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CONSTRUCTION AND INSTALLATION OF THE NEW CERN PROTON SYNCHROTRON INTERNAL BEAM DUMPS

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Abstract

In the framework of the CERN Large Hadron Collider Injectors Upgrade (LIU) Project, the Proton Synchrotron (PS) has been equipped with two new movable Internal Dumps (PSID), each of them capable of absorbing particle beams of an energy of up to 100 kJ. These dumps replace the old Internal Dumps, which have been operated in the accelerator complex since their installation in 1975 until their decommissioning and removal from the machine during the second LHC Long Shut down (LS2).

This contribution will address the construction and testing phases of the new PSIDs, including the assembly of the dump core, its actuation system and the respective shielding, mechanical running-in tests, metrology adjustments, Ultra-High Vacuum (UHV) and impedance acceptance tests. The described installation work was completed successfully, and the new generation Dumps are currently operational in the PS machine.

INTRODUCTION

In the framework of the LIU project at CERN [1], two new Internal Dumps (PSID) [2, 3] have been constructed and installed in Straight Sections 47 and 48 of the Proton Synchrotron (PS) to replace the old PSIDs which has been operated since 1975 until their decommissioning by LS2. The old dumps would not have been capable of withstanding the beam intensities following the LIU upgrade and needed replacing. The unique feature of these dumps is that they move into the beam axis whenever required: this feature is needed as the PS ring has no space for the installation of dedicated kicker magnets for an internal beam dump. The dumps are designed to withstand the higher intensity beams after LIU with minimal maintenance over the next 20 years. Prior to their construction, there were several thorough design studies and the construction of a prototype to ensure that the performances would be as intended [2, 3]. The dumps are capable of intercepting proton beams of stored energies up to 100 kJ at an interval of 300 ms, which gives them the means to dump between one extraction and the following beam injection in the PS. This movement shaves the beam turn-by turn until it has been stopped after around 6 ms of first impact.

CONSTRUCTION

This section focuses on the key construction stages of the most essential elements of the PSID, hereunder the Mechanism, the Cooling Shaft and the Dump Core assemblies.

Mechanism

The mechanism is what gives the PS Internal Dump its ability to oscillate and put the dump core into the beam trajectory and back to its original position, all within a single cycle of 300 ms. When a dump is requested, the mobile magnet consisting of stacked sheet metal soles is released form the electromagnet (consisting of sheet metal soles inside an epoxy resin impregnated copper coil), causing the spring-loaded actuation system (Fig. 1) to send the 12 kg dump core into the beam trajectory and return it during the same cycle. The spring system consists of 6 identical cylindrical compression springs, three on the dump core side and 3 on the rear side.

To ensure an even tension from each side of the shaft, several “identical” springs with a theoretical stiffness of 3.5 N/mm were acquired and their stiffnesses were tested at CERN to detect variation. Only the springs with the most similar stiffnesses (±0.05 N/mm) have been selected.

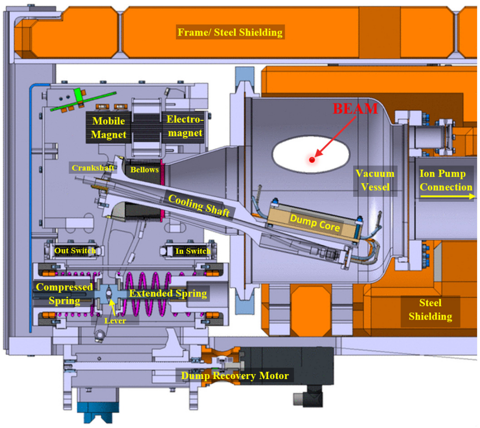

Figure 1: 2-D Section illustration of the dump assembly.

The crank shaft (Fig. 2) is another essential component in the mechanism. It has been machined from a single block of forged 316 L stainless steel and thermally threated for stress release before the final precision milling to achieve the fine tolerances. All dimensions are verified through dimensional control using a CMM machine.

A bearing greasing system, which consists of a greasing nipple at the end of a steel pipe, is accessible from behind the dump’s protective shielding.

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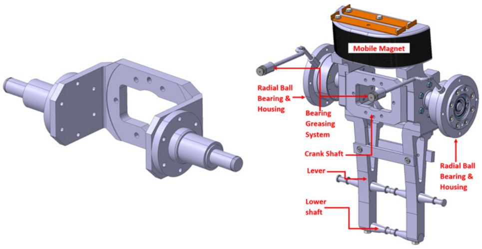

Figure 2: 3D Illustrations of the dump's crank shaft & the lever assembly.

Cooling Shaft Assembly

The Cooling Shaft assembly (Fig. 3) consists of a rigid St. Steel shaft welded onto a flexible bellows of Ø120 x Ø90 mm, and a DN350 flange. This assembly functions as the interface between the external actuation mechanism and the movement of the dump core, which is within the ultrahigh vacuum (UHV) environment. It is fixed to the crank shaft from the bellow side.

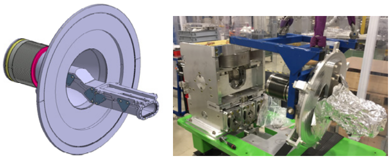

Figure 3: Illustration of cooling shaft & picture of its assembly on the mechanism.

Through the hollow cooling shaft, two flexible water-cooling tubes are connected to the dump core, through the interface of the small elliptical flange. This interface is particularly important as it separates the UHV environment from the atmosphere and the water circuit.

Dump Core

The new dump core (Fig. 4) consists of two main components, namely a block of CuCr1Zr alloy and a graphite block. The graphite block will interact directly with the beam and dilute part of the energy, while the CuCr1Zr absorbs mainly the secondary particle showers. The CuCr1Zr core consists of two blocks that are joined together with a stainless-steel water-cooling tube bonded by means of diffusion bonding via a High Isostatic pressing (HIP)-technique [4] to give the water-cooling pipes the optimal thermal contact. The graphite core is essential because of its extremely high thermal shock resistance: the dump has to withstand sudden temperature rises of up to 1400 °C at the beam impact point of the graphite [2].

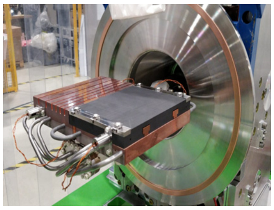

Figure 4: Dump core on the cooling shaft.

In a UHV-clean environment, the graphite core is fixed to the CuCr1Zr core body, creating a thermal interface through a mechanical contact between the two main components. The dump core is then installed on the Cooling Shaft.

TESTING AND QUALITY CONTROL

Angle, Cycle Stroke and Parameter Checks and Adjustments

To ensure that the beam makes only direct impact with the graphite core as this would damage the CuCr1Zr, the dump core is placed at a 1° angle with respect to the beam direction. To ensure the angular cycle movement of -6° to +6° into the beam path and the oscillation period of 300 ms, the pre-loaded spring system and magnet's position is finely tuned. The performance is confirmed using a specially manufactured tool to mark the oscillation stroke and a fast camera to measure the full cycle time (Fig. 5).

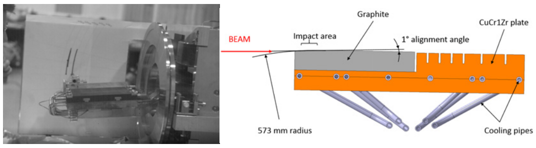

Figure 5: Fast camera photography of the -/+ 6° angular oscillation stoke of the dump and illustration of the dump core's 1° tilt with respect to the beam trajectory.

Next, to ensure the reliability and smooth cycling of the system, the voltage and current parameters for the dump's magnet is finely adjusted.

Vacuum Vessel and Steel Shielding

To close the dump, the vacuum vessel is installed onto the base plate, covering the dump core (Fig. 6).

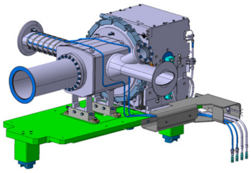

Figure 6: Illustration of the PS Internal Dump actuation system with the vacuum vessel.

The dump is shielded by means of 14 machined steel blocks to reduce residual dose to personnel. This gives the assembly a total mass of about 1600 kg. All shielding blocks are covered with anticorrosion primer and two layers of radiation resistant Polyurethane paint, RAL6018 to avoid corrosion in this highly radioactive environment.

Before the DN350 flanges connecting the mechanism and vessel are closed with a chain clamp, metrology checks are performed on the dump (Fig. 7). During this phase, the vacuum vessel's position is checked by a CMM machine, and the tank is aligned with respect to the theoretical beam trajectory, as well as confirming the 1° angle for the dump core with respect to the beam direction.

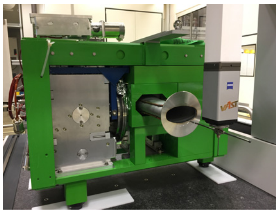

Figure 7: Photo of the steel shielding-covered dump on a CMM machine.

Final Checks and Tests

The PSID vacuum vessel has been designed to minimize its contribution to the PS machine's overall impedance budget [5] and minimize RF heating on its structure. To ensure that the assembly fulfils the required specifications, an impedance test is made after the assembly is completed.

To confirm that the system fulfils the UHV acceptance criteria for the PS machine, the system is tested and accepted within the set thresholds for helium leak rate ($1{\cdot}10^{-10}$ mbar·l·s^{-1}) and total outgassing rate ($1.5{\cdot}10^{-6}$ mbar·l·s^{-1}) in addition to Residual Gas Analysis (RGA) for unbaked systems.

Finally, the Dump is cycled for about 20 000 sequences under vacuum with cooling circuits circulating water to ensure the reliability of the whole system under an environment as close as possible to the real operating conditions.

INSTALLATION & COMMISSIONING

Installation of Dump and Equipment

The Base Support is installed in the PS accelerator, followed by the dump system (Fig. 8). After this phase, the connections to cooling water circuits for the cooling of the Vacuum Vessel and dump core, electrical connections for sensors, switches, electromagnet and dump backup recovery motor are carried out.

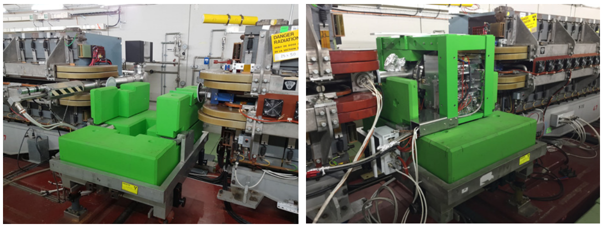

Figure 8: Photos of one of the two Dumps' base supports and the Internal Dump in the PS Ring.

Subsequently, the whole assembly is aligned with respect to the beam axis before an ion pump is installed on the rear side of the vacuum vessel. Next, all connections to the PS are closed and vacuum is made in the dump sector.

Finally, the concrete shielding blocks is installed on the Dumps (Fig. 9), which protects surrounding equipment from radiation during beam runs and minimizes the residual radiation of the walkways of the PS accelerator during technical stops or longer shutdowns.

Figure 9: Photo of the PS Internal Dumps installed with their concrete shielding.

Commissioning

A web interface is developed to monitor values such as temperatures, water flowrate and pressure, amount of dump oscillations and switches statuses of the dump during commissioning.

After confirming that all sensors and switches are operating well, the water-cooling system is commissioned and adjusted to its pre-determined settings. The Interlock systems are tested to confirm that they performed as designed. The interlock systems are connected to the Dump to protect it from potential damage in case of overheated magnet, wrong dump core position or beam intensities that exceed the dump's design specification.

Subsequently, the beam commissioning is launched, starting with lower intensities of around $2 \cdot 10^{10}$ p^+ and gradually increasing up to the maximum design intensity of $2.45 \cdot 10^{13}$ p^+. Currently, all beam tests of intensities of up to intensities of $1.2 \cdot 10^{13}$ p^+ and all temperatures, vacuum levels and systems are functioning as intended, and further tests up to max intensity are expected to follow the same trend.

CONCLUSION

The installation and commissioning of these Dumps conclude five years of engineering, development and production activities involving high precision machining, quality control, sheet metal forming, welding, HIP diffusion bonding, assemblies in UHV clean environments and the dedication of several professionals through multiple disciplines. Some of the challenges that were completed were the successful design and machining of the forged 316 L crank shaft in one single piece, the development and manufacturing of the vacuum vessel, the R&D and studies leading to the successful production of HIP components and the high reliability and low maintenance of the actuation system. To ensure the long-term reliability of the dump, in particular the cooling shaft and bellows, the prototype performed millions of oscillation cycles, which far exceeded the bellow's performance according to its specification.

At the time of writing, all tests have been successful including beam tests of intensities of up to $1.2 \cdot 10^{13}$ p^+, temperature and vacuum levels stability and functionality of cooling system. The project's next steps involve the 2021 commissioning and validation of the Run 3 performances.

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