RENOVATION OF CERN ANTIPROTON PRODUCTION TARGET AREA AND ASSOCIATED DESIGN, TESTING AND R&D ACTIVITIES

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Abstract

In the CERN Antiproton Decelerator (AD) Target Area antiprotons are produced by the collisions of 26 GeV/c proton beams with a fixed target. Secondary particles -including antiprotons- are then collected by a 400 kA pulsed magnetic horn, momentum selected by a set of magnetic dipoles and quadrupoles and injected into the AD facility. The area has been in operation since the 80s, with most of the equipment dating back to this period. A major upgrade is foreseen during the CERN Long Shutdown 2 (2019-2020) to guarantee the next decades of antiproton physics at CERN.

Among other R&D activities (which includes a new service building, a new ventilation system, new focusing magnets etc.), three main systems are within the scope of this upgrade; (i) a new antiproton target design, pressurized-air-cooled and with a new core configuration based on the results from the HiRadMat27 experiment. (ii) Manufacturing of a set of new magnetic horns and testing them using a dedicated test bench replicating the real horn setup. (iii) Design of new target and horn's trolleys, which are responsible for their positioning as well as providing an efficient long-term maintenance given the residual high radioactivity of the area.

This paper presents an overview of these and other critical activities associated to the renovation of the target area, including status and direction of the new proposed designs.

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 of the area is foreseen to guarantee the supply of antiprotons to the future antiproton physics programs and the operation of the recently built ELENA ring (Exta Low ENergy Antiproton) [2]. This upgrade is planned to take place during the CERN Long Shutdown 2 (2019-2020) and will involve a general refurbishment, including decontamination, re-cabling and replacement of equipment. In addition, most critical components of the area will be subjected to a major upgrade, namely (see Figure 1) (i) antiproton production target [3], (ii) 400 kA pulsed magnetic horn [4] and (iii) target and horn's trolleys.

During current operation, the AD-Target is impacted by $1.5 \cdot 10^{13}$ protons with a spot size of 0.5x1 mm at 1σ every 108 s. This impact is synchronized with an electric pulse of 400 kA and 60 µs duration in the focusing horn (placed a few tens of centimetres downstream the target), which creates a magnetic field that focus the secondary charged particles - including antiprotons - produced in the target and centered around 3.5 GeV/c momentum. The target and horn's trolleys (also shown in the picture of Figure 1) are responsible of supporting these devices and providing them with the necessary movements for alignment, positioning and operation as well as auxiliary systems such as cooling and powering. In addition, the trolleys allow the safe removal of the target and horn in case of failure or maintenance, given the high levels of residual radiation in the area, by displacing them transversely 4-5 m out of the beam trajectory and operational zone.

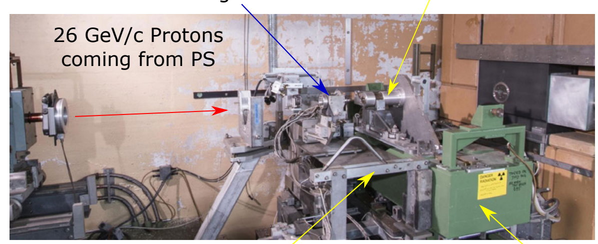

Figure 1: Picture of the current state of critical components in the AD-target area (target, magnetic horn and trolleys) which will be subjected to an upgrade.

NEW ANTIPROTON TARGET DESIGN

Overview of Current Design

The AD-Target is the only antiproton production target currently in operation in the world. Its current design consists of a water-cooled Ti-6Al-4V assembly. Inside this assembly, a 15 mm diameter graphite matrix contains the target core, which consists of a 3 mm diameter, 55 mm length, pure iridium rod. The target is therefore small and compact. This is a major requirement for antiproton production since the amount of material around the target core must be minimized in order to reduce their re-absorption and, at the same time, the target must be as close as possible to a point-like source for maximizing antiprotons collection by the downstream horn. For this reason, a high density core material such as iridium (23.3 g/cm3 density) has to be used as well as a focused primary proton beam.

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These characteristics make the design of the device very challenging due to the high levels of energy density deposited in its core when impacted by the primary proton beam. It has been estimated that during each primary beam impact a temperature rise of 2000 °C per pulse takes place in the core, leading to subsequent pressure waves above the material limits, endangering its structural consistency [5]. The uncertainties of the core material response at these extreme dynamic conditions triggered several R&D activities to try to optimize the new design, since it is believed that the potential fracture of the core leads to a loss of effective density and therefore loss of antiproton production. Some of these activities are described in the next section.

Associated R&D Activities

I Specific computational tools, called hydrocodes, have been used for simulating the extreme dynamic response of target core when subjected to proton beam impacts [6]. The material characterization of pure iridium at high strain rates and temperatures [7] (which was not found in the literature) and implementation of strength models in the hydrocodes have allowed obtaining accurate simulations and learning that a high frequency radial compressive-to-tensile pressure wave is generated after each pulse. These simulations have shown that the target core would experience fragmentation even from the first pulse received and that the containing graphite matrix may be damaged [8].

II A challenging first-of-its-kind experiment called HRMT27 was carried out in 2015 [9, 10]. In this experiment, several rods of high density materials such as Ir, W, W-La, Mo, TZM and Ta were brought to equivalent energy/power density conditions as reached in the AD-Target core by impacting them with 440 GeV protons beams using the HiRadMat facility at CERN [11]. Data of the predicted radial wave was measured and confirmed the accuracy of the hydrocode simulations performed. All of the irradiated target materials except tantalum showed internal cracking from conditions 5-7 times below the present in the AD-Target. Tantalum, on the other hand, apparently survived the AD-Target conditions without presenting internal cracking thanks to its high ductility. It is also for this reason that it has become the baseline core material for the new design.

III Prototyping activities for the AD-Target new design have started. A prototype of the target core and its containing matrix has been built and it is shown in Figure 2-(a). This design consists of several small rods of Ta, embedded in a pre-compressed expanded graphite (EG) matrix, that it is expected to improve its resistance to pressure waves thanks to its high flexibility. This prototype will be irradiated at the HiRadMat facility in May 2017 (HRMT-42 experiment) to study the efficiency of this strategy.

IV A proton irradiation campaign at Brookhaven National Laboratory has been launched to study the radiation-induced damage of iridium and other similar refractory metals (including TZM) in the context of the RaDIATE international collaboration [12]. Expanded graphite has been irradiated as well to study how the material will react to long-term damage.

New Proposed Conceptual Design

The lessons learned during the research activities described have been therefore applied to define a new target design. In this new design, the target core consists of small rods of Ta with different diameters. Larger diameters than the current 3 mm rod are proposed to try reducing the tensile pressures in the core. In addition, the target is proposed to be embedded in a matrix of compressed EG instead of graphite. Water-cooling of the current design is replaced by a serpentine of pressurized air as shown in the CFD simulations presented in Figure 2-(b). Air-cooling significantly reduces the complexity of the target interfaces and avoid problems of water activation and concerns associated to potential water leaks.

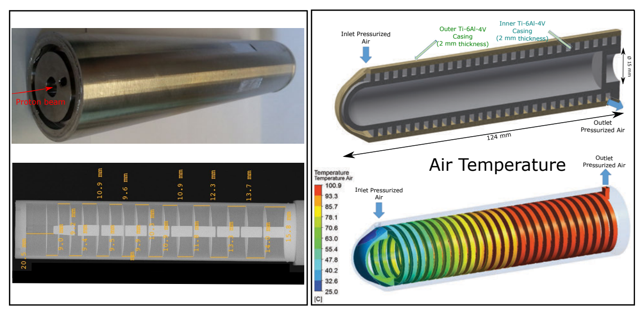

Figure 2: (a) Picture and X-ray image of a scaled prototype of the new AD-Target core configuration. (b) Proposed geometry of the new AD-Target external assembly, cooled by pressurized air instead of water.

MAGNETIC HORN

Concerning the magnetic horn, detailed thermo-mechanical calculations taking into account Joule heating and Lorenz forces have been carried out in order to identify the horn operating conditions [13]. In addition, manufacturing of a new set of magnetic horns is currently being executed. These new horns will keep in principle the current design but optimization with other horn shapes in the near future is foreseen. For this purpose, a dedicated horn test bench is currently under construction at CERN in the AD-target surface building (Figure 3). This test bench replicates the setup of the area (including high voltage junction box, stripline and conductor clamping system) and will become operational in summer 2017. Its objective is long term testing (pulsing until failure of not irradiated horns) the new set of manufactured horns and striplines. The tested horns will be instrumented with strain and temperature optical gauges to crosscheck the simulations

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and study its operational limits. The obtained information will be potentially used for the design and construction of optimized horns in the future.

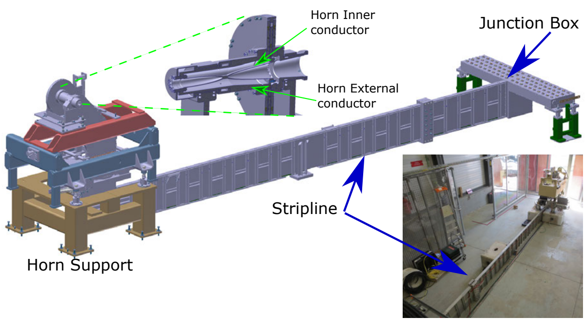

Figure 3: 3D model and picture of the surface horn test bench currently under construction.

TARGET AND HORN TROLLEYS

The other system that will be subjected to a major upgrade is the target and horn trolleys. These trolleys are fundamental for providing a proper target and horn positioning and for guaranteeing 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). In the current design, the trolleys are mounted on rails and can move up to 4 m transversely with respect to the beam for maintenance purposes. The trolleys movements are operated by several lead-screws parallel and close to the rails (below the surface level) which transmit the motion from a motor station placed behind a concrete shielding (Figure 4).

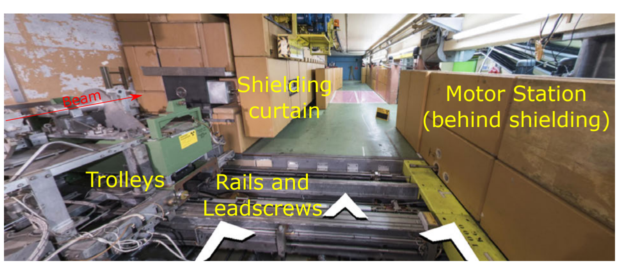

Figure 4: Picture of the current AD-Target area showing the trolleys and their rails, lead-screws, and a motor station.

All the trolleys systems described above will be removed during LS2, and a new conceptual design is being proposed for replacing them. This new design aims at simplifying the setup and making it more robust for future operation. Four main aspects to improve have been identified: (i) Poor repeatability and precision of the current positioning systems. (ii) Issues related to the lead-screws such as induced vibrations, requirement of lubricant in a high radioactive area and complex inspection and maintenance. (iii) Complex inspection and maintenance of some transmission systems, which are currently fixed in the very radioactive area (between the trolleys and the wall). (iv) The amount of radio activated mass for final disposal.

New Proposed Configuration

To solve these issues a new concept of trolleys is presented in Figure 5. In this design, each of the trolleys is divided in two subsystems: (i) A stationary support which stays in the area of operation. (ii) A motorized trolley which, only during maintenance, is displaced below the stationary support, and then would lift it and bring it to the maintenance area. During operation the motorized trolley (and all the transmission systems embarked in it) is parked and protected in a shielded area far from the high radiation emitted from the target.

With this design, the overall precision will be improved as the position of the stationary trolley will be mechanically fixed by V-supports. No lead-screws are present as the motorized trolleys have their own motors (which are always shielded during operation in the parked area). All the transmissions will be vertical and could use passive systems such as gravity in order to be always able to extract the stationary trolley out of the operational area in case of malfunction. Finally, the amount of activated mass is substantially reduced as only the stationary part is resting in the radioactive area during operation.

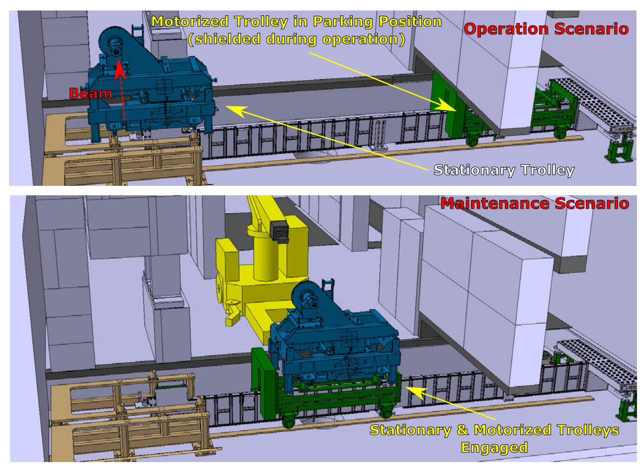

Figure 5: 3D models of the current concept of trolleys, consisting of two independent subsystems, in the operation (up) and maintenance scenarios (down).

CONCLUSION

This paper presented the current status of renovation of the CERN antiproton production target area and associated R&D activities. In particular the new design of antiproton target, testing facility for new manufactured horns, and new concept for the target and horn trolleys. Improvements of the antiproton production yield due to target core optimization and overall increase of the operational robustness of the area are expected with these upgrades.

REFERENCES

[1] S. Maury *et al.*, "The Antiproton Decelerator: AD", *Hyperfine Interact*, vol. 109, no. 1, pp 43–52, Aug. 1997.

[2] V. Chohan *et al.*, "Extra Low ENergy Antiproton (ELENA) ring and its Transfer Lines: Design Report", CERN, Geneva, Switzerland , 2014.

[3] P. Sievers *et al.*, "Some remarks concerning the $\overline{p}-$production target", CERN, Geneva, Switzerland, Rep. SPS-ABT-Tech-Note-78-11, 1978.

[4] D. Boimond *et al.*, "Consolidation of the 400 kA magnetic horn for AAC antiproton production", CERN, Geneva, Switzerland, Rep. CERN-PS-94-02-AR, May 1994.

[5] C. Torregrosa *et al.*, "Designs Characteristics and Main Inherent Concerns of the Antiproton Decelerator Target", CERN, Geneva, Switzerland, Rep. CERN-ACC-NOTE-2015-0004, Jan. 2015.

[6] C. Torregrosa *et al.*, "CERN antiproton target: Hydrocode analysis of its core material dynamic response under proton beam impact", *Phys. Rev. Accel. Beams*, vol. 19, no. 7, p. 073402, Jul. 2016.

[7] M. Scapin *et al.*, "Experimental results and strength model identification of pure iridium", *Int. J. Impact. Eng.*, vol. 106, p. 191-201, Aug. 2017.

[8] C. Torregrosa, "PhD Thesis: Comprehensive Study for an Optimized Redesign of the CERN's Antiproton Decelerator Target", unpublished.

[9] C. Torregrosa *et al.*, "The HiRadMat 27 experiment: exploring high-density materials response at extreme conditions for antiproton production", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, paper THPMY023, pp. 3705–3708.

[10] C. Torregrosa *et al.*, "The HRMT27 (Rodtarg) Experiment: Design, Operation and First Results", CERN, Geneva, Switzerland, Rep. CERN-EN-2016-004, Jul. 2016.

[11] I. Efthymiopoulos *et al.*, "HiRadMat: A new irradiation facility for material testing at CERN", in *Proc. 3th Int. Particle Accelerator Conf. (IPAC'11)*, San Sebastian, Spain, 2011, pp. 1665–1667.

[12] P. Hurh, "The RaDIATE Collaboration - Exploring High Power Target Materials Response to Radiation Damage - Goals, Status, and Future Plans", presented at Proc. 8th Int. Particle Accelerator Conf. (IPAC'17), Copenhagen, Denmark, May 2017, paper WEOCB3, this conference.

[13] E. Lopez *et al.*, "Preliminary AD-Horn Thermomechanical and Electrodynamic Simulations", CERN, Geneva, Switzerland, CERN-ACC-NOTE-2016-0334, Dec. 2016.

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