AUTO-FIELD-SHIMMING ALGORITHM FOR AN ELLIPTICALLY POLARIZED UNDULATOR

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Abstract

Shimming the magnetic-field error on each pole of an elliptically polarized undulator (EPU) is tedious work and strongly based on experience without systematic scientific methods. An auto-field-shimming program is thus developed to decrease the duration of pole shimming. The program includes two major steps to analyze where a pole is defective or imperfect. Step one is to clarify the quality of the magnetic pole: if its quality deviates much from user-defined standards, we replace the pole instead of trying to balance them for a uniform magnetic field. The magnetic pole quality is based on ratios $\Delta B/B_{avg}$ and $\Delta I/I_{avg}$ (half period of integral). The second step is to build an effective field and first integral model of the pole and a permanent-magnet calculation. If we shim the defective pole by moving vertically and transversely, it would surge intrinsic change of the $\Delta B/B_{avg}$ and $\Delta I/I_{avg}$ at the defective and adjacent poles. An auto-field shimming algorithm assists us to plan shimming strategies to treat magnetic poles.

INTRODUCTION

To obtain a uniform magnetic field in the elliptically polarized undulator (EPU), shimming is inevitable and tedious. An auto-field shimming program is thus developed to save time on pole shimming. The development environment of the program is consistent with our measurement system, which is convenient. The output of the program is the relative modification of poles and permanent magnets of each array of EPU.

The program includes two important steps. One is to assess whether values of $\Delta B/B_{avg}$ and $\Delta I/I_{avg}$ (half period of integral) of the magnetic poles are within a user-defined standard. The magnetic poles that fail to conform to that user-defined standard would not be shimmed for a uniform magnetic field, which is Test 1 in Table 1. The magnetic poles that are without a user-defined standard according to Test 1 in Table 1 would be replaced by poles that fulfil that standard. A user-defined standard that is Test 2 in Table1 would help to save the magnets for us. The content of the second step is the calculation model of the effective field and first integral model of the pole and permanent magnet. The values of the $\Delta B/B_{avg}$ and $\Delta I/I_{avg}$ at the target pole and surrounding target poles would be considered to be within the user-defined standard that is Test 3 in Table 1 in the model. The output of the program is the result of the predictive $\Delta B/B_{avg}$ and $\Delta I/I_{avg}$ of all magnets within a user-defined standard that is Test 3 in Table 1 through an iterative procedure of the model. This iterative procedure produces a satisfactory result after shimming once. Further results are based on preceding results. The scientific algorithm offers a convenient method to speed our shimming work.

Table 1: Definition of the User-defined Standard

User-defined standard	$\Delta B/B_{avg}$
Test 1 (EX: <1.5 %?)	Yes: go to test 2, Fail: Replace
Test 2(EX:±1.5 %?)	Yes: go to test 3 and exchange (+1.5 % -> -1.5 %, -1.5 % -> +1.5 %), Fail: go to test 3
Test 3 (EX: < 0.5 %?)	Model calculation: Yes: obtain the relative modification of each pole. Fail: reason for failure and suggestion

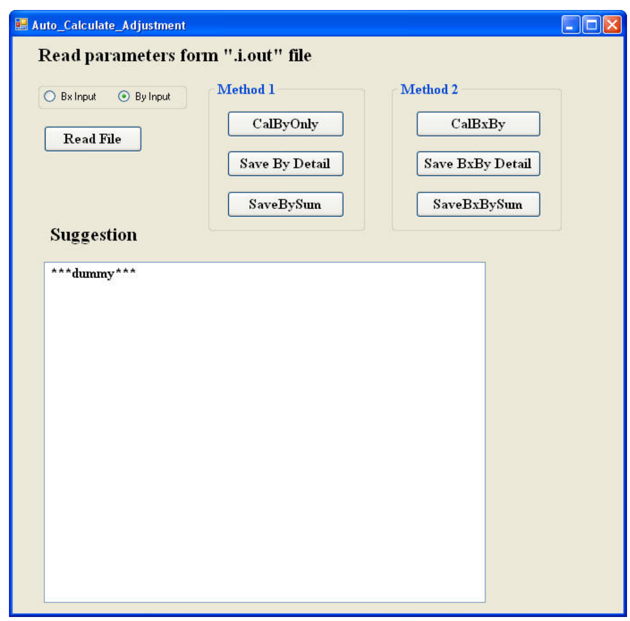


Figure 1: Interface of the auto-shimming program

ALGORITHM

The interface of the application program, developed in Visual Basic, is demonstrated in Figure 1. The user feeds the automatic calculating program the measurement data. The data include B field, half period of integral (Int), B_{avg}, I_{avg} and $\Delta B/B_{avg}$ and $\Delta I/I_{avg}$.. The hypothesis that shows that of all magnets half have a perfectly uniform field (B_{avg}, I_{avg} are correct) within the user-defined standard that is Test 3 is made to simplify the algorithm. Two calculating models are established in the algorithm because of the varied effect of tuning methods. The two models also define coordinate axes including transverse x, vertical y, and beamline direction z. The first method is to adjust the position of transverse direction x of the magnet, which affects field B_y with only a plus or minus contribution. Model one is built for the first method. The second method is to tune the position of vertical direction y of the magnet, which affects both B_x and B_y with a complicated plus or minus contribution. Model two is built for method two. Before the algorithm begins, two conditions are of concern: one is that the pole magnet causes that $\Delta B/B_{avg}$ and $\Delta I/I_{avg}$ to transcend the user-defined standard that is Test 1 of Table 1; the second is that a permanent magnet causes $\Delta I/I_{avg}$ to fail to conform to the user-defined standard that is Test 1 of Table 1. The two conditions are of concern when the program is processing. At this point the program formally begins the flow. First, the program eliminates the magnets, including poles and permanent magnets, that transcend the user-defined standard of Test 1 whether either model one or two is chosen, because it is not worth while to shim them to satisfy user-defined standard Test 3 of Table 1; abandoning them instead of shimming is preferable. Second, the program would find complementary magnets to exchange the discarded, according to Test 2 of Table 1. This exchanging method would assist to retrench the number of magnets, but this method is intricate.

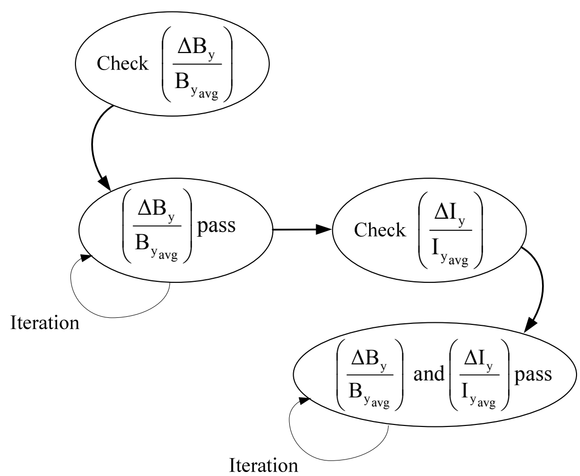
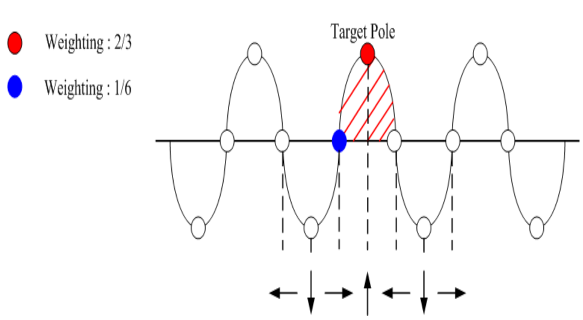


Figure 2: Schematic diagram of Model one calculation flow of the algorithm



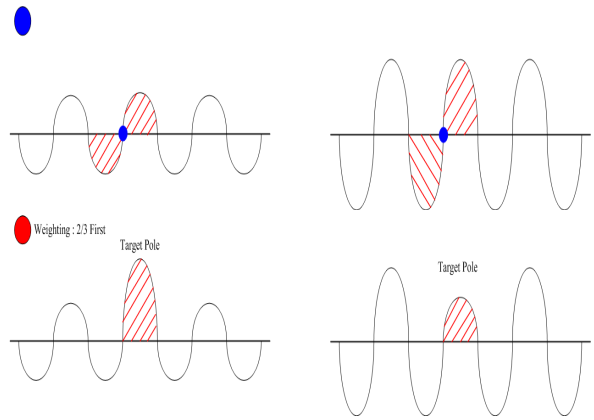


Figure 3: Schematic diagram of B field; relation of pole and permanent magnet

Third, the model parameters are provided by a user according to experimental data including the relative modification that depends on the distance of the shimming magnets. The user experimental data defines the relative modification of the B field to calculate the equations, and likewise the half integral. The equation relation of the default model is shown in figure 3. The pole has a more effective B field weighting than the permanent magnet in the default settings. The figure also indicates that a plus field at a target pole would imply a minus B field at the surrounding poles, and that a plus field at a target permanent magnet would imply a plus B field at surrounding poles, but all parameters to modify the B field and half integral are programmable and retain a flexible choice to avoid an exception. If the real model differs from our default model, it would still work normally on filling in the real case parameters.

The relative modification of equations in the model follows the flow chart in figure 2 using parameters of the user. The program verifies that $\Delta B_y/B_{y,avg}$ of all magnets is fixed to the user-defined standard, then iterates until attaining the optimum $\Delta B_y/B_{y,avg}$ solution or fails to achieve the user-defined standard. Subsequently, $\Delta I_y/I_{y,avg}$ would be considered to test to obtain the optimum $\Delta I_y/I_{y,avg}$ with the program. The iteration terminates when $\Delta B_y/B_{y,avg}$ and $\Delta I_y/I_{y,avg}$ are within specification. The comment would be suggested and recorded when the calculation is completed.

Model two is an advanced deliberation originating from the first method. It emphasizes adjustment of $\Delta B_y/B_{y,avg}$, $\Delta I_y/I_{y,avg}$, $\Delta B_x/B_{x,avg}$, and $\Delta I_x/I_{x,avg}$ simultaneously, as an extension of the first method. The theory is the same as for the first method; the difference is that the program is aimed at $\Delta B_x/B_{x,avg}$ and $\Delta I_x/I_{x,avg}$ first and saves values including $\Delta B_y/B_{y,avg}$, $\Delta I_y/I_{y,avg}$, $\Delta B_x/B_{x,avg}$ and $\Delta I_x/I_{x,avg}$ because of shimming. Then processing $\Delta B_y/B_{y,avg}$ and $\Delta I_y/I_{y,avg}$ to balance the B field within specification.

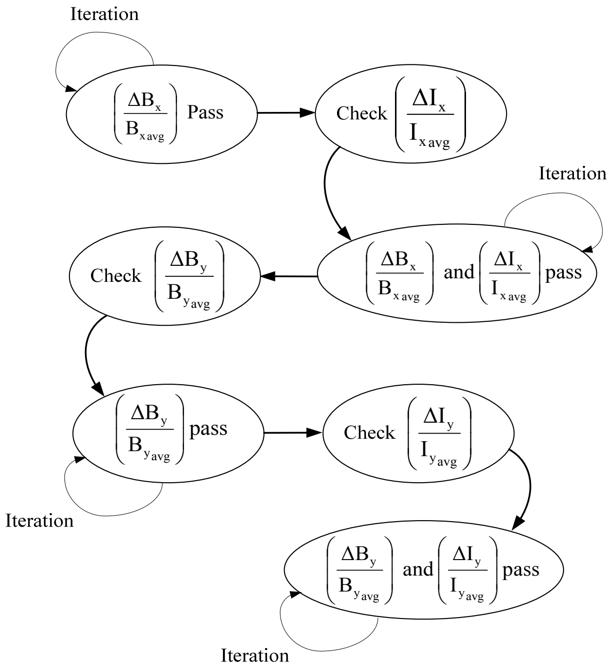


Figure 4: Schematic diagram of the calculation flow of the algorithm according to model two

RESULT OF SIMULATION

EPU46 measurement data of NSRRC is the base for the simulation test. The document is the result generated by the program. Because the second model is an extension of the first model, taking the first model is a superior example to explain how it works.

Work before shimming calculation

A sequence is described in the algorithm setup topic in figure 4. Index 7 of figure 4 are the average of B_y, and I_y that emanate from user measurement data. Index 10 of figure 4 indicates whether the pole fails or passes the user-defined standard that is Test 1 of Table 1. Index 22 of figure 4 indicates whether the pole would be exchanged with each other according to Test 2 of Table 1. The objective of exchange is to minimize the number of magnets.

```
 5 *******Prepared Work below*******
 6
 7 By_AveBmax = 4140.9, By_AveInt = 6050.3
 8
 9 ********************************************************
10 Check contributed vertical magnetic pole(By) > 1.5%
11 ********************************************************
12 Please change contributed vertical magnetic pole(By) : 4
13 Please change contributed vertical magnetic pole(By) : 8
14 Please change contributed vertical magnetic pole(By) : 11
15 Please change contributed vertical magnetic pole(By) : 16
16
17 **********************************************************
18 Check contributed horizontal magnetic pole(By) > 1.5%
19 **********************************************************
20
21 ***************************************************************
22 Check switch contributed vertical magnetic pole(By) possibility
23 ***************************************************************
24 Please switch contributed vertical magnetic pole(By) : 4 with 8
25 Please switch contributed vertical magnetic pole(By) : 4 with 16
26 Please switch contributed vertical magnetic pole(By) : 8 with 11
27 Please switch contributed vertical magnetic pole(By) : 11 with 16
28
29 *****************************************************************
30 Check switch contributed horizontal magnetic pole(By) possibility
31 *****************************************************************
32
```

Figure 4: Work preceding shimming

```
*************************************************************
We fixed By DeltaB/MeanB First, So The First State is below :
*************************************************************

*******Comment*******
The Worse DeltaB/MeanB would be add prefix : @, The low priority Worse DeltaI/MeanI

By Bad DeltaB/MeanB Pole index =  4. The Program can't Find The Best Result, Try another Range or Change the pole.
By Bad DeltaB/MeanB Pole index =  7. The Program can't Find The Best Result, Try another Range or Change the pole.
By Bad DeltaB/MeanB Pole index =  8. The Program can't Find The Best Result, Try another Range or Change the pole.
By Bad DeltaB/MeanB Pole index = 11. The Program can't Find The Best Result, Try another Range or Change the pole.
By Bad DeltaB/MeanB Pole index = 16. The Program can't Find The Best Result, Try another Range or Change the pole.
```

Figure 5: Comment of the program for the user

Comment and Suggestion of the Program

The process would follow the flow of figure 2. Fixing $\Delta B_y/B_{y,\text{avg}}$ would be accorded greater priority than $\Delta I_y/I_{y,\text{avg}}$. The comment is the recommended result of the program. It shows which pole must be adjusted and the quantity of shimming. As a possibility of failure would not be neglected, a user should change the pole or edit the user-defined standard and proceed again.

Original Data and Predictive Result

The original measurement data that a user offers to the program is at the left side. The program would mark the broken pole and show the outcome, after processing the comment in figure 5, at the right side of figure 6. The program would automatically neglect the first and last three poles to eliminate side effects. The concept of the first model is presented in figure 2.

	Original				Predicted First State			
NumPole	Bmax	P/2 Intg	DeltaB/MeanB	DeltaI/MeanI	Bmax	P/2 Intg	DeltaB/MeanB	DeltaI/MeanI
()	(G)	(G-cm)	(Percentage)	(Percentage)	(G)	(G-cm)	(Percentage)	(Percentage)
01	-1776.810	-3197.050	-57.09	-47.16	-1776.810	-3197.050	-57.09	-47.16
02	4411.116	7594.435	6.53	25.52	4411.116	7594.435	6.53	25.52
03	-4576.568	-7222.166	10.52	19.37	-4576.568	-7222.166	10.52	19.37
@								
04	4076.716	5956.520	-1.55	-1.55	4076.716	5956.520	-1.55	-1.55
05	-4142.192	-6053.363	0.03	0.05	-4142.192	-6053.363	0.03	0.05
06	4127.858	6076.958	-0.31	0.44	4127.858	6076.958	-0.31	0.44
@								
07	-4162.019	-6049.647	0.51	-0.01	-4162.019	-6049.647	0.51	-0.01
@								
08	4205.084	6144.080	1.55	1.55	4205.084	6144.080	1.55	1.55
09	-4158.781	-6060.276	0.43	0.16	-4158.781	-6060.276	0.43	0.16
10	4136.091	6053.199	-0.11	0.05	4136.091	6053.199	-0.11	0.05
@								
11	-4076.716	-5956.520	-1.55	-1.55	-4076.716	-5956.520	-1.55	-1.55
12	4149.333	6113.515	0.20	1.04	4149.333	6113.515	0.20	1.04
13	-4155.319	-6074.354	0.35	0.40	-4155.319	-6074.354	0.35	0.40
14	4144.199	6147.032	0.10	1.60	4144.199	6147.032	0.10	1.60
15	-4135.716	-6024.819	-0.13	-0.42	-4135.716	-6024.819	-0.13	-0.42
@								
16	4076.716	5956.520	1.55	1.55	4076.716	5956.520	1.55	1.55
17	-4568.670	-7125.853	10.33	17.78	-4568.670	-7125.853	10.33	17.78
18	4480.980	7620.117	8.21	25.95	4480.980	7620.117	8.21	25.95
19	-1818.035	-3310.636	-56.10	-45.28	-1818.035	-3310.636	-56.10	-45.28

Figure 6: Original data and predictive result after shimming

CONCLUSION

A dedicated program is designed to decrease the duration to shim an EPU. An innate limitation is that B_{avg} and I_{avg} are constant, which might introduce some inaccuracy into the calculation. All parameters of the user-defined standard are programmable. This advantage enables adaptation to variable model cases. The program also records all details so that users can derive clear suggestions to balance the situation.

REFERENCES

[1] Visual studio software homepage http://www.microsoft.com/visualstudio/zh-tw

[2] Hwang, C. S., and Yeh, S. "Various Polarization Features of a Variably Polarized Undulator with Different Phasing Modes," Nucl. Instrum. Method Phys. Res., Sect. A 420, 29.