A GENERAL METHOD FOR 2D MAGNET POLE DESIGN

Zeus Martí, Josep Campmany, Miquel Traveria (LLS, Bellaterra (Cerdanyola del Vallès))

Abstract

The aim of this contribution is to present a general method for designing two-dimensional pole profiles. This method has proven to converge fast to good solutions. We have developed a group of codes that can be compiled and run on MS-DOS or UNIX which use POISSON and OPERA-2d codes. This procedure also includes the evaluation of the sensitivity of the final pole profile to geometrical and current intensity errors for tolerance estimation, a big requirement in this context. In order to test the feasibility of this method, we have applied it to the case of the 1.2 T combined magnet of the new synchrotron to be built nearby Barcelona.

INTRODUCTION

A lot of effort has being devoted for years to improve the methodology of design the accelerator magnet pole profiles, taking advantage of the increasing power capabilities of computing machines. The old analytical methods[1,2,3,4] have been replaced by new numerical techniques [5,6,7,8,9].

We have developed a group of codes to integrate POISSON and OPERA-2d packages into the well-known SIMPLEX [10] minimization routine. The codes can be compiled and run on MS-DOS or UNIX. They are based respectively in BAT and SHELL archives and use some C routines we have developed to improve the fitting process. In addition, the codes also include the evaluation of the sensitivity of the final pole profile to geometrical and current intensity errors.

We have applied our procedure to the case of the 1.2 T combined magnet of the new synchrotron to be built nearby Barcelona, in order to test its feasibility.

METHODOLOGY

The model

Our 2D pole profile model consists in a central region with the theoretical shape plus a correcting polynomial of undetermined order. To round the edges we use Rogowski curves joined to the central part with splines. The coefficients of the correcting polynomial are the free parameters to be fitted.

Codes for pole optimisation

Our main work has been centered in developing a package of programs to integrate the well-known codes for magnetic field simulation, POISSON and OPERA-2d, into SIMPLEX minimization routine. In addition, some auxiliary codes have been developed in order to improve the SIMPLEX operation.

The main code runs on MS-DOS –making use of a script archives (*.bat)–, and on UNIX –making use of a shell script–.

The general structure of the code is similar to that explained elsewhere, [6,8,9], and it is shown in figure 1.

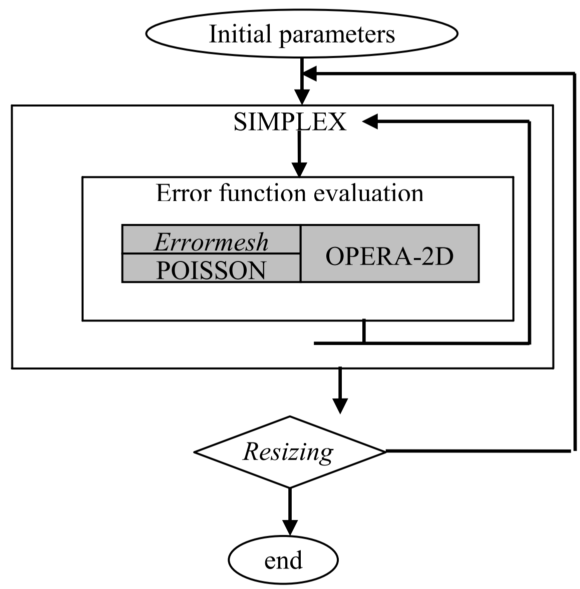

Figure 1. Flux diagram of the optimization

We have carried out the minimization using the SIMPLEX routine with some improvements: a routine to avoid meshing errors, *errormesh,* and a routine to avoid as far as possible local minima, *resizing*. Diagram in Fig.1 shows these routines integrated in the general code frame.

- *Errormesh*: The mesh automatically generated by POISSON package for some pole profiles causes the crashing of the code. We have implemented a routine running before POISSON that tests the mesh. If any error is foreseen, *Errormesh* decreases the mesh size. If the error persists after some trials, then the whole optimization is aborted.

- *Resizing*: To avoid that SIMPLEX falls in local minima, we inserted an additional routine to expand the SIMPLEX volume once it converges under a certain local minimum. The routine finishes when two consecutive minimizations fall in the same minimum.

Error function

We evaluate the goodness of a given pole profile defined by a set of parameters through the values of a scalar error function. We define the error function, σ_C, as the squared mean of quadratic deviations of the magnetic field, computed in N space points:

$$\sigma_C = \sqrt{\frac{\sum_{i=1}^{N}\left(Bx_i - Bx0_i\right)^2 + \left(By_i - By0_i\right)^2}{N}} \quad (1)$$

where Bx and By are the magnetic field components at each point calculated for a given geometry defined by a given set of parameters, and $Bx0_i$ and $By0_i$ are the same magnitudes evaluated for the ideal geometry (infinite pole profile). The N points are equally spaced in the Good field region border (GFR border). The reason to choose these points is explained in reference [9].

Optimising the pole profile

We consider an important goal the simplicity of the pole, that is, the use of a low number of parameters to describe it. Not only to save minimization time but also to reduce the number of local minima of the error function in the parameter space.

We distinguish two parts in the optimization process: first we determine how many parameters are needed, and then we find the best set of values for the parameters.

Tolerances

To study the stability with respect to mechanical errors, we model a number of defects as follows:

- Random point defects along the pole.
- Vertical error increasing linearly from the external to the inner edge of the pole.
- Constant vertical error shift along the pole.

These defects model some realistic situations, as vibrations, positioning error or torque affecting the drill used to mechanize the yoke or its cast (depending on the machining procedure), as well as attraction between poles.

Tolerances are the maximum geometrical or electric deviations that keep field error in the GFR within specified allowances. The relative field allowance has been set to 10^{-4}, according to reference [11].

RESULTS AND DISCUSSIONS

The process we have set up can be applied to any type of multipolar field. Here we have applied it to upgrade the combined storage ring magnets of the synchrotron to be built near Barcelona. The initial design detailed in [11] was proposed for a 2.5 GeV machine, but now it is planned to increase the accelerator energy to 3.0 GeV. Some features of the current 2.5 GeV model in 2D have been maintained: the magnet type (C cross section), the coil position, the gap and the yoke thickness (table 1).

Variable	Value
Yoke thickness (cm)	20.0
Gap height (cm)	2.5
Coil section (cm x cm)	68.0 x 102.0
Dipole/ Quadrupole fraction (cm)	29.11
$\Delta B/B_0$ in the GFR	10^{-4}

Table 1: Parameters of the combined dipole taken from the design at 2.5 GeV.

We define now the particular inputs we have used to run the optimization process. We consider a good field region described by an ellipse of 2.0 cm x 4.0 cm. To calculate the tolerances, we use a smaller ellipse of 1.8 cm x 3.0 cm. Some other values used in the optimization process are those given in table 2 [11].

Variable	Old value	New value
Magnetic field at origin (T)	1.010	1.212
Quadrupole (T/m)	3.470	4.164
Ampere turn per coil	20420	24504

Table 2: parameters of the combined dipole corresponding to the change in storage ring energy.

Number of parameters determination.

A 6-order polynomial is needed to obtain values of $\sigma/B0$ below 10^{-4} (B0 is a normalization factor, in this case the magnetic field in the centre of the magnet). Figure 2 shows the pole scheme along with the correcting polynomial (not scaled).

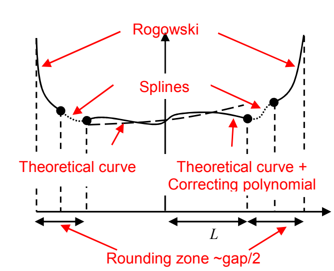

Figure 2: Parameterization of the pole profile.

Finding the best set of values

We generated up to 20 final pole profiles, starting from different initial points. In table 3 we present some statistics related to these values. All of them have $\sigma_C/B_0 \approx (0.40 \pm 0.05)\cdot 10^{-4}$.

	p_1 (10^{-5})	p_2 (10^{-4})	p_3 (10^{-4})	p_4 (10^{-3})	p_5 (10^{-3})	p_6 (10^{-2})
Mean	180	-32	132	23	-37	-8
max	190	-5	137	33	-34	-4
min	168	-47	109	-1	-39	-9
RMS	5	9	6	8	1	1

Table 3: statistical values of fitted error function and parameters from 20 different sets of initial parameters.

All results are within our requirements.

Tolerances

The estimation of tolerances is shown in tables 4.

Error type	Magnitude	*Tolerance*
Intensity	$\Delta I/I_0$	$\pm 10.0\cdot 10^{-5}$
Mech. random	Max value	±9 μm
Mech. linear	Slope	±0.55 μm/cm
Mech. global	Value	±27 μm

Table 4. Electrical and mechanical tolerances of the best solution.

Results fulfil the conditions of stability within the usual electric and mechanical tolerances.

Fitting with OPERA-2d

Just to test the goodness and portability, we have made a whole optimisation using UNIX and OPERA-2d. We implemented exactly the same model and we conclude that the results obtained with DOS and POISSON are reproducible, i.e., the solution is nearly the same for the best solution and field along the x-axis is comparable, as shown in figure 3.

We attribute the slight differences observed to the different meshing and finite-element algorithms used by those codes.

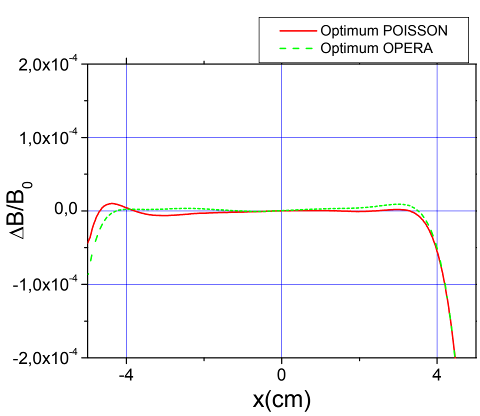

Figure 3: Comparison between field error values for the best pole profile, optimized with POISSON (continuous line) and OPERA-2d (dashed line) along the *x*-axis.

CONCLUSION

We have implemented a general method to design two-dimensional pole profiles and to estimate its tolerances, running on different computing platforms.

In order to test the feasibility of this method, we have applied it to the case of the 1.2 T combined magnet of the new synchrotron to be built nearby Barcelona. Results give always good solutions and good field quality within the usual mechanical and electrical stability requirements.

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