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Mock-up stands for a rotating target for CSNS project

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ABSTRACT

This paper summarises pre-conceptual solutions for all sub-units of a potential rotating target system for the CSNS project. In order to test the validity of this concept and to gain first experience with a rotating target, the CSNS project has decided to embark on the construction of a mock-up test stand. The purpose is to provide first demonstration of the viability of the above concept by using a full model of the target head components and shaft and a dummy target with the right diameter and weight; confirm that acceptance criteria can be reached; gain experience in running a rotating target; verify certain parameters obtained by calculations. By carrying out a development program, it should be possible to produce a sound basis for a decision as to whether or not CSNS wants to adopt a rotating target as the preferred solution.

1. Introduction

Although, by comparison to a nuclear reactor, spallation neutron sources have relatively low heat dissipation per neutron in the target, the design of a spallation target is by no means trivial. While the proton beam profile is more or less the only quantity which allows some control over the distribution of power deposition in the target and of radiation damage in the beam entry window, their distribution is very uneven over the target volume respectively the window area. Removing the heat from the target hot spot becomes a big issue, which requires a fair amount of coolant flow through the target, while radiation damage in a small area of the window is the life time limiting factor of a stationary target. As a solution to the first problem modern high power sources (ESS in Europe [1], SNS in the US [2] and J-SNS in Japan [3]) have chosen flowing heavy liquid metal as target material, which allows to move hot target material out of the beam interaction zone and remove the heat elsewhere. Apart from problems with cavitation erosion that arise from the thermal shock in a pulsed operation mode, this concept does not offer a solution to the problem of radiation damage in the target beam window. In an attempt to come to grips with both problems simultaneously, a rotating target was proposed in the first study towards a 5 MW beam power spallation neutron source in the late 1970s [4]. Although, given today's knowledge of the effect of radiation in structural target materials, the diameter of the target (2.5 m) was chosen unnecessarily big, the design had reached a fair degree of maturity, when the project was cancelled in the mid 1980s [5]. No work was done on the concept of a rotating target until recently, when a study team of researchers from the Basque Country in Spain and Forschungszentrum Jülich picked up the idea again, this time with the intent to design a target for a medium power source (250 kW) which would have a very long lifetime and hence not require a hot cell attached to the target block [6]. Since 250 kW is also the power level planned for the CSNS-Project, a series of discussions was held to review pre-conceptual design considerations.

A rotating target is designed in such a way that: (1) the heat deposited at the frequency of pulse repetition (25 Hz for CSNS) is removed during the period of the target revolution (200 ms–2 s). (2) The proton beam hits the target beam window in one position for one pulse and in a neighbouring position for the following pulse.

This offers a number of important advantages relative to the case of a stationary target like: (1) longevity – expectation is one target for the life of the facility, (2) reduced waste: independence of W-price development and manufacturer; high availability of facility; reduced life cycle cost, (3) radiation damage independent of horizontal bam profile, (4) no attached hot cell needed for replacement (if at all necessary), (5) substantial cost savings; better utilization of building, (6) reduced coolant activation; easier water loop, (7) wear parts (bearings, drive and rotating union) can be replaced hands-on and (8) more neutron beam ports.

Given these potential advantages, the concept of a rotating target seems attractive also for medium power facilities, where heat removal is also possible from a stationary target. A preliminary thermal-hydraulics and structural-mechanics study carried out for a beam power of 250 kW to 1 MW showed that rotating a suitably structured 50 cm diameter target results in very moderate temperature and stress levels, even when the target is cooled through (partly grooved) top and bottom surfaces of the target disk only [7,8]. For a beam power of 250 kW and an assumed local peak

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heat deposition of 370 MW/m^3 (time average) the following numbers were obtained:

– peak centre temperature: 120 °C above coolant inlet,
– peak surface temperature: 35 °C above coolant inlet,
– maximum thermal stress: 33 MPa.

This clearly shows that the operating parameters at 250 kW are very moderate and suggests that the same rotating target concept is suitable also for much higher power (up to 1 MW).

2. The overall concept of a rotating target for CSNS

The concept of the rotating target comprises five subassemblies, see Fig. 1.

Units 1 and 2 and the lower part of unit 3 will be buried in the target shielding and must therefore be designed for long life time, while the upper part of unit 3 and units 4 and 5 will be mounted on the target plug top plate and will be accessible for hands-on maintenance or replacement when the proton beam is shut off.

Since the target will penetrate into the helium atmosphere of the inner shield liner, an enclosure will be provided that provides a tight connection between the target plug top plate and a flange tightly welded to the housing of the rotating joint. In this way the sealing properties are taken advantage of to close the helium atmosphere. This requires, however, that the axle of the rotating joint is accessible at its rear end in order to attach the drive unit outside of the helium atmosphere.

A preliminary list with the individual target parameters is given in Table 1.

3. The target disk

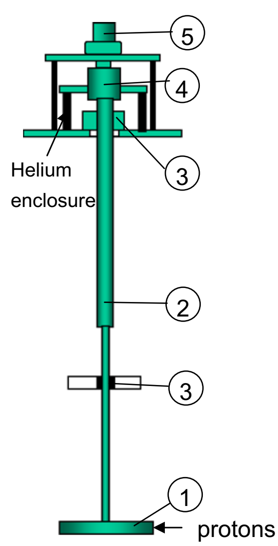
The Target disc is the part where the proton beam interacts with the target material and where the neutrons are generated. In order to produce a bright primary neuron source it should be as compact as possible, i.e. essentially a massive slab of material cooled on its surface only. A good target material for a variety of reasons is tungsten. In Ref. [7] it was shown that the thermal stress inside the target can be minimized by an internal structure which consists of a central disc made of two layers and an outer ring built up from involute shaped segments, as shown schematically in Fig. 2.

The centre disk is made up of two layers of pie-shaped segments with flat surfaces, while the outer ring consists of two layers of 32 involute shaped segments each with grooves on the outer surface as shown in Fig. 3 to guide the coolant flow and to increase the heat transfer surface. The involutes are curved in opposite directions in the top and bottom layer and can be tied together by bolts if necessary to form an essentially massive ring.

There is a risk of corrosion of tungsten in contact with water under proton irradiation. Although these conditions will prevail only at the cylindrical surface of the target disc and only for a small fraction of it (the region where the proton beam hits) at any given

Table 1
CSNS rotating target parameter list.

Parameter		Early operation	Upgrade option
General			
Proton energy	MeV	1600	1600
Beam power	kW	120	500
Power deposited in target	kW	50.00	210
Target			
Outer diameter of cylinder	cm	50.00	50
Full height of cylinder (solid part)	cm	5.00	5
Number of involute shaped segments	per layer	32	32
Involute base radius a	cm	15.30	15.30
Base width of involute segments	cm	3.00	3.00
Width of grooves	cm	0.25	0.25
Width of ribs	cm	0.25	0.25
Depth of grooves	cm	0.50	0.50
Frequency of target revolution	Hz	0.5	0.5
Target shaft			
Total length of outer shaft	m	4	4
Length of upper section	m	1.5	1.5
Upper target shaft outer diameter	cm	14	14
Upper target shaft wall thickness	cm	1	1
Length of lower section	m	2.5	2.5
Lower target shaft outer diameter	cm	10	10
Lower target shaft inner diameter	cm	8	8
Inner tube (double wall) total length	m	4.12	4.12
Inner tube outer diameter	cm	6.5	6.5
Inner tube inner diameter	cm	5	5



(1) the target proper, which has the shape of a flat cylinder (disc) with the proton beam entering through the cylindrical surface,

(2) a long shaft from which the target cylinder is suspended and through which the coolant is fed to and drained from the target,

(3) a support unit which holds the target in its position in the target block,

(4) a rotating joint through which the coolant is transferred from the stationary into the rotating part of the system,

(5) a drive unit which rotates the target at the correct revolution frequency.

Fig. 1. The rotating target assembly and its sub-units.

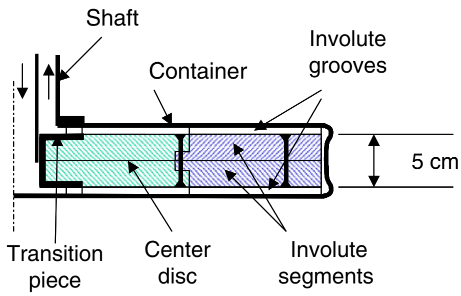


Fig. 2. Concept of a target disc.

Fig. 3. Involute shaped target ring segment with grooves on the surface.

time, it may be prudent to coat the target segments by some corrosion resistant material such as nickel. Tests to find out a suitable coating and coating procedure must still be carried out.

The array of target segments will be surrounded by a target coolant container of a suitable material. Since there exists very good experience with the AlMg3-alloy as target container material at SINQ (PSI, Switzerland) this is the preferred container material. It has survived an integrated proton fluence of 4.5×10^{25} p/m^2 without problems. Scaling to a beam power of 500 kW at 1.6 GeV and a 2D-parabolic intensity distribution with $2a_y = 32$ mm ($2a_x = 100$ mm) this corresponds to a service life for a 0.5 m diameter rotating target of 30 years at 5000 full power hours per year.

Fig. 4 shows a conceptual solution for the CSNS rotating target disk. The question whether or not such a solution is desirable for the final target depends on the outcome of the studies on thermal-hydraulics, structural mechanics and temperature evolution in the loss-of-coolant case, which have yet to be carried out.

For the mock-up test at the moment, only the dummy target disk with the right diameter and weight is being used.

4. The suspension shaft

As shown in Fig. 1, the target will be connected to the parts located outside the bulk shielding by a ca 4 m long shaft which must be designed to carry the target load, to provide for stable and vibration free rotation, to secure leakage-free feed of coolant into and out of the target, to avoid thermal short circuiting between the cool forward and the warm return flow and avoid neutron streaming through gaps to minimize activation in the target head area.

In order to fulfil this goal a system of three concentric tubes has been conceived, the distances between which are kept by spacers and which have a change in diameter at about half of the total length to meet last of the above conditions.

The outer one of the three tubes will be the load-carrying one and will be connected to the target thrust bearing. The two inner tubes are actually one double wall tube to separate the forward flow on its outside from the return flow on the inside. The double wall structure is chosen to minimize thermal short circuiting by a gas gap between the two tubes. The volume between the two tubes is closed at the top to conceal the gas, but is open at the bottom to allow unequal thermal expansion (the inner tube will be subject to temperature changes of the coolant as the beam is switched on or off, while the outer tube will remain at the relatively constant temperature of the coolant forward flow). As indicated in Fig. 5, the inner tube will end in the transition piece with a relatively tight fit but without firm connection. This may cause a minimal leakage between the forward and return coolant flow, but is of no concern.

The outer tube will have flanges welded to its top and bottom end, which must be precisely aligned to ensure smooth and deflection-free running of the target disk. The flange at the top end must be sized such that it can fit through an opening in the target top plate to ease the assembly of the whole target plug unit.

Since it is foreseen to have a radial guiding bearing in the lower part of the shaft, the upper and lower sections of the shaft must be precisely aligned. Fig. 5 shows the detailed design of the suspension shaft.

5. The target support unit

The target support unit is located outside the target shielding and connects the rotating shaft and target disk to the stationary top plate of the target plug. It has four important functions: (1) provide axial plus radial support for the target shaft, (2) support the target during an eventual change-out of the bearing, (3) allow precise adjustment of the axial position (height) of the target rela-

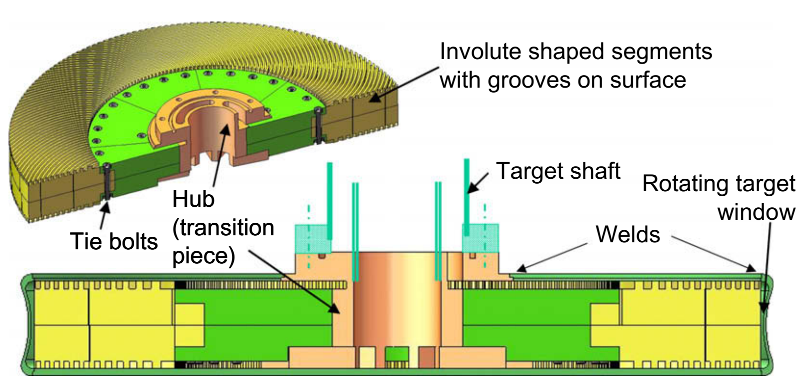


Fig. 4. A conceptual solution for the CSNS rotating target disk.

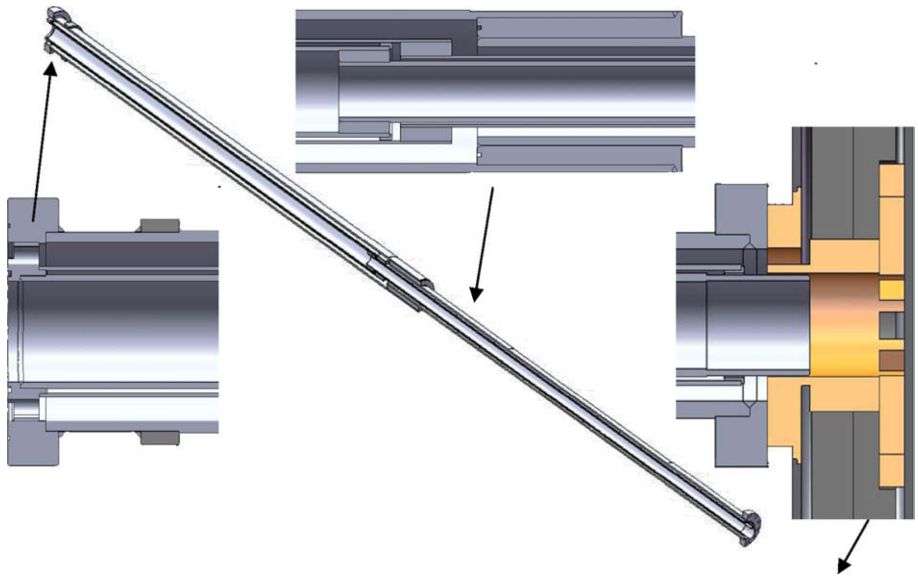


Fig. 5. The detailed design of the suspension shaft.

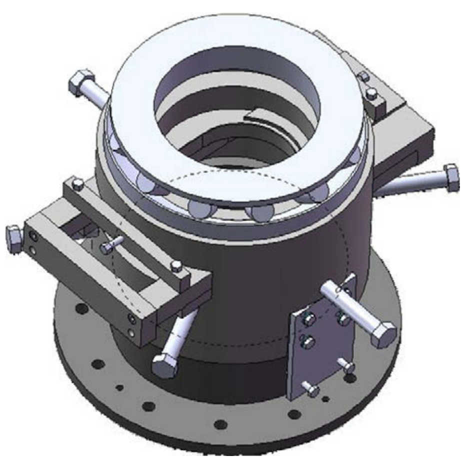


Fig. 6. A sketch of the arrangement of the target support unit.

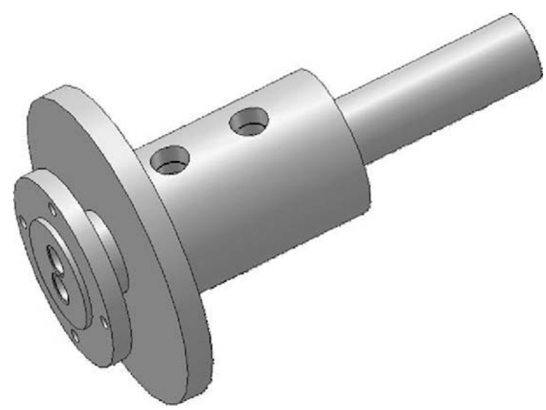


Fig. 7. The rotating joint unit.

tive to its surroundings, and (4) capture of leakage water from the rotating joint above. A sketch of the arrangement is shown in Fig. 6.

6. Rotating joint and connection to target shaft

The overall concept chosen requires a rotating joint to deed and drain the coolant to and from the rotating parts whose axle is accessible at its rear end to attach the drive unit. This is usually not the case for standard rotating joints which provide coaxial ducts for the water inlet and outlet in their rotating part. However, several manufacturers offer rotating unions with multiple passages which have the property of an accessible rear end of their axis. Attractive features of this model are: the bore in the axis, which facilitates attachment of the drive unit at the rear end, and three double seals with drain bores in between.

In order to make this model useable for our purpose, we developed the rotating joint with one of domestic manufacturer based on the commercial rotating joint product concept. The following modifications have been made: Add a flange to the housing that allows a tight connection to the end and move the drain port to the "bottom" (with respect to orientation in which it will be used). The final product is shown in Fig. 7.

7. Target drive unit

The target will be driven by a commercial electromotor of variable speed with a suitable reduction gear to be able to vary the speed between 0.5 and 5 Hz, see Fig. 8. Once the optimum speed has been determined with respect to minimal thermal cycling in the target, a narrower range may be acceptable.

The shaft of the gear will be connected to the axle of the rotating joint by a flexible connection and the gear housing will be rigidly mounted on a support connecting to the target top plate outside the helium enclosure. If the bearings of the rotating joint are not protected otherwise, a cover plate should be added to prevent dirt or debris from falling in, since the drive unit and rotating joint will be in the air atmosphere of the target head room.

8. Integration into the target plug

Integration of the rotating target into the target plug and overall shielding has, so far been dealt with only in a cursory manner. The basic idea is to surround the shaft by a divided shielding plug, which holds a lower radial bearing. This bearing will probably consist of two graphite shells mounted high enough in the shield block to prevent irradiation induced swelling, see Fig. 9.

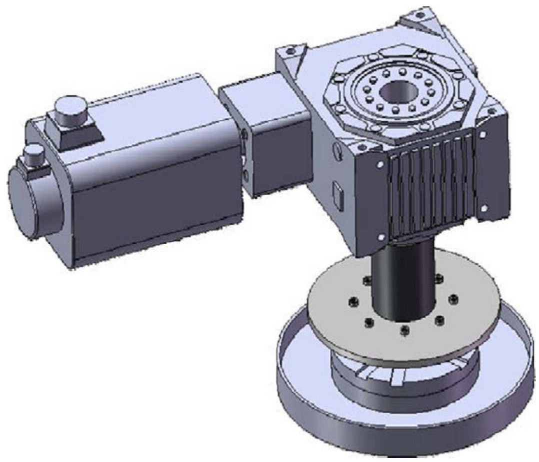


Fig. 8. Target drive unit.

The two halves of the shield plug will be bolted together with the target in place and will be rigidly connected to the target top plate in the final assembly of the target plug.

The inner shield plug will be surrounded by the cooled part of the target shield and the reflector at the bottom and by stacked shielding plates on the sides. Putting these stacked plates in place inside the target plug liner without the top plate mounted will require some auxiliary equipment to hold the target in position.

9. A mock-up test stand

In order to test the validity of the above concepts and to gain first experience with a rotating target the CSNS project has decided to embark on the construction of a mock-up test stand. The purpose is to provide first demonstration of the viability of the above concept by using a full model of the target head components and shaft and a dummy target with the right diameter and weight (angular inertia), to confirm that acceptance criteria can be reached, to gain experience in running a rotating target and to verify certain parameters obtained by calculations.

It is planned to proceed in three steps (phases):

(1) Run the test stand with a dummy target to show functionality of the various subunits, optimize position of the lower bearing and demonstrate that acceptance criteria can be reached.
(2) Use a full scale model of the target to verify its hydraulic properties. This model can either be a Plexiglas "showpiece" or an aluminium model built to demonstrate assembly techniques prior to building the real target.
(3) Test the concept of a split inner shield plug attached to the target plug top plate and guiding the target shaft.
(4) Test run the real target after manufacturing.

In order to be able to vary the position of the lower radial bearing, the height of the plate on which it is mounted should be variable. In order to ease target insertion one stabilization bar should be removable and support plate for the lower bearing should be split.

In order to save time and cost a dummy target will be used in the first phase of testing. This will be a cylinder of the same diameter and weight as the real target in which the water flow will be short circuited by a throttle valve (Fig. 10) in order to be able to adjust the pressure drop to the value determined for the real target. This will allow more realistic testing.

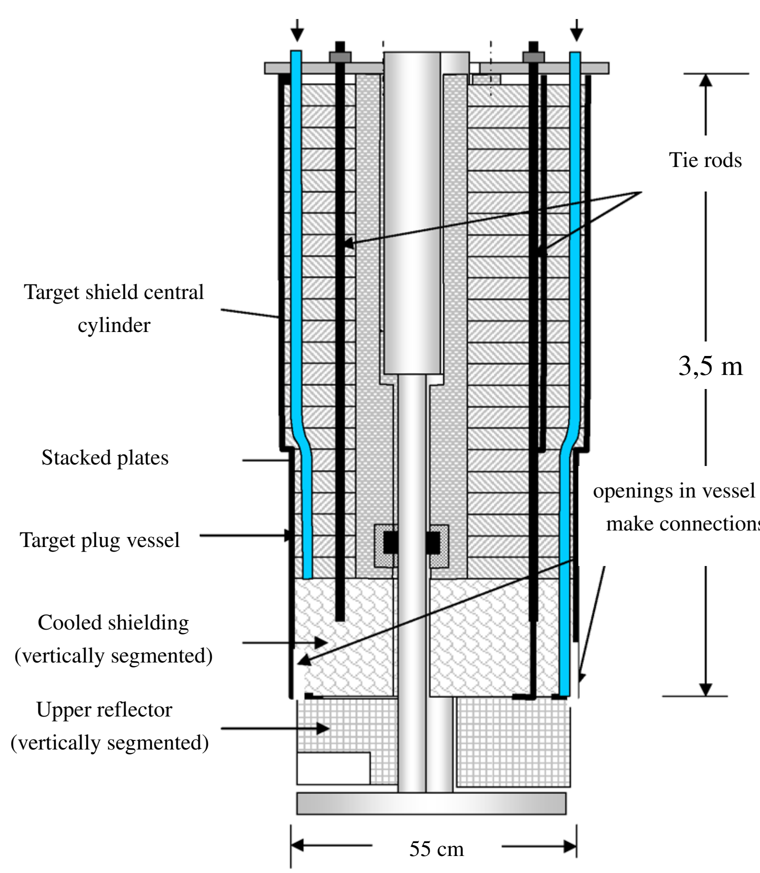


Fig. 9. Sketch of the inner shield plug surrounding the target.

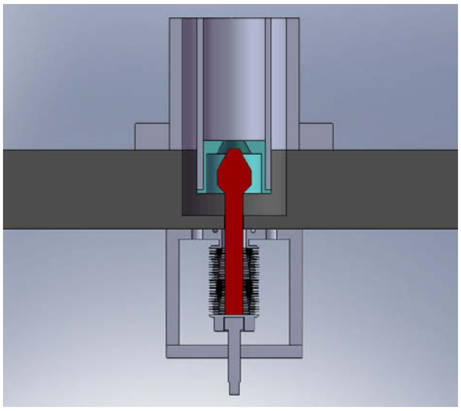


Fig. 10. Concept of a throttle valve to adjust the pressure drop in the dummy target.

Acceptance criteria for the first phase of the mock-up experiment were set as shown in Fig. 11.

10. Present status

Since May, 2008, we have established a *conceptual design* of the target systems based on the above considerations by eliminating existing ambiguities in the transition region and the target head region. Thermal-hydraulics and structural mechanics calculation has been carried out to verify, correct or complete assumed data in the parameter list, in particular pressure drop, heat transfer and thermal and stress data. On June, we developed a *detailed design* of the target disk, the target shaft and the target head region (support, height adjustment, coolant supply, and drive) and verified availability of foreseen commercial parts and feasibility of parts to be manufactured, and finalized the design of the mock-up test stand and cooling loop. By July, a cost estimate has been established for the mock-up test stand and target test unit including the cooling loop, funding was secured and the orders were placed. On November, we have completed the assembly of mock-up test stand with dummy target, the mock-up test stand are now in commis-

Fig. 12. The rotating target assembly and its sub-units.

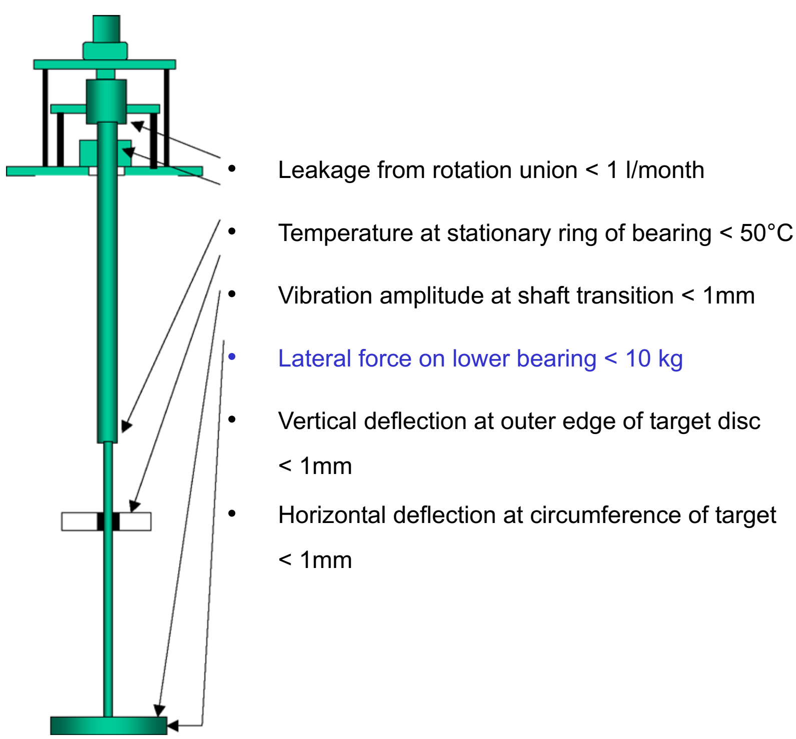


Fig. 11. Preliminary acceptance criteria set for the first phase of the mock-up experiment.

sioning stage, See Fig. 12. And hopefully the first reportable results with test stand will be obtained in earlier January of 2009.

11. Conclusion

In early May 2008 the CSNS project has decided to embark on the construction of a mock-up test stand to demonstrate the viability of the rotating target concept. Until now, the work is on good progress and hopefully the first reportable results with test stand will be obtained in earlier January of 2009.

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