OPTIONS FOR IMPROVING THE OCTUPOLES USED FOR THE MULTI-TURN EXTRACTION STUDIES

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Abstract

The proposed multi-turn extraction scheme under study in the PS machine requires magnets generating nonlinear magnetic fields, e.g. sextupoles and octupoles. These devices are used for generating stable islands in transverse phase space where particles are trapped by means of an appropriate tune variation inducing a crossing of a low-order resonance. Observations made during the experimental sessions performed throughout the 2003 PS run seems to indicate that the PS octupoles are the main culprit for the measured beam losses. In this note two options to overcome the difficulties encountered so far and for pursuing the tests during the 2004 run are presented and discussed.

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1 Introduction

In the framework of the studies for the proposed multi-turn extraction based on adiabatic capture inside stable islands generated by sextupole and octupole magnets [1], experimental tests have been carried out in the PS machine [2-4]. The required hardware has been recuperated from the PS stock. In particular, the magnets necessary to generate the nonlinear magnetic field are standard PS auxiliary magnets, e.g. the sextupoles are of type XST [5], while the octupoles are of type OST [6] (see also Ref. [7] for a parameters’ list of the PS auxiliary magnets). Although the sextupoles proved to be well adapted to the needs of the experimental tests, the octupoles are a source of additional constraint. The limitation originates from the reduced horizontal aperture\(^1\), thus imposing to install them only in locations where the horizontal beta-function has a minimum, which occurs in even sections. Otherwise, they become an aperture limit for the machine. This explains why the octupoles used in the test for the novel extraction are located in section 20 [2-4]. In the preliminary phase of the experimental tests, where a proof of principle was the main goal, the way out of this situation was found by simply increasing the strength of the octupoles to compensate for the reduction of magnetic strength due to the minimum value of the horizontal beta-function.

However, detailed measurements with high-intensity beams, for which the vertical emittance is rather large [3], revealed the presence of particle losses. A possible explanation could be the strong perturbation induced by the octupoles in the vertical plane. In fact, the very principle of the novel extraction would require acting on the horizontal plane only, trying to leave as much as possible the vertical plane unperturbed. The present location of the octupoles is clearly unfavourable, because of the large vertical beta-function (\(\beta_V \approx 22\) m). Moving the octupoles to section 21 would have two positive effects: it reduces the vertical beta-function to about 12 m, thus reducing the strong nonlinear effects in the vertical plane, and, at the same time, it increases the horizontal beta-function, therefore enhancing the octupole effect in the plane where the beam trapping occurs. Furthermore, this change would also induce an important positive side effect. In fact, this location would allow creating islands with the optimal phase at the location of the electrostatic septum [3]. However, the limited horizontal aperture prevents to implement this simple fix.

In this note two options are presented and discussed in detail to overcome the aperture limitation of the existing PS octupoles to allow installing octupole magnets in the PS section 21.

2 First Option: Modification of a standard PS octupole

2.1 Mechanical aspects

The first possibility consists in modifying the mechanical structure of the standard PS octupoles. In fact, these magnets are made by four quadrants bolted together. Therefore, one could think of inserting spacers between the quadrants so to increase the magnet aperture (see Fig. 1 for a sketch of the proposed solution).

![Figure 1: Sketch of the standard PS octupole to illustrate how the four quadrants should be moved to increase the magnet aperture (left). The spacers, represented in two pieces to reduce Eddy currents during the current-ramp, are also shown (right).](image)

The spacers, made of soft iron, would be inserted between the four parts. The magnet is laminated in order to reduce Eddy currents and being capable of fast pulsing. Therefore, also the spacers should be

\(^1\) This is due to the original use of the octupoles in the PS ring that is to cure beam instabilities.
designed in order to reduce perturbing effects during the current-ramp phase. Of course, it would be too difficult to produce these pieces by means of iron laminations. Therefore, it is proposed to split the spacers in two parts. This should already decrease the Eddy currents. Of course, more refined solutions might be implemented in case of need.

The dimensions of the spacers required to accommodate a PS standard vacuum chamber (see Fig. 2), which is the type of chamber presently installed in section 21, have been estimated by drawing the pole profile of the octupole [6] and by shifting it along the radial direction so that the vacuum chamber can be installed inside.

![Figure 2: Mechanical drawing of the PS vacuum chamber.](image)

Two sets of dimensions have been determined, corresponding to spacers 12 mm thick, 63.3 mm wide, 264 mm long, and to spacers 16 mm thick, 63.3 mm wide, 264 mm long. Both configurations fit with the PS standard vacuum chamber size; the latter allows more safety margin for mechanical tolerance of the pipe shape. An example of the assembly corresponding to the first case is shown in Fig. 3.

![Figure 3: Example of the proposed assembly with spacers 12 mm thick.](image)

### 2.2 Field quality

The proposed modification of the PS octupole will preserve the cylindrical symmetry of the magnet. Therefore, if the standard notation for multipolar components is used, i.e. \( b_n \) stands for the normal field component corresponding to a 2n-pole, while \( a_n \) the skew component corresponding to a 2n-pole, then \( b_1 \) is expected to be zero. However, the pure octupolar symmetry is broken, as the two poles in the same quadrant have not been separated following the radial displacement. This gives rise to spurious multipoles. To simulate the field quality of the modified PS octupole, the computer code ROXIE [8] has been used. Various configurations have been simulated, corresponding to the nominal magnet cross-section and to the spacers’ thickness of 12 mm and 16 mm, respectively. In Fig. 4 the magnetic field for the configuration corresponding to spacers 12 mm thick is shown.
Figure 4: Magnetic field distribution for the modified PS octupole. The configuration with 12 mm thick spacers and without any modification of the pole shape is shown.

More quantitative analysis is reported in Table 1, where the multipoles for the three configurations studied are listed. Due to the different aperture of the cross-sections considered, the actual strength of the octupolar field differs in the various cases, decreasing with increasing aperture. Therefore, the value of the current was increased in the numerical simulation to compensate the reduction in strength of the octupole field.

<table>
<thead>
<tr>
<th>Normal multipole of order n</th>
<th>Original configuration</th>
<th>Modified octupole: spacer 12 mm thick</th>
<th>Modified octupole: spacer 16 mm thick</th>
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Table 1: Value of the magnetic multipoles for three configurations of the PS octupole, namely standard configuration, 12 mm, and 16 mm thick spacers. The reference radius is 45 mm. The numerical simulations have been performed increasing the current in the octupole so to have always the same field corresponding to the one used in the experimental tests.

According to the numerical simulations the standard configuration of the PS octupole has a very good field quality, the largest non-zero field components being $b_{12}$ and $b_{20}$. For the modified configurations, as already mentioned, the circular symmetry imposes to have a zero dipole component as well as all the skew

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multipoles. The vast majority of the normal multipoles are equal to zero: only $b_8$ sticks out of the background, being the largest spurious multipole, much larger than in the nominal configuration. On the other hand, $b_{12}$ and $b_{20}$ are indeed reduced with respect to the actual configuration. It is also worth mentioning that $b_2$ (quadrupole component) is larger in magnitude than for the case of the nominal configuration.

![Graphic representation of the normal multipoles for the three cross-sections considered in the numerical simulations.](image)

If the two cases with increased aperture are compared, the most important feature is that with 16 mm spacers’ thickness saturation phenomena are no more negligible. In fact, the value of the current to be used in the numerical simulation does not scale with the ratio $0.75=12/16$, but it is found to be about 0.85.

For the sake of completeness, it is worth mentioning that more refined configurations have been simulated. The aim was to reduce the $b_8$ component by changing the shape of the magnet poles. Although some interesting solutions were found, the difficulties due to machining radioactive laminations were not worth the efforts (see Fig. 6 for a cross-section of the modified PS octupole with poles cut).

![Cross-section of the modified PS octupole with poles cut along a straight line from the pole tip to the extremity of the coils.](image)

From this analysis it turns out that the field quality of the modified octupole requires more detailed studies to assess the impact on the beam dynamics of the spurious multipoles. The reduction of octupolar strength, due to the enlarged aperture, does not seem to be a serious obstacle, as the increased value of the horizontal beta-function would largely compensate the field loss. In fact, as shown in Ref. [9], the required octupolar strength depends only on the value of the horizontal beta-function at the location of the magnetic element.

### 3 Second option: Use a SPS octupole

#### 3.1 Mechanical aspects

The SPS injection octupoles (LOE) are located in the arcs and are installed with a quadrupole vacuum pipe with exterior dimensions of 156 mm (H) and 45.5 mm (V). The diameter of the inscribed circle is 134 mm. The structure of the two vacuum chambers, PS and SPS, is different. In particular, the PS vacuum pipe
is larger in the vertical direction. Therefore, it might need some modifications to fit the LOE octupole. In Fig. 7 the SPS pole shape is shown together with the standard PS vacuum chamber.

Figure 7: Detail of the cross-section of the SPS octupole with the standard PS vacuum chamber (red dashed-dotted) and a modified version (black continuous). One quadrant is shown and only the pole nearest to the median plane is plotted. The grid step is 1 mm.

Only the pole nearest to the median plane is shown, being the most severe constraint for the vacuum pipe. The green line represents the PS standard vacuum chamber: it fits barely the available aperture. In black a modified version of the PS vacuum chamber is shown. The radius of the larger arc has been reduced from 137.5 mm (see Fig. 2) to 121.1 mm, while the smaller one from 23.8 mm to 20.0 mm. The external size of the chamber has been kept the same as that of the standard PS vacuum pipe. By doing so, the modified chamber fits the LOE aperture and the acceptance of the machine is almost unaffected. Indeed, it would be possible to reduce even less the cross-section of the vacuum pipe, by simply chopping off a small bit of pipe nearby the magnetic pole.

From this analysis it turns out that the SPS octupole could fit a standard PS chamber with minor modifications and with negligible impact on the acceptance of the PS.

As far as other mechanical aspects are concerned, the available longitudinal space is rather tight to allow the installation of the SPS octupole together with the two PS sextupoles. However, this does not seem to be a real obstacle. Finally, the support of the magnet is not compatible with the PS alignment tables and some modifications have to be foreseen.

To summarise, from the mechanical point of view the installation of the SPS octupole in section 21 seems feasible although it requires some care.

3.2 Powering and magnetic aspects

According to experts [11], the Tekelec power converters presently used for the tests of the multi-turn extraction can be used together with the LOE octupole.

As far as the magnetic properties are concerned, the strength of the SPS octupole is certainly enough to replace the two PS octupoles presently installed in section 20: the increase in the value of the horizontal beta-function has a key role in increasing the available strength.

4 Conclusions

Two options have been presented and discussed to provide an octupolar magnet better fitting the needs of the experimental tests of the novel multi-turn extraction. The first option consists in modifying a PS octupole so to increase its horizontal aperture thus matching the size of the vacuum chamber installed in the section 21 of the PS ring. Although, the proposed solution overcomes the aperture limitation issue, the field quality suffers from the broken octupolar symmetry, mainly due to a rather large $b_8$ component.

A second option consists of utilising an SPS octupole of type LOE. In this case the main issue consists in designing a vacuum chamber, the standard PS vacuum chamber being slightly too large, without losing too much in mechanical aperture. In this note is shown that this goal is indeed feasible. Of course, the field quality is excellent, as the mechanical structure of the magnet is not modified. Furthermore, the same power converter used in the experimental tests to power the standard PS octupole would fit the electrical characteristics of the SPS magnet. Finally, the analysis of the space occupancy of the section 21 shows that
enough space is available to install the SPS octupole in the chosen section provided some special solutions are used for the bellows.

For these reasons, the second solution has been retained and the appropriate steps have been taken to build a modified PS vacuum chamber, modify the connections, and produce new supports to allow completing the installation of the SPS octupole during the 2003/2004 shutdown.

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**References**


