

**EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH****CERN - AB Department****CERN-AB-2006-065****Cern Proton Synchrotron Working Point Control Using An Improved Version Of The Pole-face-windings And Figure-of-eight Loop Powering**

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The working point of the CERN Proton Synchrotron, which is equipped with combined function magnets, is controlled using pole-face-windings. Each main magnet consists of one focusing and one de-focusing half-unit on which four pole-face-winding plates are mounted containing two separate coils each, called narrow and wide. At present they are connected in series, but can be powered independently. In addition, a winding called the figure-of-eight loop, contours the pole faces and crosses between the two half units, generating opposite fields in each half-unit. The four optical parameters, horizontal and vertical tune and chromaticity, are adjusted by acting on the pole-face-winding currents in both half units and in the figure-of-eight loop, leaving one physical quantity free. The power supply consolidation project opened the opportunity to use five independent power supplies, to adjust the four parameters plus an additional degree of freedom. This paper presents the results of the measurements that have been made in the five-current mode together with the influence of the magnetic nonlinearities, due to the unbalance in the narrow and wide winding currents, on the beam dynamics.

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# CERN PROTON SYNCHROTRON WORKING POINT CONTROL USING AN IMPROVED VERSION OF THE POLE-FACE-WINDINGS AND FIGURE-OF-EIGHT LOOP POWERING

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## Abstract

The working point of the CERN Proton Synchrotron, which is equipped with combined function magnets, is controlled using pole-face-windings. Each main magnet consists of one focusing and one de-focusing half-unit on which four pole-face-winding plates are mounted containing two separate coils each, called narrow and wide. At present they are connected in series, but can be powered independently. In addition, a winding called the figure-of-eight loop, contours the pole faces and crosses between the two half units, generating opposite fields in each half-unit. The four optical parameters, horizontal and vertical tune and chromaticity, are adjusted by acting on the pole-face-winding currents in both half units and in the figure-of-eight loop, leaving one physical quantity free. The power supply consolidation project opened the opportunity to use five independent power supplies, to adjust the four parameters plus an additional degree of freedom. This paper presents the results of the measurements that have been made in the five-current mode together with the influence of the magnetic nonlinearities, due to the unbalance in the narrow and wide winding currents, on the beam dynamics.

## MAIN MAGNET AND POLE FACE WINDINGS

The pole-face-windings (PFW's) and the figure-of-eight loop are mounted inside the main magnets in order to control the working point during the acceleration cycle. At present they are powered by three power converters.

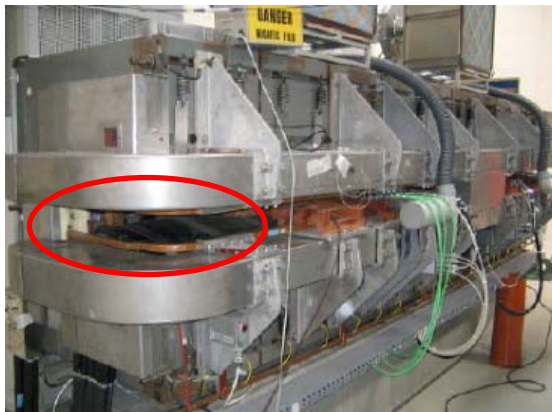


Figure 1: Reference main magnet unit with the PFW's on the poles and the figure-of-eight loop contouring the poles.

One power converter to power the narrow and wide focussing windings in one half of the main magnet, one to power the narrow and wide de-focussing windings in the other half of the main magnet and a third power converter to power the figure-of-eight loop that contours both poles of the main magnet. Each operational power converter has its dedicated spare, which means that there are in total six power converters available.

This configuration precluded specific working point that was required for the novel Multi Turn Extraction studies [1], which was one of the reasons that led to study the improved powering scheme.

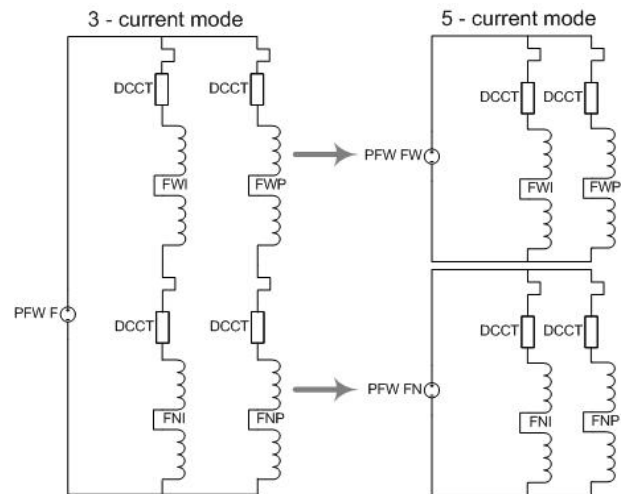


Figure 2: 3-CM and 5-CM schematics for the focussing circuits.

The cabling between the power converters, patch panel and the PFW's is designed such that it is possible to switch semi-automatically between different configurations, by means of a locally controlled electro-mechanic patch panel. However, only one configuration, the 3-current mode (3-CM) [2], is used for beam operation until now. Figure 2 illustrates the connections for the PFW-F circuit in 3-CM at the left and 5-current mode (5-CM) [3] on the right, separating the narrow and wide circuits. The parallel branches in both schematics represent the PFW's in the odd (FWI) and even (FWP) main magnet units.

The PFW-D circuit is connected in exactly the same way as the PFW-F, while the figure-of-eight-loop powering remains unchanged. The control for the five power converters was also modified in order to be able to execute five independent reference functions.

### 3-CM AND 5-CM MEASUREMENTS

The beam based measurements were started by verifying the regulation followed by measuring the 5-CM matrices at 14 GeV/c and 26 GeV/c which relate the five individual PFW and figure-of-eight loop currents:  $I_{FN}$ ,  $I_{FW}$ ,  $I_{DN}$ ,  $I_{DW}$ ,  $I_{8L}$  with the 4 working point parameters:  $Q_h$ ,  $Q_v$ ,  $\xi_h$ ,  $\xi_v$ .

#### Regulation problems

When the main magnetic field is ramped it induces a voltage in the PFW's, which alters the final currents in the various circuits. In the 3-CM these currents partly cancel-out as they have opposite polarity for the wide and narrow windings. However, in the 5-CM they are sufficiently important, especially for the wide circuit, that the present regulation cannot correct for it, as the induced currents on the injection plateau rises to -40A for the focussing wide circuit and +15A for the focussing narrow circuit (Fig. 3). Slightly lower currents were observed for the de-focussing circuits.

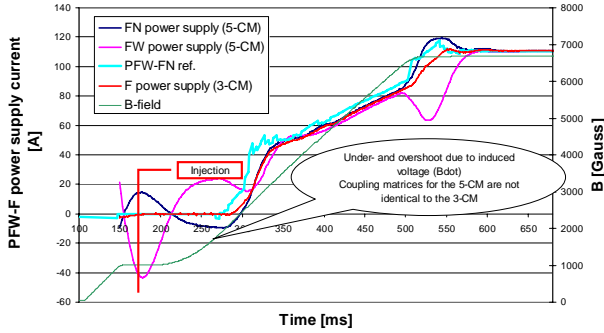


Figure 3: 3-CM and 5-CM currents for the focussing circuit using the present regulation.

The regulation was temporarily modified, for the machine development sessions, in order to reject the induced voltage by adding the Bdot signal, which is the image of the induced voltage, to the regulation. Figure 4 shows the reduction of the induced currents for the PFW-F circuit. A reduction to about  $\pm 5A$  for the focussing and approximately  $\pm 1A$  for the de-focussing circuit were realized. The remaining induced currents were acquired and subtracted from the current functions calculated by the working point application and were therefore not seen by the beam.

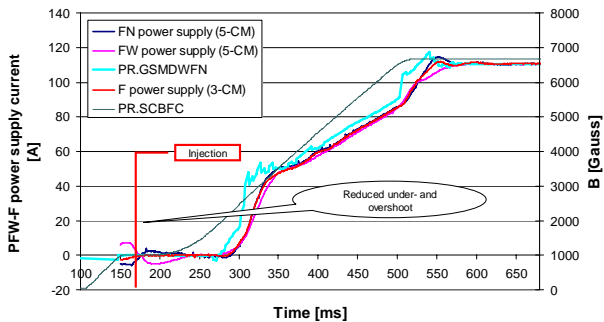


Figure 4: 3-CM and 5-CM currents for the focussing circuit using the modified regulation

### 14 GeV/c measurements

The obtained 14 GeV/c matrix was used to measure the influence of unbalancing the currents in the narrow and wide windings, by keeping the working point similar. Therefore a standard 3-CM working point was transformed to the same 5-CM working point, by programming the same currents in the wide and narrow windings of each focussing and defocussing circuit. In order to change the balance between the narrow and wide windings, the current of the figure-of-eight loop was then reduced by 30 A from 636 A to 606 A and the initial working point was re-calculated using the measured matrix, by varying only the four currents of the PFW-F and PFW-D narrow and wide windings.

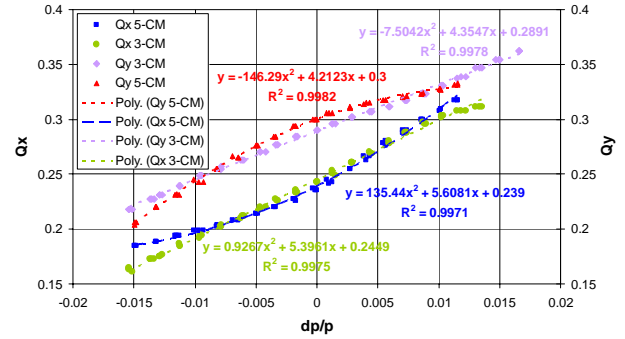


Figure 5: 3-CM and 5-CM working point comparison with figure-of-eight loop reduced by 30 A at 14 GeV/c.

The results of the non-linear chromaticity measurements for the initial and final currents are plotted in Fig. 5, where the initial working point shows a very linear behaviour over a nearly 3% range of  $dp/p$ . After the reduction of the figure-of-eight loop current and the re-calculation of the working point the non-linearities were enhanced slightly, but did not cause any beam blow up or losses. Table 1 shows the numerical values for the required and measured working point and the final currents that were applied to the different windings. The errors between the required and measured values confirm that the matrix is correct.

Table 1: Numerical values for the 5-CM working point with figure-of-eight loop reduced by 30 A at 14 GeV/c.

| Comparison between initial and final measured working point |          |          |          |          |
|---|----------|----------|----------|----------|
|   | $Q_h$    | $\xi_h$  | $Q_v$    | $\xi_v$  |
| required  | 0.2361   | 0.880021 | 0.2995   | 0.65629  |
| measured  | 0.239    | 0.898878 | 0.3      | 0.668619 |
| error   | 0.0029   | 0.018857 | 0.0005   | 0.012329 |
| Measured PFW power supply currents [A]                      |          |          |          |          |
| $I_{FN}$  | $I_{FW}$ | $I_{DN}$ | $I_{DW}$ | $I_{8L}$ |
| 101.32  | 109.98   | -123.35  | -111.34  | 606.50   |

### 26 GeV/c measurements

The same measurements were repeated on a 26 GeV/c cycle, where the main magnets are in saturation. Figure 6 compares the 3-CM working point with the 5-CM working point for which the figure-of-eight loop current was reduced by 300 A from 1535 A to 1235 A. Unfortunately there is not enough data available in the 3-CM at this moment to make a full comparison between

the 3-CM and 5-CM. The green and purple data points clearly indicate the presence of non-linearities for the 5-CM working point, but no beam blow-up or losses were observed. The numerical values are given in Table 2 where the errors between the required and measured values show that there is a considerable difference for the vertical chromaticity that after more detailed analysis turned out to be due to wrong matrix coefficients relating the currents in the PFW-F windings and the vertical chromaticity. Unfortunately no additional measurements could be made as the CERN PS was shut down in 2005 and has just restarted.

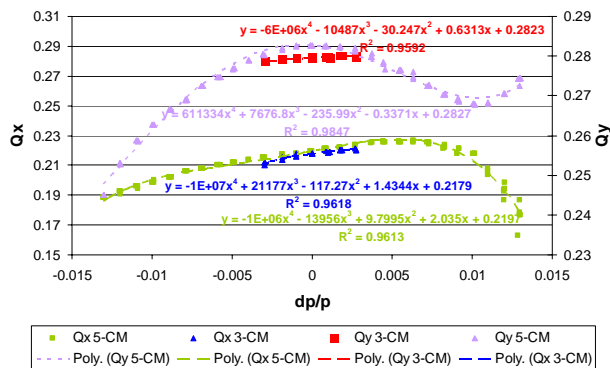


Figure 6: 3-CM and 5-CM working point comparison with figure-of-eight loop reduced by 300 A at 26 GeV/c.

Table 2: Numerical values for the 5-CM working point with figure-of-eight loop reduced by 300 A at 26 GeV/c.

| Comparison between initial and final measured working point |          |           |          |                |
|---|----------|-----------|----------|----------------|
|   | Qh       | $\xi_h$   | Qv       | $\xi_v$        |
| required  | 0.2179   | 0.230689  | 0.2823   | 0.100489       |
| measured  | 0.2197   | 0.327186  | 0.2827   | -0.05366       |
| error   | -0.0018  | -0.096497 | 0.0004   | <b>0.15414</b> |
| Measured PFW power supply currents [A]                      |          |           |          |                |
| $I_{FN}$  | $I_{FW}$ | $I_{DN}$  | $I_{DW}$ | $I_{SL}$       |
| 405.54  | 380.89   | 179.73    | 208.19   | 1235.75        |

Figure 7 compares the two 5-CM working points for two different reductions on the figure-of-eight loop current: -100 A and -300 A. As the current in the figure-of-eight loop is decreased from -100 A to -300 A the currents in the PFW-F and PFW-D circuits need to be increased by nearly a factor of 2, in order to maintain the same working point. The non-linearities, which depend mainly on the difference between the narrow and wide winding currents, are nevertheless enhanced slightly from one case to the other, but have no real effect on the beam.

Table 3: Numerical values for the 5-CM working point with figure-of-eight loop reduced by 100 A at 26 GeV/c.

| Comparison between initial and final measured working point |          |          |          |                 |
|---|----------|----------|----------|-----------------|
|   | Qh       | $\xi_h$  | Qv       | $\xi_v$         |
| required  | 0.2179   | 0.230689 | 0.2823   | 0.100489        |
| measured  | 0.2212   | 0.312544 | 0.2798   | -0.02358        |
| error   | -0.0033  | -0.08186 | 0.0025   | <b>0.124069</b> |
| Measured PFW power supply currents [A]                      |          |          |          |                 |
| $I_{FN}$  | $I_{FW}$ | $I_{DN}$ | $I_{DW}$ | $I_{SL}$        |
| 205.33  | 201.93   | 86.91    | 88.74    | 1435.20         |

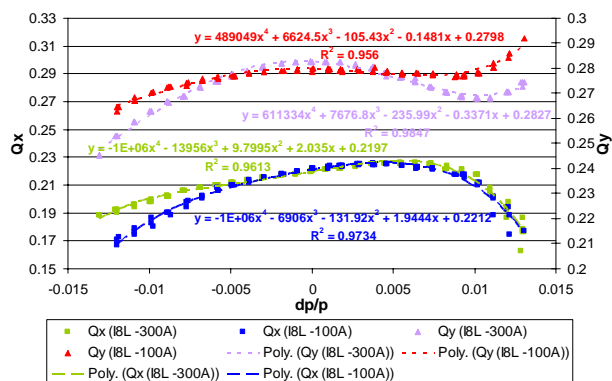


Figure 7: 5-CM working point comparison with figure-of-eight loop reduced by 100 A and 300 A at 26 GeV/c.

## CONCLUSION AND PLANNING

From the beam based measurements it can be concluded that the 5-CM can be used, gives more freedom in working point adjustments and that the enhanced non-linearities that were observed do not influence the beam performance negatively. The project to renovate the power converters [4] and to implement the 5-CM at the same time has been approved and will be executed over the next two years. The mile stones are as following:

- 2004: beam based measurements were made in order to study the feasibility and the effect of unbalancing the wide and narrow windings on the magnetic non-linearities.
- 2005 and beginning 2006: development and construction of the new power converters.
- End 2006 and 2007: installation and tests of the proto-type power converter. After final validation of the proto-type the remaining power converters will be installed. The 5-CM matrices for the different energies will be measured and a smooth transition to the 5-current mode can be made during the run, followed by beam based studies in the 5-CM in parallel with physics operation.
- 2008: start-up in 5-current mode and continue studies to explore the behaviour of the non-linearities as a function of the PFW currents.

## REFERENCES

- [1] M. Giovannozzi et al, these proceedings
- [2] P. Lefèvre and R. Gouiran, "Projet de Nouveaux enroulements Polaires Pour le CPS" MPS/DL/Note 74-11, June 1974.
- [3] R. Gouiran, "Projet d'un Nouveau Systeme d'Enroulements polaires a Cinq Courants", MPS/SM/Note 75-21, 13 August 1975.
- [4] J.-P. Burnet and O. Michels, "Projet de Consolidation des Convertisseurs PFW" Note Technique AB-PO N°10, EDMS: 585302, April 2005.