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State of Design of the SNQ-Target

H. Stechemesser 1), G. Thamm 2),

KFA Jülich, D-5170 Jülich,
1) Zentralabteilung Allgemeine Technologie
2) SNQ-Projekt, Teilprojekt 3 "Neutronentargetanlage"

Abstract:

As the requirements for the SNQ-target and the target station at all have been well defined, an improved design and essential dimensions and geometries could be fixed recently. Important nuclear data for the uranium and tungsten target have been calculated using the improved technical design of the rotating target. These nuclear data have been taken as a basis for temperature- and stressprofile calculations especially in the hot spot plane of the uranium target pin. Furthermore the feasibility of the target wheel design has been proven in several manufacturing and functional tests.

1. Introduction

The neutron target facility of the SNQ has to meet the following two basic requirements:

1. Generation of neutrons by conversion of protons supplied by the accelerator with as high as possible a yield.

2. Provision of all technical means for optimum utilization of the generated neutron radiation.

The technical realization of the neutron target facility must in addition to these two basic requirements also take into account the following essential conditions:

- safety during normal and abnormal operation situations,
- high availability of the facility (about 6000 hours of operation per year),
- design flexibility of the facility for adaptation to the developing ideas about utilization (probably different operation modes) and for the use of different target materials.

As the basic requirements and the conditions for realization can by no means be met independently of each other, the present overall conceptual design of the neutron target facility is to be regarded as an "optimum technical compromise".

2. General outline of the target facility

The main data of the proton beam determining the design of the target are shown in Tab. 1

final energy	1100 MeV
dc beam current during pulse	200 mA
average time current	5 mA
repetition frequency	100 Hz
beam pulse duration	0,25 ms.

Tab. 1: Main data of the proton beam

The essential part of the facility is the heavy metal target, to be built as a rotating wheel. The target wheel has a diameter of about 2.5 m and is to be rotated at a frequency of 0.5 s^{-1}.

The heavy metal material (depleted uranium; tungsten during start-up phase) is arranged in an annular space of 40 cm width at the periphery of the wheel. Size and rotation frequency of the target wheel prevent the same target material from being hit by two successive proton pulses thus significantly reducing the thermomechanical and irradiation induced stresses of target and structural material (especially of the rotating window) compared with a static arrangement (factor of 200). The part of the target hit by a proton pulse can be cooled down to a fairly low temperature level by relatively simple water cooling within the following 2 seconds until the next impact.

Fig 1 and 2 give an overview of the neutron target facility. Protons from the linear accelerator are guided through a special beam tunnel to the neutron target. The rotating target is imbedded in a shielding block immediately adjacent to the end part of the proton beam tunnel. The target block ensures safe shielding of the radiation emitted from the target, and also contains the main installations for the experimental use of the facility, for instance moderation and extraction of the neutrons generated in the target. The target wheel, positioned in the centre of the target block in a cavern combined with its

drive unit (KLA), which also serves to cool and support the target wheel, is mounted as a substructure on a movable shielding plug. It slides on a track inclined at an angle of 45° in a forward direction relative to the proton beam from the cavern (operation position) to the target cell (handling position). In the target cell all necessary handling of the target disc and all the other components mounted on the plug can be carried out by remote control safely and without delay.
Below the target wheel a lead reflector and an H_2O-moderator are installed. Eight to ten multiple beam tubes with at least two beam switches lead to the H_2O-moderator, two more to a cold source located in the centre of a large reflector above the target. In addition two bundles of six neutron guides lead from the cold source into the neutron guide hall adjacent to the target hall.

Furthermore the neutron target facility comprises ancillary systems, mainly cooling loops with purification and degassing installations, as well as vacuum systems and control equipment (internal control installations) providing for safe operation, as well as for high operational availability. The components of these installations are mainly housed in the basement of the target hall.

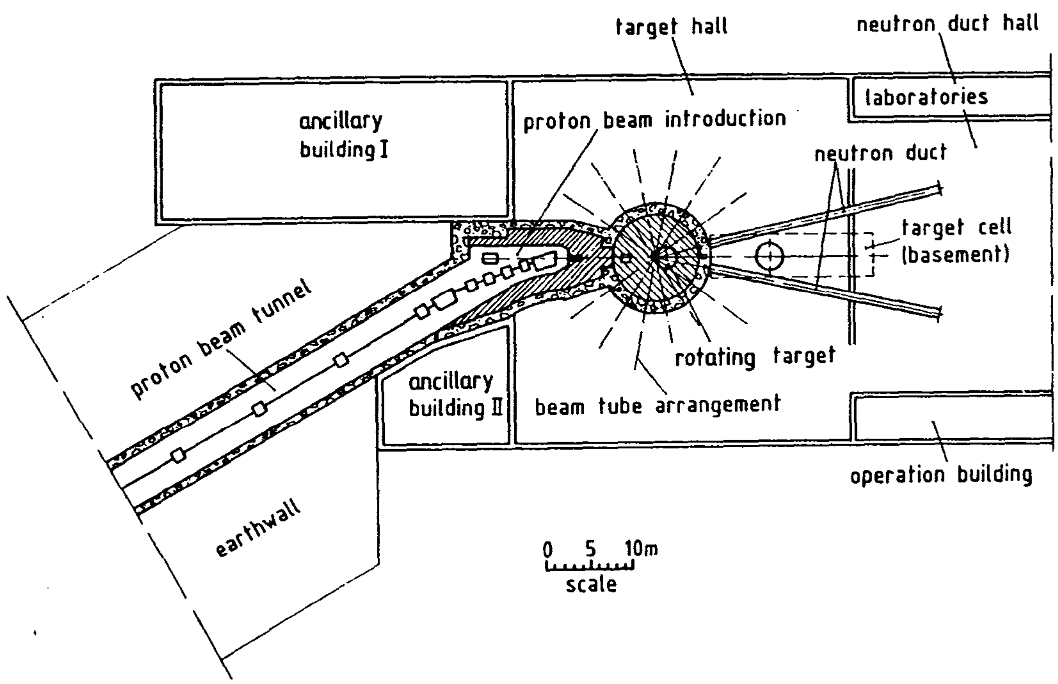

Fig 1: SNQ-neutron target facility (schematic)

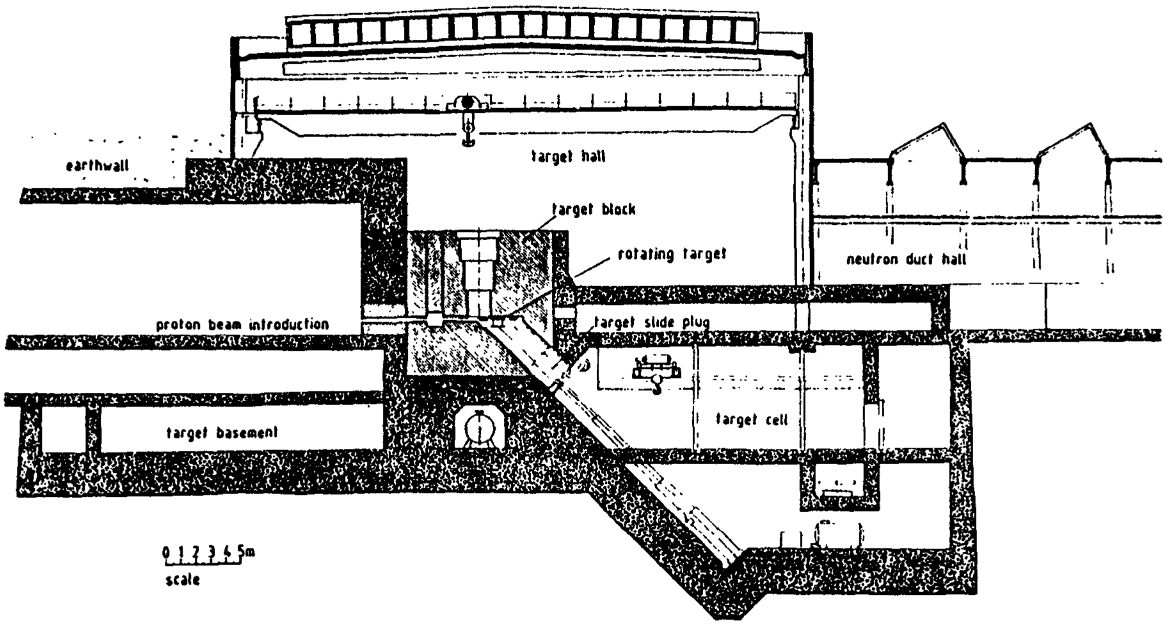

Fig. 2: Neutron target facility (longitudinal section)

3. The rotating target

The rotating target, depicted in Fig. 3, is a combination of the target wheel and the KLA assembly (KLA = german abbreviation of cooling water supply, support bearing, drive).

- The target wheel contains at its periphery the target material from which the heat, generated by the spallation process, is removed within one turn of the wheel by the cooling water.

- The KLA supports the target wheel, rotates it around its axis and connects the cooling water in- and outlet of the target wheel with the stationary substructure.

- The target wheel and KLA are bolted together and the joint is sealed watertight by metallic seals. This joint can be handled remotely.

The rotating target unit is mounted onto the sliding plug as a substructure.

Target wheel

The target wheel unit consists of two subunits

- wheel structure
- target structure.

The structural design of the target wheel is radially symmetric. The evaluation of the various geometric arrangements of the target material inside the target wheel with respect to the influence of temperature, stresses, target material packing density, penetration depth of the proton beam, pressure losses of the flowing cooling water and special manufacturing techniques lead to the so-called "pin target", having the following advantages:

- low thermal stresses in the pins due to the possibility of free expansion in radial and axial direction;

- quasi homogeneous arrrangement of the target material relative to the proton beam axis;

- good cooling water guidance within the target pin arrangement.

Target wheel structure

The design minimizes the number of welding joints by forming the target wheel from three forged parts. Those three forged parts are: the bottom support disc, the lid disc and the rotating window (Fig. 4).

The technical data of the target wheel are presented in Tab. 2.

The cooling water enters the target wheel from the KLA at its centre and flows evenly distributed in a radial direction through the target pin arrangement from the centre to the periphery. At the periphery of the target structure the outgoing cooling water is diverted by the rotating window and returns through channels inside the lid and bottom support disc.

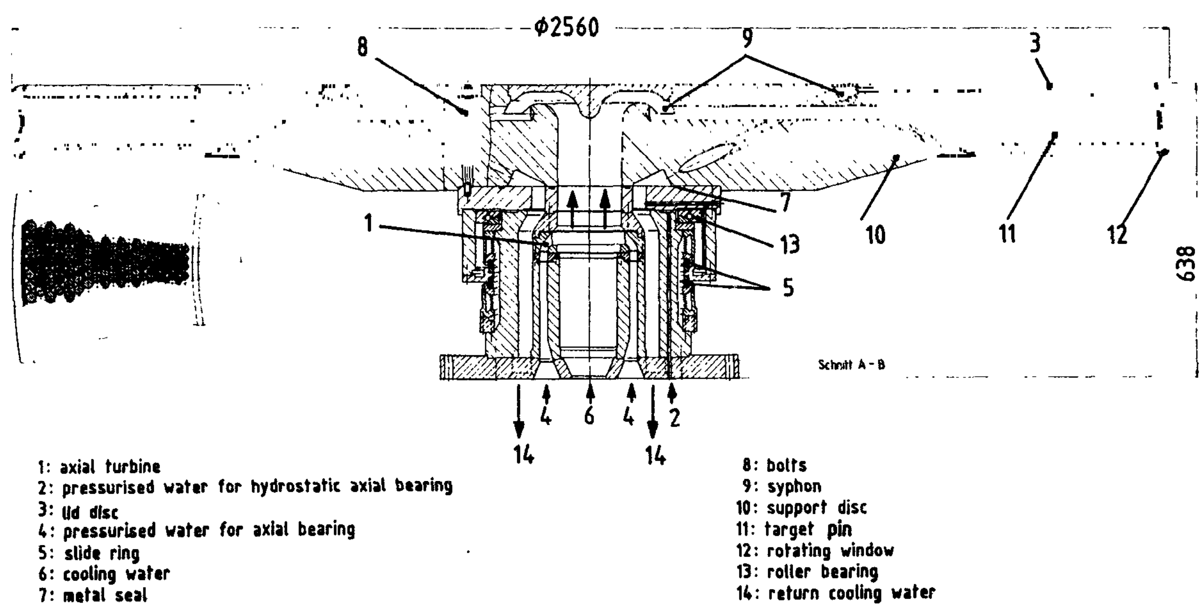

Fig. 3: Target wheel for tungsten or uranium target for 1100 MeV mounted on KLA type II

The channels bored in the lid and bottom support disc are connected by annular channels and the cooling water is guided from the bottom annular channnel in vertical bores into the annular channel of the lid. From the annular channel in the lid the cooling water flows through bores towards the centre of the target wheel, where itreturns through an annular gap arranged concentrically around the water inlet bore. Water in- and outlets of the target wheel are in the form of syphons, so that in the case of pipe rupture in the cooling water system the target pins remain under water.

The design of the target wheel structure facilitates the disassembling after termination of its operation.

The structure of the target wheel carries the weight of the target material and provides for guidance of the cooling water as described above. It easily withstand the tangential acceleration forces caused by the target wheel rotation. The average centrifugal acceleration is less than 10 $m \cdot s^{-2}$ due to the low rotation frequency of 0.5 s^{-1}. The weight load of the target material of about 35 KN is also of minor importance for the stresses of the target wheel structure.

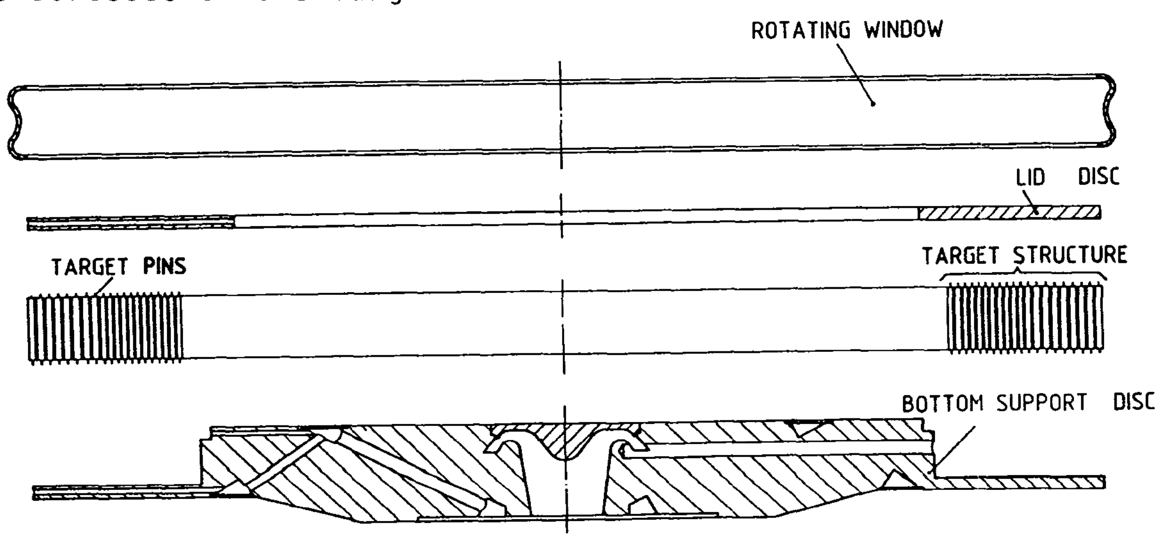

Fig. 4: Exploded view of target wheel

The dominating factor for the dimensioning of the target wheel structure is the static water pressure of 2.5 to 3.5 bars in the target structure. Detailed stress calculations have been carried out.

In order to verify the pressure loss calculations for this complex cooling water channel system in the target wheel, measurements on a 1:1 model are being carried out. In addition welding tests with electron beam and argon arcwelding of target wheel structures on a 1:6 and 1:4 scale are being performed.

revolution frequency	0,5 Hz	
outer dimensions		
diameter	2565 mm	
height	166 mm	
inner structure of target	cylindrical target pins in staggered rows	
technical target depth	362 mm	
number of target pins	8464 mm	
number of staggered rows	23 mm	
outer diameter of target rods	20,2 - 14,3 mm	
clad of target pin		
material	circaloy/AlMgSi1	
clad thickness	0,5 mm	
structural material of target wheel	AlMgSi1	
target material	uranium (UMo 10)	(tungsten)
target cooling		
cooling water flow rate	500 m^3/h	(250 m^3/h)
temperature increase	21,5 K	(10,3 K)
pressure loss over target depth	1,0 bar	(0,4 bar)
total pressure loss over target wheel	1,5 bar	(0,6 bar)
weight target wheel		
total	4672 kg	(4864 kg)
target material	2957 kg	(3149 kg)
structural material	1715 kg	(1715 kg)

Tab. 2: Target wheel (technical data)

Thermal/nuclear data

Table 3 shows essential thermonuclear data for the uranium and tungsten target which have recently been calculated by Filges et at /1/ using an improved technical design of the rotating target.

	uranium	tungsten
range of protons (cm)	48.3	44.4
target depth for 95% of neutron production (cm)	36.0	36.0
target depth for max. neutron discharge (cm)	8.0	7.5
max. energy deposition (J/cm^3)		
-per pulse	149	99
-during rotation through the proton beam	238	127
temperature increase during rotation through the proton beam in hot spot (K)	107	57
average capacity in target (MW)	12.5	3.0

Tab. 3: Thermal and nuclear data of target

Target structure

Cylindrical target pins in symmetrical geometric arrangement in the interior of the target wheel form the target structure. Each pin consists of an inner target material core covered by a wall (cladding). This clad ends in an upper and a lower cylinder, which fix the target pin in the corresponding positioning bores of the bottom support and the lid disc (see Fig. 5).

The arrangement of the target pins in the target wheel is given for the uranium target for an energy of the proton beam of 1100 MeV (Fig. 3. The target wheel with tungsten target pins is identical in its arrangement).

Target wheels of this arrangement for both heavy metals can most likely also be used for significantly lower proton beam energies (from 600 MeV up). In this target there are 8464 single target pins arranged on 23 concentric circles. 368 target pins are positioned on each of these concentric circles. The angular separation of the pins is the same on each of the circles thus necessitating different diameters of the target pins for each of the circles. Between neighbouring pins there are 1 mm gaps for the cooling water flow. The target pins are cladded (0.5 mm wall thickness) in order to prevent the direct release of spallation products from the pin surfaces of the target material into the cooling water and in addition to avoid the contact of uranium with water. In order to keep the release of spallation products from the surfaces of the cladding material into the cooling water as small as possible, a cladding material with a low atomic weight and a low density will be given preference.

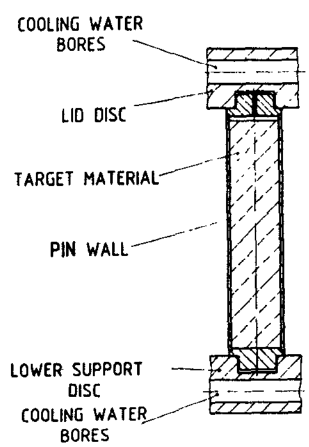

Fig. 5: Target pin

Thermal and stress analysis

The heat energy impact to a target pin is limited to a certain time interval by the rotation of the target wheel. The temperature rise takes place instantaniously within 250 µs because the rotation speed of the wheel is adapted so that each pin is exposed to one full proton pulse only. After this heat-up event the target pin is cooled down by the cooling water flow outside of the proton beam for the time of the wheel revolution of 2 seconds. So the time dependent temperature trend of one pin is also pulsed having of course a significantly smaller repetition frequency (0,5 s^{-1}) compared with that of the proton beam (100 s^{-1}).

The temperature rise for the target pin (hot spot in the pin centre, including proton beam rim effects) is 107 K for the uranium; 57 K for the tungsten material (see Fig. 6).

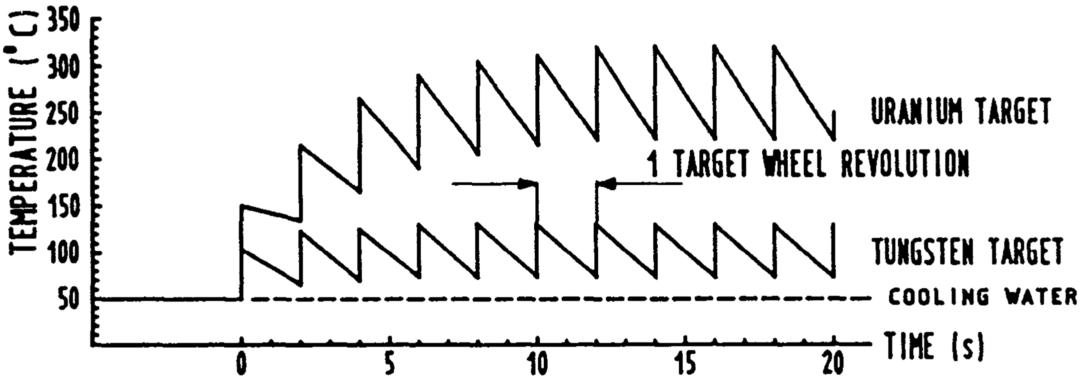

Fig. 6: Time dependent temperature trend for the target pin hot spot (start up behaviour for 1100 MeV, 5 mA, uranium, tungsten).

Due to the different energy impacts and heat conductivities of uranium and tungsten (UMo 10 = 0,16 W/cm K; W: 0,90 W/cm K) the temperature levels in the pin centre at equilibrium are also different. After start up of the proton beam the temperature equilibrium is achieved for the tungsten target after 4 cycles (8 s) and for the uranium target after 7 cycles (14 s).

To keep the temperature level in the target material as low as possible the cladding tube is solid bonded to the pin to achieve a good heat transfer between the target material and the cladding. The temperature gradient over the pin cross section generates linked mechanical stresses, which are increasing with growing radius. The actual stresses, however, are well below the yield strenght of the target and cladding material (see Fig. 7).

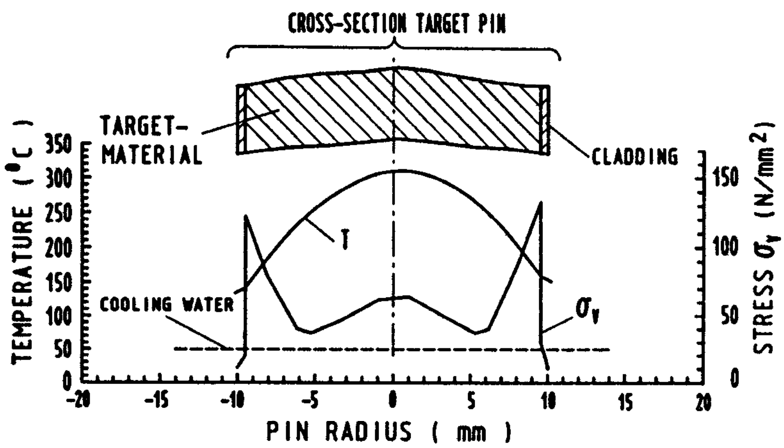

Fig. 7: Temperature and stress profile in the hot spot plan of the uranium target.

KLA-unit

The KLA-unit has to serve the following functions:

- function 1: Providing cooling water flow to and from the target wheel rotating in a vacuum atmosphere where only slight water losses are permitted.

- function 2: Taking up all generated forces, i.e. the weight of the target wheel as an axial force and the effects of imbalance and gyroscopic moment.

- function 3: Effecting the rotation of the target wheel at 30 rpm.

To fulfil function 1 all KLA-versions tested so far need a sliding ring seal. Sliding ring seals are proven standard components. However, in this special case they have to function in a vacuum environment and in a field of high level radiation. Therefore corresponding tests are being carried out at present.

Different approaches are examined to fulfil function 2. In a first tested version the axial and radial forces are taken up by hydrostatic pressurized water bearings.

The experience gained so far and the results of the tests of the KLA type I led to the design of a second version (KLA type II, see Fig. 8). KLA type II also has the proven hydrostatic axial water bearing of type I but has only one radial bearing. This radial bearing is a ball bearing of 430 mm diameter running without additional lubrication in the cooling water. This kind of application is not state of the art, so that corresponding development work and tests on an original-sized ball bearing have been started. Furthermore the KLA type II is equipped with an axial water turbine instead of a radial turbine as used in type I. By this method outside ducts for the cooling water as in type I are avoided, so that all water connections between the support and the KLA are only inside the bottom flange. By this means remote handling is facilitated.

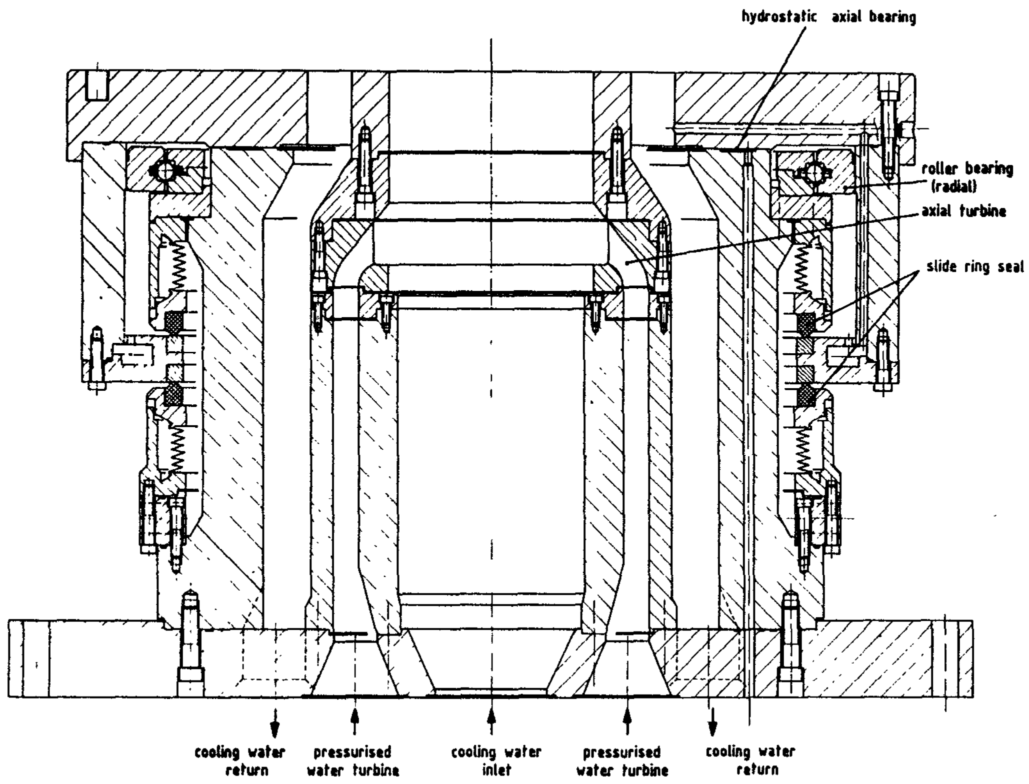

Fig. 8: KLA type II for cooling water supply, support bearing and drive of target wheel (hydrostatic axial bearing, radial roller bearing and axial turbine as drive)

Another difference of the KLA type II to type I is a second sliding ring seal instead of a labyrinth seal. Both form an annular vacuum chamber, that surrounds the first slide ring seal. Thus the monitoring of the leak rate of the first slide ring seal becomes possible. Tests of a corresponding dry running slide ring seal on a 1:1 scale have been started.

The material for the slide ring seals is under development. Since the combination of tungsten carbide against carbon is well established functional and radiation tests for these materials are under way. Furthermore the combination of silicon carbide and carbon is under investigation (reaction bonded SiC, SiC/graphite compound materials, carbon/graphite materials), because less friction and less radiation damage could be expected for these materials.

The long time tests of a slide ring seal on a 1 : 1 scale with non radiated tungsten carbide under original temperature and pressure conditions show good results with a total water leakrate of about 1 $cm^3 \cdot h^{-1}$ into the surrounding vacuum atmosphere.

References

/1/ D. Filges et al., "Nuclear Aspects in the SNQ Target Design", Proc. ICANS-VIII, Rutherford Appleton Laboratory, 1985 July 8 - 12, this volume