Interactive program for Nuclotron orbit correction

Veksler and Baldin Laboratory of High Energy Physics

Joint Institute for nuclear research (JINR)

Supervisors: Dr. Grigory V. Trubnikov , Dr . Vladimir A. Mikhailov

Author: Valeriya O. Khomutova, Saint-Petersburg State University

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Introduction

Nuclotron-based Ion Collider fAcility (NICA) is the new accelerator complex being constructed in Joint Institute for Nuclear Research. General goal of the project is to start experimental study of hot and dense strongly interacting QCD matter and search for possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions.

At the Summer student program 2015 I studied the Nuclotron, its magnetic structure and the problem of orbit distortion. There is a goal to develop an interactive program for correction of the horizontal orbit projection. A further application involves the use of software as a simulator for scientists to conduct virtual experiments.

The magnetic structure of the Nuclotron

One of NICA accelerators – the superconducting synchrotron Nuclotron is used presently for fixed target experiments on extracted beams and experiments with internal target. This program is planned to be developed further and will be complementary to that one to be performed at Collider in heavy ion mode operation. The program includes experimental studies on relativistic nuclear physics, spin physics in few body nuclear systems (with polarized deuterons) and physics of flavors. At the same time, the Nuclotron beams are used for radiobiology and applied researches.

The superconducting heavy ion synchrotron Nuclotron is under operation since March 1993. The Nuclotron ring includes 96 dipoles and 64 quadrupoles. The dipole and quadrupole magnets have iron yokes and coils made of a hollowsuperconductor and cooled with a two-phase helium flow.

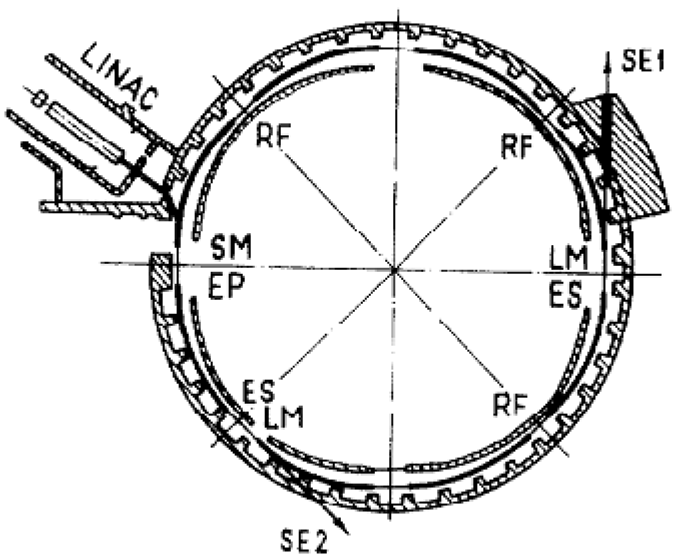


Fig.1. Nuclotron layout (SM —septum-magnet, EP — electrostatic plates, RF — radio-frequency cavity, ES — electrostatic septum, LM — Lambertson magnet).

The selected magnetic structure includes 8 super periods, each of which includes three regular period and a period which does not contain the dipole magnets. Regular period includes focusing and defocusing quadrupole lenses, four dipole magnets and two small free period for posting the multipole correctors and diagnostic equipment. Schems of two types of periods are given on Fig. 2.

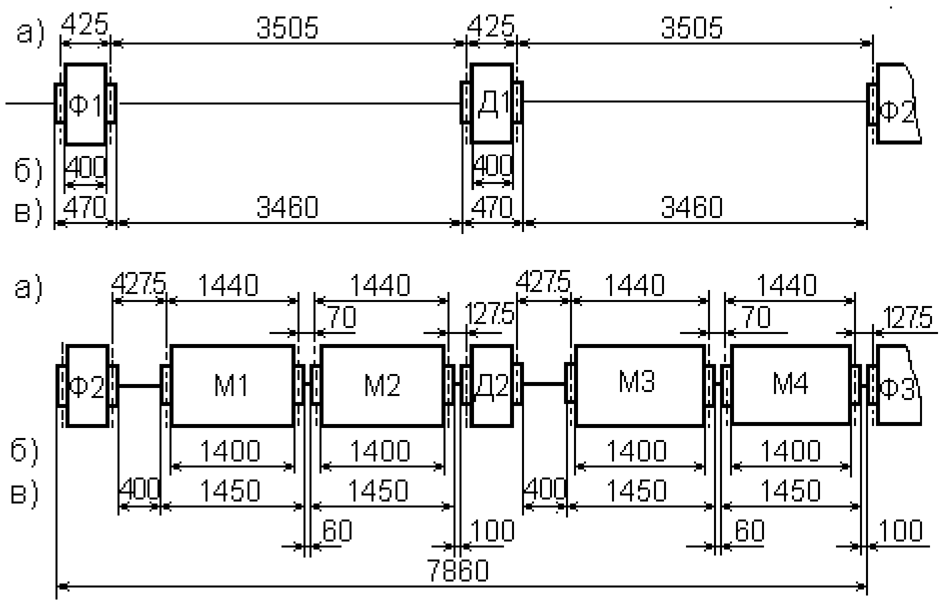


Fig.2 Types of periods.

General scheme of periods of the Nuclotron:

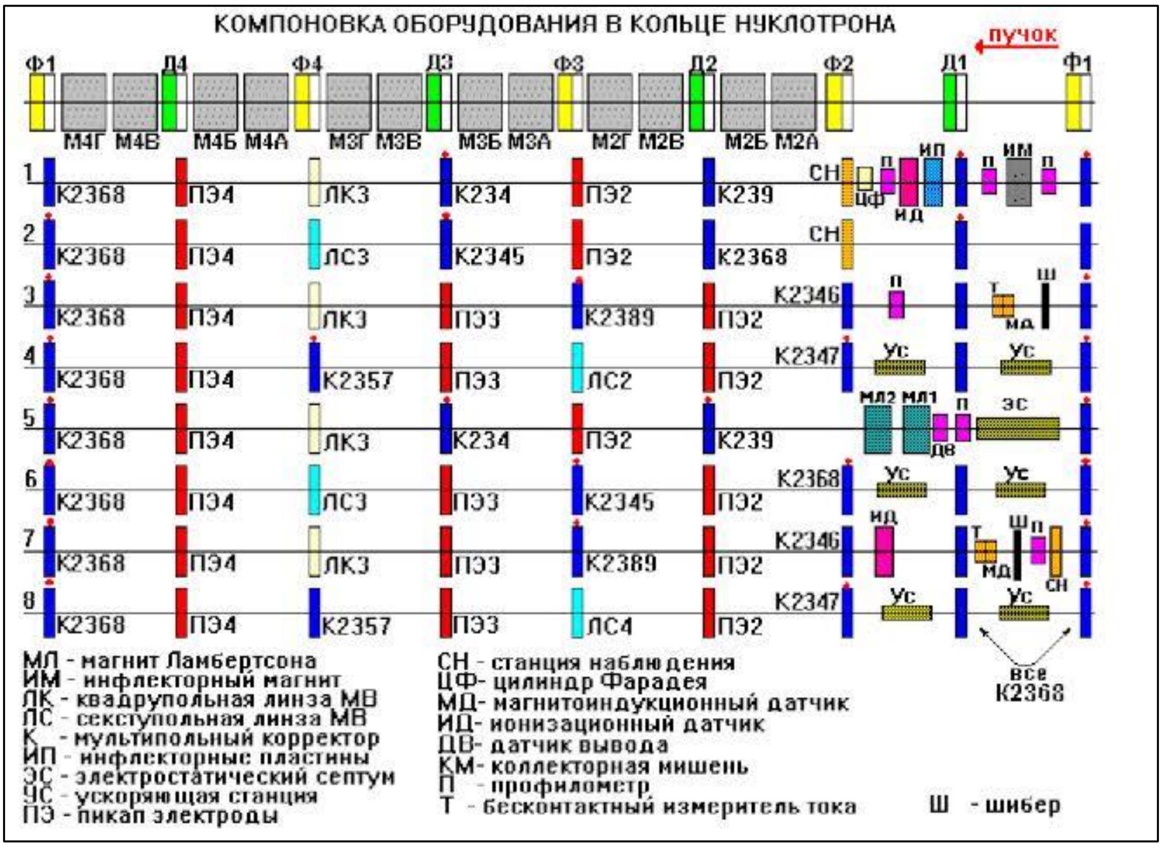


Fig.3. Arrangement of equipment in the ring of the Nuclotron

Orbit

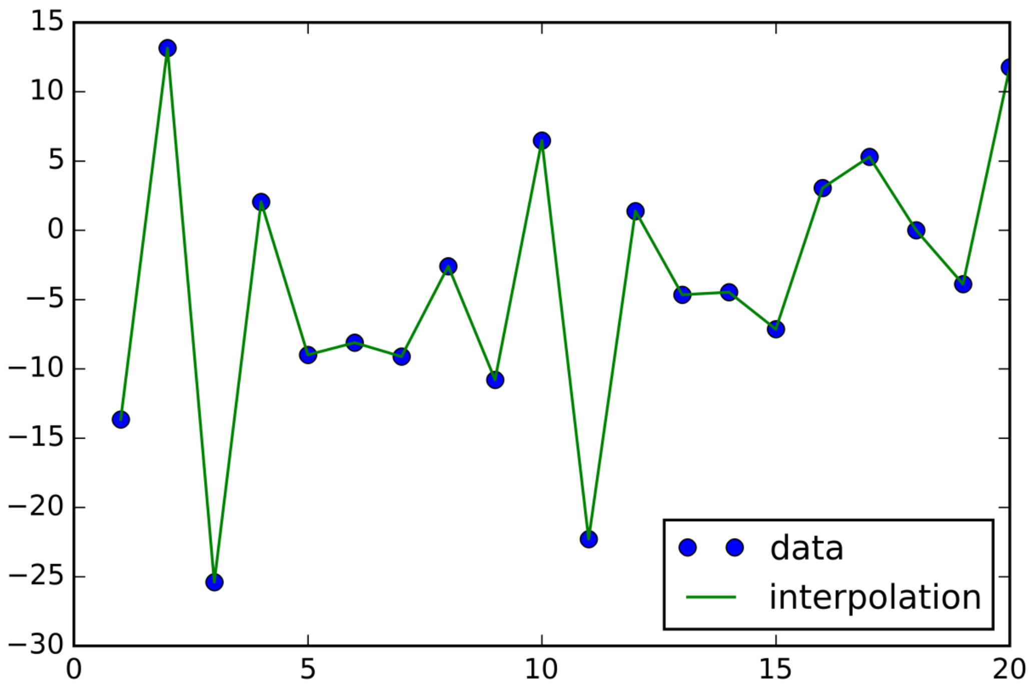
The system used on the Nuclotron is "Orbit". Measurements are made at one or more values of the magnetic field, while not necessarily for all the pickup electrodes. The measurements are processed in «On line» and presented on the monitor, and the values obtained from the processing of orbit at the azimuth pickup electrodes are connected by line segments.

This representation does not give full information on the orbit around the ring of the Nuclotron, in particular, the maximum values of the orbit. In this regard, one of the major open issue is the problem of approximating orbit. Standard methods of approximation and interpolation, applied to this problem, are presented below.

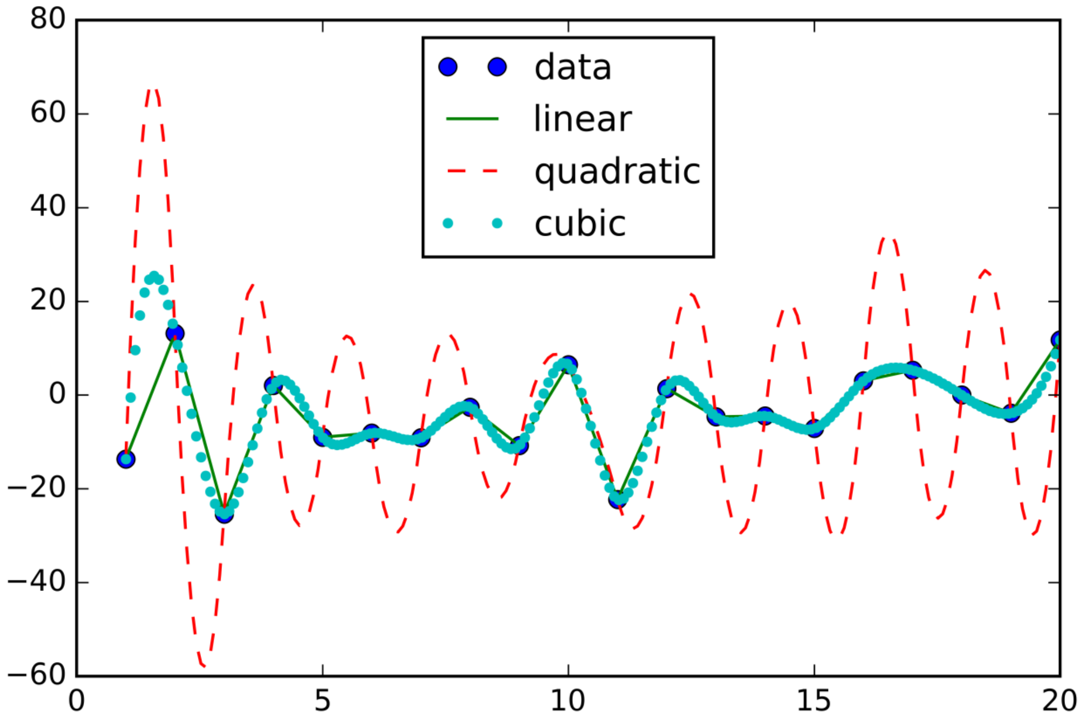
Interpolation

There is taken model input data of future program. Charts are built with Python modules.

- linear

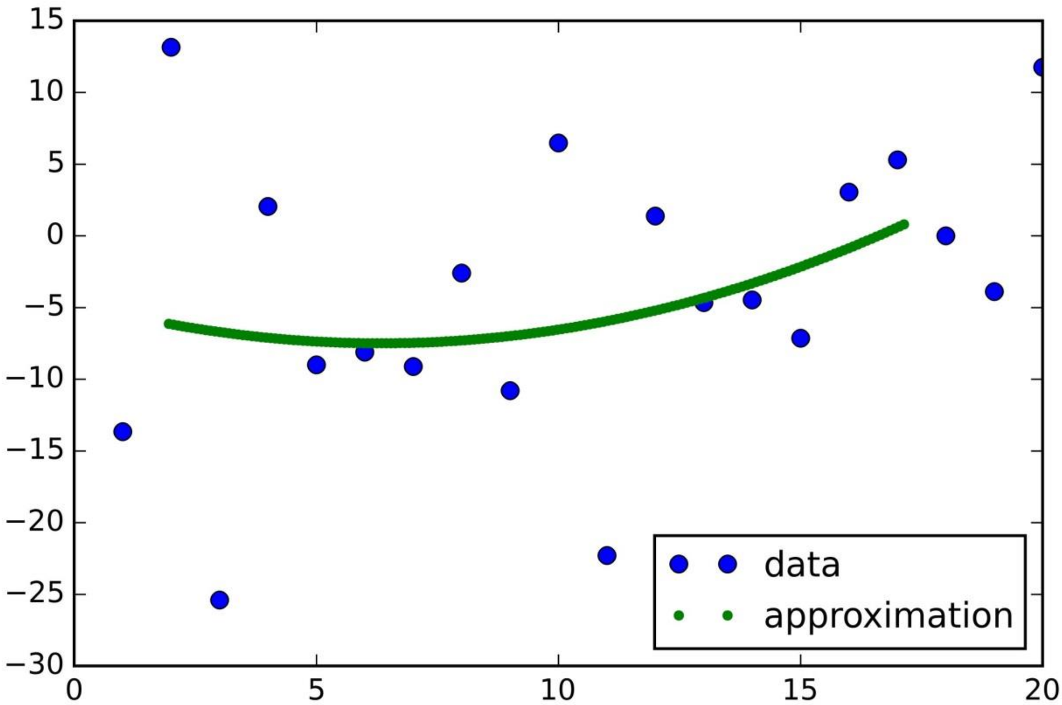


- spline

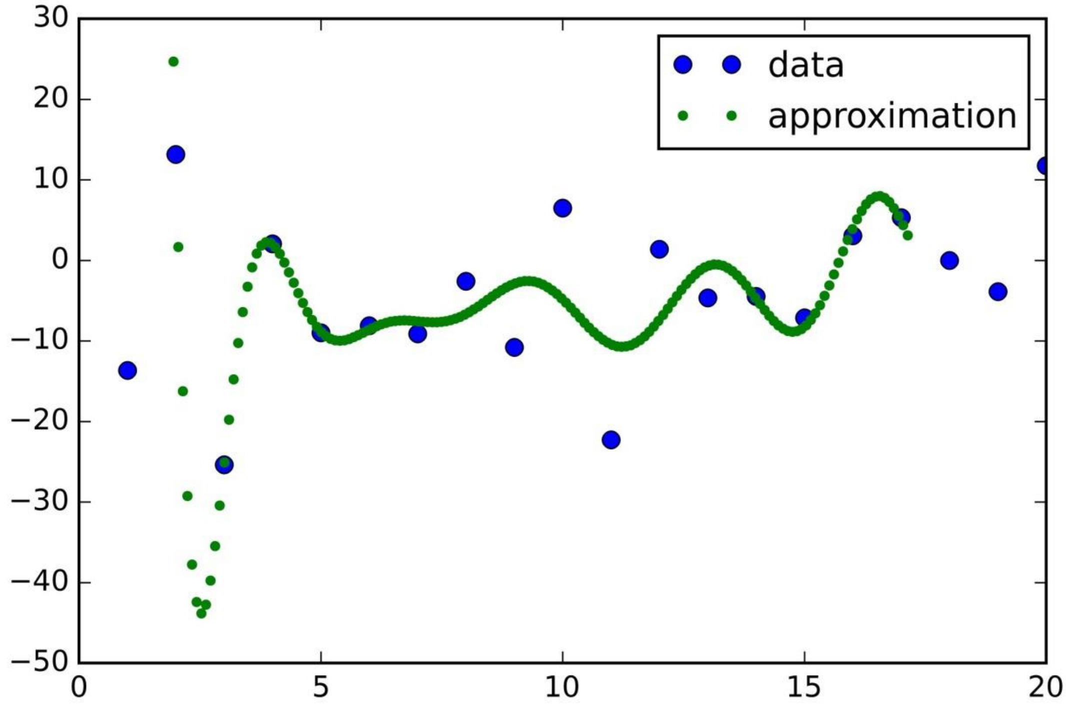


Approximation

- quadratic



- polynomial of the 15th level



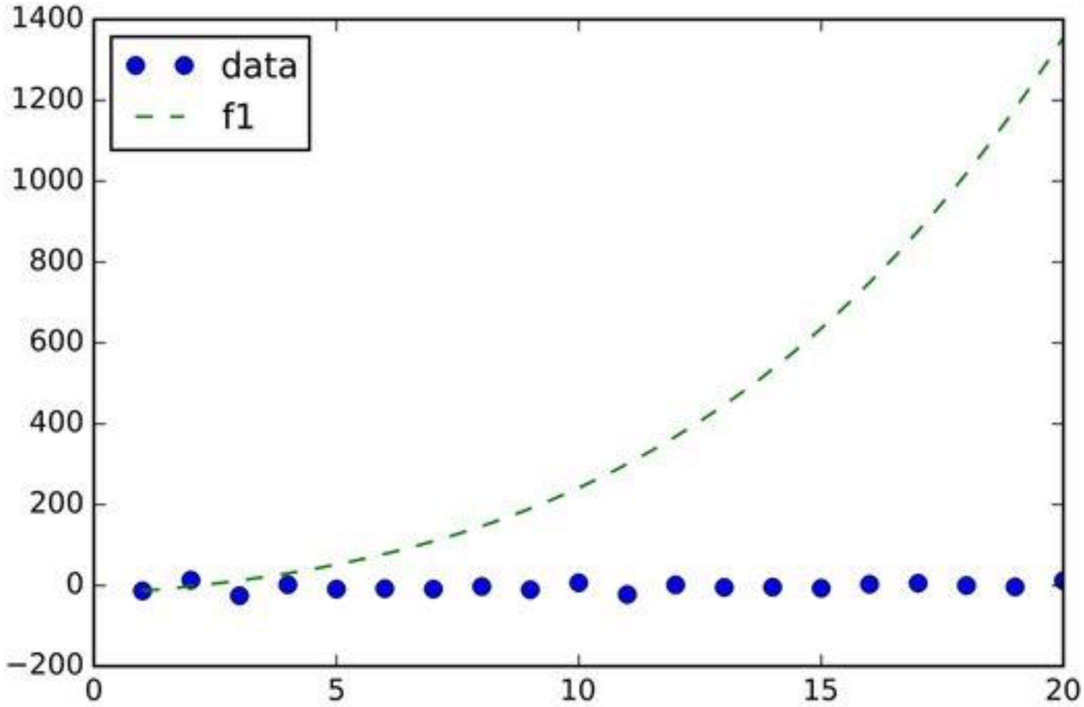
$$4.331e{-10}\,x^{15} - 6.875e{-08}\,x^{14} + 4.966e{-06}\,x^{13} - 0.0002161\,x^{12} + 0.006323\,x^{11} - 0.1314\,x^{10} + 2\,x^{9} - 22.61\,x^{8} + 190.8\,x^{7} - 1197\,x^{6} + 5505\,x^{5} - 1.812e{+04}\,x^{4} + 4.097e{+04}\,x^{3} - 5.94e{+04}\,x^{2} + 4.862e{+04}\,x - 1.656e{+04}$$

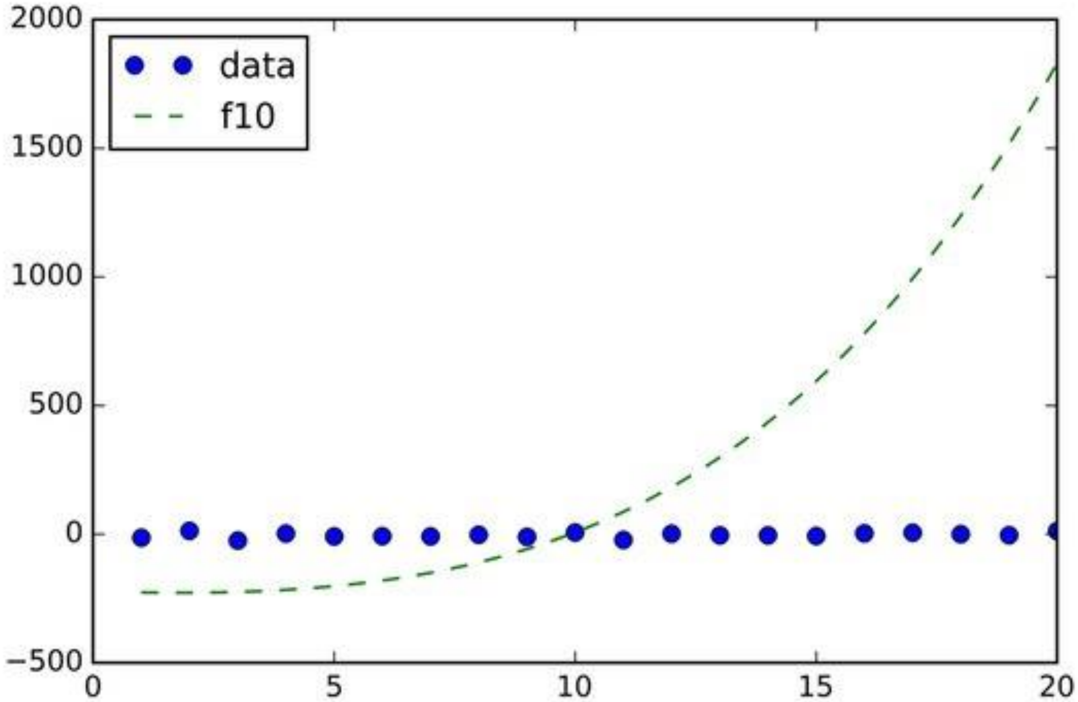
- selection of integrand function f(t)

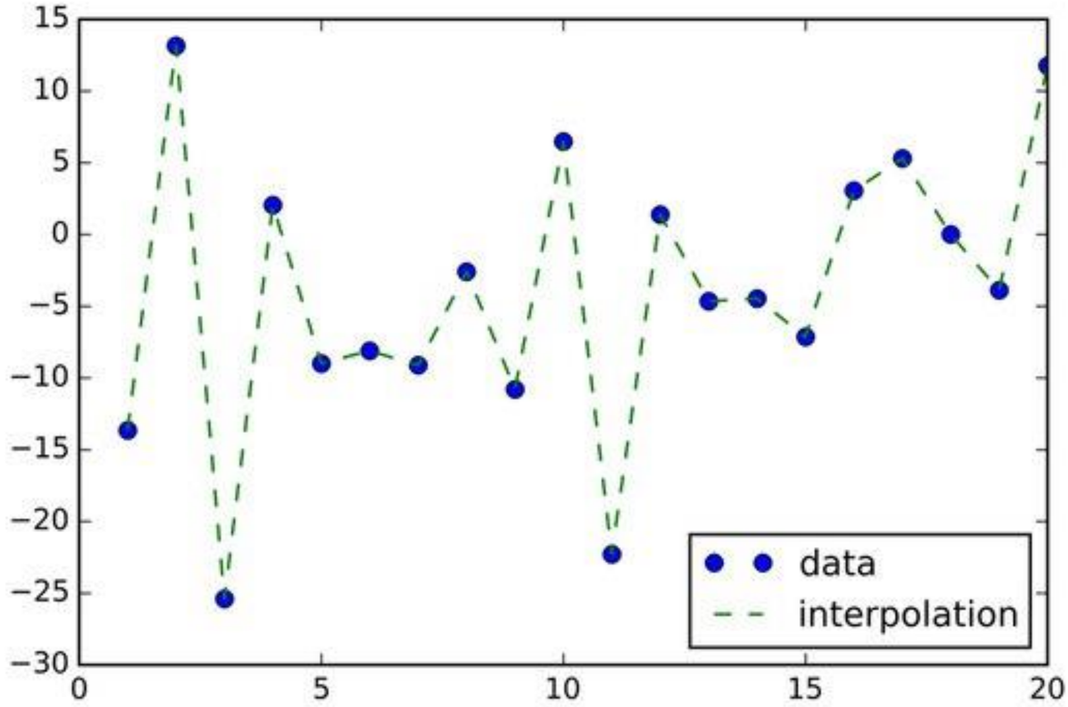
$$\eta_f(\theta) = \frac{\nu}{2\sin\pi\nu}\int_{\theta}^{\theta+2\pi} f(t)\cos\nu(\theta+\pi-t)\,dt$$

Approximation was carried out by a polynomial of 5th levels.

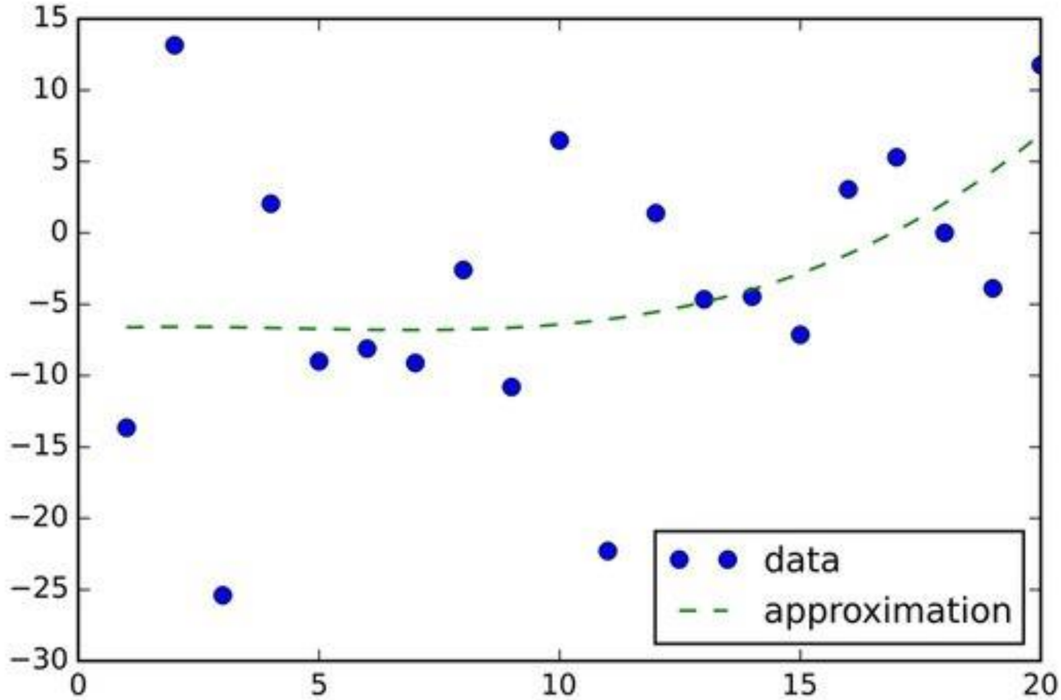
We make selection of coefficients by method of the linear optimization on a gradient vector for each point. T.o. we receive piecewise function which we smooth weight addition.


data
f1
1400
1200
1000
800
600
400
200
0
−200
0
5
10
15
20

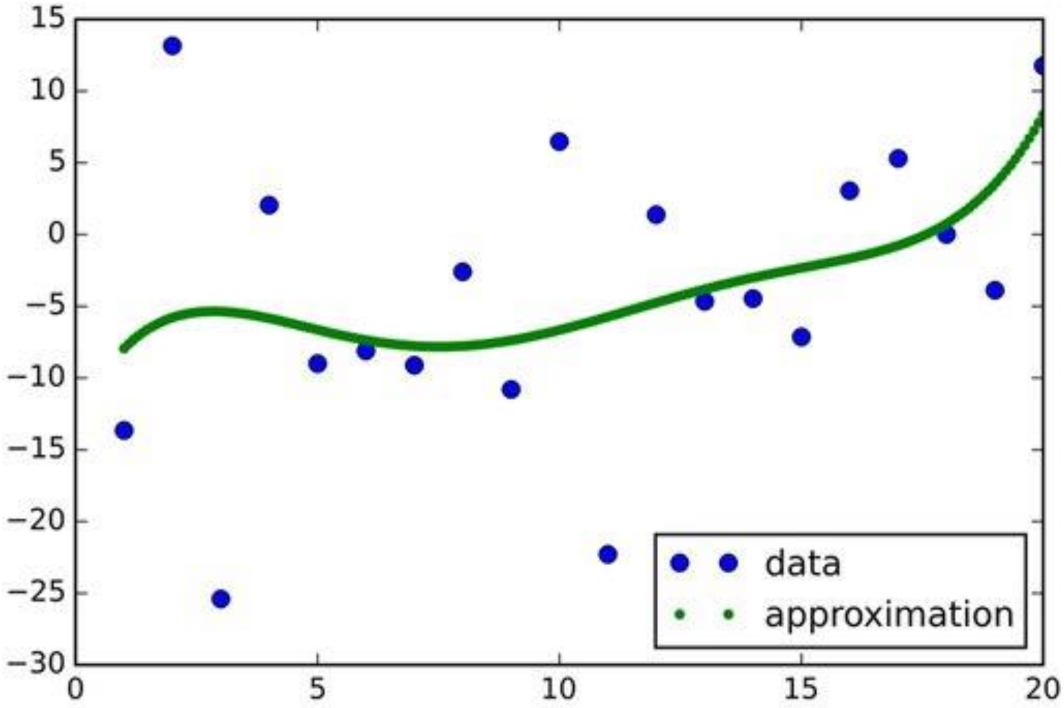

data
f10
2000
1500
1000
500
0
−500
0
5
10
15
20



In addition found the function approximating a set of input points, selection of coefficients for a polynomial of the 5th level.



For comparing the diagram of an approximating polynomial of the 5th level is provided.



Development of the program

Input data

[1] X0.txt — Distortion of an orbit.

[2] File.txt — The data obtained in MADX - values of dynamic functions.

The first three poles in [2]:

* NAME	KEYWORD	S
$ %s	%s	%le
"NUCLOTRON$START"	"MARKER"	0
"DRIFT_0"	"DRIFT"	0.0225
"F11"	"QUADRUPOLE"	0.4475
"DRIFT_1"	"DRIFT"	3.9525
"D11"	"QUADRUPOLE"	4.3775
"DRIFT_1"	"DRIFT"	7.8825
"F21"	"QUADRUPOLE"	8.3075
"DRIFT_2"	"DRIFT"	8.735
"M2A1"	"RBEND"	10.1752606
"DRIFT_3"	"DRIFT"	10.245
"M2B1"	"RBEND"	11.6852606
"DRIFT_4"	"DRIFT"	11.8125
"D21"	"QUADRUPOLE"	12.2375
"DRIFT_2"	"DRIFT"	12.665
"M2V1"	"RBEND"	14.1052606
"DRIFT_3"	"DRIFT"	14.175
"M2G1"	"RBEND"	15.6152606
"DRIFT_4"	"DRIFT"	15.7425
"F31"	"QUADRUPOLE"	16.1675

Poles of dynamic functions values in [2]:

BETX	ALFX	MUX
%le	%le	%le
12.11359507	-2.186430343	0
12.21222601	-2.197167101	0.0002944211161
12.24082755	2.13326402	0.005690660913
2.857504251	0.5438610309	0.106647337
2.863005558	-0.5574146539	0.1309562268
12.39468323	-2.162036894	0.2310736096
12.36699334	2.223903127	0.2364025665
10.55342086	2.01837168	0.2423595852
5.772845715	1.310500884	0.2718749013
5.59234803	1.27767293	0.2738284182
2.906036403	0.5928946901	0.331930132
2.762686773	0.5337188605	0.3390795627
2.765677587	-0.5410873581	0.3642403183
3.313734014	-0.7409159792	0.3867905351
6.433707795	-1.43162494	0.4372397786
6.635694437	-1.464681116	0.4389385413
11.87156958	-2.181231891	0.4648607149
12.43449901	-2.242943657	0.4665275071
12.46791338	2.168287497	0.4718263377

Formulas for calculations

If the Twiss parameters at points s_1, s_2 are ($\boldsymbol{\beta}_1$, $\boldsymbol{\alpha}_1$, $\boldsymbol{\gamma}_1$) and ($\boldsymbol{\beta}_2$, $\boldsymbol{\alpha}_2$, $\boldsymbol{\gamma}_2$), respectively, te 2x2 transfer matrix from s_1 to s_2 can be written as

$$M(s_2|s_1) = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} =$$

$$= \begin{pmatrix} \sqrt{\frac{\beta_2}{\beta_1}}(\cos\Delta\psi + \alpha_1 \sin\Delta\psi) & \sqrt{\beta_1\beta_2}\sin\Delta\psi \\ -\left[\frac{(1+\alpha_1\alpha_2)\sin\Delta\psi + (\alpha_2-\alpha_1)\cos\Delta\psi}{\sqrt{\beta_1\beta_2}}\right] & \sqrt{\frac{\beta_1}{\beta_2}}(\cos\Delta\psi - \alpha_2\sin\Delta\psi) \end{pmatrix},$$

$$\Delta\psi = \psi(s_2) - \psi(s_1)$$

Algorithm

Firstly we change value in the corrector field. By data from the table [2] we calculate a transfer matrix. On it we calculate a bunch deviation in each pickup truck. We sum up the received values with values [1] and we build the plot of dependence x(s).

Output data

New file of misstatement of an orbit of X0_new.txt; plot x (s).

Realization

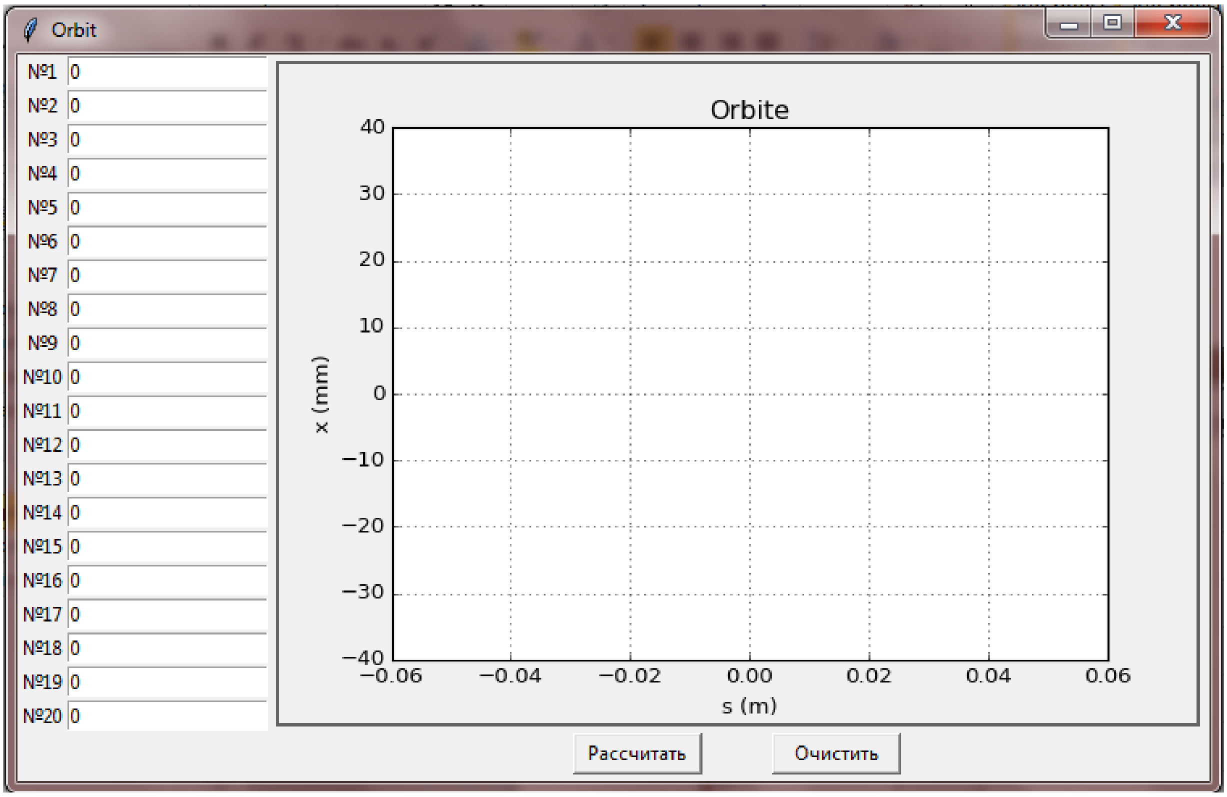
The program is coded on means of Python language.

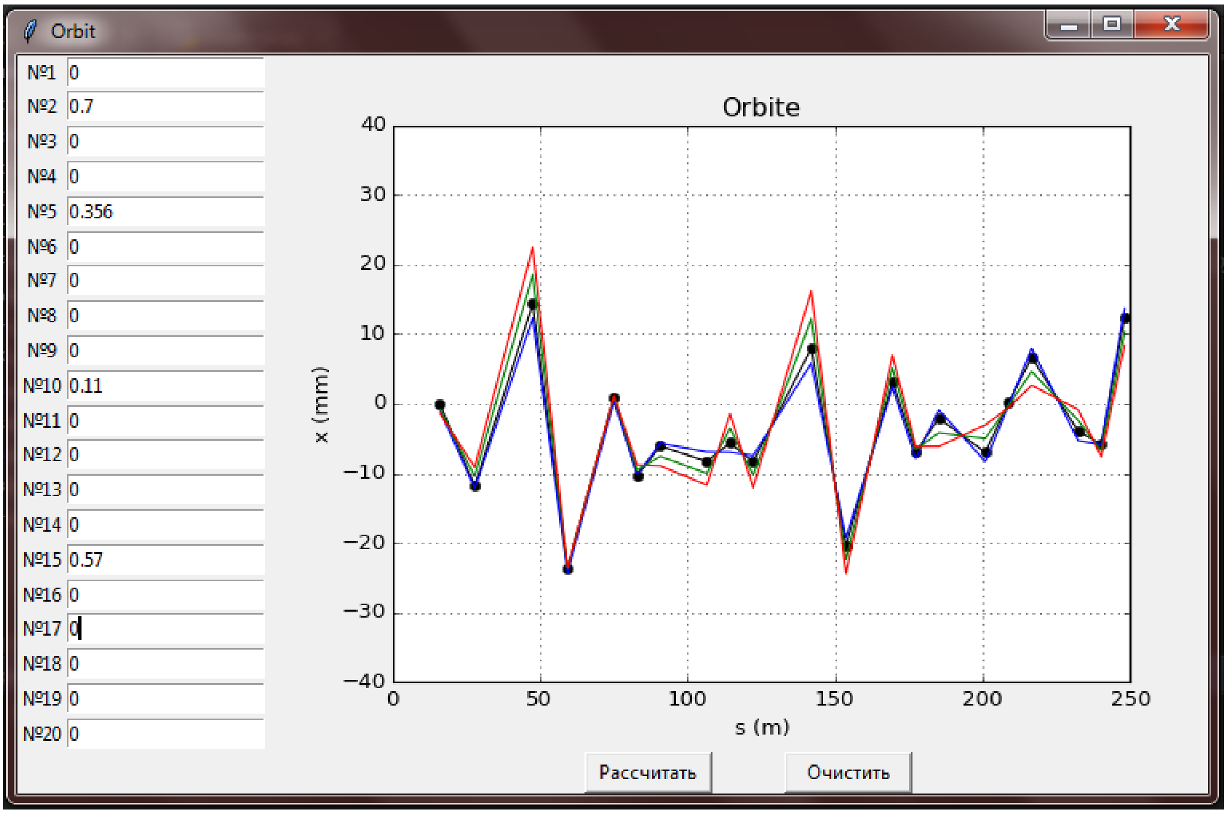
```
class Corrector:
    def __init__(self, n_T=0, s=0.0, betta=0.0, alpha=0.0, mu=0.0):
        self.n_T = n_T
        self.s = s
        self.betta = betta
        self.alpha = alpha
        self.mu = mu
```

```
class Pickup:
    def __init__(self, n_T=0, s=0.0, betta=0.0, mu=0.0, x=0.0):
        self.x = x
        self.mu = mu
        self.betta = betta
        self.s = s
        self.n_T = n_T

    def solve(self, corrector):
        self.x += corrector.alpha * sqrt(self.betta * corrector.betta) * sin(
        self.mu * (2 * pi * 7.4) / self.n_T - corrector.mu * (2 * pi * 7.4) / corrector.n_T)
        return self.x
```

Interface


Orbit
№1 0
№2 0
№3 0
№4 0
№5 0
№6 0
№7 0
№8 0
№9 0
№10 0
№11 0
№12 0
№13 0
№14 0
№15 0
№16 0
№17 0
№18 0
№19 0
№20 0
Orbite
x (mm)
s (m)
Рассчитать
Очистить


Orbit
№1 0
№2 0.7
№3 0
№4 0
№5 0.356
№6 0
№7 0
№8 0
№9 0
№10 0.11
№11 0
№12 0
№13 0
№14 0
№15 0.57
№16 0
№17 0
№18 0
№19 0
№20 0
Orbite
x (mm)
s (m)
Рассчитать
Очистить

Conclusions

On the Summer Student Program I got a valuable work experience, it is a lot of knowledge. I will continue to be engaged in this task and to work with supervisors. Plan is to improve the interface of the program and to try to find a method of the best approximation of function of an orbit.

Results of practice:

- ✓ The magnetic structure of a Nuclotron was studied.
- ✓ The analysis of measurements of misstatement of an orbit is made.
- ✓ The practice programmed in language a python is received.
- ✓ The interactive program of Nuclotron orbit correction manually is created.

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