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**AUTOMATED CONTROL SYSTEM (ACS)  
FOR SMITH–GARREN (SG) CURVES MEASUREMENT**

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Автоматизированная система управления (АСУ) для измерения кривых Смита–Гаррена (СГ)

Кривые Смита–Гаррена (СГ) — это зависимость тока пучка от тока в главной катушке изохронного циклотрона. Кривые СГ используются для расчета фазового движения ускоряемых частиц в абсолютных и относительных значениях с последующим расчетом фазоэнергетического интеграла. Результаты расчетов динамики пучка используются для коррекции среднего магнитного поля до изохронного с точностью лучшей, чем  $\pm 3$  Гс, с последующим определением оптимального значения тока главной катушки и расчетом эффективности вывода ускоренного пучка.

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Automated Control System (ACS) for Smith–Garren (SG) Curves Measurement

The Smith–Garren (SG) curve is dependence of beam current on the main coil's current for different radii in an isochronous cyclotron. The SG curves are used for calculation of phase motion of accelerated particles in absolute and relative values followed by calculation of phase-energy integral. The results of beam dynamics calculations are used for correction of mean magnetic field to the isochronous one with accuracy better than  $\pm 3$  G followed by detection of an optimal value of the main coil's current, and for calculation of extraction efficiency of accelerated beam.

The investigation has been performed at the Laboratory of Information Technologies and the Dzheleпов Laboratory of Nuclear Problems, JINR.

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## INTRODUCTION

The Smith–Garren (SG) curve is dependence of beam current on the main coil’s current for different radii in an isochronous cyclotron. The SG curves are used for calculation of phase motion of accelerated particles in absolute and relative values followed by calculation of phase-energy integral. The results of beam dynamics calculations are used for correction of mean magnetic field to the isochronous one with accuracy better than  $\pm 3$  G followed by detection of an optimal value of the main coil’s current, and for calculation of extraction efficiency of accelerated beam. This article presents the main principles of building and algorithms of operating of ACS for measuring SG curves for the AIC-144 multi-purpose isochronous cyclotron [1] located at the INP of PAS (Krakow, Poland). This cyclotron is used for proton therapy of eye’s melanoma (as reserved cyclotron) and for executing of physical experiments. The main operating mode of the AIC-144 cyclotron is acceleration of protons with kinetic energy of particle extraction:  $E_k \sim 60.7$  MeV. The control part of ACS is the SG Curves Measurement Program 2014–2019. The communication between PC (personal computer) and PS (power supply) is realized through Ethernet network with the help of MOXA NPort 5150 Server. This server allows using a virtual serial port for programming.

The AIC-144 cyclotron is “warm” cyclotron. Similar ACS for measuring SG curves with accounting of “quench” state was developed for the SC-200 superconducting isochronous cyclotron [2], which is designed at the Institute of Plasma Physics of the Chinese Academy of Sciences (IPP CAS) (Hefei, China). The SG Curves Measurement Program II 2018–2019 was developed for the SC-200 cyclotron and successfully tested with beam emulator at low currents of the main coil at the end of 2018. In this variant, the communication between PC and PS is realized through Ethernet network directly on the basis of use of MS Windows Sockets technology. The SG Curves Measurement Program 2014–2019 and SG Curves Measurement Program II 2018–2019 were developed in the framework of technology of Parallel Computations.

The next description of the structure of ACS is provided for the AIC-144 cyclotron.

## 1. STRUCTURE OF ACS

The structure of ACS is presented in kind of a block-diagram in Fig. 1. The development environment is MS Visual Studio 2010 and MS Visual Studio 2017. The standard of the SG Curves Measurement Program 2014–2019 is Single Document Interface (SDI). The driver for serial port control was developed on the basis of use of Windows API functions. The C++ language is used for programming of the driver and program interface. The specialized languages are used for programming of the power supply (PS) and pico-ammeter (PA).

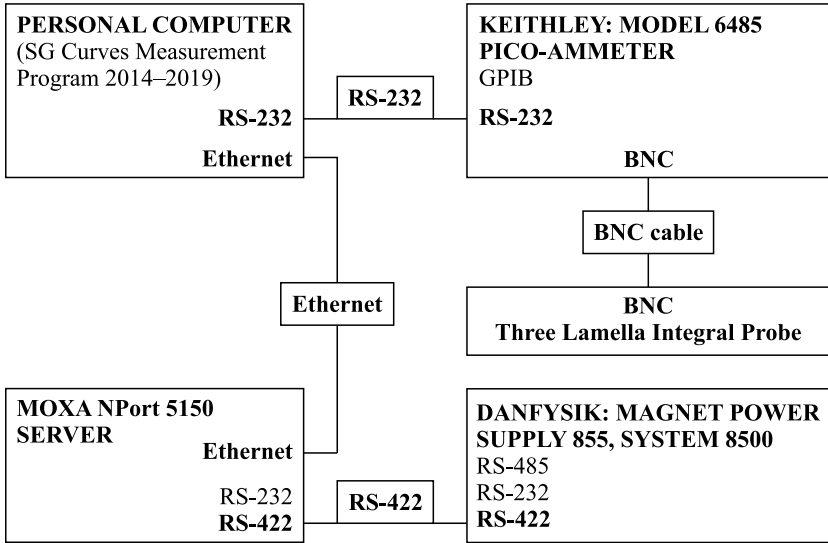


Fig. 1. Block-diagram of ACS

## 2. COMMUNICATION PARAMETERS

1) Interface EtherNet/RS-422 between PC (personal computer) & PS (power supply) through virtual serial port (Moxa Technology Inc.: NPort Administrator-COM Mapping Program):

- |   |         |
|---|---------|
| • Line Type (Local, Remote):                | Remote  |
| • Line Address (0–255):                     | 2       |
| • FIFO (Enable, Disable):                   | Enabled |
| • Port Number (Virtual Serial Port Number): | COMX    |
| • Baud Rate (1200, 2400, . . . , 115 200):  | 9600    |
| • Data Bits (7 or 8):                       | 8       |
| • Stop Bits:                                | 1       |

- Parity (None, Odd, Even): None
- Flow Control (None, X\_ON/X\_OFF): None
- Terminator (command): CR

2) Interface USB/RS-232 between PC (personal computer) & PA (picammeter) through real serial port:

- Port Number (Real Serial Port Number): COMX
- Baud Rate (300, 600, . . . , 57 600): 9600
- Data Bits (7 or 8): 8
- Stop Bits: 1
- Parity (None, Even, Odd): None
- Flow Control (None, X\_ON/X\_OFF): None
- Terminator (command): CR

The communication mode is synchronous. The time delay after sending command to PS is 200 ms.

### **3. OPERATING ALGORITHMS OF THE SG CURVES MEASUREMENT PROGRAM 2014–2019**

The calibration curve of the AIC-144 cyclotron is dependence of induction of magnetic field on the main coil's current in the center of the cyclotron. The calibration curve is measured according to hysteresis loop in the direction from maximal to minimal level of the main coil's current. According to the calibration curve measured for the AIC-144 cyclotron, the three ranges of changing main coil's current were determined. The corresponding rate of changing main coil's current was selected for each range. The values of rate are determined by conditions of safety operation with magnetic elements of different systems of the AIC-144 cyclotron. The ranges and corresponding rates of changing main coil's current are presented in the Table.

**The ranges and corresponding rates of changing main coil's current**

No.	$I_{mc}$ range, A	$dI_{mc,rate}$ , A/s
1	0–75	2
2	75–300	5
3	300–650	10

In the first and the second ranges, the rate of changing induction of the magnetic field is less than 200 G/s and in the third range — less than 100 G/s. When measuring SG curves, the reaction rate of the magnetic system on changing main coil's current must be taken into account. The corresponding time delays must be introduced. The numbering of the block-diagram elements cor-

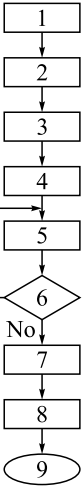


Fig. 2. Program algorithm

responds to the numbering of the positions in the descriptions of the algorithms. If necessary, the descriptions of the algorithms are presented in C++ terms.

**3.1. Program Algorithm.** The program algorithm of measuring SG curves is presented in Fig. 2. The program interface for measuring SG curves is presented in Fig. 5 (Dialog No. 2).

1. Starting the program and input of the source data: virtual and real COM port numbers for communication with PS and PA; terminators of control commands; address of PS; user commentary; path of the source data file with the ranges of changing main coil's current depending on the radius (Dialog No. 1).

2. Determination of the common parameters of SG curve measurement: turning on/off of possibility for taking into account the stability of beam current ( $I_b$  Stability control); determination of maximally allowed instability of beam current ( $dI_{b,max}$  (nA)); determination of direction of changing main coil's current ( $I_{mc,min} \rightarrow I_{mc,max}$ ); selection of limit of beam current measurements ( $I_b$  Diapason (nA)); determination of coefficients to calculate the time delays: after setting an initial value and

next value of current of the main coil (for taking into account the slowed-down reaction of the magnetic system on changing main coil's current) ( $K_{set}$  (s/A),  $K_{msr}$  (s/A)); setting radius of the probe location ( $Radius$  (m)); setting bottom and upper boundaries of changing main coil's current at the certain radius of the probe location ( $I_{mc,min}$  (A),  $I_{mc,max}$  (A),  $Set dI_{mc}$  (R)); *SG Curve Point Number* (Dialog No. 2).

3. Communications to PS and PA and initializations of PS and PA (*Start PS, Start/Restart PA*) (Dialog No. 2). Determination of the communication parameters for virtual and real serial ports: baud rate, data bits, stop bits, parity selection, flow control (Dialogs No. 3 and 4).

4. Setting an optimal value of main coil's current ( $I_{mc}$  (A), *Set  $I_{mc}$* ) (Dialog No. 2).

5. Measuring SG curve (*Measure...*); indication of the measured values: installed current of the main coil ( $I_{mc,set}$  (A)), measured current of the main coil ( $I_{mc,msd}$  (A)), measured current of beam ( $I_b$  (A)), time of measurement (*TimeStamp* (s)), status of the PA (*PA Status:*), status of the PS (*PS Status:*), absolute and relative errors of measurement of beam current ( $dI_b$  (nA),  $\sigma I_b$  (%)); plotting a measured curve's graph; optional saving of intermediate results of measurements in kind of ASCII file (*Save As...*) (Dialog No. 2) (the SG curve measurement algorithm).

6. Next measurement?

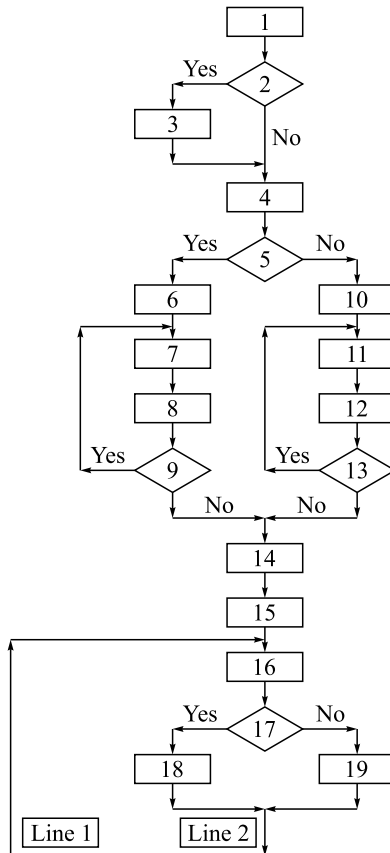
7. Setting main coil's current to zero ( $I_{mc}$  (A), *Set  $I_{mc}$* ) (Dialog No. 2).

8. Exit from the dialog (*Exit*) (Dialog No.2). Browsing of graphs of the measured curves in arbitrary order. Saving of the measured values in kind of binary and/or ASCII files.

9. Exit from the program.

**3.2. The SG Curve Measurement Algorithm.** The SG curve measurement algorithm is presented in Fig. 3.

1. Select:  $I_b$  diapason (nA):.
2. New range?
3. Setting new range.
4. Calculate:  $dI_{mc} = \frac{I_{mc,max} - I_{mc,min}}{N_{SGCP} - 1}$ .
5.  $I_{mc,min} \rightarrow I_{mc,max}$ ?
6.  $i = 0, I_{mc, wrk, i} = I_{mc,min}$ .
7. Calculate:  $I_{mc, wrk, i+1} = I_{mc, wrk, i} + dI_{mc}$ .



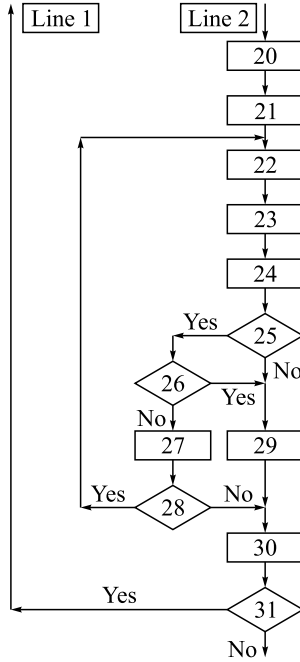


Fig. 3. The SG curve measurement algorithm

8.  $i = i + 1$ .
9.  $(i + 1) < N_{\text{SGCP}}$ ?
10.  $i = 0$ ,  $I_{\text{mc, wrk}, i} = I_{\text{mc, max}}$ .
11. Calculate:  $I_{\text{mc, wrk}, i+1} = I_{\text{mc, wrk}, i} - dI_{\text{mc}}$ .
12.  $i = i + 1$ .
13.  $(i + 1) < N_{\text{SGCP}}$ ?
14.  $i = 0$ ,  $j = 0$ .
15. Measure:  $I_{\text{mc, set}, j}$ ,  $I_{\text{mc, msd}, j}$ ,  $I_{b, j}$ .
16. Set:  $I_{\text{mc, wrk}, i}$  (algorithm of setting main coil's current).
17.  $i == 0$ ?
18. Set:  $T_d = K_{\text{set}} |I_{\text{mc, set}, j} - I_{\text{mc, wrk}, i}|$ , s.
19. Set:  $T_d = K_{\text{msr}} |I_{\text{mc, set}, j} - I_{\text{mc, wrk}, i}|$ , s.
20.  $j = j + 1$ ;  $j_{\text{max}} = j + N_{\text{max}}$ .
21. Measure:  $I_{\text{mc, set}, j}$ ,  $I_{\text{mc, msd}, j}$ ,  $I_{b, j}$ .
22. Set:  $T_d = 1$  s.
23. Measure:  $I_{\text{mc, set}, j+1}$ ,  $I_{\text{mc, msd}, j+1}$ ,  $I_{b, j+1}$ .



24. Calculate:

$$dI_{b,j+1} = |I_{b,j} - I_{b,j+1}|;$$

$$\sigma I_{b,j+1} = \frac{dI_{b,j+1}}{I_{b,j+1}} \cdot 100.$$

25. Is stability of beam current taken into account?

$$26. dI_{b,j+1} \leq dI_{b,\max}?$$

$$27. j = j + 1.$$

$$28. j < j_{\max}?$$

$$29. j = j + 1.$$

$$30. i = i + 1.$$

$$31. i < N_{\text{SGCP}}?$$

Where  $I_{\text{mc,min}}$ ,  $I_{\text{mc,max}}$ ,  $I_{\text{mc,wrk}}$ ,  $I_{\text{mc,set}}$ ,  $I_{\text{mc,msd}}$  are two limits of range of changing main coil's current, operating, installed and measured main coil's currents,  $N_{\text{SGCP}}$  is SG curve point number,  $dI_{\text{mc}}$  is step of changing main coil's current,  $I_b$  is beam current,  $T_d$  is time delay,  $K_{\text{set}}$ ,  $K_{\text{msr}}$  are coefficients for calculation of time delays after setting an initial value and next value of current of the main coil,  $dI_b$ ,  $\sigma I_b$  are absolute and relative errors of measurement,  $dI_{b,\max}$  is maximally allowed instability of beam current,  $N_{\max}$  is maximal number of iterations.

As the main coil of the SC-200 cyclotron is superconducting, the process of measuring current of the main coil has effects on the measured value. For this reason, the process of measuring main coil's current is repeated with time delay equal to 1 s until:  $|I_{\text{mc,msd,prv}} - I_{\text{mc,msd,next}}| \leq \varepsilon$ , where  $I_{\text{mc,msd,prv}}$ ,  $I_{\text{mc,msd,next}}$  are previous and next measured values of the main coil's current and  $\varepsilon$  is maximally allowed absolute error of measuring main coil's current. Only after achievement of this condition, beam current value is measured.

**3.3. Algorithm of Setting Main Coil's Current.** The total range of changing main coil's current is divided into three subranges with the following limits:  $I_{\text{mc,lim,0}} = 0$  A,  $I_{\text{mc,lim,1}} = 75$  A,  $I_{\text{mc,lim,2}} = 300$  A,  $I_{\text{mc,lim,3}} = 650$  A. The corresponding rates of changing main coil's current are  $dI_{\text{mc,rate,0}} = 2$  A/s,  $dI_{\text{mc,rate,1}} = 5$  A/s,  $dI_{\text{mc,rate,2}} = 10$  A/s (see the Table). Two sets of subintervals, where each set consists of three subintervals, exist. If the first subinterval is from the first set and the second subinterval is from the second set, the number of such combinations of pairs of subintervals is:  $N = C_6^2 - 2C_3^2 = 9$ , where  $C_n^m = n!/(m! \cdot (n - m)!)$  is number of all combinations from  $n$  elements by  $m$ . In other words, if installed current of the main coil is from the first set and operating current of the main coil is from the second set, we have to take into account nine variants of work. The rate of changing main coil's current is set from a few commands. This approach is used for the power supply of the AIC-144 cyclotron (DANFYSIK: Magnet Power Supply 855, System 8500). For clarity, the considered algorithm assumes setting rate by one command. This approach

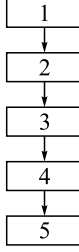


Fig. 4. The main part of the algorithm of setting main coil's current

is used for the power supply of the SC-200 cyclotron (SigmaPhi: Magnet Power Supply System PSSYS +/-50/175).

The main part of the algorithm of setting main coil's current is presented in Fig. 4.

1. Set:  $dI_{mc, rate}$ .

2. Set:  $I_{mc}$ .

3. Calculate:

$$dI_{mc} = |I_{mc} - I_{mc, prv}|;$$

$$dT = \frac{dI_{mc}}{dI_{mc, rate}}.$$

4. Set:  $dT$ .

5. Get:  $I_{mc, set}$ ;  $I_{mc, msd}$ .

This is standard block of commands (BOC). It is included in the description of the variants of work. The variants of work of the SG Curves Measurement Program 2014–2019 are given below.

1. If  $((I_{mc, lim, 0} \leq I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 1}) \&\& (I_{mc, lim, 0} \leq I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 1}))$

$dI_{mc, rate} = dI_{mc, rate, 0}$ ;  $I_{mc} = I_{mc, wrk}$ ;  $I_{mc, prv} = I_{mc, set}$ ; BOC.

2. If  $((I_{mc, lim, 0} \leq I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 1}) \&\& (I_{mc, lim, 1} < I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 2}))$

$dI_{mc, rate} = dI_{mc, rate, 0}$ ;  $I_{mc} = I_{mc, lim, 1}$ ;  $I_{mc, prv} = I_{mc, set}$ ; BOC.

$dI_{mc, rate} = dI_{mc, rate, 1}$ ;  $I_{mc} = I_{mc, wrk}$ ;  $I_{mc, prv} = I_{mc, lim, 1}$ ; BOC.

3. If  $((I_{mc, lim, 0} \leq I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 1}) \&\& (I_{mc, lim, 2} < I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 3}))$

$dI_{mc, rate} = dI_{mc, rate, 0}$ ;  $I_{mc} = I_{mc, lim, 1}$ ;  $I_{mc, prv} = I_{mc, set}$ ; BOC.

$dI_{mc, rate} = dI_{mc, rate, 1}$ ;  $I_{mc} = I_{mc, lim, 2}$ ;  $I_{mc, prv} = I_{mc, lim, 1}$ ; BOC.

$dI_{mc, rate} = dI_{mc, rate, 2}$ ;  $I_{mc} = I_{mc, wrk}$ ;  $I_{mc, prv} = I_{mc, lim, 2}$ ; BOC.

4. If  $((I_{mc, lim, 1} < I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 2}) \&\& (I_{mc, lim, 0} \leq I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 1}))$

$dI_{mc, rate} = dI_{mc, rate, 1}$ ;  $I_{mc} = I_{mc, lim, 1}$ ;  $I_{mc, prv} = I_{mc, set}$ ; BOC.

$dI_{mc, rate} = dI_{mc, rate, 0}$ ;  $I_{mc} = I_{mc, wrk}$ ;  $I_{mc, prv} = I_{mc, lim, 1}$ ; BOC.

5. If  $((I_{mc, lim, 1} < I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 2}) \&\& (I_{mc, lim, 1} < I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 2}))$

$dI_{mc, rate} = dI_{mc, rate, 1}; I_{mc} = I_{mc, wrk}; I_{mc, prv} = I_{mc, set};$  BOC.

6. If  $((I_{mc, lim, 1} < I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 2}) \&\& (I_{mc, lim, 2} < I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 3}))$

$dI_{mc, rate} = dI_{mc, rate, 1}; I_{mc} = I_{mc, lim, 2}; I_{mc, prv} = I_{mc, set};$  BOC.

$dI_{mc, rate} = dI_{mc, rate, 2}; I_{mc} = I_{mc, wrk}; I_{mc, prv} = I_{mc, lim, 2};$  BOC.

7. If  $((I_{mc, lim, 2} < I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 3}) \&\& (I_{mc, lim, 0} \leq I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 1}))$

$dI_{mc, rate} = dI_{mc, rate, 2}; I_{mc} = I_{mc, lim, 2}; I_{mc, prv} = I_{mc, set};$  BOC.

$dI_{mc, rate} = dI_{mc, rate, 1}; I_{mc} = I_{mc, lim, 1}; I_{mc, prv} = I_{mc, lim, 2};$  BOC.

$dI_{mc, rate} = dI_{mc, rate, 0}; I_{mc} = I_{mc, wrk}; I_{mc, prv} = I_{mc, lim, 1};$  BOC.

8. If  $((I_{mc, lim, 2} < I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 3}) \&\& (I_{mc, lim, 1} < I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 2}))$

$dI_{mc, rate} = dI_{mc, rate, 2}; I_{mc} = I_{mc, lim, 2}; I_{mc, prv} = I_{mc, set};$  BOC.

$dI_{mc, rate} = dI_{mc, rate, 1}; I_{mc} = I_{mc, wrk}; I_{mc, prv} = I_{mc, lim, 2};$  BOC.

9. If  $((I_{mc, lim, 2} < I_{mc, set}) \&\& (I_{mc, set} \leq I_{mc, lim, 3}) \&\& (I_{mc, lim, 2} < I_{mc, wrk}) \&\& (I_{mc, wrk} \leq I_{mc, lim, 3}))$

$dI_{mc, rate} = dI_{mc, rate, 2}; I_{mc} = I_{mc, wrk}; I_{mc, prv} = I_{mc, set};$  BOC.

Where  $dI_{mc, rate}$  is rate of changing main coil's current,  $I_{mc}$ ,  $I_{mc, prv}$  are required and previous main coil's currents.  $dI_{mc}$ ,  $dT$  are difference of currents of the main coil and time delay.  $I_{mc, set}$ ,  $I_{mc, msd}$ ,  $I_{mc, wrk}$  are installed, measured and operating currents of the main coil.

#### 4. PROGRAM INTERFACE AND EXPERIMENT RESULTS

The ACS for measuring SG curves was integrated into common ACS of the AIC-144 cyclotron. The program interface for measuring SG curves is presented in Fig. 5 (Dialog No. 2). The description of the main positions of Dialog No. 2 was given above (see Sec. 3, subsec. 3.1). The SG curves measured for the main operating mode of the AIC-144 cyclotron are presented in Fig. 6. Measured SG curves are used for the beam dynamics calculations, namely, phase motion of particles in absolute [3] and relative [4] values. The calculation of phase motion in relative values can be performed on the basis of use of equations of motion, which describe closed equilibrium orbits [5].

Value  $I_{mc, msd} = 592.235$  A is the optimal value of the main coil's current. It provides maximal efficiency of extraction of the proton beam. The most internal curve was measured at the largest radius of the probe location. The range of changing main coil's current is reduced with growth of the radius values. The profile of the extracted beam in the beginning of the beam transportation line (after the first correction magnet) for the main operating mode of the AIC-144

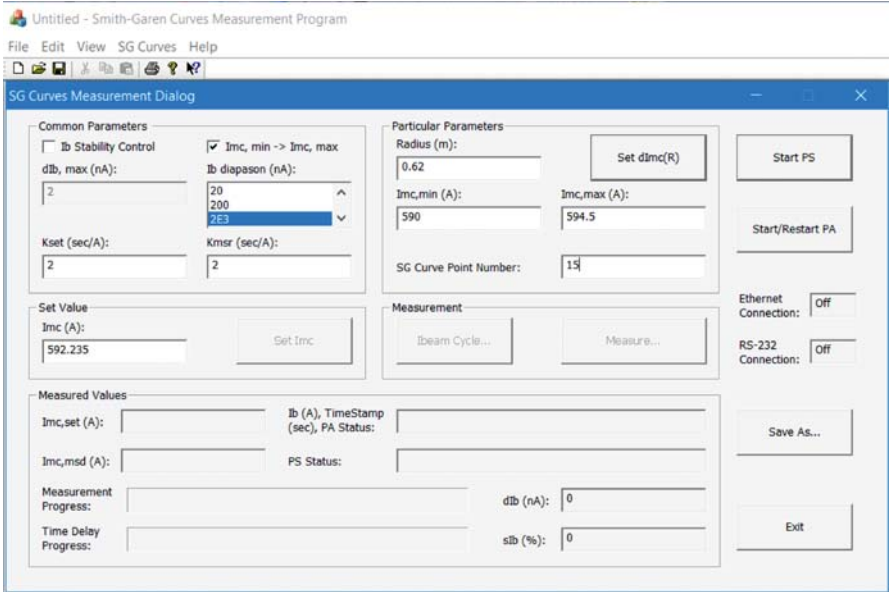


Fig. 5. Dialog 2: Program interface for measuring SG curves

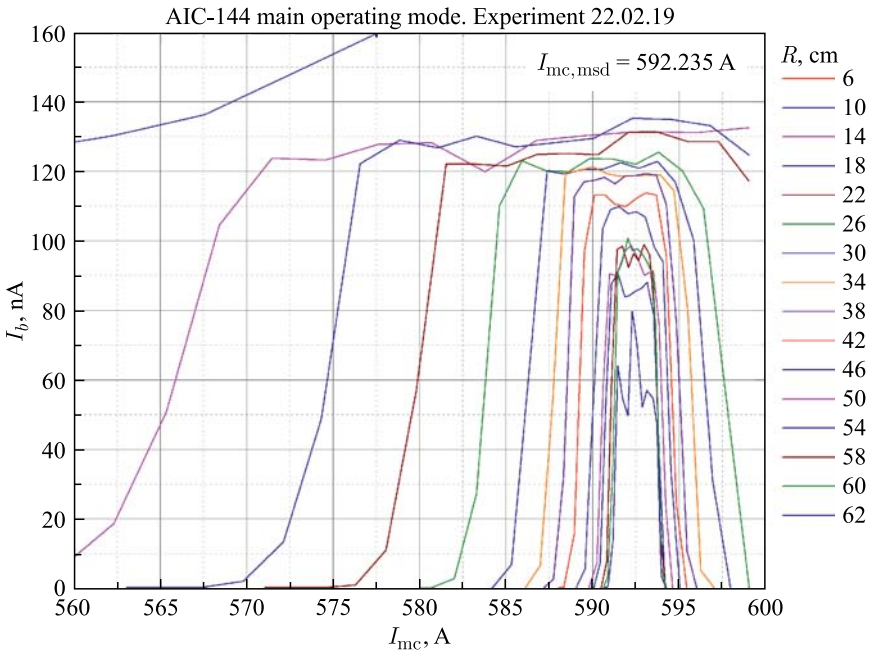


Fig. 6. Measured SG curves for the main operating mode of the AIC-144 cyclotron

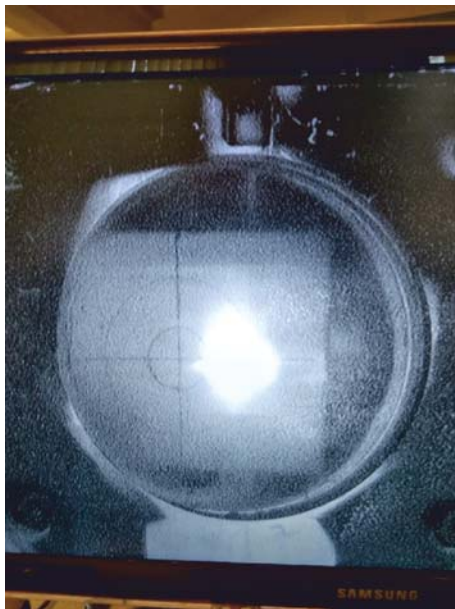


Fig. 7. The profile of the extracted beam (on February 25, 2019)

cyclotron is presented in Fig.7. This profile of the extracted beam has enough rounded shape. The current stability of the extracted beam is  $\sigma < 3 \cdot 10^{-2}$  during 100 s. The beam parameters correspond to requirements of proton therapy of eye's melanoma.

## SUMMARY

The SG curves were measured in February 2019 for the main operating mode of the AIC-144 cyclotron. The measured curves were used for beam dynamics calculation with purpose of compensation of residual influence of the magnetic channels on mean magnetic field and with purpose of formation of required phase of central particle of beam's bunch in the certain radius. The certain radius is radius of throwing the beam into the electrostatic deflector. This approach allowed getting the optimal value of the extraction coefficient of the proton beam:  $K_{\text{ext}} = (30 \pm 5)\%$ . The extraction coefficient of the proton beam for the AIC-144 cyclotron is relation of the beam current value in the beginning of the beam transportation line (after the first correction magnet) to the beam current value inside cyclotron in radius  $R = 60$  cm.

This work is the basis for mathematical and computer modelling of beam dynamics. The description of the technique of correction of mean magnetic field

and presentation of results of beam dynamics calculations, which were gotten on the basis of use of measured SG curves for the main operating mode of the AIC-144 cyclotron, go beyond the scope of this article.

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## ANNEX

The output ASCII file with the results of measurements of SG curves presented in Fig. 6 follows:

2d.txt

Comment: 22.02.2019. 2d. R=62->6 cm.

Path: D:\Experiment\Physical\2019\AIC-144\SG\SG Curves Source Data 2019.txt

Np	R (m)	Imc,set (A)	Imc,msd (A)	Ib (nA)	dIb (nA)	sIb (%)
+17						
+0.620	+590.000	+590.043	+0.0	+0.0	+136.0	
+0.620	+590.281	+590.355	-0.0	+0.0	-115.4	
+0.620	+590.562	+590.615	+0.1	+0.1	+75.1	
+0.620	+590.843	+590.882	+0.7	+0.00	+1.3	
+0.620	+591.125	+591.168	+14.1	+0.2	+1.4	
+0.620	+591.406	+591.447	+64.0	+0.6	+0.9	
+0.620	+591.687	+591.720	+54.8	+0.1	+0.2	
+0.620	+591.969	+592.039	+49.8	+1.2	+2.4	
+0.620	+592.249	+592.292	+79.7	+0.6	+0.7	
+0.620	+592.531	+592.559	+70.1	+0.3	+0.5	
+0.620	+592.812	+592.864	+52.3	+0.4	+0.9	
+0.620	+593.094	+593.137	+57.1	+0.6	+1.0	
+0.620	+593.375	+593.488	+54.7	+0.0	+0.1	
+0.620	+593.656	+593.716	+47.3	+0.7	+1.4	
+0.620	+593.937	+593.976	+3.6	+0.4	+12.3	
+0.620	+594.218	+594.262	+0.0	+0.00	+9.4	
+0.620	+594.500	+594.541	-0.0	+0.0	-89.8	
+17						
+0.600	+590.000	+590.043	+0.0	+0.0	+73.4	
+0.600	+590.281	+590.355	+0.00	+0.0	+160.7	
+0.600	+590.562	+590.615	+0.1	+0.00	+5.4	
+0.600	+590.843	+590.875	+3.4	+0.1	+1.6	
+0.600	+591.125	+591.161	+35.2	+1.0	+2.7	
+0.600	+591.406	+591.447	+90.9	+1.3	+1.5	
+0.600	+591.687	+591.720	+94.2	+0.2	+0.3	
+0.600	+591.969	+592.039	+100.8	+0.6	+0.6	
+0.600	+592.249	+592.292	+97.2	+0.6	+0.6	
+0.600	+592.531	+592.572	+97.7	+0.2	+0.2	
+0.600	+592.812	+592.858	+96.4	+1.8	+1.9	

+0.600	+593.094	+593.124	+94.1	+0.5	+0.6
+0.600	+593.375	+593.495	+90.0	+0.6	+0.7
+0.600	+593.656	+593.709	+63.1	+1.0	+1.5
+0.600	+593.937	+593.976	+6.0	+0.4	+7.2
+0.600	+594.218	+594.262	+0.2	+0.2	+107.5
+0.600	+594.500	+594.541	+0.0	+0.0	+173.1
+17					
+0.580	+589.500	+589.549	+0.0	+0.0	+95.7
+0.580	+589.812	+589.848	+0.1	+0.1	+102.4
+0.580	+590.125	+590.251	+0.0	+0.0	+133.9
+0.580	+590.437	+590.479	+0.1	+0.1	+57.5
+0.580	+590.750	+590.804	+7.7	+0.1	+1.6
+0.580	+591.062	+591.090	+58.9	+1.1	+1.9
+0.580	+591.374	+591.421	+97.5	+0.6	+0.7
+0.580	+591.687	+591.720	+98.5	+0.2	+0.2
+0.580	+592.000	+592.065	+92.4	+0.1	+0.1
+0.580	+592.312	+592.357	+96.4	+0.3	+0.4
+0.580	+592.624	+592.663	+94.3	+2.5	+2.6
+0.580	+592.937	+592.968	+99.0	+0.5	+0.6
+0.580	+593.250	+593.293	+96.0	+0.6	+0.6
+0.580	+593.562	+593.644	+75.4	+0.5	+0.7
+0.580	+593.874	+593.930	+15.6	+1.0	+6.3
+0.580	+594.187	+594.203	+0.0	+0.1	+468.1
+0.580	+594.500	+594.535	+0.0	+0.00	+48.7
+17					
+0.540	+588.999	+589.042	+0.1	+0.1	+120.1
+0.540	+589.343	+589.387	+0.0	+0.0	+31.0
+0.540	+589.687	+589.718	+0.1	+0.0	+28.5
+0.540	+590.031	+590.063	+0.3	+0.000	+0.0
+0.540	+590.375	+590.427	+7.4	+0.2	+2.6
+0.540	+590.719	+590.765	+52.9	+0.2	+0.3
+0.540	+591.062	+591.090	+87.7	+0.5	+0.5
+0.540	+591.406	+591.454	+90.7	+0.2	+0.2
+0.540	+591.750	+591.863	+83.9	+0.0	+0.0
+0.540	+592.093	+592.130	+84.3	+0.9	+1.0
+0.540	+592.437	+592.481	+85.6	+0.4	+0.5
+0.540	+592.781	+592.832	+86.4	+0.2	+0.2
+0.540	+593.125	+593.150	+88.1	+0.5	+0.5
+0.540	+593.468	+593.534	+78.8	+0.9	+1.2
+0.540	+593.812	+593.865	+37.3	+0.5	+1.4
+0.540	+594.156	+594.184	+0.1	+0.00	+8.5
+0.540	+594.500	+594.541	+0.1	+0.0	+66.6
+17					
+0.500	+588.500	+588.594	+0.0	+0.00	+2.4
+0.500	+588.906	+588.964	-0.00	+0.1	-1043.3
+0.500	+589.312	+589.361	+0.1	+0.000	+1.2
+0.500	+589.718	+589.764	+0.2	+0.1	+33.7
+0.500	+590.125	+590.245	+7.4	+0.1	+1.5
+0.500	+590.531	+590.589	+57.1	+1.0	+1.8
+0.500	+590.937	+590.979	+90.6	+0.3	+0.3

+0.500	+591.343	+591.369	+90.0	+0.4	+0.4
+0.500	+591.750	+591.863	+97.0	+0.9	+0.9
+0.500	+592.156	+592.214	+98.8	+0.8	+0.8
+0.500	+592.562	+592.617	+95.0	+0.3	+0.4
+0.500	+592.968	+592.988	+90.1	+0.9	+1.0
+0.500	+593.375	+593.495	+91.5	+0.8	+0.8
+0.500	+593.781	+593.839	+76.0	+0.1	+0.1
+0.500	+594.187	+594.223	+23.8	+0.3	+1.3
+0.500	+594.593	+594.619	+0.1	+0.0	+24.3
+0.500	+595.000	+595.035	+0.0	+0.0	+40.2
+17					
+0.460	+588.000	+588.028	+0.0	+0.0	+88.4
+0.460	+588.500	+588.581	-0.0	+0.0	-108.2
+0.460	+588.999	+589.029	-0.0	+0.1	-364.4
+0.460	+589.500	+589.549	+5.6	+0.6	+11.4
+0.460	+590.000	+590.037	+55.0	+0.9	+1.6
+0.460	+590.500	+590.570	+103.5	+0.6	+0.6
+0.460	+590.999	+591.038	+109.0	+0.4	+0.4
+0.460	+591.500	+591.525	+109.9	+0.4	+0.4
+0.460	+592.000	+592.058	+107.9	+1.5	+1.4
+0.460	+592.500	+592.533	+108.4	+0.1	+0.1
+0.460	+592.999	+593.046	+106.9	+0.0	+0.0
+0.460	+593.500	+593.560	+98.2	+0.00	+0.00
+0.460	+594.000	+594.054	+94.0	+0.6	+0.7
+0.460	+594.500	+594.541	+33.3	+0.4	+1.1
+0.460	+595.000	+595.035	+0.1	+0.1	+93.9
+0.460	+595.499	+595.549	+0.00	+0.0	+571.2
+0.460	+596.000	+596.036	-0.00	+0.00	-118.6
+17					
+0.420	+586.499	+586.533	-0.000	+0.0	-1703.4
+0.420	+587.094	+587.144	-0.000	+0.00	-1110.5
+0.420	+587.687	+587.729	+0.0	+0.000	+1.9
+0.420	+588.281	+588.327	+0.5	+0.0	+6.0
+0.420	+588.875	+588.938	+15.7	+0.1	+0.4
+0.420	+589.469	+589.510	+97.0	+1.0	+1.1
+0.420	+590.062	+590.108	+113.2	+0.5	+0.4
+0.420	+590.656	+590.687	+113.3	+0.2	+0.2
+0.420	+591.250	+591.278	+110.6	+1.1	+1.0
+0.420	+591.843	+591.902	+109.9	+0.3	+0.3
+0.420	+592.437	+592.481	+112.1	+0.6	+0.5
+0.420	+593.031	+593.079	+113.8	+0.4	+0.3
+0.420	+593.625	+593.683	+113.2	+0.3	+0.3
+0.420	+594.218	+594.262	+95.7	+0.2	+0.2
+0.420	+594.812	+594.840	+24.4	+0.3	+1.1
+0.420	+595.406	+595.451	+0.0	+0.1	+319.3
+0.420	+596.000	+596.036	+0.00	+0.0	+922.0
+17					
+0.380	+586.499	+586.533	+0.0	+0.0	+210.5
+0.380	+587.094	+587.144	+0.1	+0.0	+10.5
+0.380	+587.687	+587.729	+2.7	+0.2	+8.4



+0.380	+588.281	+588.321	+32.0	+0.0	+0.1
+0.380	+588.875	+588.932	+112.8	+0.5	+0.4
+0.380	+589.469	+589.491	+117.0	+0.9	+0.8
+0.380	+590.062	+590.102	+117.5	+0.3	+0.3
+0.380	+590.656	+590.693	+118.3	+0.8	+0.6
+0.380	+591.250	+591.291	+116.5	+1.2	+1.0
+0.380	+591.843	+591.902	+118.7	+0.5	+0.4
+0.380	+592.437	+592.481	+118.8	+1.9	+1.6
+0.380	+593.031	+593.079	+119.4	+0.3	+0.3
+0.380	+593.625	+593.683	+118.9	+0.9	+0.7
+0.380	+594.218	+594.268	+110.4	+1.6	+1.4
+0.380	+594.812	+594.834	+76.5	+0.6	+0.7
+0.380	+595.406	+595.471	+10.7	+0.1	+1.4
+0.380	+596.000	+596.023	+0.0	+0.0	+137.2
+17					
+0.340	+584.499	+584.518	-0.0	+0.0	-211.7
+0.340	+585.281	+585.331	-0.00	+0.0	-805.8
+0.340	+586.062	+586.098	+0.2	+0.00	+2.1
+0.340	+586.843	+586.962	+6.6	+0.2	+3.2
+0.340	+587.625	+587.684	+54.0	+6.6	+12.2
+0.340	+588.406	+588.431	+119.6	+0.3	+0.2
+0.340	+589.187	+589.224	+120.3	+0.8	+0.6
+0.340	+589.969	+590.017	+121.4	+0.2	+0.2
+0.340	+590.750	+590.804	+119.4	+0.1	+0.0
+0.340	+591.531	+591.564	+118.6	+0.2	+0.1
+0.340	+592.312	+592.351	+118.7	+0.1	+0.1
+0.340	+593.094	+593.131	+119.0	+0.3	+0.3
+0.340	+593.874	+593.937	+118.9	+0.8	+0.7
+0.340	+594.656	+594.704	+114.4	+0.6	+0.5
+0.340	+595.437	+595.497	+80.0	+0.3	+0.4
+0.340	+596.218	+596.251	+5.3	+0.1	+1.7
+0.340	+597.000	+597.050	-0.0	+0.0	-85.4
+17					
+0.300	+582.000	+582.061	+0.0	+0.00	+19.5
+0.300	+583.062	+583.095	+0.0	+0.1	+647.1
+0.300	+584.124	+584.187	+0.2	+0.0	+18.1
+0.300	+585.187	+585.298	+6.9	+0.3	+4.5
+0.300	+586.250	+586.299	+61.7	+0.2	+0.3
+0.300	+587.312	+587.359	+120.1	+0.5	+0.4
+0.300	+588.375	+588.412	+119.3	+0.7	+0.6
+0.300	+589.437	+589.465	+120.6	+0.8	+0.6
+0.300	+590.500	+590.557	+120.5	+0.7	+0.6
+0.300	+591.562	+591.616	+122.5	+0.5	+0.4
+0.300	+592.624	+592.669	+120.9	+0.3	+0.3
+0.300	+593.687	+593.748	+122.9	+0.9	+0.8
+0.300	+594.750	+594.788	+116.8	+0.7	+0.6
+0.300	+595.812	+595.841	+100.1	+0.3	+0.3
+0.300	+596.875	+596.940	+31.0	+1.0	+3.1
+0.300	+597.937	+597.986	+0.0	+0.0	+141.0
+0.300	+599.000	+599.039	+0.0	+0.00	+27.8

+17					
+0.260	+577.999	+578.044	-0.0	+0.00	-23.4
+0.260	+579.312	+579.344	+0.1	+0.00	+5.9
+0.260	+580.625	+580.690	+0.3	+0.0	+14.6
+0.260	+581.937	+582.003	+2.9	+0.00	+0.1
+0.260	+583.249	+583.277	+27.3	+0.2	+0.7
+0.260	+584.562	+584.616	+110.1	+0.3	+0.3
+0.260	+585.875	+585.909	+123.1	+1.0	+0.8
+0.260	+587.187	+587.248	+120.3	+1.6	+1.3
+0.260	+588.500	+588.600	+119.9	+0.7	+0.6
+0.260	+589.812	+589.848	+123.7	+0.00	+0.00
+0.260	+591.125	+591.181	+123.5	+1.2	+1.0
+0.260	+592.437	+592.487	+122.1	+0.4	+0.3
+0.260	+593.750	+593.800	+125.5	+3.8	+3.0
+0.260	+595.062	+595.185	+120.2	+0.5	+0.4
+0.260	+596.375	+596.413	+109.3	+1.0	+0.9
+0.260	+597.687	+597.720	+54.5	+0.4	+0.7
+0.260	+599.000	+599.052	+0.1	+0.1	+72.5
+17					
+0.220	+571.000	+571.044	+0.3	+0.0	+13.8
+0.220	+572.749	+572.786	+0.4	+0.0	+5.3
+0.220	+574.500	+574.541	+0.4	+0.1	+22.4
+0.220	+576.250	+576.276	+1.0	+0.0	+4.1
+0.220	+577.999	+578.044	+11.1	+0.2	+1.8
+0.220	+579.750	+579.793	+56.9	+0.6	+1.1
+0.220	+581.500	+581.535	+122.2	+0.8	+0.7
+0.220	+583.249	+583.283	+122.1	+0.3	+0.2
+0.220	+585.000	+585.038	+121.5	+0.7	+0.6
+0.220	+586.750	+586.774	+124.9	+3.2	+2.6
+0.220	+588.500	+588.594	+125.2	+1.5	+1.2
+0.220	+590.250	+590.316	+124.8	+1.1	+0.8
+0.220	+592.000	+592.058	+131.2	+0.3	+0.2
+0.220	+593.750	+593.800	+131.2	+1.0	+0.8
+0.220	+595.499	+595.549	+128.5	+1.1	+0.9
+0.220	+597.250	+597.284	+128.5	+1.5	+1.2
+0.220	+599.000	+599.046	+117.2	+0.8	+0.7
+17					
+0.180	+562.999	+563.036	+0.4	+0.0000	+0.0
+0.180	+565.250	+565.291	+0.3	+0.0	+4.9
+0.180	+567.500	+567.540	+0.5	+0.00	+0.8
+0.180	+569.750	+569.789	+2.1	+0.0	+0.8
+0.180	+572.000	+572.123	+13.4	+0.1	+0.5
+0.180	+574.250	+574.307	+48.8	+0.4	+0.9
+0.180	+576.500	+576.543	+122.2	+0.2	+0.1
+0.180	+578.750	+578.824	+129.0	+0.6	+0.5
+0.180	+581.000	+581.054	+126.8	+1.6	+1.2
+0.180	+583.249	+583.277	+130.1	+0.6	+0.5
+0.180	+585.500	+585.539	+127.1	+2.7	+2.1
+0.180	+587.749	+587.788	+128.2	+1.1	+0.8
+0.180	+590.000	+590.037	+129.5	+1.8	+1.4

+0.180	+592.249	+592.299	+135.3	+0.3	+0.2
+0.180	+594.500	+594.548	+134.9	+1.3	+1.0
+0.180	+596.750	+596.816	+133.1	+1.1	+0.9
+0.180	+599.000	+599.039	+124.7	+0.1	+0.1
+17					
+0.140	+550.000	+550.042	+0.3	+0.0	+6.6
+0.140	+553.062	+553.110	+0.4	+0.0	+8.4
+0.140	+556.125	+556.185	+1.2	+0.0	+2.5
+0.140	+559.187	+559.233	+5.9	+0.0	+0.8
+0.140	+562.250	+562.308	+18.7	+0.2	+1.1
+0.140	+565.312	+565.343	+50.9	+0.8	+1.5
+0.140	+568.375	+568.411	+104.6	+1.5	+1.4
+0.140	+571.437	+571.466	+123.8	+0.3	+0.3
+0.140	+574.500	+574.541	+123.3	+3.6	+2.9
+0.140	+577.562	+577.615	+127.8	+0.1	+0.1
+0.140	+580.625	+580.690	+128.2	+0.3	+0.2
+0.140	+583.687	+583.764	+119.9	+0.5	+0.4
+0.140	+586.750	+586.780	+129.0	+0.1	+0.0
+0.140	+589.812	+589.855	+130.4	+0.0	+0.0
+0.140	+592.875	+592.916	+131.5	+0.8	+0.6
+0.140	+595.937	+595.984	+131.1	+0.0	+0.0
+0.140	+599.000	+599.039	+132.6	+1.8	+1.3
+17					
+0.100	+514.999	+515.046	-0.0	+0.0	-33.7
+0.100	+520.249	+520.272	+0.2	+0.0	+9.7
+0.100	+525.500	+525.550	+1.3	+0.1	+11.1
+0.100	+530.750	+530.776	+4.0	+0.1	+1.7
+0.100	+536.000	+536.047	+11.5	+0.4	+3.8
+0.100	+541.250	+541.286	+27.2	+0.0	+0.2
+0.100	+546.500	+546.545	+54.0	+0.2	+0.4
+0.100	+551.750	+551.778	+99.2	+0.2	+0.2
+0.100	+557.000	+557.036	+126.0	+0.1	+0.0
+0.100	+562.250	+562.295	+130.3	+0.9	+0.7
+0.100	+567.500	+567.547	+136.3	+1.9	+1.4
+0.100	+572.749	+572.786	+148.5	+2.1	+1.4
+0.100	+577.999	+578.051	+160.9	+2.0	+1.2
+0.100	+583.249	+583.277	+168.6	+0.4	+0.3
+0.100	+588.500	+588.594	+176.4	+0.3	+0.2
+0.100	+593.750	+593.800	+181.3	+0.4	+0.2
+0.100	+599.000	+599.046	+189.1	+1.0	+0.5
+17					
+0.060	+400.000	+400.021	+7.7	+0.1	+1.3
+0.060	+412.437	+412.488	+12.3	+0.0	+0.1
+0.060	+424.875	+424.903	+22.5	+0.4	+2.0
+0.060	+437.312	+437.344	+39.7	+0.5	+1.3
+0.060	+449.750	+449.785	+65.6	+0.1	+0.1
+0.060	+462.187	+462.213	+96.7	+0.4	+0.4
+0.060	+474.625	+474.635	+121.7	+0.4	+0.3
+0.060	+487.062	+487.089	+146.7	+0.5	+0.4
+0.060	+499.499	+499.517	+171.4	+2.8	+1.6

+0.060	+511.937	+511.978	+191.6	+1.3	+0.7
+0.060	+524.374	+524.419	+222.7	+1.1	+0.5
+0.060	+536.812	+536.847	+252.8	+1.8	+0.7
+0.060	+549.250	+549.294	+280.5	+2.3	+0.8
+0.060	+561.687	+561.716	+310.5	+2.4	+0.8
+0.060	+574.125	+574.164	+342.3	+2.3	+0.7
+0.060	+586.562	+586.592	+372.1	+1.1	+0.3
+0.060	+599.000	+599.046	+409.8	+3.5	+0.9

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