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TOWARDS THE LAST STAGES OF THE CERN'S AD-TARGET AREA CONSOLIDATION PROJECT AND RECOMMISSIONING PLANS TO RESUME OPERATION

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Abstract

Antiprotons are produced at CERN at the Antiproton Decelerator (AD) Target Area by impacting 26 GeV/c proton beams from the CERN Proton Synchrotron (PS) onto a fixed target. Further collection, momentum selection, and transport of the secondary particles - including antiprotons - towards the AD ring is realised by a 400 kA pulsed magnetic horn and a set of magnetic dipoles and quadrupoles. A major consolidation of the $\bar{p}$ production area - in operation since the 80 s - has taken place during the CERN Long Shutdown 2 (2019-2021). Among other activities, such upgrade included: (i) Installation of a new air-cooled target design and manufacturing of a new set of magnetic horns, including a surface pulsing test-bench for system validation and fine-tuning (ii) Installation of a new positioning and maintenance system for the target and horn (iii) Refurbishment and decontamination of the Target Area and its equipment, (iv) Construction of a new surface service building to house new nuclear ventilation systems. This contribution presents an overview of such activities and lesson learnt. In addition, it provides the latest results from refractory metals R&D for the antiproton target and a summary of the recommissioning and optimization plans.

INTRODUCTION

The CERN AD-Target Area consists of an underground hall to house the equipment necessary for supplying antiprotons to the Antiproton Decelerator facility [1].

A major upgrade has taken place during 2019-2021 to guarantee the supply of antiprotons to the future physics programs and the operation of the recently built ELENA ring (Exta Low ENergy Antiproton) [2]. This upgrade involved four major activities which are described in present contribution. In addition, a summary of the re-commissioning plans scheduled within April-August 2021 before resuming physics operation is provided.

Figure 1 shows an overview of the distribution of the consolidation activities within the AD-Target Area (underground), as well as withing three surface buildings*: b. 232, where a mock-up of the new positing trolleys has been installed; b. 195, where new powering cubicles and a magnetic horn test bench has been installed; b.196, which has been built from scratch to house new ventilation and service systems after demolition of the previous building.

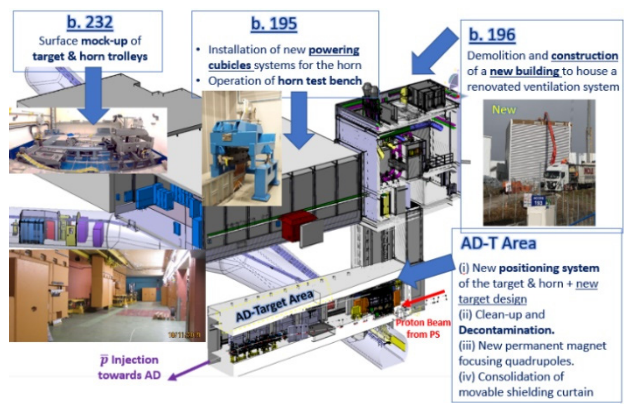

Figure 1: Scheme of the AD-Target area and related surface buildings involved in the consolidation activities.

NEW ANTIPROTON TARGET DESIGN AND MAGENETIC HORN TESTING

During resumed operation, the AD-Target is impacted by $1.5{\cdot}10^{13}$ protons with a spot size about 0.5x0.5 mm^2 at 1σ every 60 - 90 s (depending on the operation mode), which are extracted at 26 GeV/c from the PS [3]. This impact is synchronized with a current pulse of 400 kA and 60 μs duration in the focusing horn (placed a few tens of centimetres downstream the target), which creates a >10 T magnetic field that focus the secondary charged particles - including antiprotons - produced in the target and centred around 3.5 GeV/c momentum [4]. Some of the beam parameters have been slightly modified with respect the pre-LS2 operation. In particular, the beam spot size on the target, which previously was about 1x0.5 mm^2 at 1σ, and it is now defined by a set of new rad-hard SmCo permanent quadrupoles installed upstream the target.

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*Buildings are identified by "b." plus a number.

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The New Antiproton Target Design

The new AD-Target is currently the only antiproton production target in operation in the world. Its new design consists in a double-walled Ti-6Al-4V assembly, in which a pressurized air-cooling system is integrated [5]. This is a significant change with respect the old design, which was water-cooled because of the SP$\bar{P}$S operation and high repetition rate [6]. Inside this assembly, a 15 mm diameter graphitic matrix contains the target cores, made of high-density materials, such as iridium and/or tantalum. The goal of the new design is to improve the current yield of $2.2{\cdot}10^{-5}$ $\bar{p}$/p estimated at the AD injection by Monte Carlo simulations. The new target core material selection and geometry is a result of extensive R&D activities during the last years to study in detail its extreme thermo-mechanical dynamic response every time is impacted by the primary proton beam, leading to a temperature rise in the order of 2000 °C and subsequent pressure waves above the material limits. These activities included the use of hydrocodes to compute this response [7] and the execution of dedicated experiments using the 440 GeV/c proton beams at the CERN's HiRadMat facility [8], such as HRMT-27 (2015) [9], HRMT-42 (2017) [10] and HRMT-48 (2018). These activities concluded in 2020 with the post irradiation examination of the HRMT-48 PROTAD targets, which were six real-size prototypes of the new air-cooled design, containing different geometry configurations of Ir, Ta and W-alloys cores [5, 11].

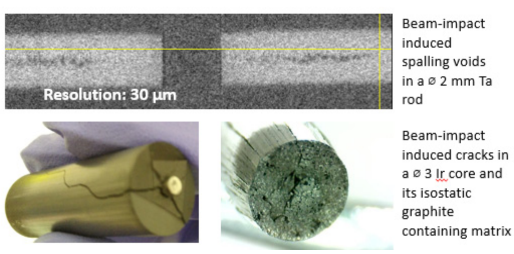

Figure 2: Images of a neutron tomography of in-beam tested Ta cores. Pictures of a fractured Ir core and graphite matrix after extraction from the prototypes tested in HRMT-48.

Figure 2 shows some images of neutron tomographies of such prototypes after in-beam testing, as well as pictures of an iridium core after its extraction. This experiment confirmed the appearance of cracks of iridium and spalling voids in tantalum as consequence of the proton beam impacts. In addition, it revealed that the use of expanded graphite as matrix material may lead to thin cores misalignments, while cracks may appear in isostatic graphite matrixes [11].

Based on the results of all the experiments and studies, it has been decided to adopt a conservative approach with regards the antiproton core, consisting in starting the post LS2 operation with a Ir target mirroring the previous design, and to test progressively new core geometrical configurations, keeping the option to come back to the old design based on the observed antiproton production performance. Four targets have been manufactured and closed following this approach, leaving two additional Ti-6Al-4V assemblies as spares to be filled in the future (Fig. 3-a). Three out of the four closed targets are equipped with 6 rods of Ø3 mm by 9 mm made of Ir (54 mm in total as shown in (Fig. 3-b). The fourth target is equipped with 4 rods of Ø10 mm by 8 mm made of Ta in the upstream part, plus four rods of Ø 2 mm by 8 mm made of Ir in the downstream part (64 mm in total). Regarding the matrix material, some of these new operational targets are equipped with CfC composite to improve its mechanical response. Figure 2-c-d shows a 3D model and a picture of a new target integrated in its newly designed robot-handling and instrumented module, which will allow fast targets exchanges during operation. The new pressurized air-cooling system consists in a flow of ~15-20 Nm3/h at ~5 bars in the inlet, keeping the air exhaust temperatures well below 80 ºC even with a 60 s repetition rate [3].

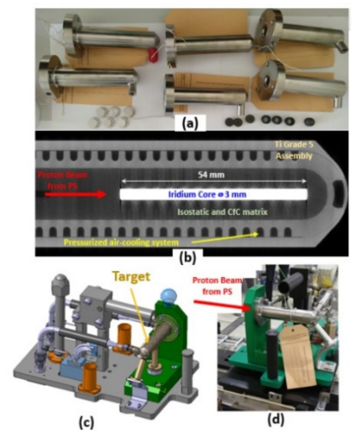

Figure 3: (a) Six manufactured Ti-6Al-4V external assemblies. (b) x-ray image of one of the targets equipped with Ø3 mm Ir cores before its installation. (c) New target integrated in its module.

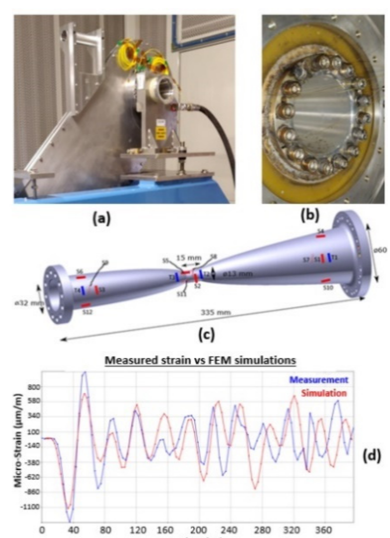

Figure 4: (a) Picture of a new horn in its test bench assembly. (b) Damaged horn during testing. (c) 3D model of the horn with the position of the optical strain gauges. (d) Measured dynamic response and simulation crosscheck.

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New Manufactured and Tested Magnetic Horns

Detailed thermo-mechanical calculations taking into account Joule heating and Lorenz forces were carried out in order to clarify the horn operating conditions and anticipate failures [12]. A new set of four magnetic horn systems and its associated power chain equipment (Junction-Box, Stripline, Clamp) were manufactured and tested in a dedicated test bench (Fig. 4-a). Such new horns keep the same shape as the old ones. The assigned operational lifetime is 5 years. During such tests, some of these spares were subjected up to 2.21·105 electric pulses at 430 kA (required to overcome the operational magnetic rigidity of about 12 Tm), compatible with several years of current AD operations. Specific high acquisition rate optical strain gauges at 250 kHz were glued on the horn (Fig. 4-c), capturing the 15 kHz vibrations induced by each of the intense electric pulses. Figure 4-d shows a preliminary crosscheck of the measurements and simulations, showing the capture of the main longitudinal vibration mode (~60 µs period), predicted by simulations. During these tests one of the horns was seriously dam-aged by electric arcs as shown Fig. 4-c. The reason was bolts untightens due to strong vibrations induced by current pulses. This issue was solved by the addition of Nord-Lock X© washers in the design.

NEW TARGET AND HORN TROLLEYS

The other system subjected to a major upgrade is the target and horn positioning trolleys. These trolleys are essential for providing a proper target and horn positioning as well as for guaranteeing a safe and efficient maintenance of these devices given the high levels of radiation in the area (up to 50 mSv/h residual dose at target's contact and above 1 MGy/year cumulated dose). The new design provides an innovative concept aiming at mitigating previous operational and maintenance issues such as position reliability, presence of lubricants in high radiation areas, and complex accesses for maintenances of some of the highly activated systems.

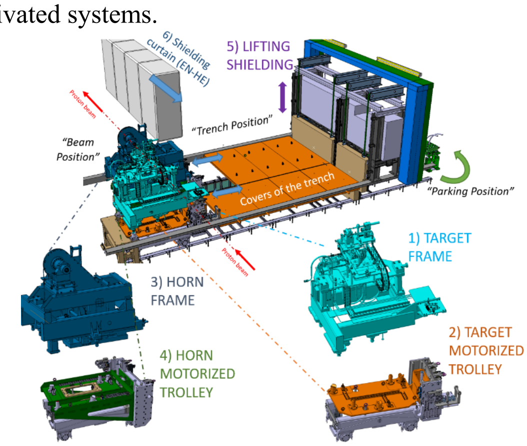

Figure 5: Sketch of the new trolleys system.

In the new concept, shown in Fig. 5, each of the trolleys is divided in two subsystems: (i) A stationary support which stays in the operational area. (ii) A motorized trolley which, only during maintenance, is displaced below the stationary support, lifting it, and bringing it to the maintenance area. During operation, the motorized trolleys (and all the mechatronic systems embarked in them) are parked in an area protected by a shielded shutter made 12 cm of steel and 5 cm of 5% borated polyethylene, keeping the dose of the resulting mixed field below 200 Gy/year [13].

NEW SURFACE BUILDING

The new surface building houses the renovated nuclear ventilation system of the AD-target area, providing its under pressure atmosphere necessary for operation. In addition, it houses and radiation monitoring systems, as well as the new target digital BTV camera.

REFURBISHMENT AND DECONTAMNATION OF THE AREA

The AD-target Area has been emptied, decontaminated, and repainted following ALARA principles. All its magnets and components were removed, tested and re-installed. New permanent magnet focusing quadrupoles have been installed upstream the target as well as a new BTV (beam TV) system with a new optical path up to the surface service building.

CONCLUSIONS AND RECOMMISIONING PLANS

This paper summarizes the works executed during the AD-Target Area consolidation activities. From April to August 2021 recommissioning is planned to take place, divided in four main phases: (I) Integration and geometrical check-out phase, including rigours alignment and mechanical checks and calibrations, as well as target remote exchange rehearsals. (II) Operational check-out phase, including electrical systems checks (horn and magnets) control, interlocks and beam instrumentation as well as water and ventilation systems. (III) Validation with beam phase, including beam position, tuning and steering, as well as a progressive ramp-up of on target intensity while monitoring target instrumentation and antiproton yield measured indirectly by a new BCT installed at the AD injection. (IV) Optimization phase, in which beam on target parameters such as position, size, and focal point, as well as target-horn distance will be optimized to increase the antiproton yield. After this phase, a new "fresh" target with the same Ir core configuration will be installed, being impacted directly with high intensity beams to resume operation. The goal of this exchange is to study the potential antiproton production drop in the early operation due to the unavoidable core fragmentation. An additional target exchange may take place in November 2021, in order to test by the very first time a target equipped with hybrid cores, made of Ø 10 mm of Ta rods at its upstream part and Ø 2 mm Ir at the downstream.

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