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# Design and Testing of a Prototype Spallation Neutron Source Rotating Target Assembly

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## ABSTRACT

*The mechanical aspects of an extended vertical shaft rotating target have been evaluated in a full-scale mockup test. A prototype assembly based on a conceptual target design for a 1 to 3-MW spallation facility was built and tested. Key elements of the drive/coupling assembly implemented in the prototype include high integrity dynamic face seals, commercially available bearings, realistic manufacturing tolerances, effective monitoring and controls, and fail-safe shutdown features. A representative target disk suspended on a 3.5 meter prototypical shaft was coupled with the drive to complete the mechanical tests.*

*After1800 hours of operation the test program has confirmed the overall mechanical feasibility of the extended vertical shaft rotating target concept. Precision alignment of the suspended target disk; successful containment of the water and verification of operational stability over the full speed range of 30 to 60 rpm were primary indications the proposed mechanical design is valid for use in a high power target station.*

## 1. Rotating Target Mock-up Test Arrangement

Rotating targets are potentially capable of absorbing the high energy of future, long-pulse spallation sources for periods of several years. Significantly reduced radiation damage, and low operating temperatures and stresses in the target material are the primary benefits achieved by distributing the beam energy uniformly over a large moving disk. Corresponding improvements in reliability, reduced maintenance and operating costs are expected to result in excellent target system availability.

This paper describes the fabrication and testing of a full-scale, mechanically prototypical mock-up of a proposed 1.5 to 3.0 MW [1] rotating target in a collaborative effort between Oak Ridge National Laboratory (ORNL) and ESS-Bi. Target facility layout issues, design analysis and neutronic considerations of the proposed target are discussed in companion papers [2] and [3]; therefore, only a summary of a complete target system is provided here.

The target disk is based on a water-cooled, tantalum-clad tungsten block target layout. This choice primarily derives from the successful application of these materials in fixed solid targets at ISIS [4]. The target blocks are contained in a stainless steel housing measuring approximately 1.2 meters in diameter, 8 cm high and weighing 1500 to 2000 kg. Water cooling of the clad blocks and shroud is routed through the target hub. The primary life limiting factor is proton beam induced radiation damage to the shroud face. Assuming a relatively flat beam profile the target disk assembly will have an operating life of up to 10 years.

Given the long expected life for the target, the use of commercial components and proven target maintenance techniques has been proposed [2]. Key to the design is the low, 30 to 60 rpm, rotational speed of the target [1]. This rate avoids overlapping of successive pulses at 20 Hz and gives uniform material damage on the window and distributes the heating. It also results in minimal loading and wear of the mechanical components such as bearings and seals. The low speed benefit is extended by steady-state operation that further limits wear on these components. In addition, cooling water temperatures of 30 to 60 C combined with pressures between 0.3 to 0.6 MPa are ideally suited to commercially available bearing, lubricant and sealing components. In order to reduce radiation damage to the drive components, the target disk is suspended on an extended axle approximately 3.5 meters above the disk. This is similar to the configuration proposed in [5]. This arrangement, made possible by the low rotational velocity and large diameter axle, limits the radiation exposure of the drive system to the estimated background of 2 Gy/hr emitted by the returning target cooling water.

The proposed target arrangement effectively divides into two modules; the target disk and axle, and the drive subassembly which includes all the active mechanical and electrical components. The two modules are coupled with a static joint located outside the target vessel where it can be accessed for hands-on make-up. This arrangement allows for the independent change-out and maintenance of the individual drive components without removal of the activated target module.

### *1.1. Mock-up Target Test Goals*

While the proposed configuration conforms to the life and reliability goals of a rotating target, several fabrication and operating aspects of the design required validation in a full-scale mock-up. The primary objectives of the test program were:

1. Demonstrate leak-free containment of the cooling water with practical and reliable rotating seals.
2. Achieve acceptable alignment and stability of the target disk using commercially available components and industry-standard machining techniques and tools without the use of a bearing in the high radiation area.
3. Demonstrate a modular drive design compatible with accepted maintenance procedures in a spallation target station.
4. Validate individual drive module components.

### *1.2. Prototype Drive Module*

The mock-up drive module duplicates the key features of the proposed target system drive (Figure 1). It combines the three active subassemblies (drive, rotary water coupling and shaft support bearings) in one modular assembly. This arrangement allows independent, hands-on exchange and maintenance while the unitized structural support frame provides the necessary stiffness.

The prototype rotary coupling is identical to the subassembly currently proposed for the target. The dynamic seals are commercially available stellite-on-graphite, bellows sealed assemblies designed for high integrity systems. A prototypic clearance seal, with an expected leak rate of less than 2% of the total flow, separates the feed and discharge water channels in the gap between the rotary coupling housing and the axle. A conventional three horsepower variable speed motor with a 28:1 reducer is used to drive the mock-up target. The drive is set with a 50 sec, linearly ramped acceleration to full speed to reduce the start-up load on the motor.

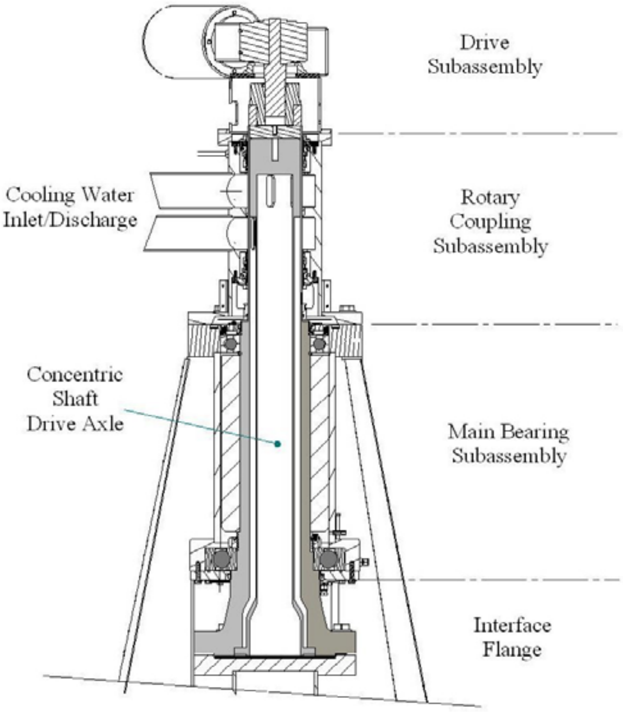

**Figure 1. Section view of proposed rotating target drive module [1].**

### *1.3 Prototype Target Module*

The mock-up target module is composed of two concentric stainless steel 4m long prototypic shafts and a 1.2m diameter carbon steel dummy disk with prototypic mass and inertia properties. Four openings at the lower part of the inner shaft conduct the water from the inner to the outer channel. A bolted clamp joins the disk to the shafts to enable replacement with another disk incorporating more features of a proposed target.

Precision manufacturing of the long hollow shafts is one of the key elements required for disk alignment and stability. The process for the main shaft started from an ingot that was forged and pre-turned to pre-form the shaft in an initial step and then went through a two-stage deep drilling, final external turning, hard-chromium treatment of the vessel seal area and drilling of flange and mounting holes. The inner shaft was formed by deep drilling and turning of a stainless steel rod. In both cases the external turning was performed in steps to allow for relaxation of the deformations induced by the machining process. Figure 2 shows the target module after fabrication and assembly.

The balancing was carried out in various steps: the shafts and the disk were balanced independently, additional measurements were taken with the hub sub-assembly coupled to them, and final balancing was performed with the complete target module assembled. Both static and dynamic unbalances were measured, and all measurements showed unbalances well below specifications. Tolerances on the interface with the drive module were also within specifications, which were stated at 0.025 mm for the perpendicularity of the interface flange with respect to the assembly rotating axis. A 0.1 mm runout was measured on the disk, which is considered representative of what can be reasonably achieved.

**Figure 2. Laser tracker measurements on target module assembly performed to double check the validity of clock gauges measurements on horizontal setup.**

## 2. Testing

The proposed extended shaft rotating target configuration was tested in two phases. First, ORNL constructed and tested a full-scale prototype drive unit to verify the basic drive module concept. The successful completion of this initial test was then followed by a series of tests in which the drive module was combined with a target module constructed by ESS-Bilbao.

### *2.1 Initial drive module tests*

The prototypical drive module test installation is shown in Figure 3. A spring-loaded tensioning device was used to apply a force equivalent to the weight of the target module. A small flow of water was routed through the primary water coupling to remove heat generated by the rotary face seals. The water was not temperature controlled; consequently, changes in ambient conditions and seal friction factor prominently in the data. An immediate calibration of the final alignment of the assembly was indicated by a total-indicated-runout (TIR) of 0.05 mm at the target interface flange.

During the initial 1049 hour test, water at 0.35 to 0.45 MPa was circulated at approximately 0.3 l/s through the rotary coupling. This both wetted the seals and controlled friction heating. Temperatures for all the components varied about 10 degrees through the run due to changes in seal friction and the ambient air temperature. No water leaks were detected during the testing period.

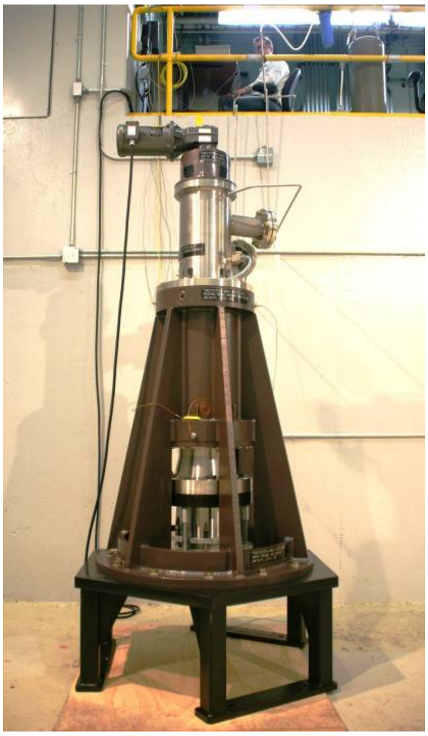

**Figure 3. Full-scale rotating target drive module.**

### *2.2 Full assembly tests*

Figure 4 shows the complete full-scale rotating target mock up facility. The deck of the structural frame represents the top of a target vessel in the proposed extended shaft configuration. The drive module prototype used in the initial drive tests was mounted to this deck, and the target module was mounted to the drive module. A prototypical, non-contact guide with 5 mm of clearance to prevent a run-away up-set of the target is located under the disk. Controls and a low-flow water system adapted and improved from the drive module test were reused in this assembly. As with the drive test, the water temperature was not actively controlled; therefore, ambient conditions and seal friction are easily identified in the measured data.

Successful coupling of the drive and target modules during the initial mock-up installation (see Figure 5) demonstrated the planned maintenance handling scheme. This operation began with the placement of the target module as it would be positioned in a monolith. The drive module was then lowered onto the target module to complete the assembly with the coupling of the mating flanges. Achieving an adequate target disk positioning tolerance (<0.5 cm, total runout at the outer rim) was a primary goal of the full scale mock-up. The system was operated through the planned operating range of 30 to 60 rpm with dial indicating gages located at two locations 90 degrees with respect to each other to measure runout at the perimeter of the disk. The average runout measurements from the two indicators after initial assembly and after a period of mechanical settling are shown in Figure 6. The results are significantly better than the design requirement. A small natural response at around 34 rpm seen with the displacement sensors was also sensed by the vibration monitor mounted on the drive frame. The resulting increase in runout remains well within the acceptable target disk alignment criteria.

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Figure 4. Full-scale, prototypical rotating target mockup assembly.

Figure 5. Installation of the rotating target drive module on the in-place target module.

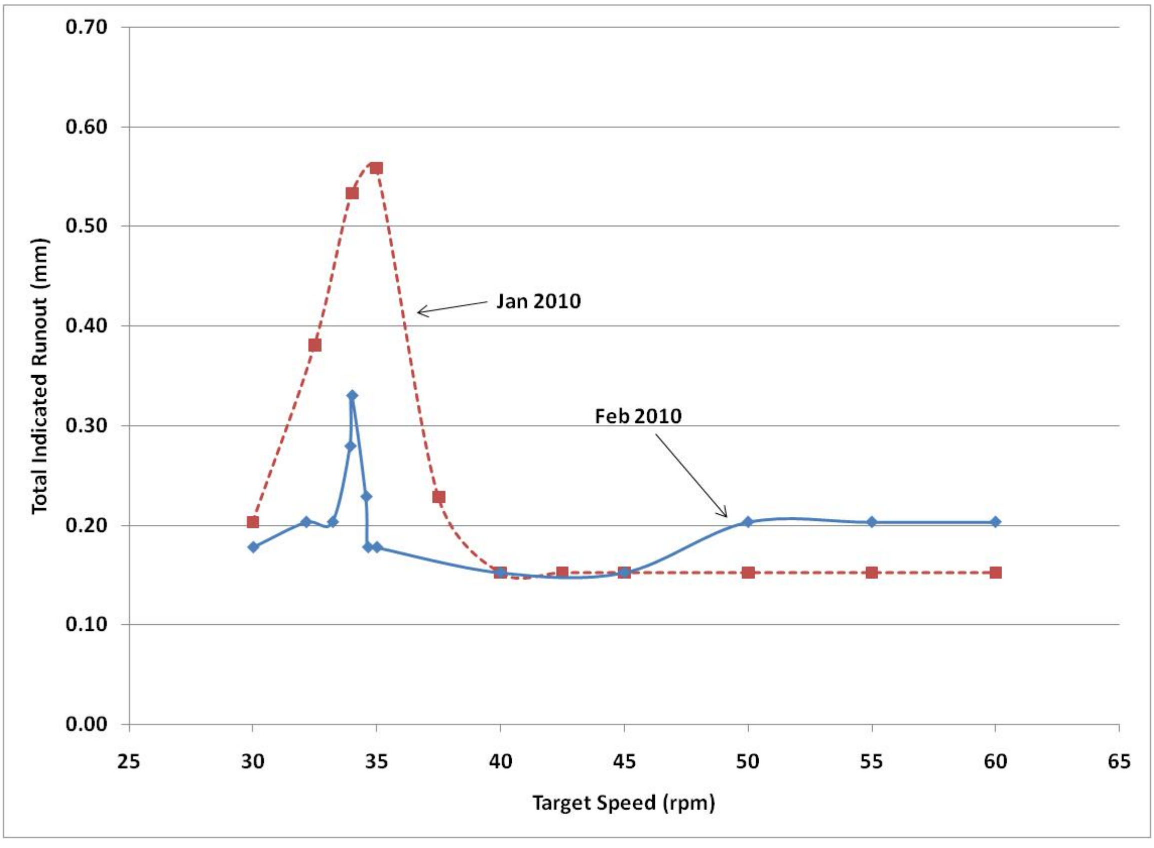

Figure 6. Target disk perimeter total indicated runout.

Performance of the over-running between the drive and axle clutch was also checked prior to unattended operation by simulating a power outage. Complete stoppage of the motor was visually confirmed to verify that the motor was not back-driving. From a running speed of 50 rpm the target coasted to a stop in 26 seconds.

Vibration of the target was measured at various rotational speeds. Results are shown in Figure 7. While an in-depth frequency analysis on these measurements was not performed, a definite change in vibration frequency during can be seen in Figure 7 which occurred while rotating at speed of approximately 35 rpm. This correlates to the peak in runout measurements shown in Figure 6.

Temperature data accumulated over a period of 10 days during which the mockup was operated from 30 to 55 rpm is shown in Figure 8. In general, the temperature of the bearings and seals are very similar to those experienced during the initial drive tests. More uniform lower seal temperatures can be accounted for by a routing of the water flow to impinge directly on the seal rather than relying on convective flow as was the case with the drive test arrangement. Bearing and seal temperatures generally tracked the ambient temperature well and were not dependent on the rotational speed.

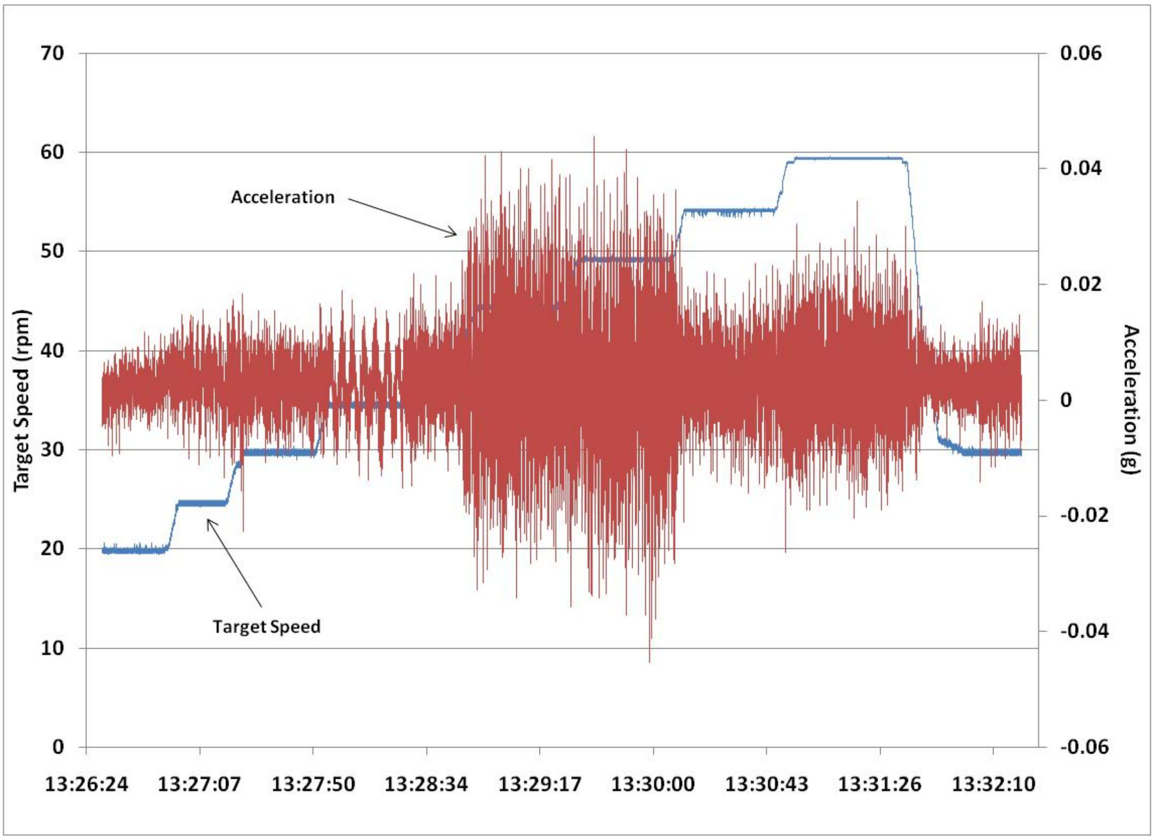

**Figure 7. Target vibration measured at various speeds.**

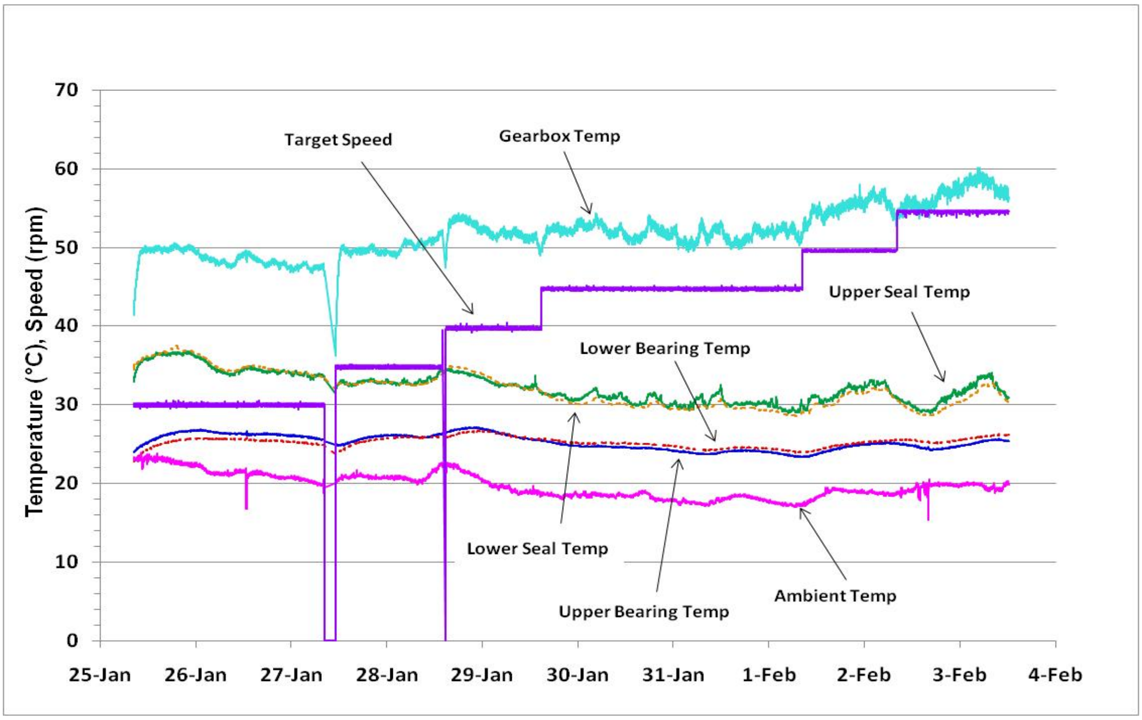

**Figure 8. Full scale rotating target temperature data.**

## 3. Conclusion

Full-scale, prototypical tests demonstrated the feasibility of the proposed 1.5 to 3.0 MW long-pulse extended-shaft rotating target design. To date the program has completed over 2600 hours of run-time. Long term operational testing of the full scale mockup is expected to continue during 2010 to further test the reliability of the system. Design refinements identified during the fabrication and test program are expected to further improve the performance of the system.

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## 4. References

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