbacks with increased stress and leakage. The operation pressure finaly was adjusted to 1,0 MPa. The Wheel has to fulfill stress criteria according to an operation pressure of 1,0 MPa. The concept design of the Wheel, composed of two plates welded together with ribs in between, forms a solid structure to meet those stress criteria. Final thermal-mechanical calculations are ongoing and minor design adjustments are foreseen.

The pressure drop in the Target Helium Cooling System is calculated to be just around 0.06 MPa. With an operation pressure of 1.0 MPa the helium compressor can by this figure be more considered as a circulator than a compressor. The increased operation pressure, from 0.36 MPa to 1.0 MPa significantly reduces the helium compressor power. A preliminary investigation of possible compressor vendors indicates that the cost for the compressor reduces significantly with these new design parameters.

A Preliminary Design Review of the Target Helium Cooling Concept Design has been performed. The result of the review was that the review committee endorsed the preliminary system design and with a few recommendations proposed that the system is ready to be progressed to its final design phase.

Regarding the Wheel and the Shaft these subsystems of the Target Station is close up to the Preliminary Design Review. The concept design of the Spallation Material is ready and also the concept design of the Wheel. The shaft is however undergoing redesign and optimization to better satisfy requirements on shielding performance and prevention of neutron streaming. The Driving Unit and the Sealing, connecting the Helium Cooling System to the rotating Shaft, also needs minor clarification of the design concept.

3. In-Kind

The construction of the ESS in Lund is strongly based on In-Kind contributions from member states. During 2014 In-Kind collaboration meetings have been performed. Institute within ESS member states were invited and the different work scopes presented. Regarding the Target Helium Cooling System and the Target Wheel and Shaft, the goal is to have an In-Kind Collaboration Agreement ready before the end of 2014.

References

[1] S. Peggs, “ESS Technical Design Report”, ISBN 978-91-980173-2-8.