

Адиабатический захват ионов в 22 сгустка.

Рассмотрен процесс группирования продольно-однородного пучка в 22 сгустка при адиабатическом поднятии напряжений ВЧ2,3, с учетом наведенного пучком напряжения, в зависимости от времени затухания. В конце группирования среднеквадратичные длина сгустков и разброс по импульсам должны находиться в указанных в таблице пределах, а боковые сепаратрисы должны быть пустыми.

Исходные параметры.

Ek, GeV/u	1	3	4.5
I0, A	0.04	0.386	0.359
U2min, kV	1?		
U2max, kV	100		
U3max, kV	500	800	500
U3min, kV	1 ?		
$\sigma_{p_{end}}, 10^{-3}$	0.62	1.25	1.65
$\sigma_{p_{start}} = \sigma_{p_b} / 3, 10^{-3}$	0.24	0.37	0.6
$\sigma_{z_{end}}, m$	0.6		
F0, MHz	0.522	0.579	0.587

Параметры резонаторов:

	ВЧ2	ВЧ3
q	22	66
Rsh, Ohms	3.12e5	2.68e6
Q	3900	6700
Скорость перестройки частоты резонатора	1 полоса в секунду	
a_0 (нач. расстройка на $f_0/2$)	177.3	101.5

Время подъема напряжения 177 сек. для ВЧ2 и 101 сек. для ВЧ3.

Адиабатический подъем напряжения.

Параметр адиабатичности $\alpha_c = \frac{1}{A} \frac{dA}{dt} T_s(U(t)) \ll 1$

A – площадь внутри сепаратрисы, $A \sim U^{1/2}$, T_s - период синхротронных колебаний, $T_s \sim U^{-1/2}$.

Без учета наведенного напряжения

$$U(t) = U_{\min} \left(\frac{1 + a_{30}^2}{1 + a_3(t)^2} \right)^{1/2} = U_{\max} \left(\sqrt{\frac{U_{\max}}{U_{\min}}} - \frac{\alpha_c(t)t}{T_s(U_{\max})} \right)^{-2}, \quad U(T_1) = U_{\max}$$

1) *Изоадиабатический подъем:*

При этом амплитуда напряжения зависит от времени как

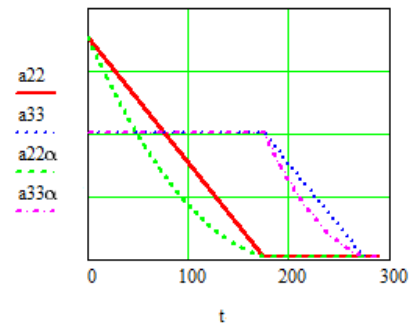
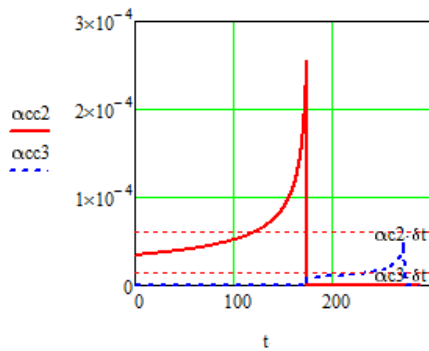
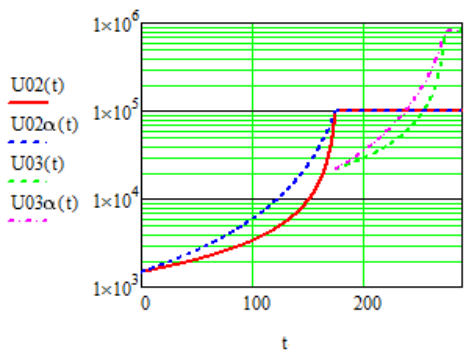
$$\alpha_c = \frac{T_s(U_{\max})}{T_1} \left(\sqrt{\frac{U_{\max}}{U_{\min}}} - 1 \right) = const, \quad \Rightarrow a(t)$$

2) *Подъем напряжения при $da/dt = const$*

При максимальной скорости $da/dt = const$ время подъема напряжения минимально. В этом режиме коэффициент адиабатичности не будет постоянным:

$$a_3(t) = a_{30} - a_3' t, \quad A \sim U^{1/2}, \quad T_s \sim U^{-1/2} \quad \Rightarrow \quad \alpha_c(t) = \frac{1}{A} \frac{dA}{dt} T_s(U) = \frac{U'}{2U} T_s(U_{\max}) \sqrt{\frac{U_{\max}}{U}}.$$

Рис. Напряжение ВЧ системы, расстройка и параметр адиабатичности для режимов 1, 2:



Выбор начального напряжения

Суммарное напряжение ВЧ 2,3:

$$U_k(t) = \frac{(I_{ak}(t) + I_{qk}(t))R_{sk}}{1 + ia_k(t)}, \quad k = 2, 3$$

I_a – анодный ток генератора, I_q – наведенный пучком ток.

Минимальная мощность генератора:

В конце группировки $I_a \parallel U \Rightarrow a_f = \frac{2I_0 R_s}{U_{\max}} \Rightarrow U_{\min} = U_{\max} \sqrt{\frac{1 + a_{3f}^2}{1 + a_{30}^2}}$

Отсутствие статической неустойчивости:

$$U_{\min 32} > U_{q3}(t_{3\text{вкл}}) = \frac{I_0 A_{66} R_{s3}}{a_{30}} = (11 \div 21) \text{ kV},$$

$$I_0 = 0.4 \text{ A}, \quad A_{66} = 1 \div 2$$

$E_k, \text{ GeV}$	$I_0, \text{ A}$	a_{2f}	$U_{2\text{min}}$	a_{3f}	$U_{3\text{min}1}$	$U_{3\text{min}2}$
1	0.04	0.25	0.58	0.43	5.36	2.11
3	0.4	2.5	1.52	4.3	22.5	21.1
4.5	0.4		1.52	4.3	21.7	21.1
1	0.4	2.5	1.52	4.3	21.7	21.1

Уравнения, описывающие процесс группировки пучка.

$$\left\{ \begin{array}{l} \frac{d\varepsilon}{dt} = \frac{Zef_0}{E_s} (U(\Delta\varphi, t) - U(0, t)) + F_{e0}(\varepsilon) \\ \frac{d\Delta\varphi}{dt} = 2\pi qf_0 K\varepsilon \end{array} \right.$$

$$\varepsilon = \frac{\Delta E}{E}, \quad \varphi = q\theta, \quad \theta \in [0, 2\pi], \quad q = 22, \quad K = \frac{\alpha - \gamma^{-2}}{\beta^2}, \quad \varphi_s = -\pi / 2$$

$$U(\Delta\varphi, t) = U_2(t) \cos(\varphi_s + \Delta\varphi) + \begin{cases} U_3(t) \cos(3\varphi_s + 3\Delta\varphi), & U_3(t) > 0 \\ U_{q3}(t), & U_3(t) = 0 \end{cases}$$

$$F_{e0}(\varepsilon) = \frac{-\varepsilon}{\tau_{e0} \left(1 + (\varepsilon / \varepsilon_{eff})^2\right)^{3/2}}$$

$$U_k(t) = \frac{(I_{ak}(t) + I_{qk}(t))R_{sk}}{1 + ia_k(t)}, \quad k = 2, 3$$

Модель макрочастиц.

$I_{q_3}(t), I_{q_2}(t)$ - по текущему распределению частиц:

$$I_{qk} = -I_0 \frac{1}{N_p} \sum_{n=1}^{N_p} \Delta\varphi_n \exp(-i\Delta\varphi_n q / q_2),$$

$$U_{qk}(\Delta\varphi) = \text{Re} \left\{ I_{qk} Z_k(a_k(t)) \left(\exp(i\Delta\varphi q / q_2) - 1 \right) \right\},$$

$$\Delta\varphi = \varphi - \varphi_s$$

Сокращение времени расчета в 1000 раз (адиабатичность сохраняется).

Задаем $U(t), a(t) \Rightarrow I_q(t) \Rightarrow I_a(t)$.

Ограничение на $I_a(t) \Rightarrow$ меняем режим (растягиваем $a(t)$ во времени).

Пример расчета.

Список графиков (в зависимости от времени):

- a) Амплитуды полного и наведенного напряжения на резонаторах ВЧ2,3.
- b) Амплитуды гармоник наведенного пучком тока.
- c) Синхротронная частота отдельно от напряжений на резонаторах ВЧ2,3 и от суммарного напряжения.
- d) Доля частиц, сохраненных в центральной сепаратрисе напряжения 66-й гармоники и в боковых сепаратрисах.
- e) Среднеквадратичные отклонения фазы и энергии для частиц в центральной сепаратрисе.
- f) фазовый портрет в конце группировки.

$E_k, GeV/u$	I_0, A	τ_e, sec	$N_{центр}, N_{бок}$	$\sigma\varphi$	$\sigma\varepsilon, \sigma p$
3	0.386	200	0.916;0.084	0.234	1.43e-3,1.51e-3
3	0.386	100	0.978;0.022	0.21	1.29e-3; 1.37e-5
3	0.386	50	0.95;0.05	0.2	1.23e-3;
3	0.386	30	0.988;0.012	0.154	0.96e-3
3	0.386	10	1;0	8.6e-3	7.2e-5
1	0.04	70	0.995;0.005	0.09	2.5e-4
1	0.04	50	1;0	0.054	1.32e-4
1	0.04	30	1	0.025	9.7e-5
1	0.04	10	1	5.3e-6	2e-8

1. Результаты для $E_k = 3\text{GeV}/u$, $I_0 = 0.386\text{A}$, $\tau_e = 50\text{sec}$

$$E_k = 3 \times 10^9$$

$$I_0 = 0.386$$

$$\sigma p_0 = 3.7 \times 10^{-4}$$

$$\tau = 50$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.747$$

$$dda_2 = 1$$

$$dda_3 = 1$$

$$a_{20} = 177.273$$

$$a_{2f} = 2.411$$

$$a_{30} = 101.515$$

$$a_{3f} = 2.589$$

$$\frac{|I_{q3, kmax1}|}{I_0} = 0.851$$

$$U_{min2} = 1.472 \times 10^3$$

$$U_{max2} = 1 \times 10^5$$

$$U_{min3} = 2.187 \times 10^4$$

$$U_{max3} = 8 \times 10^5$$

$$\max(U_{q3}) = 5.655 \times 10^3$$

$$F_{ss_0} = 0.107$$

$$F_{ss_{k00}} = 0.875$$

$$F_{ss_{kmax1}} = 3.398$$

$$\Delta N_0 = 0.951$$

$$\Delta N_{1-2} = 0.049$$

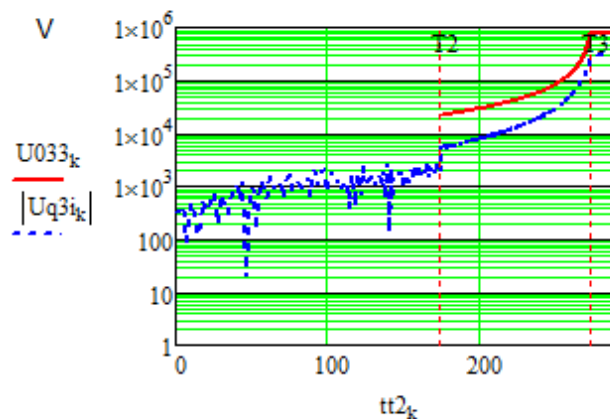
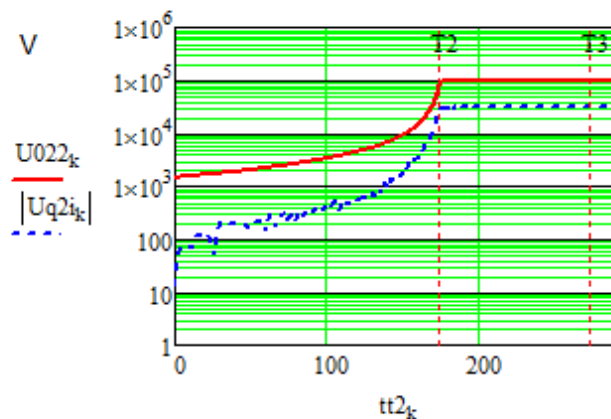
$$\sigma \varphi_{\text{av}_{kmax1}} = 0.496$$

$$\sigma \varepsilon_{\text{av}_{kmax1}} = 1.211 \times 10^{-3}$$

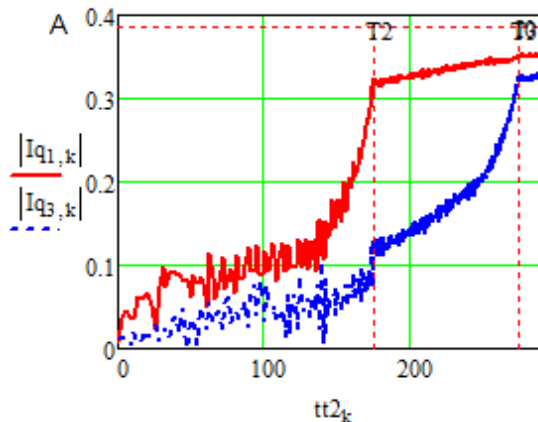
$$\sigma \varphi_{2\text{-av}_{kmax1}} = 0.202$$

$$\sigma \varepsilon_{2\text{-av}_{kmax1}} = 1.229 \times 10^{-3}$$

a)



b)



$$\frac{|I_{q3,kmax1}|}{I_0} = 0.851$$

$$|U_{q3i_{k00}}| = 5.655 \times 10^3$$

$$\frac{|I_{q3,k00}|}{I_0} = 0.339$$

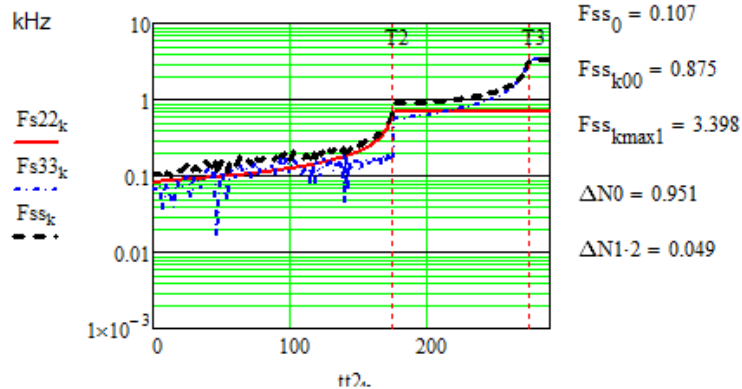
$$U_{min2} = 1.472 \times 10^3$$

$$U_{min3} = 2.187 \times 10^4$$

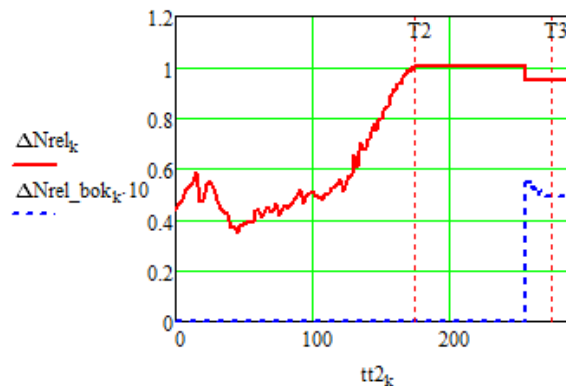
$$U_{max2} = 1 \times 10^5$$

$$U_{max3} = 8 \times 10^5$$

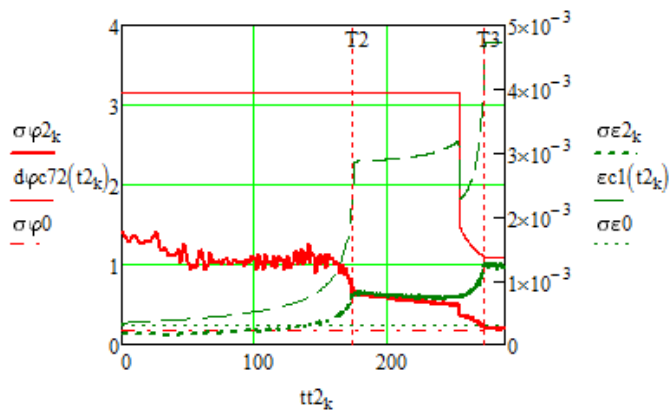
c)



d)



e)



$$\sigma \varphi_{av_{kmax1}} = 0.496$$

$$\sigma \varepsilon_{av_{kmax1}} = 1.211 \times 10^{-3}$$

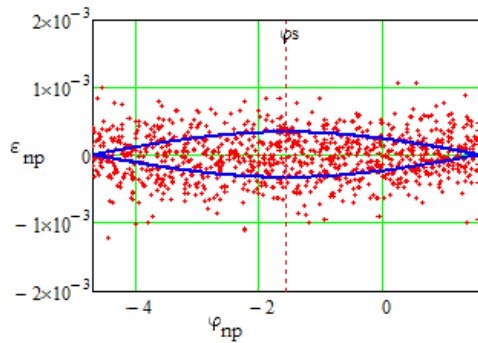
$$\sigma \varphi^2_{kmax1} = 0.195$$

$$\sigma \varepsilon^2_{kmax1} = 1.267 \times 10^{-3}$$

f)

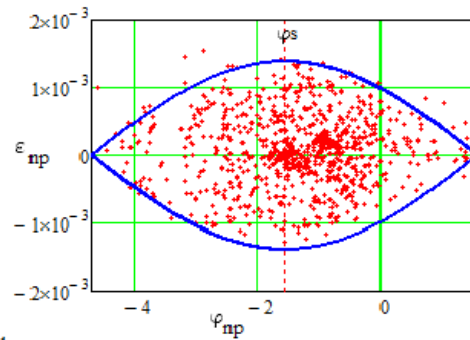
$k_2 := 0$

$$tt_{k_2} = 0 \quad U_{02}(t_{2,k_2}) = 1.5 \times 10^3 \quad U_{03}(t_{2,k_2}) = 0$$



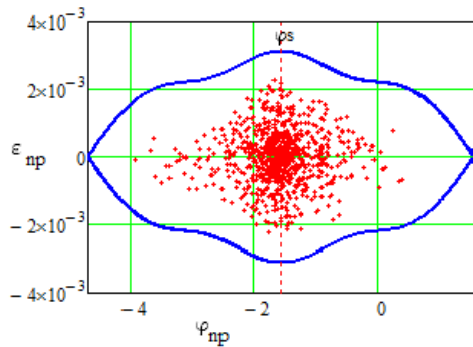
$k_3 := 100$

$$tt_{k_3} = 166.9 \quad U_{02}(t_{2,k_3}) = 2.5 \times 10^4 \quad U_{03}(t_{2,k_3}) = 0$$



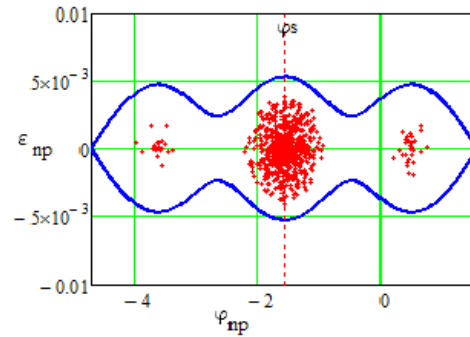
$k_4 := 450$

$$tt_{k_4} = 248.5 \quad U_{02}(t_{2,k_4}) = 1 \times 10^5 \quad U_{03}(t_{2,k_4}) = 8 \times 10^4$$



$k_5 := k_{max1}$

$$tt_{k_5} = 288.6 \quad U_{02}(t_{2,k_5}) = 1 \times 10^5 \quad U_{03}(t_{2,k_5}) = 8 \times 10^5$$



2. Результаты для $E_k = 3\text{GeV}/u$, $I_0 = 0.386\text{A}$, $\tau_e = 10\text{sec}$

$$E_k = 3 \times 10^9$$

$$I_0 = 0.386$$

$$\sigma p_0 = 3.7 \times 10^{-4}$$

$$\tau = 10$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.747$$

$$\text{dda2} = 1$$

$$\text{dda3} = 1$$

$$\text{a20} = 177.273$$

$$\text{a2f} = 2.411$$

$$\text{a30} = 101.515$$

$$\text{a3f} = 2.589$$

$$\frac{|I_{q3, \text{kmax1}}|}{I_0} = 0.999$$

$$U_{\text{min2}} = 1.472 \times 10^3$$

$$U_{\text{max2}} = 1 \times 10^5$$

$$U_{\text{min3}} = 2.187 \times 10^4$$

$$U_{\text{max3}} = 8 \times 10^5$$

$$\max(U_{q3}) = 9.892 \times 10^3$$

$$F_{\text{ss}0} = 0.106$$

$$F_{\text{ss}_{k00}} = 0.875$$

$$F_{\text{ss}_{\text{kmax1}}} = 3.398$$

$$\Delta N_0 = 1$$

$$\Delta N_{1-2} = 0$$

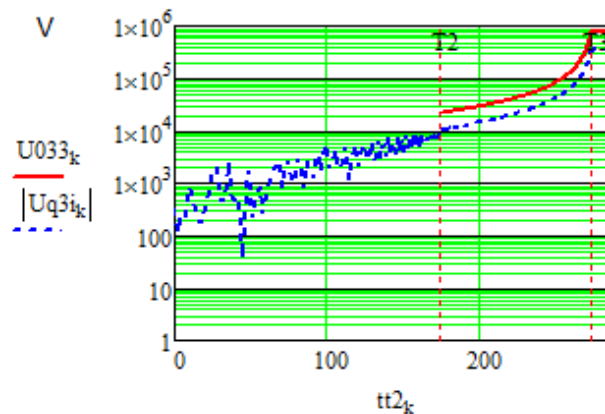
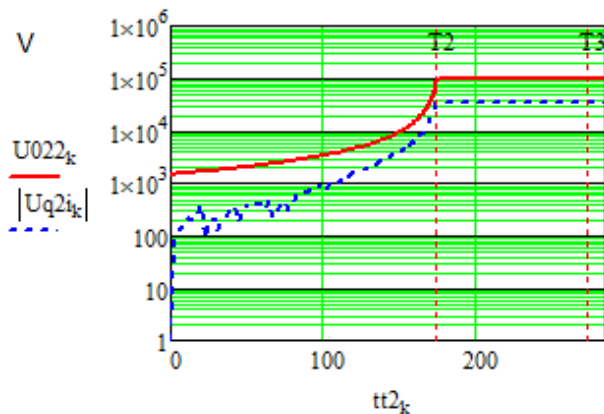
$$\sigma\varphi_{\text{av}_{\text{kmax1}}} = 8.631 \times 10^{-3}$$

$$\sigma\varepsilon_{\text{av}_{\text{kmax1}}} = 7.184 \times 10^{-5}$$

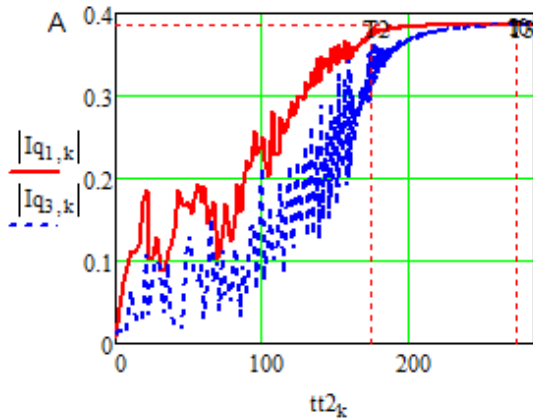
$$\sigma\varphi_{2\text{av}_{\text{kmax1}}} = 8.631 \times 10^{-3}$$

$$\sigma\varepsilon_{2\text{av}_{\text{kmax1}}} = 7.184 \times 10^{-5}$$

a)



b)



$$\frac{|Iq_{3,kmax1}|}{I0} = 0.999$$

$$|Uq3i_{k00}| = 9.892 \times 10^3$$

$$\frac{|Iq_{3,k00}|}{I0} = 0.807$$

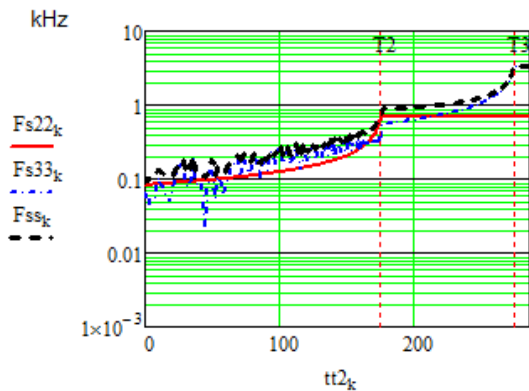
$$Umin2 = 1.472 \times 10^3$$

$$Umin3 = 2.187 \times 10^4$$

$$Umax2 = 1 \times 10^5$$

$$Umax3 = 8 \times 10^5$$

c)



$$F_{ss_0} = 0.106$$

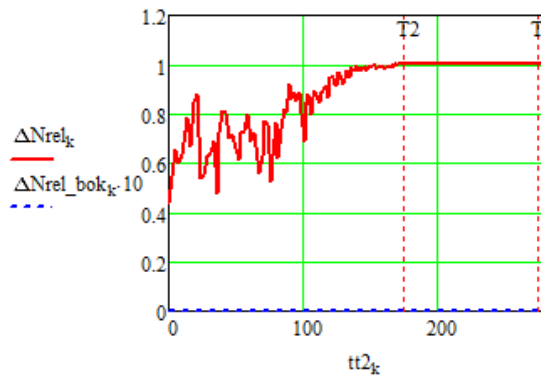
$$F_{ss_{k00}} = 0.875$$

$$F_{ss_{kmax1}} = 3.398$$

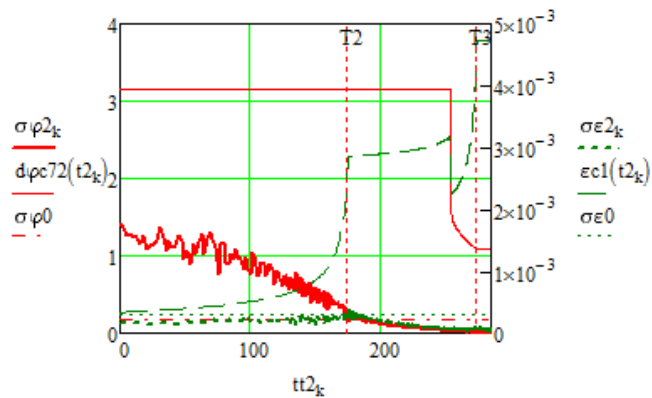
$$\Delta N_0 = 1$$

$$\Delta N_{1-2} = 0$$

d)



e)



$$\sigma\varphi_{_av_kmax1} = 8.631 \times 10^{-3}$$

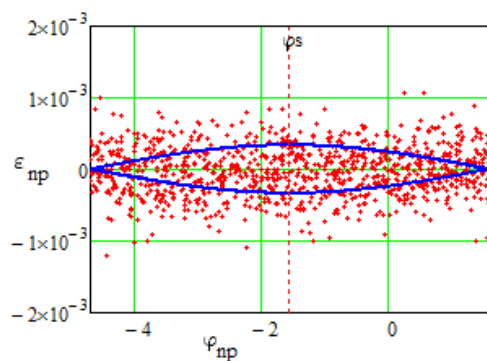
$$\sigma\varepsilon_{_av_kmax1} = 7.184 \times 10^{-5}$$

$$\sigma\varphi^2_{kmax1} = 0.013$$

$$\sigma\varepsilon^2_{kmax1} = 5.074 \times 10^{-5}$$

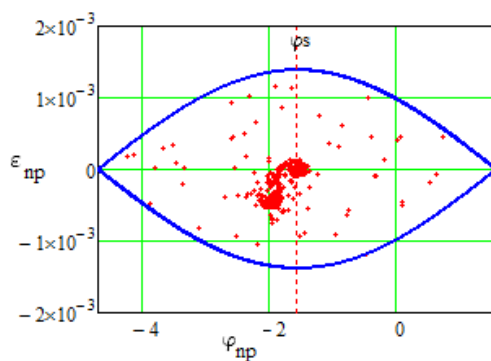
f) $k_2 := 0$

$$tt_{k_2}^2 = 0 \quad U_{02}(t_{k_2}^2) = 1.5 \times 10^3 \quad U_{03}(t_{k_2}^2) = 0$$



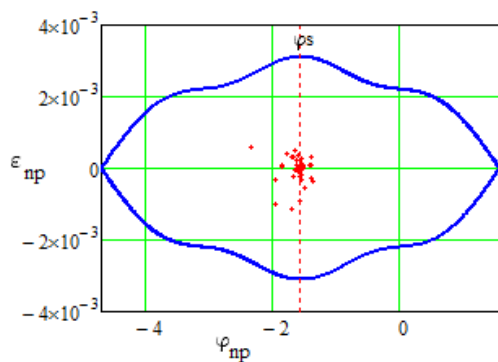
$k_3 := 100$

$$tt_{k_3}^2 = 166.9 \quad U_{02}(t_{k_3}^2) = 2.5 \times 10^4 \quad U_{03}(t_{k_3}^2) = 0$$



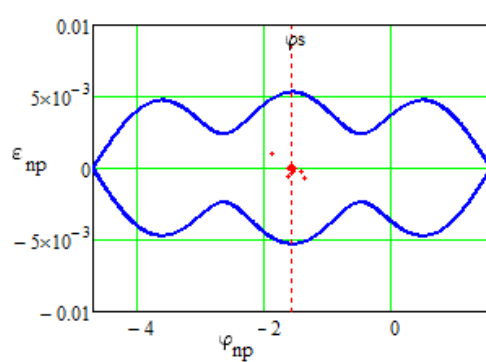
$k_4 := 450$

$$tt_{k_4}^2 = 248.5 \quad U_{02}(t_{k_4}^2) = 1 \times 10^5 \quad U_{03}(t_{k_4}^2) = 8 \times 10^4$$



$k_5 := k_{max1}$

$$tt_{k_5}^2 = 284.6 \quad U_{02}(t_{k_5}^2) = 1 \times 10^5 \quad U_{03}(t_{k_5}^2) = 8 \times 10^5$$



3. Результаты для $E_k = 1\text{GeV}/u$, $I_0 = 0.04\text{A}$, $\tau_e = 10\text{sec}$

$$E_k = 1 \times 10^9$$

$$I_0 = 0.04$$

$$\sigma_{p0} = 2.4 \times 10^{-4}$$

$$\tau = 10$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.139$$

$$dda2 = 1$$

$$dda3 = 1$$

$$a20 = 177.273$$

$$a2f = 0.249$$

$$a30 = 101.515$$

$$a3f = 0.428$$

$$\frac{|I_{q3, kmax1}|}{I_0} = 1$$

$$U_{min2} = 581.329$$

$$U_{max2} = 1 \times 10^5$$

$$U_{min3} = 5.357 \times 10^3$$

$$U_{max3} = 5 \times 10^5$$

$$\max(U_{q3}) = 1.054 \times 10^3$$

$$F_{ss0} = 0.189$$

$$F_{ss_{k00}} = 2.526$$

$$F_{ss_{kmax1}} = 9.379$$

$$\Delta N_0 = 1$$

$$\Delta N_{1-2} = 0$$

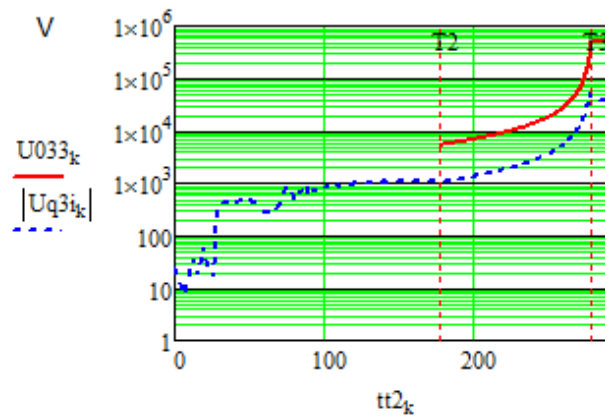
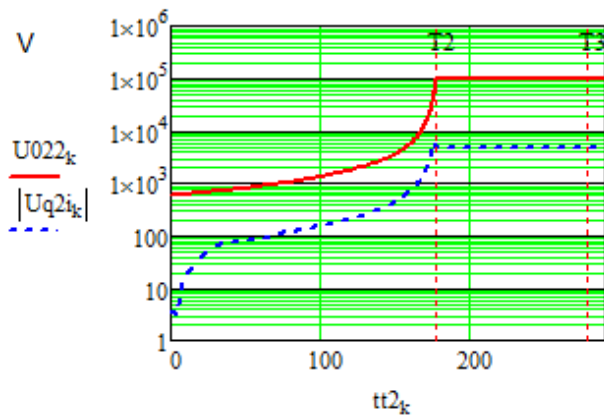
$$\sigma\varphi_{\text{av}_{kmax1}} = 5.299 \times 10^{-6}$$

$$\sigma\varepsilon_{\text{av}_{kmax1}} = 2.166 \times 10^{-8}$$

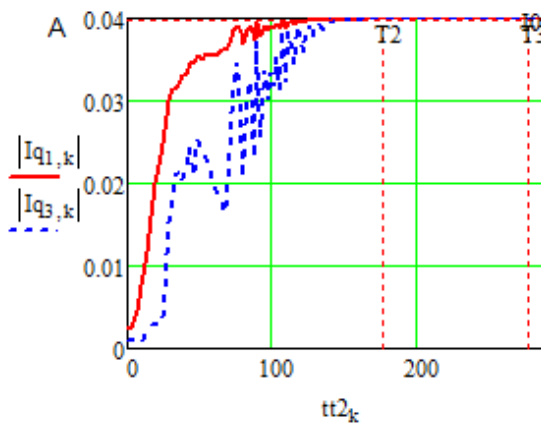
$$\sigma\varphi_{2\text{av}_{kmax1}} = 5.299 \times 10^{-6}$$

$$\sigma\varepsilon_{2\text{av}_{kmax1}} = 2.166 \times 10^{-8}$$

a)



b)



$$\frac{|I_{q3,kmax1}|}{I_0} = 1$$

$$|U_{q3i_{k00}}| = 1.054 \times 10^3$$

$$\frac{|I_{q3,k00}|}{I_0} = 1$$

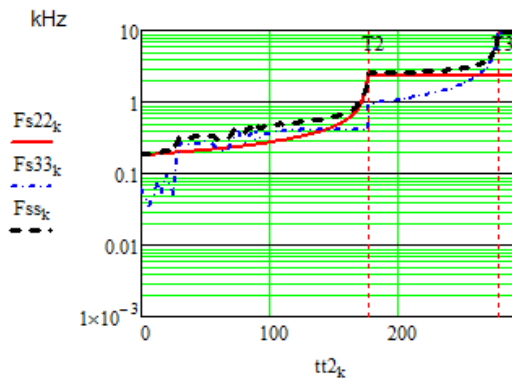
$$U_{min2} = 581.329$$

$$U_{min3} = 5.357 \times 10^3$$

$$U_{max2} = 1 \times 10^5$$

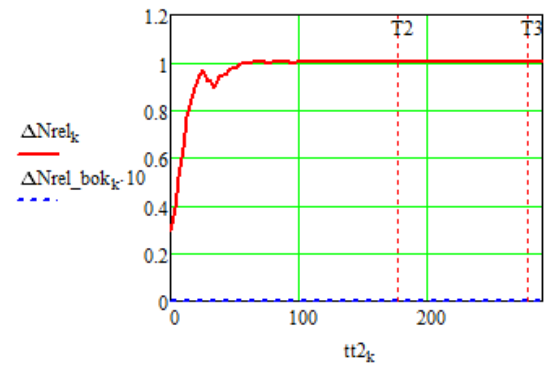
$$U_{max3} = 5 \times 10^5$$

c)



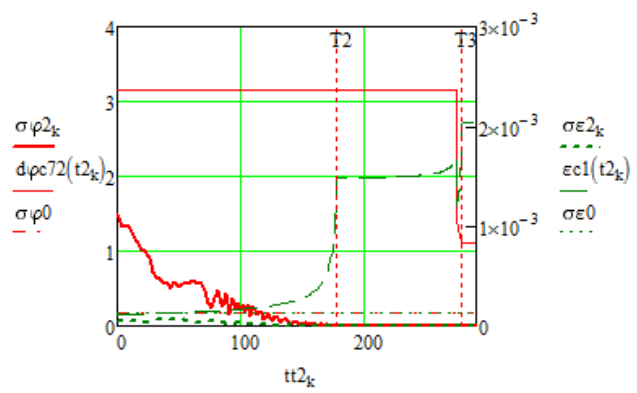
$F_{ss0} = 0.189$
 $F_{ss_{k00}} = 2.526$
 $F_{ss_{kmax1}} = 9.379$
 $\Delta N0 = 1$
 $\Delta N1-2 = 0$

d)



$\sigma\varphi_{av_{kmax1}} = 5.299 \times 10^{-6}$
 $\sigma\varepsilon_{av_{kmax1}} = 2.166 \times 10^{-8}$
 $\sigma\varphi2_{kmax1} = 5.75 \times 10^{-6}$
 $\sigma\varepsilon2_{kmax1} = 2.192 \times 10^{-8}$

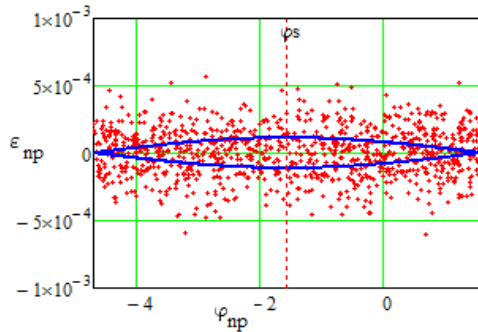
e)



f)

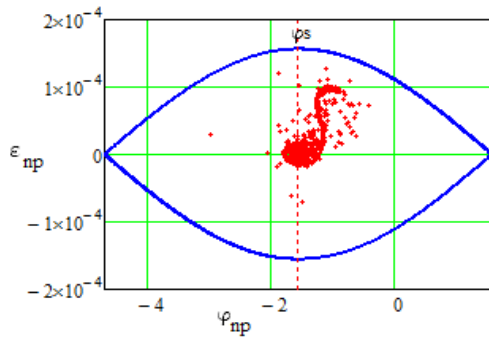
$k_2 := 0$

$$tt_{k_2} = 0 \quad U_{02}(t_{k_2}) = 581.3 \quad U_{03}(t_{k_2}) = 0$$



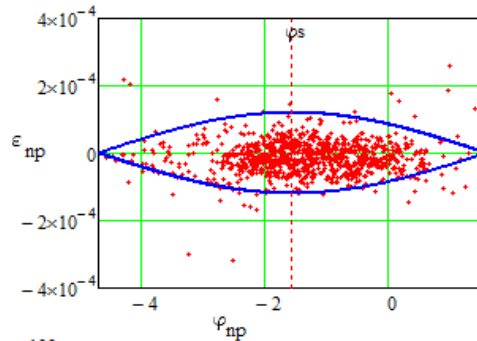
$k_4 := 30$

$$tt_{k_4} = 85.6 \quad U_{02}(t_{k_4}) = 1.1 \times 10^3 \quad U_{03}(t_{k_4}) = 0$$



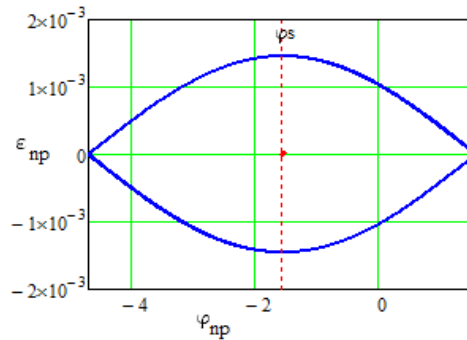
$k_3 := 7$

$$tt_{k_3} = 22.5 \quad U_{02}(t_{k_3}) = 665.6 \quad U_{03}(t_{k_3}) = 0$$



$k_5 := 100$

$$tt_{k_5} = 176.9 \quad U_{02}(t_{k_5}) = 9.8 \times 10^4 \quad U_{03}(t_{k_5}) = 0$$



4)

$$E_k = 1 \times 10^9$$

$$I_0 = 0.04$$

$$\sigma_{p0} = 2.4 \times 10^{-4}$$

$$\tau = 30$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.139$$

$$dda2 = 1$$

$$dda3 = 1$$

$$a_{20} = 177.273$$

$$a_{2f} = 0.249$$

$$a_{30} = 101.515$$

$$a_{3f} = 0.428$$

$$\frac{|I_{q3, kmax1}|}{I_0} = 0.997$$

$$U_{min2} = 581.329$$

$$U_{max2} = 1 \times 10^5$$

$$U_{min3} = 5.357 \times 10^3$$

$$U_{max3} = 5 \times 10^5$$

$$\max(U_{q3}) = 1.016 \times 10^3$$

$$F_{ss0} = 0.198$$

$$F_{ss_{k00}} = 2.526$$

$$F_{ss_{kmax1}} = 9.379$$

$$\Delta N_0 = 1$$

$$\Delta N_{1-2} = 0$$

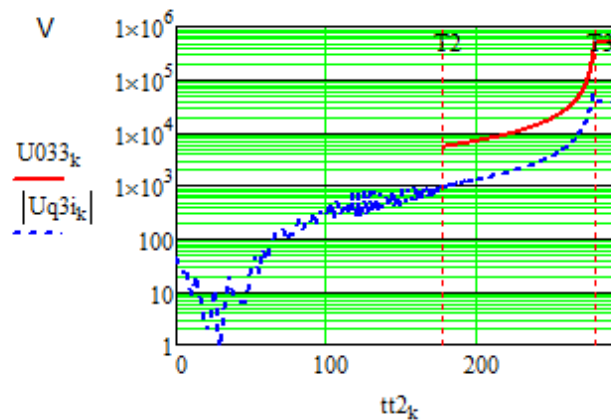
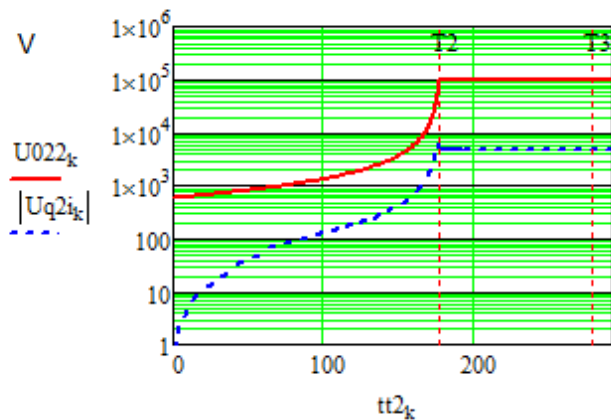
$$\sigma_{\varphi_{av, kmax1}} = 0.025$$

$$\sigma_{\varepsilon_{av, kmax1}} = 9.701 \times 10^{-5}$$

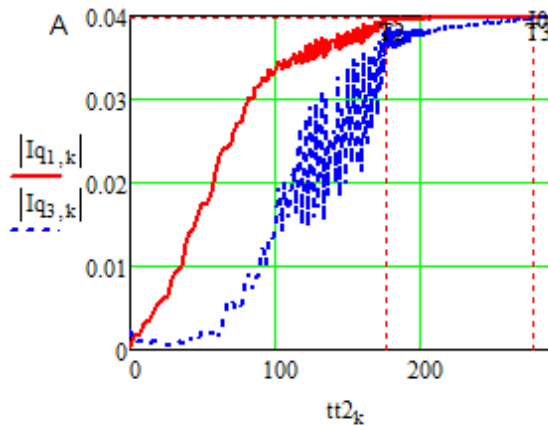
$$\sigma_{\varphi_{av}^2, kmax1} = 0.025$$

$$\sigma_{\varepsilon_{av}^2, kmax1} = 9.701 \times 10^{-5}$$

a)



b)



$$\frac{|I_{q3, kmax1}|}{I_0} = 0.997$$

$$|U_{q3i_{k00}}| = 991.588$$

$$\frac{|I_{q3, k00}|}{I_0} = 0.95$$

$$U_{min2} = 581.329$$

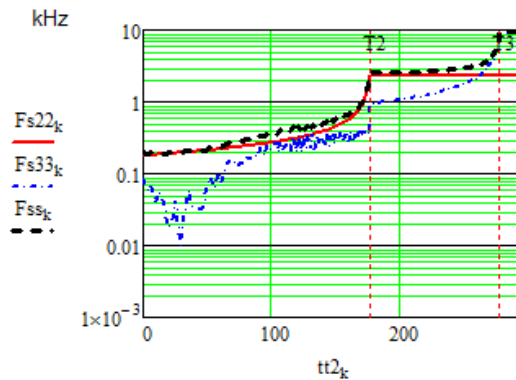
$$U_{min3} = 5.357 \times 10^3$$

$$U_{max2} = 1 \times 10^5$$

$$U_{max3} = 5 \times 10^5$$

$$I_0 \cdot \frac{Rs3}{a30} = 1.054 \times 10^3$$

c)



$$F_{ss_0} = 0.198$$

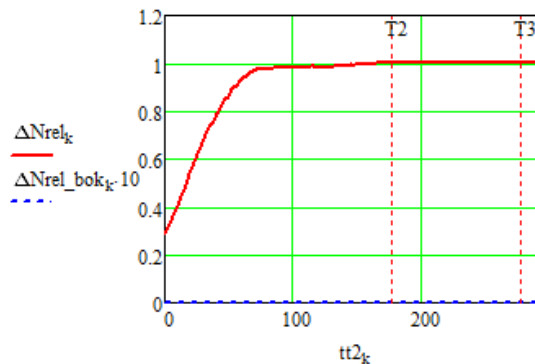
$$F_{ss_{k00}} = 2.526$$

$$F_{ss_{kmax1}} = 9.379$$

$$\Delta N_0 = 1$$

$$\Delta N_{1-2} = 0$$

d)



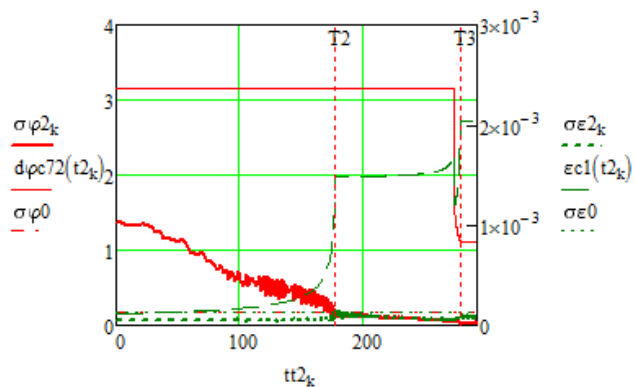
$$\sigma \varphi_{av_{kmax1}} = 0.025$$

$$\sigma \varepsilon_{av_{kmax1}} = 9.701 \times 10^{-5}$$

$$\sigma \varphi_{kmax1}^2 = 0.027$$

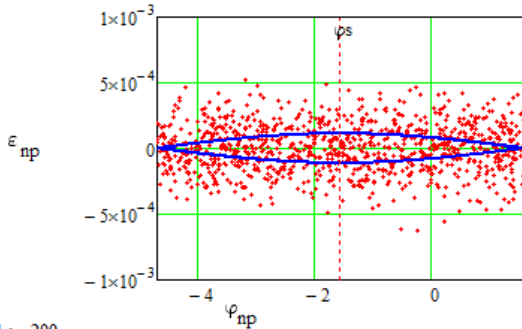
$$\sigma \varepsilon_{kmax1}^2 = 9.284 \times 10^{-5}$$

e)



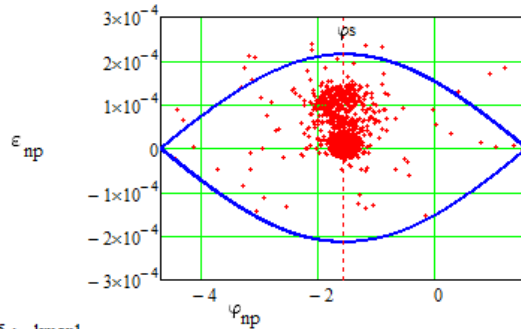
f) $k_2 := 0$

$$tt_{k_2} = 0 \quad U02(t_{k_2}) = 581.3 \quad U03(t_{k_2}) = 0$$



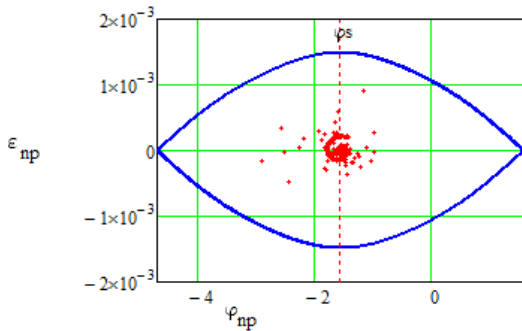
$k_3 := 50$

$$tt_{k_3} = 128.7 \quad U02(t_{k_3}) = 2.1 \times 10^3 \quad U03(t_{k_3}) = 0$$



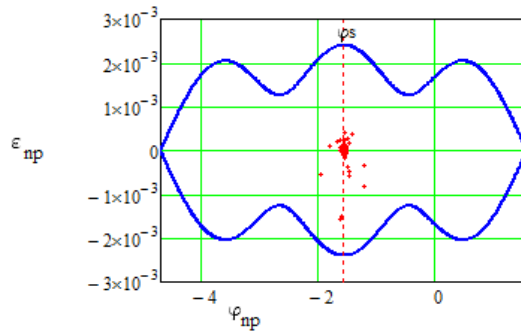
$k_4 := 200$

$$tt_{k_4} = 200.7 \quad U02(t_{k_4}) = 1 \times 10^5 \quad U03(t_{k_4}) = 7 \times 10^3$$



$k_5 := kmax1$

$$tt_{k_5} = 291.2 \quad U02(t_{k_5}) = 1 \times 10^5 \quad U03(t_{k_5}) = 5 \times 10^5$$



$$E_k = 3 \times 10^9$$

$$I_0 = 0.386$$

$$\sigma_{p0} = 3.7 \times 10^{-4}$$

$$\tau = 30$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.747$$

$$\text{dda2} = 1$$

$$\text{dda3} = 1$$

$$a_{20} = 177.273$$

$$a_{2f} = 2.411$$

$$a_{30} = 101.515$$

$$a_{3f} = 2.589$$

$$\frac{|I_{q3, k_{\max 1}}|}{I_0} = 0.907$$

$$U_{\min 2} = 1.472 \times 10^3$$

$$U_{\max 2} = 1 \times 10^5$$

$$U_{\min 3} = 2.187 \times 10^4$$

$$U_{\max 3} = 8 \times 10^5$$

$$\max(U_{q3}) = 5.799 \times 10^3$$

$$F_{ss0} = 0.106$$

$$F_{ss_{k00}} = 0.875$$

$$F_{ss_{k_{\max 1}}} = 3.398$$

$$\Delta N_0 = 0.988$$

$$\Delta N_{1 \cdot 2} = 0.012$$

$$\sigma\varphi_{\text{av}_{k_{\max 1}}} = 0.27$$

$$\sigma\varepsilon_{\text{av}_{k_{\max 1}}} = 9.552 \times 10^{-4}$$

$$\sigma\varphi_{2_{\text{av}_{k_{\max 1}}}} = 0.154$$

$$\sigma\varepsilon_{2_{\text{av}_{k_{\max 1}}}} = 9.577 \times 10^{-4}$$

$$E_k = 1 \times 10^9$$

$$I_0 = 0.04$$

$$\sigma_{p0} = 2.4 \times 10^{-4}$$

$$\tau = 50$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.139$$

$$\text{dda2} = 1$$

$$\text{dda3} = 1$$

$$a_{20} = 177.273$$

$$a_{2f} = 0.249$$

$$a_{30} = 101.515$$

$$a_{3f} = 0.428$$

$$\frac{|I_{q3, k_{\max 1}}|}{I_0} = 0.991$$

$$U_{\min 2} = 581.329$$

$$U_{\max 2} = 1 \times 10^5$$

$$U_{\min 3} = 5.357 \times 10^3$$

$$U_{\max 3} = 5 \times 10^5$$

$$\max(U_{q3}) = 908.283$$

$$F_{ss0} = 0.194$$

$$F_{ss_{k00}} = 2.526$$

$$F_{ss_{k_{\max 1}}} = 9.379$$

$$\Delta N_0 = 1$$

$$\Delta N_{1 \cdot 2} = 0$$

$$\sigma\varphi_{\text{av}_{k_{\max 1}}} = 0.054$$

$$\sigma\varepsilon_{\text{av}_{k_{\max 1}}} = 1.323 \times 10^{-4}$$

$$\sigma\varphi_{2_{\text{av}_{k_{\max 1}}}} = 0.054$$

$$\sigma\varepsilon_{2_{\text{av}_{k_{\max 1}}}} = 1.323 \times 10^{-4}$$

$$E_k = 1 \times 10^9$$

$$I_0 = 0.04$$

$$\sigma_{p0} = 2.4 \times 10^{-4}$$

$$\tau = 70$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.139$$

$$dda2 = 1$$

$$dda3 = 1$$

$$a_{20} = 177.273$$

$$a_{2f} = 0.249$$

$$a_{30} = 101.515$$

$$a_{3f} = 0.428$$

$$\frac{|I_{q3, k_{\max 1}}|}{I_0} = 0.964$$

$$U_{\min 2} = 581.329$$

$$U_{\max 2} = 1 \times 10^5$$

$$U_{\min 3} = 5.357 \times 10^3$$

$$U_{\max 3} = 5 \times 10^5$$

$$\max(U_{q3}) = 785.306$$

$$F_{ss0} = 0.194$$

$$F_{ss_{k00}} = 2.526$$

$$F_{ss_{k_{\max 1}}} = 9.379$$

$$\Delta N_0 = 0.995$$

$$\Delta N_{1-2} = 5 \times 10^{-3}$$

$$\sigma\varphi_{\text{av}_{k_{\max 1}}} = 0.169$$

$$\sigma\varepsilon_{\text{av}_{k_{\max 1}}} = 2.506 \times 10^{-4}$$

$$\sigma\varphi_{2_{\text{av}_{k_{\max 1}}}} = 0.09$$

$$\sigma\varepsilon_{2_{\text{av}_{k_{\max 1}}}} = 2.499 \times 10^{-4}$$

$$E_k = 3 \times 10^9$$

$$I_0 = 0.386$$

$$\sigma_{p0} = 3.7 \times 10^{-4}$$

$$\tau = 100$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.747$$

$$dda2 = 1$$

$$dda3 = 1$$

$$a20 = 177.273$$

$$a2f = 2.411$$

$$a30 = 101.515$$

$$a3f = 2.589$$

$$\frac{|I_{q3, kmax1}|}{I_0} = 0.822$$

$$U_{min2} = 1.472 \times 10^3$$

$$U_{max2} = 1 \times 10^5$$

$$U_{min3} = 2.187 \times 10^4$$

$$U_{max3} = 8 \times 10^5$$

$$\max(U_{q3}) = 4.551 \times 10^3$$

$$F_{ss0} = 0.106$$

$$F_{ss_{k00}} = 0.875$$

$$F_{ss_{kmax1}} = 3.398$$

$$\Delta N_0 = 0.978$$

$$\Delta N_{1-2} = 0.022$$

$$\sigma_{\varphi_{\text{av}_{kmax1}}} = 0.37$$

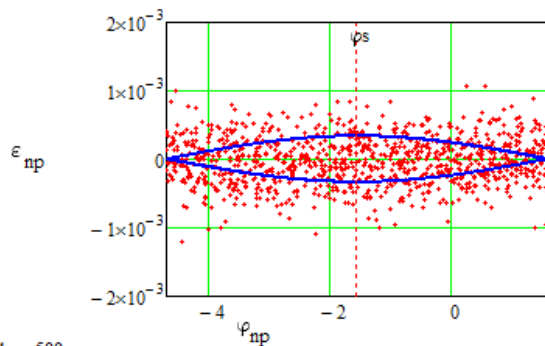
$$\sigma_{\varepsilon_{\text{av}_{kmax1}}} = 1.283 \times 10^{-3}$$

$$\sigma_{\varphi_{2_{\text{av}_{kmax1}}}} = 0.208$$

$$\sigma_{\varepsilon_{2_{\text{av}_{kmax1}}}} = 1.293 \times 10^{-3}$$

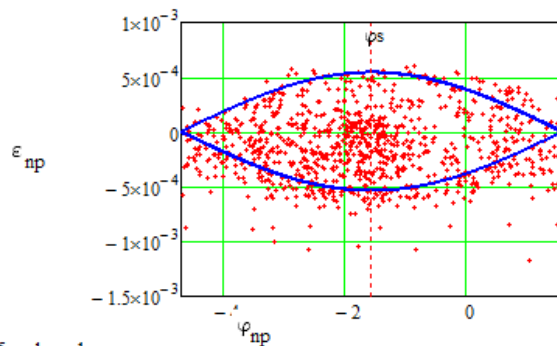
$k2 := 0$

$$tt_{k2} = 0 \quad U02(t_{k2}) = 1.5 \times 10^3 \quad U03(t_{k2}) = 0$$



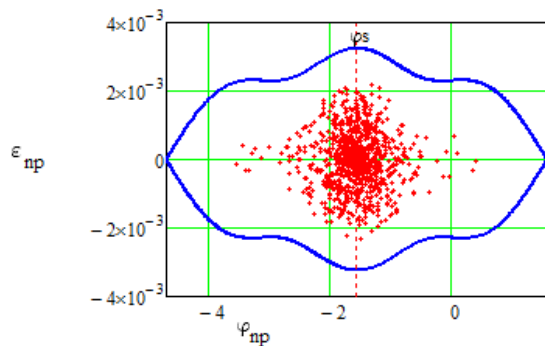
$k3 := 50$

$$tt_{k3} = 108.7 \quad U02(t_{k3}) = 3.8 \times 10^3 \quad U03(t_{k3}) = 0$$



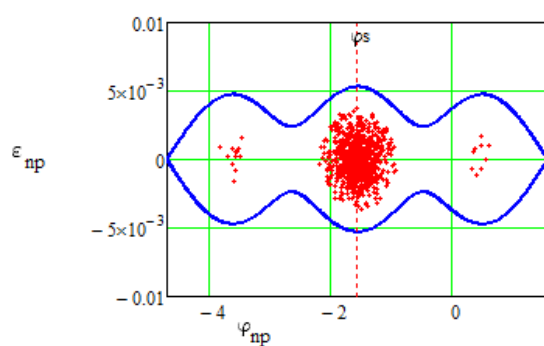
$k4 := 500$

$$tt_{k4} = 256.8 \quad U02(t_{k4}) = 1 \times 10^5 \quad U03(t_{k4}) = 1.1 \times 10^5$$



$k5 := kmax1$

$$tt_{k5} = 293.6 \quad U02(t_{k5}) = 1 \times 10^5 \quad U03(t_{k5}) = 8 \times 10^5$$



$$E_k = 3 \times 10^9$$

$$I_0 = 0.386$$

$$\sigma_{p0} = 3.7 \times 10^{-4}$$

$$\tau = 200$$

$$\frac{\varepsilon_{\text{eff}}}{\sigma\varepsilon} = 2.747$$

$$\text{dda2} = 1$$

$$\text{dda3} = 1$$

$$a_{20} = 177.273$$

$$a_{2f} = 2.411$$

$$a_{30} = 101.515$$

$$a_{3f} = 2.589$$

$$\frac{|I_{q3, \text{kmax1}}|}{I_0} = 0.794$$

$$U_{\text{min2}} = 1.472 \times 10^3$$

$$U_{\text{max2}} = 1 \times 10^5$$

$$U_{\text{min3}} = 2.187 \times 10^4$$

$$U_{\text{max3}} = 8 \times 10^5$$

$$\max(U_{q3}) = 3.958 \times 10^3$$

$$F_{ss0} = 0.106$$

$$F_{ss_{k00}} = 0.875$$

$$F_{ss_{\text{kmax1}}} = 3.398$$

$$\Delta N_0 = 0.916$$

$$\Delta N_{1-2} = 0.084$$

$$\sigma_{\varphi_{\text{av}_{\text{kmax1}}}} = 0.638$$

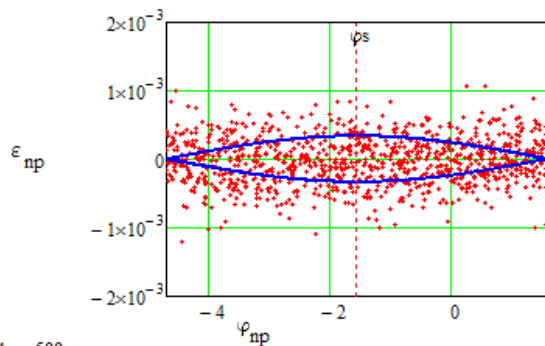
$$\sigma_{\varepsilon_{\text{av}_{\text{kmax1}}}} = 1.382 \times 10^{-3}$$

$$\sigma_{\varphi_{2_{\text{av}_{\text{kmax1}}}}} = 0.234$$

$$\sigma_{\varepsilon_{2_{\text{av}_{\text{kmax1}}}}} = 1.429 \times 10^{-3}$$

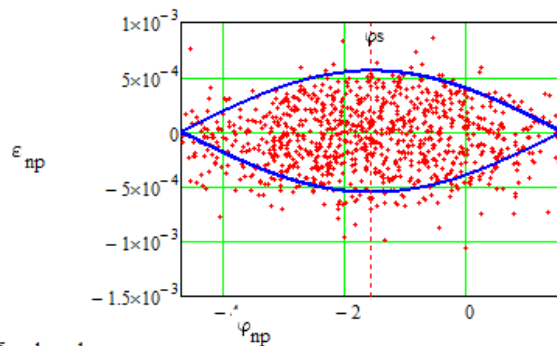
$k2 := 0$

$$tt_{k2} = 0 \quad U02(t_{k2}) = 1.5 \times 10^3 \quad U03(t_{k2}) = 0$$



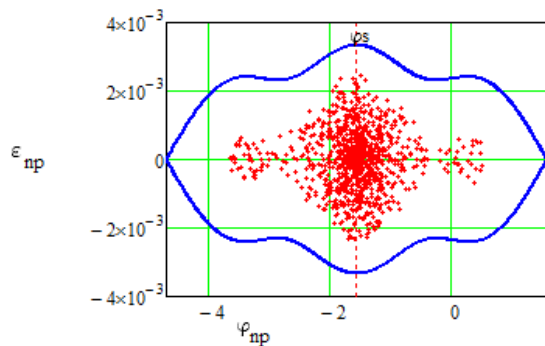
$k3 := 50$

$$tt_{k3} = 112.5 \quad U02(t_{k3}) = 4 \times 10^3 \quad U03(t_{k3}) = 0$$



$k4 := 500$

$$tt_{k4} = 260.2 \quad U02(t_{k4}) = 1 \times 10^5 \quad U03(t_{k4}) = 1.4 \times 10^5$$



$k5 := kmax1$

$$tt_{k5} = 303.6 \quad U02(t_{k5}) = 1 \times 10^5 \quad U03(t_{k5}) = 8 \times 10^5$$

