

# INSTALLATION AND HARDWARE COMMISSIONING OF THE MULTI-TURN EXTRACTION AT THE CERN PROTON SYNCHROTRON

S. S. Gilardoni, D. Allard, M. J. Barnes, O. E. Berrig, A. Beuret, D. Bodart, P. Bourquin, R. Brown, M. Caccioppoli, F. Caspers, J.-M. Cravero, C. De Almeida Martins, C. Dehavay, T. Dobers, M. Dupont, G. Favre, T. Fowler, A. Franchi, M. Giovannozzi, J. Hansen, M. Karppinen, C. Lacroix, E. Mahner, V. Mertens, J.-L. Monteiro, R. Noulibos, E. Page, R. Principe, C. Rossi, L. Sermeus, R. R. Steerenberg, G. Vandoni, G. Villiger, Th. Zickler, CERN, Geneva, Switzerland

## Abstract

The implementation of the new Multi-Turn Extraction (MTE) at the CERN Proton Synchrotron required major hardware changes for the nearly 50-year old accelerator. The installation of new Pulse Forming Networks (PFN) and refurbished kicker magnets for the extraction, new sextupole and octupole magnets, new power converters, together with an in-depth review of the machine aperture leading to the design of new vacuum chambers was required. As a result, a heavy programme of interventions had to be scheduled during the winter shut-down 2007-8. The newly installed hardware and its commissioning is presented and discussed in details.

## INTRODUCTION

Early in 2001, a new scheme was proposed to extract beam from the CERN Proton Synchrotron (PS) [1]. The method consists of splitting the beam in the horizontal plane in stable islands, creating five beamlets and extracting them over five consecutive turns. The capture is realised by crossing the 1/4 horizontal resonance excited by a series of sextupoles and octupoles. Once the beamlet separation is sufficient, the beam is pushed by a slow bump towards the extraction septum blade. Fast kickers then act on five turns to extract each of the beamlets. The commissioning of the new extraction is reported in [3].

An important hardware renovation campaign was done in the PS to implement this new type of extraction. The PS is composed of 100 combined function dipoles (Main Units, MU) interleaved by 100 Straight Sections (SS) in which auxiliary magnets are installed. The control of the linear and non-linear working point is performed by powering four extra coils mounted on top of each MU poles and one supplementary winding of the main coil. The auxiliary magnets used to create extraction bumps or to excite high order resonances are installed in the SS, typically in odd numbered SS where the horizontal betatron function reaches the maximum.

The implementation of MTE [2], described in the following sections, required different interventions: a) design, production and installation of new octupoles; b) construction of new power converters for the new extraction bump; c) enlargement of the extraction region aperture; d) construc-

**Accelerator Technology - Subsystems**

**T12 - Beam Injection/Extraction and Transport**

tion of new extraction kickers and their Pulse Forming Network (PFN). A large fraction of the PS circumference has

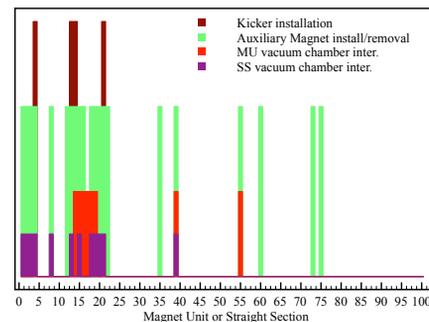


Figure 1: Summary of the hardware interventions related to the MTE installation.

been affected by those interventions, summarized in Fig. 1, and they were done over two consecutive winter shutdown periods, the peak of activities occurring during 2007-2008.

## NEW NON-LINEAR MAGNETS

The creation of stable islands is possible by setting correctly the linear and non-linear chromaticity, i.e. by powering the extra circuits of the main magnets mentioned before plus four sextupoles and two octupoles specific for MTE operation. Whereas the four sextupoles were already existing, three new octupoles, two operative magnets plus one spare, have been constructed and tested. The octupolar gradient difference between the three magnets is well below the 0.3%, as shown in Fig. 2, where also the octupolar gradients versus current are presented. The magnet saturation occurs at about 500 A, whereas the operative currents is below 200 A, depending on the choice of the second order chromaticity. Two octupoles have been installed, one in SS39 and the other SS55, in a tightly packed installation together with two sextupoles, shown in Fig. 3.

## OPTIMISATION OF PS APERTURE

The standard PS vacuum pipe is elliptical with a vertical maximum aperture of 70 mm and horizontal of 140 mm. The mechanical aperture is quite variable around the

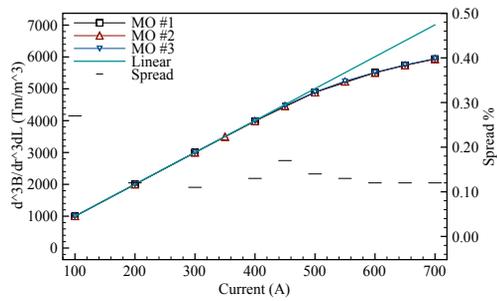


Figure 2: Measured gradient of the three octupoles available for installation.



Figure 3: Picture of the SS39. The two yellow sextupoles are interleaved by the violet octupole.

machine circumference, as presented in Fig. 4 that compares the horizontal aperture before and after the interventions for MTE. The horizontal aperture is enlarged with respect to the standard one in correspondance of: a) the extraction region to the Super Proton Synchrotron (SPS), between SS14 and SS22; b) the ion injection region, between SS25 and SS30; c) the proton injection region, between SS40 and SS45; d) the slow extraction region, between SS57 and SS65. The study of the MTE island trajectories at extraction proved that the existing PS mechanical aperture available in the extraction region was critical, in particular in the horizontal plane in correspondance of the MUs 14,15,16,18,19 and the SS in between. The beamlets are pushed radially at the limit of the aperture at the maximum of the slow extraction bump and are pushed even further during the last five turns. A redesign of the area, with the result shown in Fig. 5 together with the beamlet envelopes, turned out to be necessary during extraction. Whereas for MU 18 and 19 a standard enlarged vacuum chamber could be installed, for the other units new INCONEL chambers have been designed and built as for the SS. Fig. 6 shows the design of the new extraction vacuum chamber of the MU16 compared to the old one. The Y-shaped vacuum chamber hosts the circulating beam and the first part of the extraction line. Other beams produced by the PS could profit by the enlargement of the aperture, in particular on the MU16 where the enlarged part has been prolonged basically up to the half of the MU, before the bifurcation towards the extraction line.

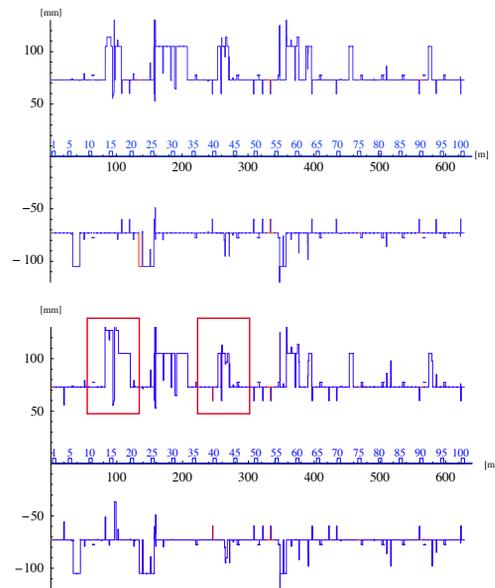


Figure 4: PS horizontal mechanical aperture in 2006, before the MTE installation (top), and in 2008, after the MTE renovation (bottom). The MU number (from 1 to 100) is indicated by the boxes every 5 MUs.

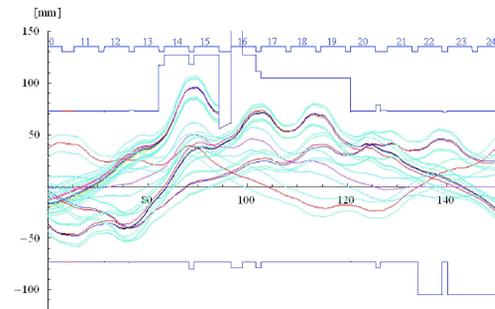


Figure 5: Horizontal PS aperture in the extraction region after the MTE-related work together with the five beamlet envelopes during the first extraction turn. The MU number is indicated on top of the picture. The extraction septum is installed just upstream of MU16.



Figure 6: Old (top) and new (bottom) MU16 extraction vacuum chamber design.

## SLOW BUMP POWER CONVERTERS

Existing PS extractions used four dipole magnets connected in two parallel circuits of two magnets fed by a

unique converter to create a slow extraction bump 15 ms long. The trajectories of the beamlets at extraction require instead 6 bumpers individually powered to optimise the bump shape and maximize the aperture. Existing power converter capacitor banks had been re-arranged and the electronic crate regulation cards have to be adjusted accordingly to generate a shorter 12 ms long pulse. Four new DCCTs had to be ordered on account of the increase of the discharge current. Furthermore the power converter of one of dipoles must allow polarity reversal of its output current. A new system, with thyristors and appropriate electronic control, had to be implemented on this converter and its spare device.

## NEW MTE KICKERS

The extraction of the beamlet is done by firing fast kickers during the last five turns (1 PS turn is  $\approx 2.1 \mu\text{s}$  long at extraction), creating a closed fast bump around the extraction septum SMH16. In total, five kickers (KFA) are used to extract the beam: those located in SS13, SS21 and SS9, deflect the beam constantly for five turns, whereas those in SS4 and SS71 are used in addition to the others to extract the remaining central island during the last turn. The installation layout of the kickers in the ring is shown in Fig. 7, together with the two supplementary fast dipoles, the DFA242 and 243 installed in the PS-SPS transfer line used to correct the extracted beamlet trajectories, as described in [4]. The extracted beamlets, in fact, have different contours and centroids due to the closure of the extraction bumps only for the central core. This in turn generates slice-dependent horizontal oscillations in the transfer line and, if not corrected, they would induce transverse oscillations in the SPS with consequent emittance blow up after lamentation. The optimisation of this correction lead to the displacement of the original DFA243 22 m downstream in the PS-SPS transfer line.

The KFA13, KFA21 and KFA4 have been implemented

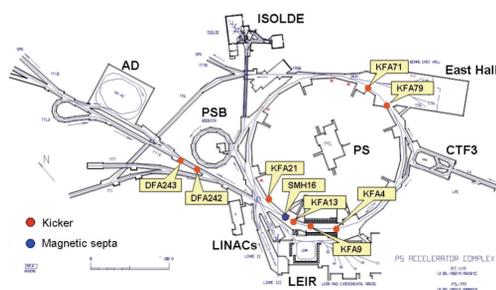


Figure 7: Kickers used for MTE extraction.

by re-using and modifying existing hardware from the lepton operation, no more in use now, and from the old multi-pulsing extraction system. The main modifications consisted in the installation of transition contacts pieces between magnets and their vacuum tank to reduce the impedance seen by the beam. High voltage connection

**Accelerator Technology - Subsystems**

**T12 - Beam Injection/Extraction and Transport**

boxes filled with SF<sub>6</sub>, vacuum feedthroughs and high current contact fingers have also been upgraded to cope with the more severe pulsed power conditions. The 12  $\mu\text{s}$  pulses exciting KFA13 and 21 are generated by new 80 kV pulse forming networks operated in short-circuit mode. The renovation included also new vacuum equipments like new ion pumps, Ti sublimation pumps and gauges. The KFA71-KFA79 system is used for the PS fast extraction, with the KFA79 used for MTE as backup in case of unavailability of KFA71 module(s). KFA9 is an existing magnet, presently used for the continuous transfer scheme, which will be re-used in the MTE scheme. The coil of the original two turn DFA242 magnet has been reduced to one turn to improve magnet rise time. Both DFA magnets are equipped with new connection boxes featuring a series inductor adjusted to have magnet rise time close to 350 ns and are now identical. The parameters of the kickers are summarized in Table 1. The kicker rise time is a fundamental parameter to reduce beam losses at extraction. As the beam is debunched at top energy, during the kicker rise time a fraction of the beam intercepts the extraction septum. The losses related to this process are estimated to about 1-2% of the circulating intensity. These values have been confirmed during the MTE commissioning and, together with measurement directly on the kicker, verifies the expected rise times.

Table 1: Required Kicker Strength and Rise Time Values (10% and 90%). The strengths are computed for a beam rigidity of 46.68 Tm.

Turn	BFA9	KFA13	KFA21	KFA71	KFA4
1	-0.114	1.839	1.887	0	0
2	-0.114	1.839	1.887	0	0
3	-0.114	1.839	1.887	0	0
4	-0.114	1.839	1.887	0	0
5	-0.114	1.839	1.887	-1.834	-0.400
Rise time	340	350	350	70	80
Max kV	35	80	80	9x80	80

## ACKNOWLEDGMENTS

The members of the MTE project are grateful to the CERN various groups participating in the installation of the MTE related hardware, for their precious support and efficiency.

## REFERENCES

- [1] R. Cappi *et al.*, Phys. Rev. Lett. 88 (2002) 104801.
- [2] M. Giovannozzi (editor) *et al.*, "The CERN PS multi-turn extraction based on beam splitting in stable islands of transverse phase space", Design Report, CERN2006011.
- [3] S. Gilardoni *et al.*, TU6RFP022, these proceedings.
- [4] A. Franchi *et al.*, "Trajectory Correction in the Transfer Line TT2-TT10 for the Continuous Transfer (CT)", CERN-AB-Note-2008-005.