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System Description Document- Solution Target Wheel, Drive and Shaft

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1. INTRODUCTION

1.1. Scope of the document

This document presents technical solutions for the Target Wheel, Drive and Shaft system in the Target station.

Chapter 2 describes the technical solutions that are, or will be, engineered in order to fulfil given functions and to satisfy specified requirements.

Chapter 3 addresses behavioural aspects of the system design, applied to fulfil specified functions. Chapter 3 and 4 contain references to all existing and planned documentation and models relevant for the system engineering.

Chapter 4.2 assesses the safety aspects of the system design.

2. TECHNICAL SOLUTION

2.1. Mechanical design

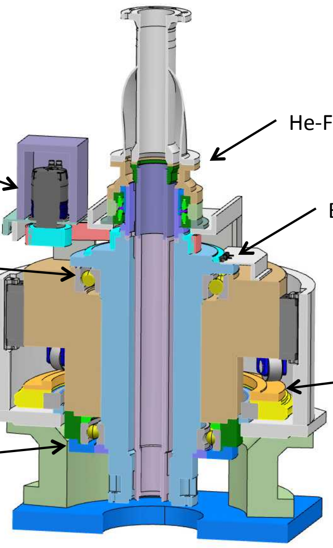
2.1.1. Mechanical design and assembly

The Target Wheel, Drive and Shaft has the following operational functions and subsystems.

Function	Subsystem	Sub- sub system
Rotation and speed control	Drive and shaft	Drive system
Friction and position control	Drive and shaft	Bearing system
Helium connection to stationary Helium Cooling System	Drive and shaft	Helium Feedthrough system
Alignment and suspension	Drive and shaft	Static positioning system
Fine vertical adjustment	Drive and shaft	Fine adjustment system
Helium transport, rotation and shielding	Drive and shaft	Shaft
Helium distribution and shielding	Wheel	Central part/ Distributor
Wheel structural integrity and tightness	Wheel	Shroud
Spallation material position and temperature control	Wheel	Cassettes
Spallation material	Wheel	Tungsten blocks

Table 1. System overview

2.1.2. Structural design



Cut Bearing and Drive Unit

Figure 1.

Drive system

The Target Wheel drive unit unit consists of motor, speed measurement system and Control Unit, see Figure 1. Motor and speed sensors are positioned in the Connection Cell while Control Unit is placed outside Connection Cell.

In the current concept transmission is done through a Polyurethane timing belt. The preferred solution is a **built- in torque motor**, since it would make it able to exclude transmission.

The reason for showing a solution with a belt is uncertainty regarding radiation resistance of permanent magnets of a torque motor. If it can be shown that sufficient lifetime can be reached with Neodynium Magnets, alternatively that activation of Cobalt-Samarium Magnets can be avoided, a Torque motor would be the preferred option.

Sub part	Description	Designation	Remark
Motor + gearbox	Wittenstein Radiation-hard servo motor with planetary gearhead	TPMA 050 S	Nominal motor speed 1537 rpm Nominal torque 330 Nm
Belt	Optibelt Polyurethane timing belt B= 100 mm	AT 10	Shaft force 6107 N Gearing 1:3 Nominal shaft torque 1000 Nm
Encoder	Lenord Bauer Minicoder including measuring wheel diameter e.g. 570 with 1200 - 4000 teeth	GEL 244	

Table 2. Component specification of Drive system concept design.

Bearing and lubrication system

The bearing system consists of one large thrust bearing, designed to take up the axial load, and one radial bearing to stabilize rotation and take up radial loads. The radial bearing is designed for axial prestress. Its outer ring is mounted in a separate sleeve whose inner surface shall be coated or hardened to ensure that the bearing outer ring can slide.

The lubrication system consists of a grease pump including grease container with level switch. Grease is administered to the bearings through a system of grease channels in the bearing house, and is separated from athmosphere through radial shaft seals.

Containers for used grease is connected to grease outlet channels. Used grease will be collected in stainless steel containers and disposed as low active waste.

Estimated amount of used grease will be less than 10 kg per year.

Sub part	**Description**	**Designation**	**Remark**
Thrust bearing	Angular Contact Ball Bearing Steel, or steel with ceramic roller elements Cage material PEEK or brass	7092 BM	Axial load 125 kN Radial load 25 kN
Radial bearing	Deep Groove Ball Bearing Steel, or steel with ceramic roller elements Cage material PEEK or brass	6084 M	Axial load 15 kN (prestress) Radial load 25 kN
Shaft seals	Freudenberg Simrit , Polyurethane	680 mm 500 mm	
Lubrication pump	To be decided		

Table 3. Component specification of bearing- and lubrication unit concept design.

Bearings will be supervised through a Condition Monitoring system- compare [12].

Selection of lubricants

A list of candidate lubricants for use in Target Wheel drive unit has been compiled.

Detailed activation analysis and lubricant life analysis will determine which lubricant will be used.

Name	Base oil	Thickener	Base oil viscosity	Rad resistance	Max temperature
Klueber Barrierta L55	PFPE	PTFE	400 mm^2/s		260
Klueber Petamo	Mineral Oil + Synthetic Hydrocarbon	Polyurea	165 mm^2/s		160
Dupont Krytox 240	PFPE	PTFE	Not found	10^7 - 10^8 Rad	
Rocol Advance Sapphire 2	Mineral Oil	Lithium Complex fortified with PTFE	145 mm^2/s		160
Mobilux EP 3	Mineral Oil	Lithium Complex	160 mm^2/s		130
Castrol Nucleol G121	Mineral Oil	Inorganic	475 mm^2/s	10^9 rad	150
Shell Aeroshell 22	Synthetic Hydrocarbon	Microgel	30,5 mm^2/s		204
Chevron SRI Grease 2	Mineral oil	Polyurea	116 mm^2/s		177

Table 4. List of candidate lubricants.

Helium Feedthrough system

To minimize leakage from Helium Cooling system, a design with dual seal chambers has been chosen as baseline design.

Function

Incoming Helium pressure (p1)

Buffer gas pressure stage 1 (p2)

Back pressure stage 1 (p3) In drawing below denoted (g).

Buffer gas pressure stage 2 (p4). Below denoted (i).

Ambient pressure (p5).

The upper seal is connected to a helium buffer tank with actual atmospheric pressure [g]. The buffer tank pressure control will pump back the helium to PCool.

The pressure in the second stage seal chamber will be kept slightly above the pressure in the buffer tank, i.e. [i] is approximately 1.05 bar. Flow [b] is buffer gas flow and the leakage to rooms is flow [a]

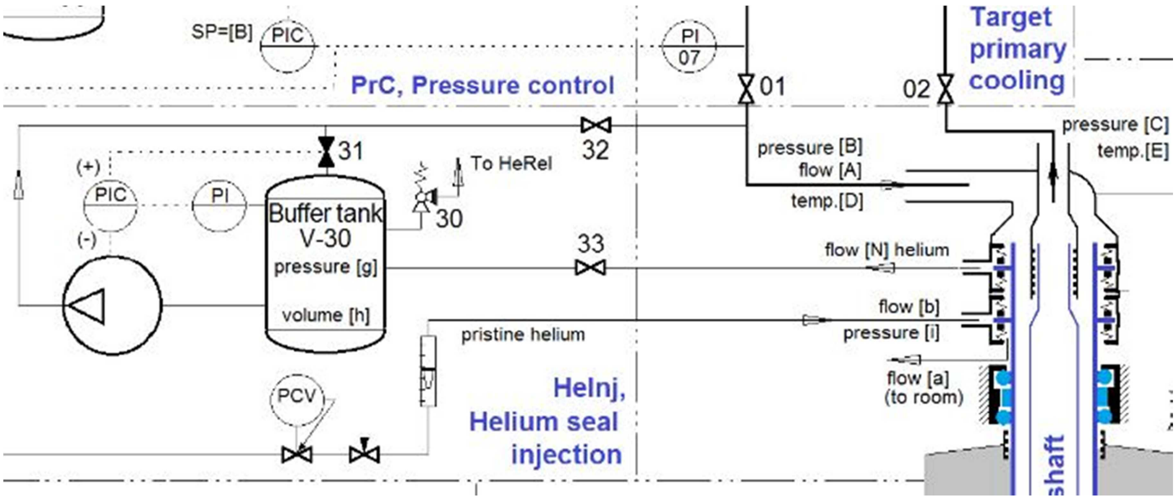


Figure 2. Baseline concept for Helium feedthrough.

A leak in the seal ring nearest process will lead to an increase in flow towards buffer tank. As pressure in the seal chamber increases, leak rate from first to second seal chamber also increase.

To make sure that Process Helium is contained within the circuit, allowable pressure in buffer tank must be slightly lower than pressure of buffer gas into secondary seal chamber. However, with a suitable selection of buffer gas volume and compressor capacity, operational margins against leakage are possible to achieve.

In the final dimensioning of seal draining and buffer gas system, figures of anticipated leak rates during operation and with anticipated contamination of seal rings must be used, to arrive at a realistic final design.

Leak flow with this combination of two seals can be kept low. Anticipated leak rate of clean Helium from secondary seal chamber to connection cell, is below 1 mg / second.

Labyrinth seal

The labyrinth seal is mounted from the inside to the housing of the seal arrangement and centered to the inner tube of the rotating shaft end using feeler gauges for adjustment when assembling. In the current concept an axial , open labyrinth is used, but a radial labyrinth is also possible.

Axial labyrinth seal

The seal will be assembled and well centered with a distance of 1,0 mm at assembly. The gap will decrease to 0,2 mm during operation with outlet Helium temperature 250^{o} C.

An extrapolation of values from Julich calculations[1] assuming austenitic stainless steel Coefficient of Thermal Expansion shows leak rate will be close to 50 g/s at startup, but decrease gradually to about 10 g/s as gap decreases with increasing temperature.

Radial labyrinth seal

This seal type demands more place radially, but has the advantage of constant radial clearance as temperature change. A preliminary estimation of leak rate for a possible design is presented in [xx]. For this design, radial clearance is constant, 0,3 mm. Allowance for axial thermal expansion of the inner shaft to 250^{o} C must be accommodated in the design.

Sub part	**Description**	**Designation**	**Remark**
Cartridge seal	A combination of two serially connected contacting seals.	Type John Crane 3300	Inner diameter is 250 mm
Axial Labyrinth seal	-	-	Installation clearance 1,0 mm, operational clearance 0,2 mm at maximum anticipated temperature.
Alternative-Radial Labyrinth seal	-	-	Constant clearance 0,3 mm

Table 5. Concept design for helium feedthrough system.

Static Positioning system

The function of the Static Adjustment System is to provide the possibility to perform a proper alignment of the Target Wheel within the monolith.

The alignment has to be performed independently in Z, X and Y direction.

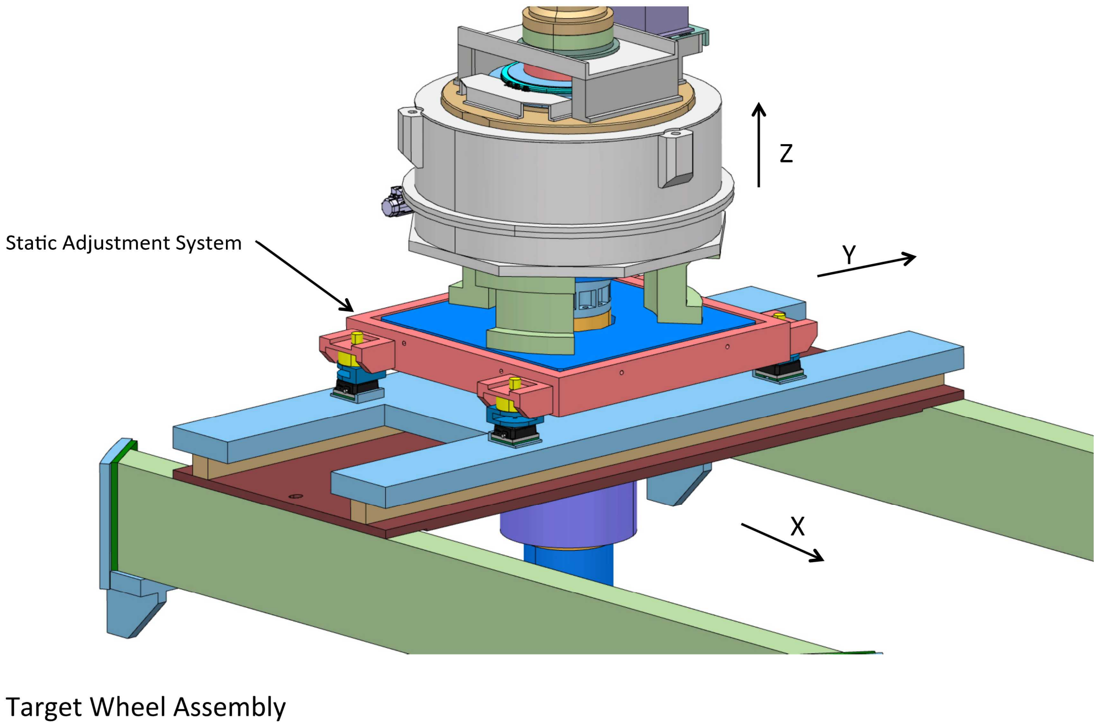


Figure 3. Static adjustment system.

The upper part, the X-Y Adjustment Base contains slide plates in its bottom on which the Bearing and Drive unit is standing. By horizontally positioned screws the X-Y positioning can be performed.

Sub part	Description	Designation	Remark
Wedge Mounts	Allowable load 150 kN per foot	-	Air-Loc 515 KSKC
Slide Plates	Graphite/ Bronze slide plates	-	National / Enduralube

Table 6. Concept design for static adjustment system.

Fine Adjustment system

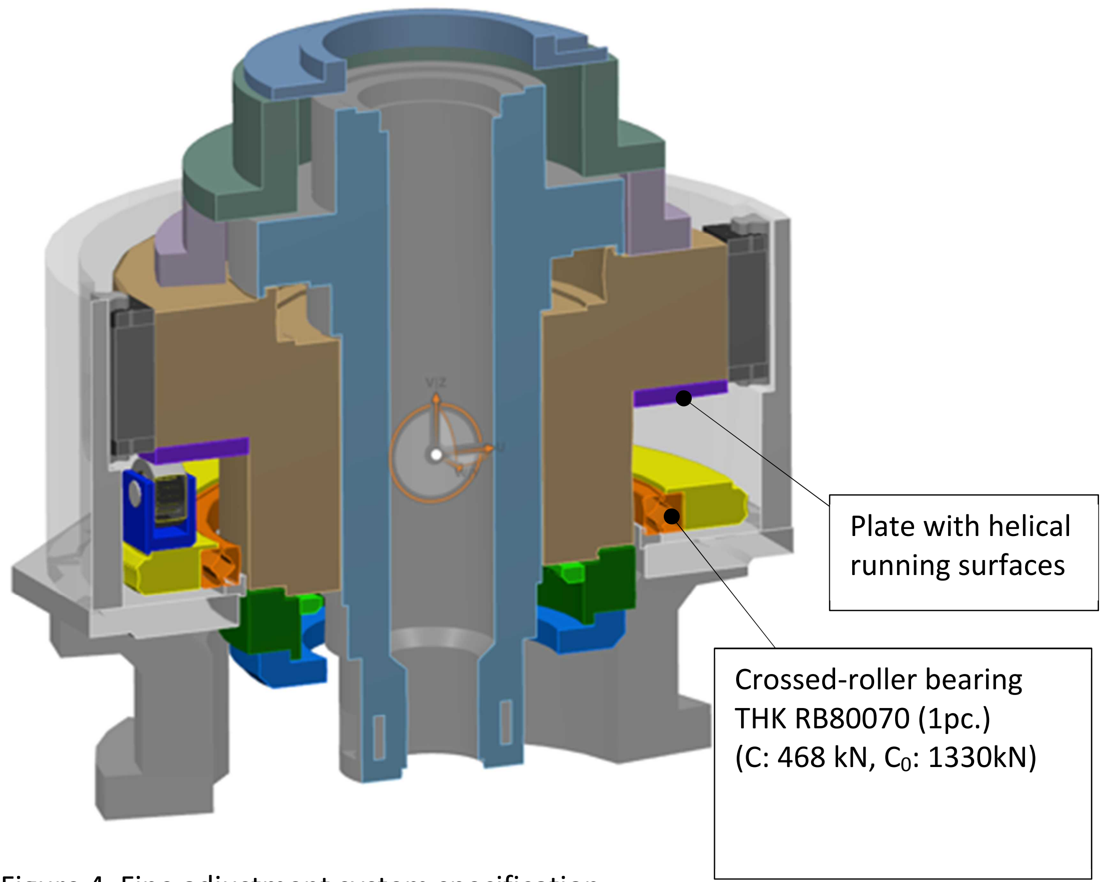


Figure 4. Fine adjustment system specification

The adjustment of bearing house is achieved through motion of the worm drive which is in contacts with cams lifting bearing house. The whole load is transmitted through the Cross- roller ring to the base frame.

The contact pressure between cams and rollers must be evaluated. The cams should be hardened and coated.

There is a concern that the cross roller ring will be sensitive to lubrication conditions.

Therefore there is an alternative, SKF axial- radial bearing NRT 850 A which is less sensitive to bad lubrication conditions and possibly could be used. Compare ref [11].

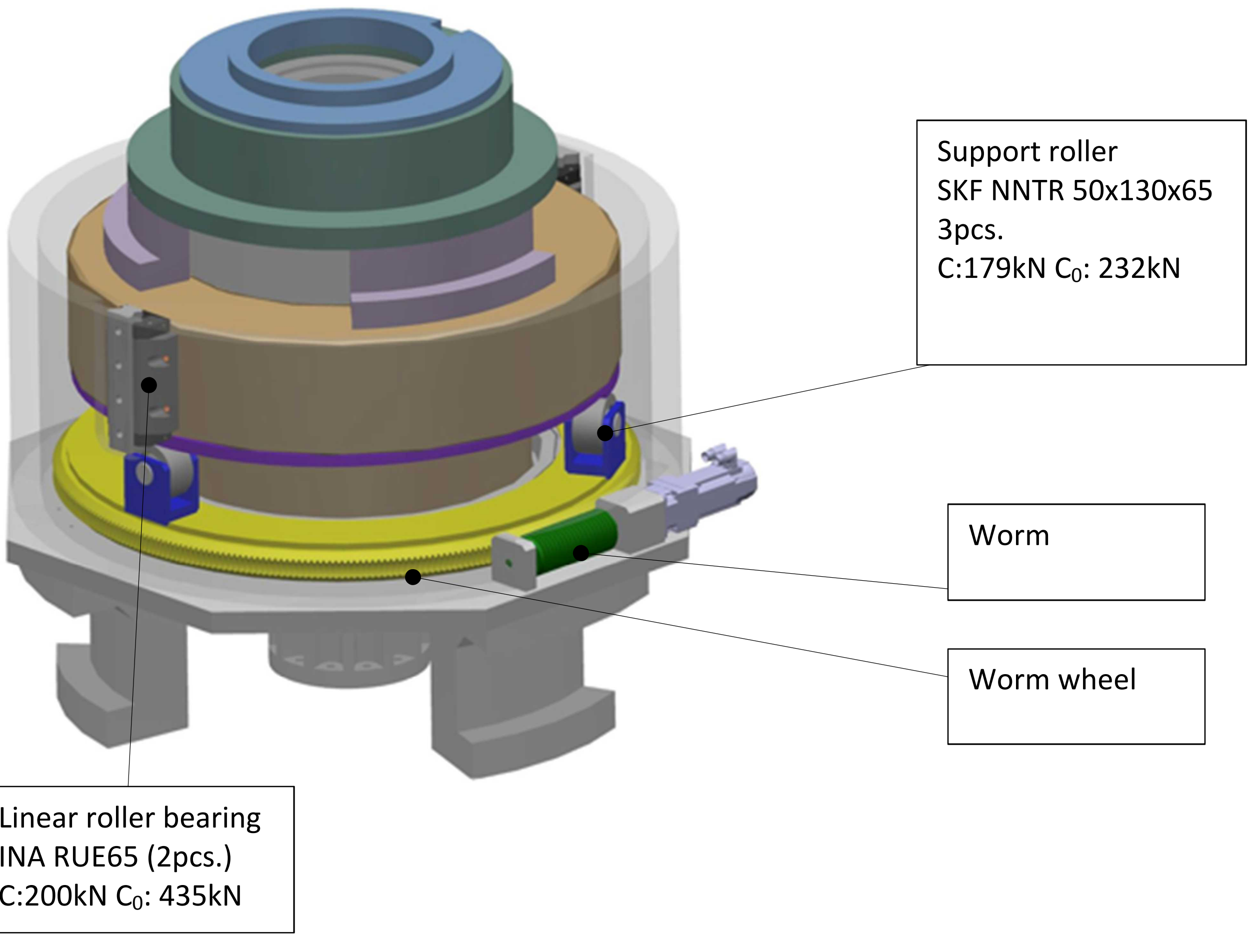


Figure 5. Fine adjustment system specification.

Sub part	**Description**	**Designation**	**Remark**
Support rollers	NNTR 50 x130 x 65	-	
Cross Roller Ring	THK RB 80070	-	
Alternative bearing (not shown)	SKF NRT 850 A	-	
Linear Guides	Schaeffler RUE 65 or RUE 65L	-	

Table 7. Component specification for Fine adjustment system

Shaft

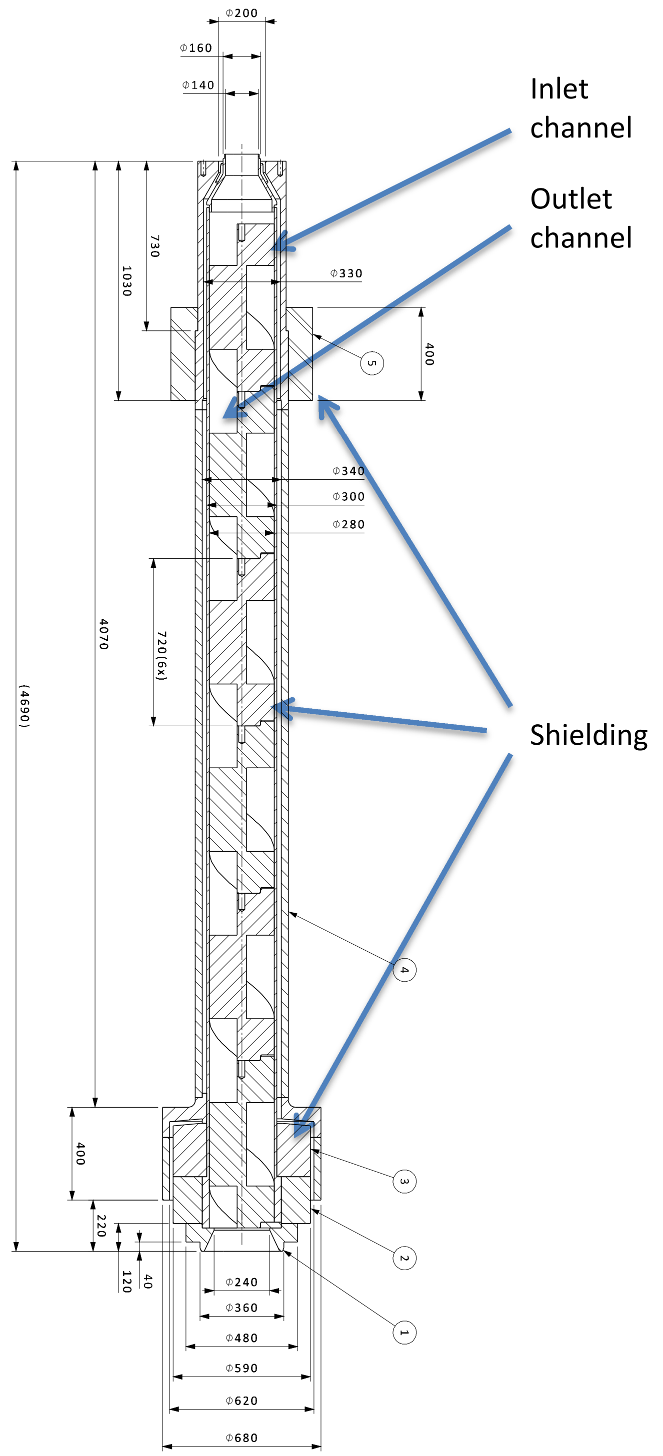


Figure 6. Shaft nomenclature.

The shaft design is a tradeoff between the need to achieve a low pressure drop and the need to limit neutron flux through open passages to connection cell.

Shielding material has been applied to achieve 50 % shielding (equivalent to solid steel with 50 % porosity) in the outlet channel.

To close the gap between shaft and shielding a rotating shielding block, connected to the shaft, has been applied.

Studies have shown that it is necessary to close the gap in the inlet channel as well, to achieve acceptable results there should be 50 % shielding or equivalent reduction in free sight.

Studies made by ESS Bilbao show a significant reduction in streaming by closing gaps in inlet- and outlet channel. Currently achieved radiation level at top of shielding is presented below. Compare [2].

Shielding performance

Based on the detail shielding analysis the dose rates, the objectives on top of the vessel can be achieved. Consequently, for the drive unit we do not need hard radiation resistance equipment.

Dose Rate on top of the shaft

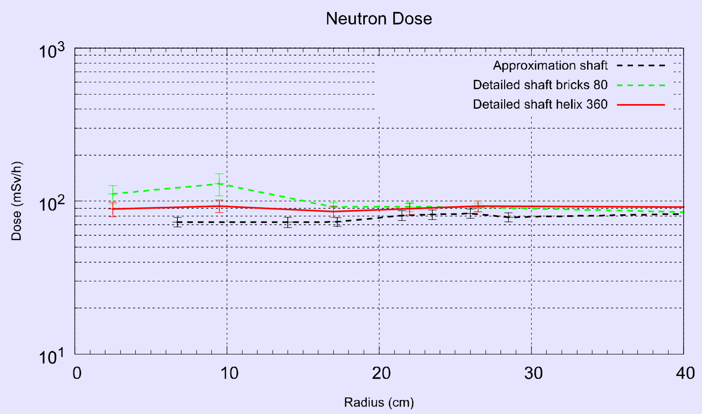


Figure 6. Dose levels in Connection cell, from reference [2].

Sub part	Description	Designation	Remark
Whole shaft including shielding	316 L	-	Outer diameter 400 mm Length 4690 mm Weight 3258 kg

Table 8. Concept design specification for shaft.

Target Wheel

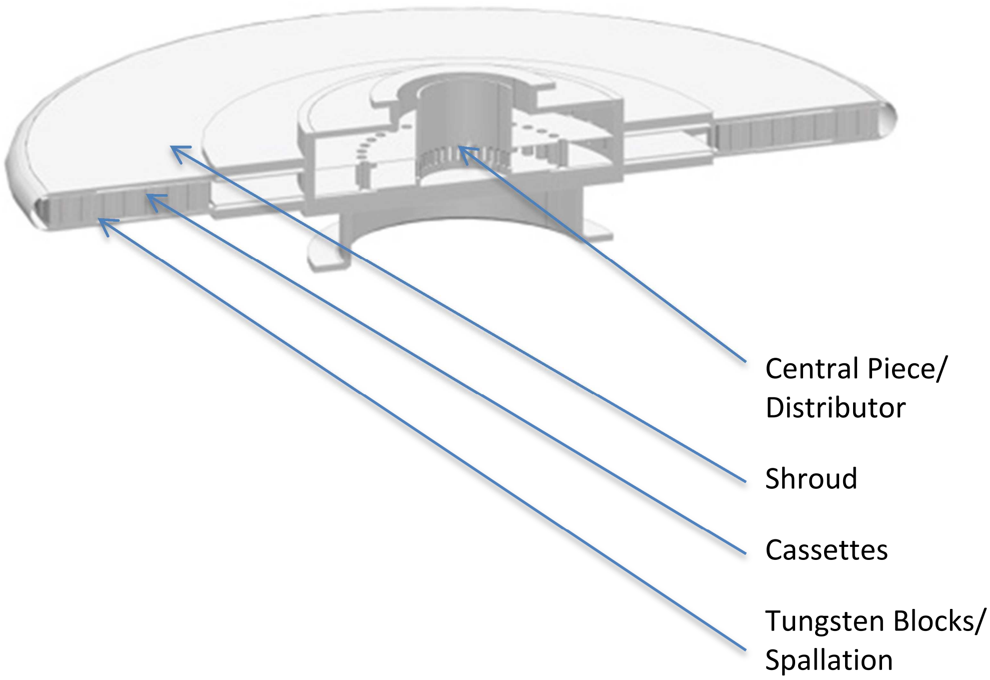


Figure 6. Target wheel nomenclature

Introduction

Target Wheel consists of subparts according to Figure 6. It has been verified for design and operational loads by ESS Bilbao according to ref [3]. See also ref [4].

Central Piece- Distributor

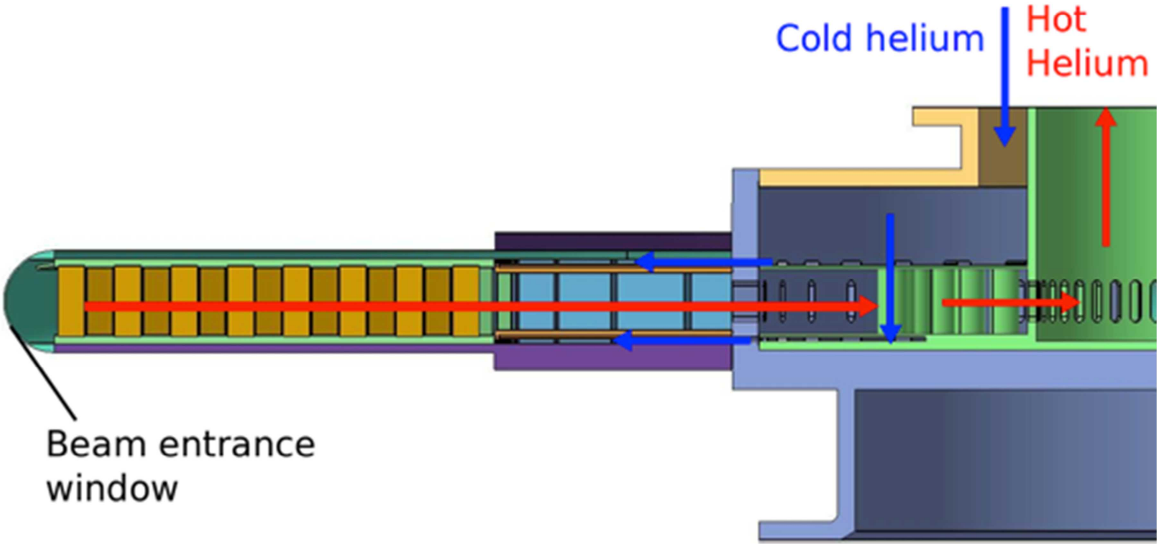


Figure 7. Principal coolant flow path through wheel and central part.

The function of the distributor is to direct Helium flow and distribute it evenly across the Spallation material. At nominal flow pressure drop has been calculated to be close to 0,5 bar including effects of cassettes. Flow is distributed evenly along shroud walls and between sectors.

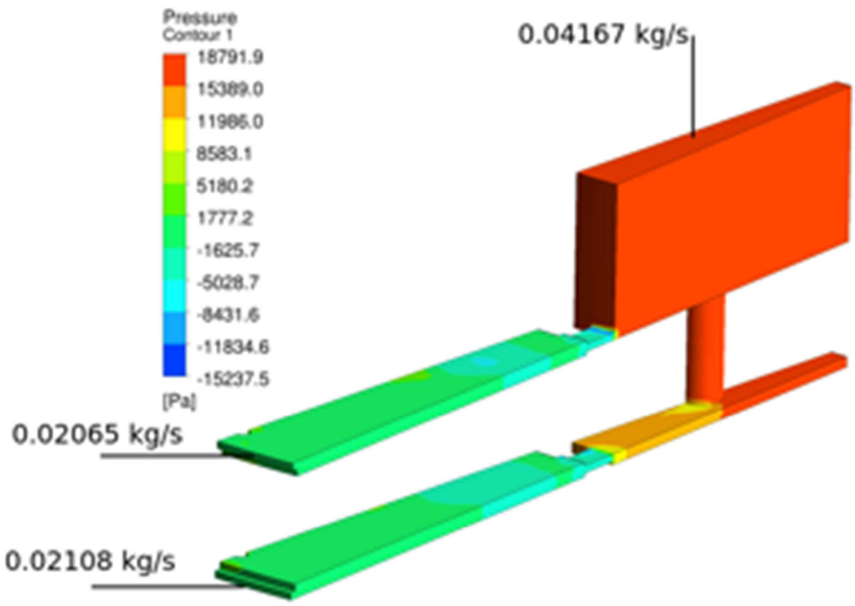


Figure 8. Pressure drop through central Part and inlet to sectors. Note- only half sector depicted, therefore half sector flow.

Shroud, including Beam Entrance Window

The shroud function is to provide a tight and structurally stable structure, keeping spallation material in place, separating process atmosphere from monolith atmosphere.

Shroud material is 316 L. It has been chosen because there are a lot of studies describing its performance under irradiation. Compare [9].

Figures 9 below shows calculated results from a first estimation of stress where a temperature distribution resulting from a normal beam footprint was used to predict a steady- state stress distribution (thermal stresses).

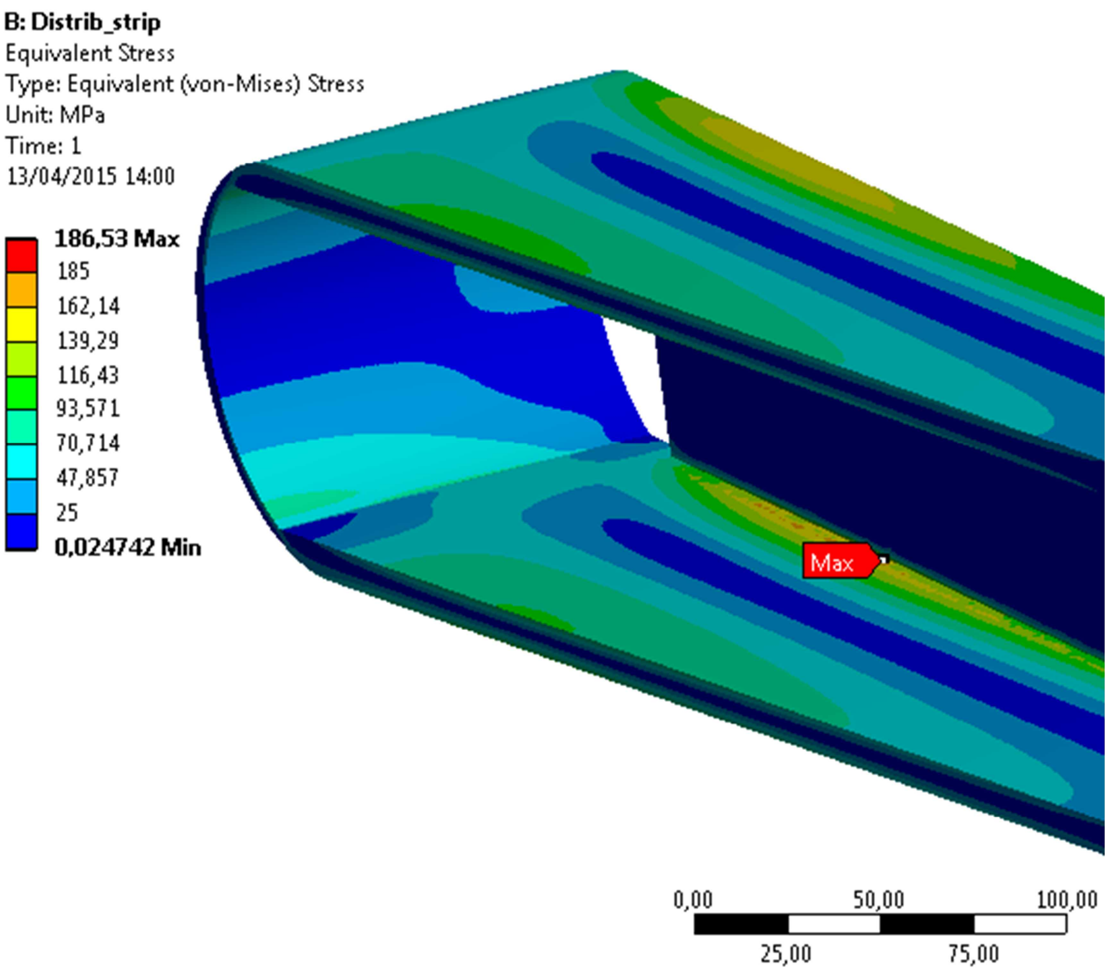


Figure 9- Results from initial steady- state calculation of thermal stress in shroud.

The Beam Entrance window will be exposed to thermal stress from cyclic loadings. At the same time, radiation effects will reduce ductility in the material. In [3], ESS- Bilbao have made an initial study of fatigue due to secondary stress.

Input to the calculation is expected temperature amplitude- temperature just before a pulse in the BEW has been calculated to 135^{o}C while it just after the pulse increases to 152 ^{o}C.

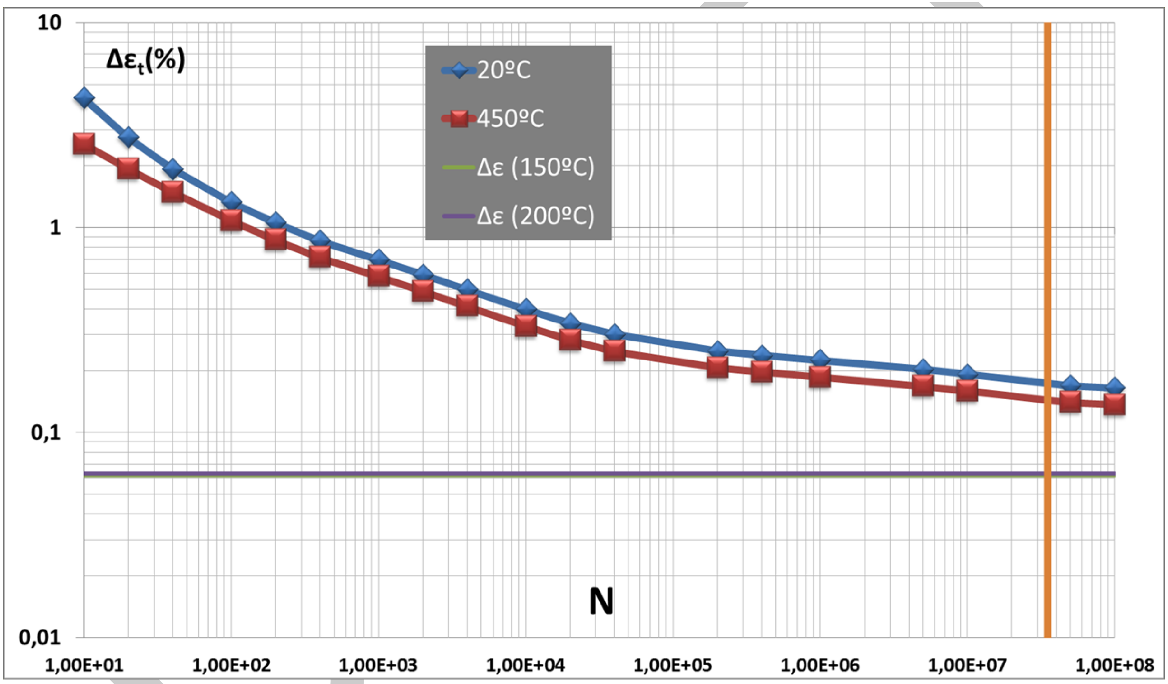


Figure 10. Fatigue calculation result for calculation of thermal fatigue caused by secondary stress in the Beam Entrance Window.

In Figure 10 above, the orange coloured line denotes number of thermal cycles achieved after 5 years of operation. The Magenta line denotes calculated strain, and the blue- and red curves denotes allowable strain at 20^{o}C and 450^{o}C respectively.

Cassettes

The function of the cassettes is to provide stable and reliable suspension for the spallation material. Helium cooling is provided through channels integrated on the outside of the cassettes. Material for the cassette will be 316 L.

The design of the cassette with a very close fit between Tungsten blocks and cassette structure makes it necessary to align bottom part and top part exactly. Therefore cassettes will be machined with tight tolerances and screwed together.

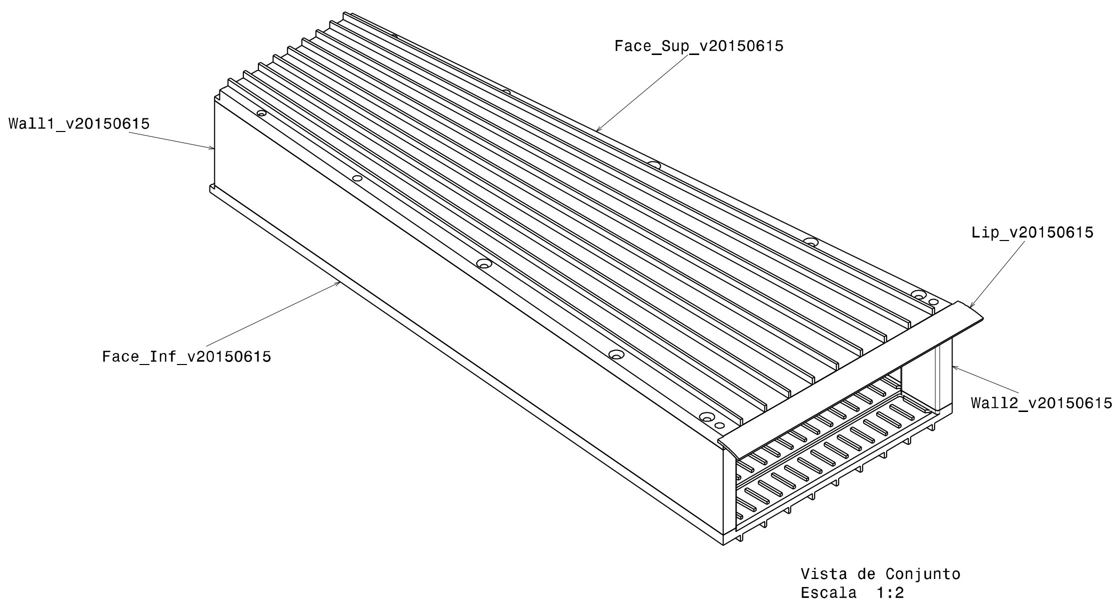


Figure 11. Cassette design.

It is not decided at this point, if the Tungsten blocks should be fixed to the bottom plate, using a brazed spot, or constrained only through a defined clearance to the cassette structure.

ESS Bilbao has started a feasibility study to find out if brazing of Tungsten blocks is a realistic way forward.

Experimental validation:

The FEM analysis of the W-SS 316L brazing shows that a 5 mm surface in the center of the brick produces stress below 50 MPa. In order to evaluate this option, a brazing test campaign was started on February 2015. The first step of the experiments has been completed with promising results.

Figure 12. Brazing of Tungsten blocks- current status. Compare [2].

Spallation material

The spallation material consist of Tungsten blocks of high quality arranged in a pattern according to figure 13 below.

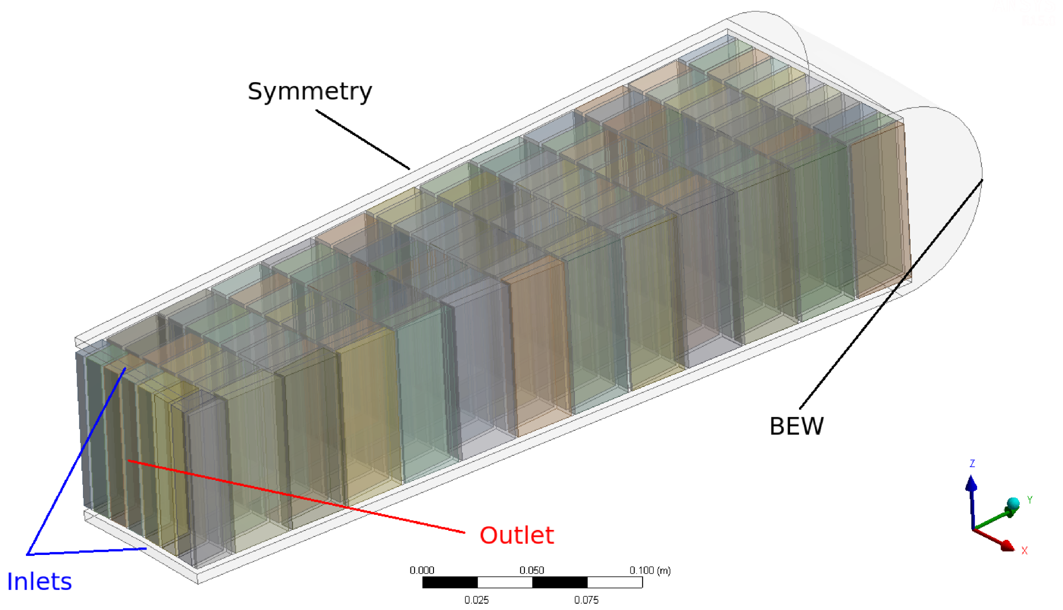


Figure 13. Geometry for spallation material

Temperature distribution- steady state

ESS Bilbao have made calculation of thermal stress by applying a temperature profile associated with the expected proton beam footprint.

This resulted in a temperature distribution in the spallation material according to figure 14 below.

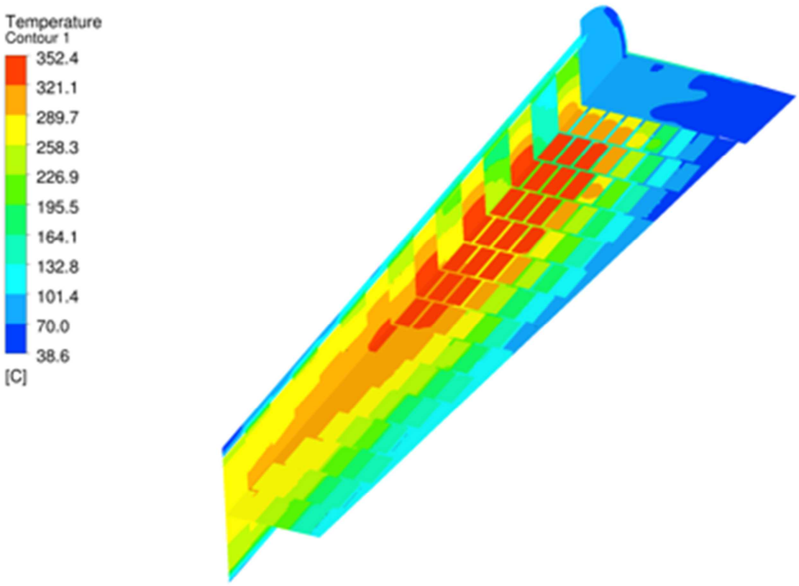


Figure 14- steady- state temperature due to application of temperature distribution from design beam footprint, calculated with the Bertini model.

Stress profile

Maximum thermal stress for the spallation material is between 80- 90 MPa depending on which model (CEM or Bertini) that is used to calculate temperature distribution. See [14].

2.1.3. Location and layout

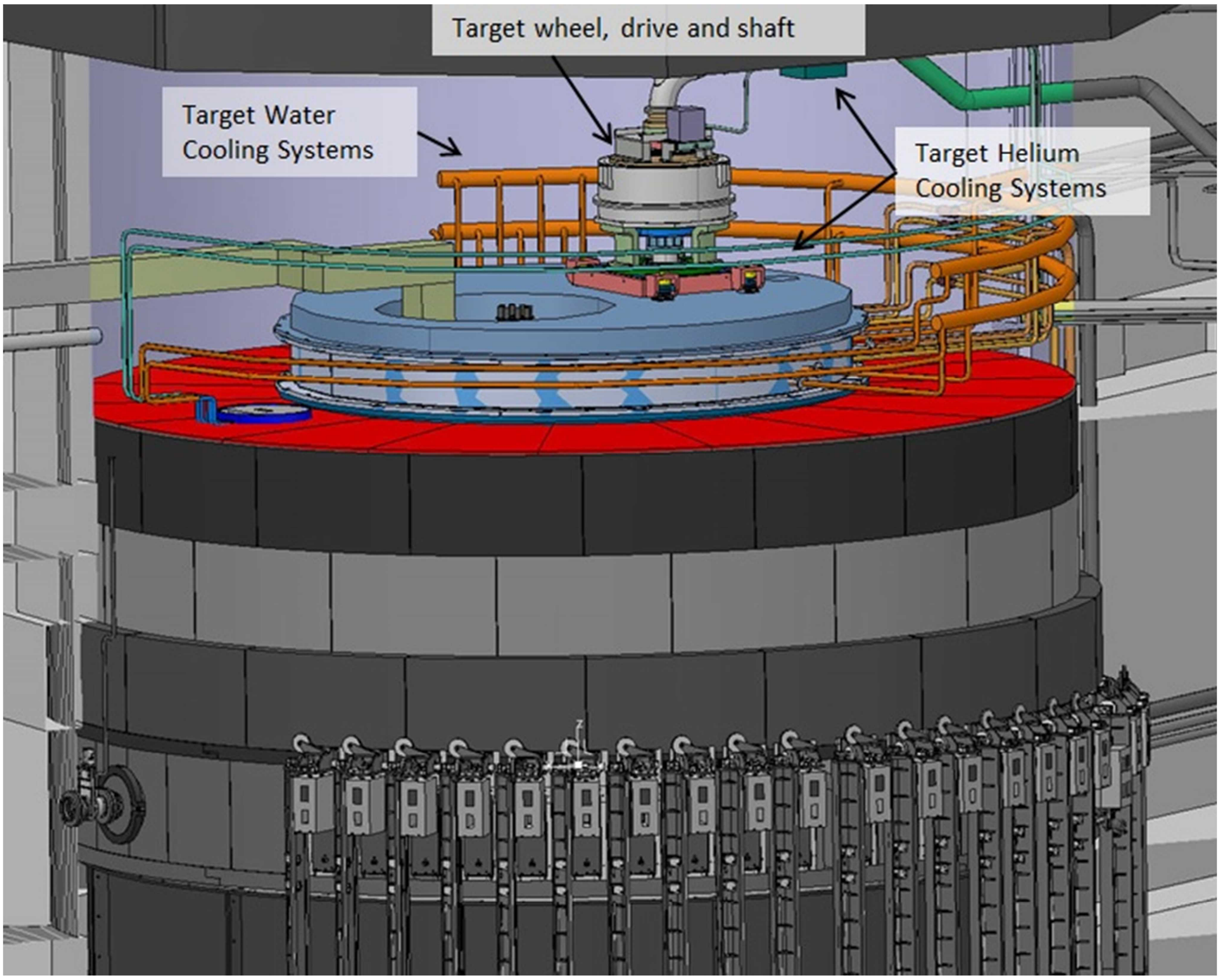


Figure 15- Connection cell layout.

The Drive- and suspension unit of the Target Wheel, drive and shaft system is situated outside Monolith, see figure 15, while the wheel and shaft is situated in the monolith. There is a ferrofluidic seal sealing the cover penetration, compare figure 16 below.

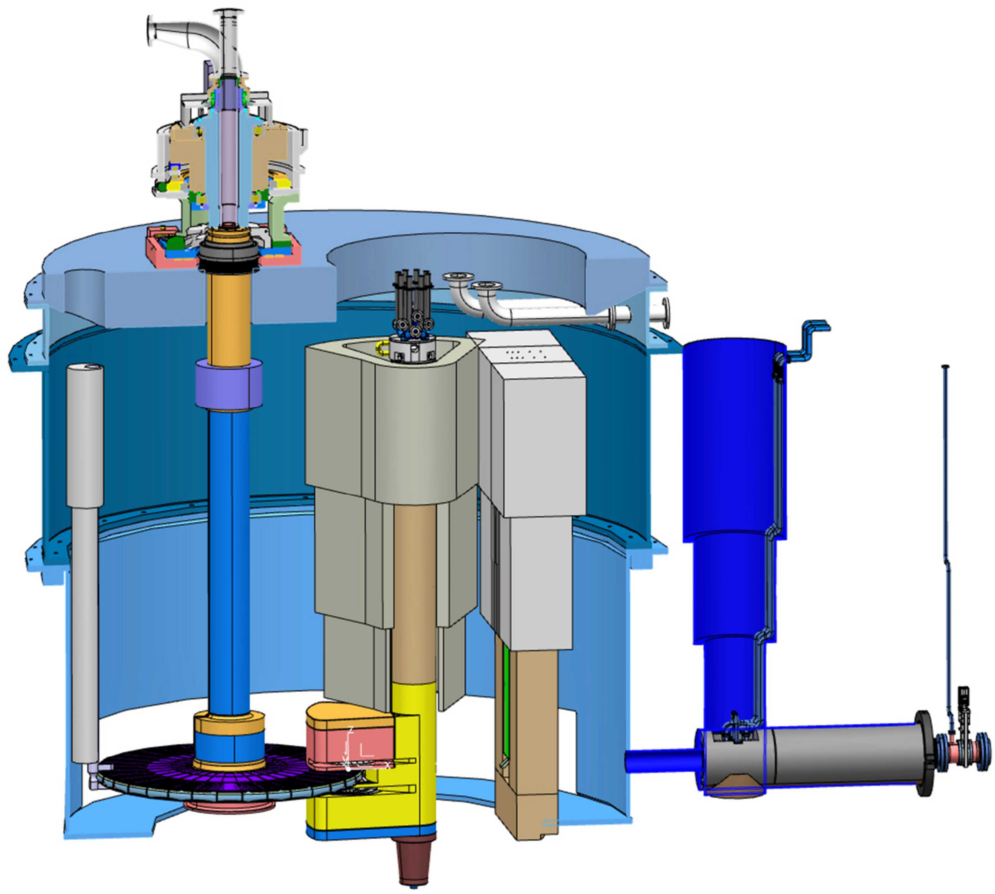


Figure 16- Monolith layout showing ferrofluidic seal between shaft and Monolith cover

2.1.4. P&ID

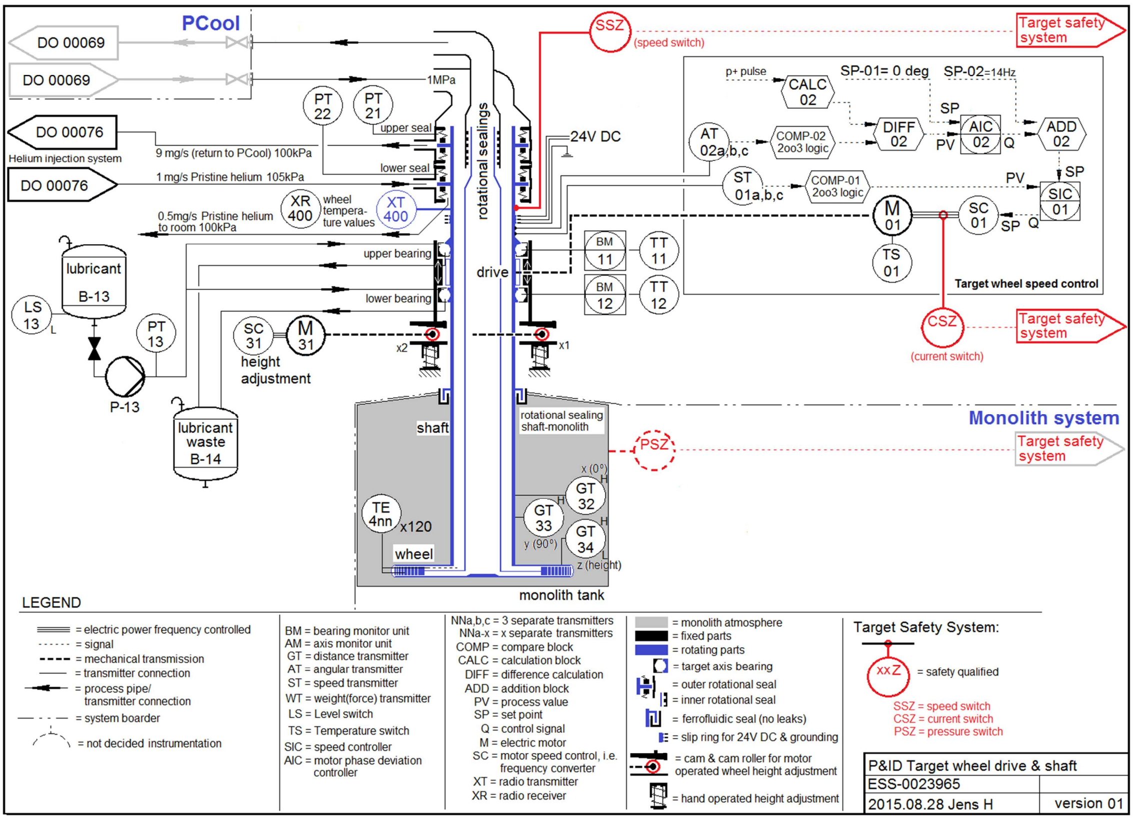


Figure 17- Process- and instrumentation diagram.

The diagram above shows instrumentation for the Target Wheel, Drive and Shaft. For a description of functions and instrumentation see [7].

2.1.5. Maintenance and handling solutions

See reference [5].

2.2. Radiation protection and shielding

To fulfil radiation protection and shielding requirements, shielding is important design criteria for Target Wheel central part and shaft.

This work is on-going- compare [6].

2.3. Over-pressure protection

The Target Wheel and shaft is protected against overpressure through its connection to the Helium Cooling System.

The function of isolating Target from Helium Cooling System is pending decision based on final Safety Analysis of the Target Helium Cooling System.

If isolation valves should be introduced, there must be additional overpressure protection for the enclosed volume.

2.4. Process Control System and Modes of operation

See reference [7]

2.5. Balancing

See reference [8]

2.6. Material selection

See reference [9] and [10].

2.7. Abnormal system operation

Component	Number of components	Function	Failure mode	Possible causes
Target Wheel, Drive and Shaft	**1**			
Main bearing	1	Allow the rotation of the shaft	Loss of performance	Corrosion, wear, fatigue
			Loss of performance	Radiation damage to bearings or lubricant
			Fail to function	Complete unexpected failure
Motor and angular/speed positioning system	1	Drive the target wheel rotation	Fail to run	Radiation damage to motor
			Fail to function	Hardware or software fault
			Fail to funciton	Radiation damage to measuring system
Rotor XYZ positioning system bearings, servo, actuator.	1	Adjust and control the target wheel rotation		Corrosion, wear, fatigue
				Radiation, damage to motor
				Hardware or software fault
				Radiation damage to positioning measuring system
Seal	1	Seal the joint between the static shaft and rotating shaft	Large leakage, leading to stop of the system.	Loss of seal gas
				Complete unexpected failure
				Wear, contamination

Table 9- Component failure modes for Target Wheel, Drive and shaft. Extract from ongoing reliability and availability analysis.

3. DOCUMENTATION

3.1. Reference drawings and specifications

Drawing Number	Drawing Title	Rev
ESS-0011843.2	Target Wheel ASM	1.9
ESS-0016500.2	Target Rotor	1.3
ESS-0016503.2	Target Wheel Shaft	1.0
ESS-0017051.2	Target Wheel Disc	1.1
ESS-0017885.2	Feedthrough ASM	1.0
ESS-0023295.2	Bearing and Drive Unit	1.0
ESS-0023674.2	Static Adjustment System	1.0

Table 10- Drawings produced as part of concept design.

4. MODELS

4.1. Geometrical models

ESS-0011843 rev 1.12

4.1.1. Neutronic

See reference [17]

4.1.2. Hydro-thermo-mechanical

See reference [15]

4.2. Safety assessment

See reference [16]

5. GLOSSARY

Term	Definition
Requirement	A "requirement" is a statement of need from a stakeholder, i.e. a user, operator or interfacing system.
Function	A "function" is something that a system or subsystem does or perform in order to fulfil a requirement.
Constraint	A "constraint" is a statement of a restriction that may limit the range of possible solutions.
Affordance	An "affordance" is a requirement that expresses a capability offered to a user, operator or interfacing system. An affordance is only performed upon request from such stakeholders.

6. REFERENCES

[1] ESS-0038193 *Seminar- Reibungsfreie Labyrinthdichtung fur die Drehdurchfuhrung des Target- Schaftes* Julich Forschungszentrum, 2014.

[2] *ESS-Bilbao Presentation for Collaboration Board* F.Sordo, June 19, 2015.

[3] ESS-0037323 *Mechanical Design Following RCC- MRx Code.* ESS Bilbao 2015.

[4] ESS-0037287 *Radiation Damage Analysis for the ESS Target.* ESS Bilbao 2015.

[5] ESS-0038144 *Maintenance and Handling of Target Wheel, Drive and Shaft*

[6] *ESS-Bilbao Presentation Streaming through Target with and without shielding* F.Sordo, 2015

[7] ESS-0038137 *Specification for Control System for Target Wheel, Drive and Shaft*

[8] ESS-0023773 *Target Wheel balancing*

[9] ESS-0028465 *Target Materials Handbook*

[10] ESS-0023781 *Elastomer seals for Target Wheel, Drive and Shaft*

[11] ESS-0023779 *Specification for Vertical positioning system for Target Wheel, Drive and Shaft*

[12] ESS-0026696 *Specification for Condition Monitoring System for Target Wheel, Drive and Shaft*

[13] ESS-0039035 *Leakage calculation on an alternative labyrinth seal design*

[14] ESS-0036673 *ESS Bilbao Target proposal*

[15] ESS-0023073 *Target Shaft and Drive Unit- Natural Frequency analysis*

[16] ESS-0037526 *Hazard analysis- Target Wheel and Cooling system*

[17] ESS-0034495 *Design Beam Footprints for the Target- Accelerator Interface*

DOCUMENT REVISION HISTORY

Version	Reason for revision	Date
1.0	Created	20150424