

Исходные данные

Коэф. запаса:

safety = 1.3

Горючее:

Fuel = "Керосин"

turbine = "ТНД"

Высота движения (м):

H<sub>v</sub> = 0

Массовый расход перед Т (кг/с):

Массовый расход утечек Т (кг/с):

Массовый расход на охл Т (кг/с):

G<sub>T</sub>

G<sub>leak</sub>

G<sub>cooling</sub>

=

32.30

106.96·10<sup>-3</sup>

3240.8·10<sup>-3</sup>

if turbine = "ТВД"

=

	1
1	35.43
2	0.04
3	0.81

35.43

35.65·10<sup>-3</sup>

810.2·10<sup>-3</sup>

if turbine = "ТНД"

Мощность Т (Вт):

N<sub>T</sub> = 10<sup>6</sup> · 

14.893 if turbine = "ТВД"

15.181 if turbine = "ТНД"

 = 15.181·10<sup>6</sup>

Полное давление перед Т (Па):

P\*<sub>T</sub> = 10<sup>3</sup> · 

2731.8 if turbine = "ТВД"

927.5 if turbine = "ТНД"

 = 927.5·10<sup>3</sup>

Полная температура перед Т (К):

T\*<sub>T</sub> = 

1773 if turbine = "ТВД"

1368.9 if turbine = "ТНД"

 = 1368.9

Коэф. избытка воздуха в Т:

α<sub>ох</sub> = 

2.267 if turbine = "ТВД"

2.493 if turbine = "ТНД"

 = 2.493

Полное давление отбора охлаждающего воздуха (К):

P\*<sub>cooling</sub> = 10<sup>3</sup> · 

2845.6 if turbine = "ТВД"

319.4 if turbine = "ТНД"

 = 319.4·10<sup>3</sup>

Полная температура отбора охлаждающего воздуха (К):

T\*<sub>cooling</sub> = 

806.9 if turbine = "ТВД"

418.2 if turbine = "ТНД"

 = 418.2

Коэф. сохранения полного давления охлаждения:

σ<sub>cooling</sub> = 0.97

Подогрев охл. от КС [К]:

ΔT<sub>охл.подогрев</sub> = 40

Газовая постоянная (Дж/кг/К):

R<sub>газ</sub>(α<sub>ох</sub>,Fuel) = 288.5

Допустимая температура Л (К):

T<sub>Л,доп</sub> = 1373

Абс. скорость перед Т (м/с):

Абс. скорость после Т (м/с):

[1, с.15]

$80 \leq c_T \leq 400 = 1$

Лопаточный КПД Т:

$\eta_{ЛТ} = 88\%$

$88\% \leq \eta_{ЛТ} \leq 95\% = 1$

Угол входа в Т:

$\alpha_T = 90.^{\circ}$

Окр. скорость Л последней ступени на ср. диаметре Т (м/с):

$$\begin{pmatrix} c_{Г} \\ c_{Т} \end{pmatrix} = \begin{cases} \begin{pmatrix} 100 \\ 180 \end{pmatrix} & \text{if turbine = "ТВД"} \\ \begin{pmatrix} 180 \\ 260 \end{pmatrix} & \text{if turbine = "ТНД"} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 180.0 \\ \hline 2 & 260.0 \\ \hline \end{array}$$

$$u_T = \begin{cases} 520 & \text{if turbine = "ТВД"} \\ 260 & \text{if turbine = "ТНД"} \end{cases} = 260.0$$

$z = \text{ORIGIN}..N_T$

Полное давление отбора охлаждающего воздуха (K):  
 $P_{cooling}^* = P_{cooling}^* \cdot \sigma_{cooling} = 309.8 \cdot 10^3$

Полная температура отбора охлаждающего воздуха (K):  
 $T_{cooling}^* = T_{cooling}^* + \Delta T_{\text{охл.подогрев}} = 458.2$

Массовый расход перед Т (кг/с):  
 $G_{T_{in}} = G_T - G_{leak} = 35.4$

Массовый расход после Т (кг/с):  
 $G_T = G_T + G_{cooling} = 36.2$

Удельная работа Т (Дж/кг):  
 $L_T^* = \frac{N_T}{\text{mean}(G_T, G_T)} = 424.1 \cdot 10^3$

$L_T^* \leq 550 \cdot 10^3 = 1$

Располагаемый теплоперепад в Т (Дж/кг):  
 $H_T = \frac{L_T^* + 0.5c_T^2}{\eta_{\text{л}}} = 520.3 \cdot 10^3$

iteration

k<sub>Г</sub>

P<sub>Г</sub>

T<sub>Г</sub>

=

iteration = 0

k<sub>Г</sub> = k<sub>ад</sub>(Cp<sub>Газ</sub>(P\*<sub>Г</sub>, T\*<sub>Г</sub>, α<sub>оx</sub>, Fuel), R<sub>Газ</sub>(α<sub>оx</sub>, Fuel))

while 1 > 0

iteration = iteration + 1

Cp<sub>Г</sub> =  $\frac{k_{Г}}{k_{Г} - 1} \cdot R_{\text{Газ}}(\alpha_{\text{оx}}, \text{Fuel})$

T<sub>Г</sub> =  $T^*_{Г} - \frac{c_{Г}^2}{2 \cdot Cp_{Г}}$

P<sub>Г</sub> =  $P^*_{Г} \cdot \left(\frac{T_{Г}}{T^*_{Г}}\right)^{\frac{k_{Г}}{k_{Г}-1}}$

k'<sub>Г</sub> = k<sub>ад</sub>(Cp<sub>Газ</sub>(P<sub>Г</sub>, T<sub>Г</sub>, α<sub>оx</sub>, Fuel), R<sub>Газ</sub>(α<sub>оx</sub>, Fuel))

if |eps("rel", k<sub>Г</sub>, k'<sub>Г</sub>)| ≤ epsilon

k<sub>Г</sub> = k'<sub>Г</sub>

break

k<sub>Г</sub> = k'<sub>Г</sub>

(iteration k<sub>Г</sub> P<sub>Г</sub> T<sub>Г</sub>)<sup>T</sup>

	1
1	1.0
2	1.3
3	890047.3
4	1356.0

Количество итераций:      iteration = 1

Показатель адиабаты перед Т:      k<sub>Г</sub> = 1.298

Статическое давление перед Т (Па):      P<sub>Г</sub> = 890·10<sup>3</sup>

Статическая температура перед Т (K):      T<sub>Г</sub> = 1356

Теплоемкость перед Т (Дж/кг/К):      Cp<sub>Г</sub> = Cp<sub>Газ</sub>(P<sub>Г</sub>, T<sub>Г</sub>, α<sub>оx</sub>, Fuel) = 1256

<u>iteration</u>		
k <sub>T</sub>	=	iteration = 0
P <sub>T</sub>		k <sub>T</sub> = k <sub>T</sub>
T <sub>T</sub>		while 1 > 0
		iteration = iteration + 1
		k <sub>cp</sub> = mean(k <sub>T</sub> , k <sub>T</sub> )
		Cp = $\frac{k_{cp}}{k_{cp} - 1} \cdot R_{газ}(\alpha_{ox}, Fuel)$
		$P_T = P^*_{\Gamma} \cdot \left(1 - \frac{H_T}{Cp \cdot T^*_{\Gamma}}\right)^{\frac{k_{cp}}{k_{cp} - 1}}$
		$T_T = T^*_{\Gamma} - \frac{H_T \cdot \eta_{л}}{Cp}$
		k' <sub>T</sub> = k <sub>ад</sub> (Cp <sub>газ</sub> (P <sub>T</sub> , T <sub>T</sub> , α <sub>ox</sub> , Fuel), R <sub>газ</sub> (α <sub>ox</sub> , Fuel))
		if  eps("rel", k <sub>T</sub> , k' <sub>T</sub> )  ≤ epsilon
		k <sub>T</sub> = k' <sub>T</sub>
		break
		k <sub>T</sub> = k' <sub>T</sub>
		(iteration k <sub>T</sub> P <sub>T</sub> T <sub>T</sub> ) <sup>T</sup>

	1
1	2
2	1.32
3	191463.061
4	994.672

Количество итераций:      iteration = 2

Показатель адиабаты после T:      k<sub>T</sub> = 1.320

Статическое давление после T (Па):      P<sub>T</sub> = 191.5·10<sup>3</sup>      **P<sub>T</sub> ≥ P<sub>атм</sub>(H<sub>υ</sub>) = 1**

Статическая температура после T (K):      T<sub>T</sub> = 994.7

Теплоемкость после T (Дж/кг/К):      Cp<sub>T</sub> = Cp<sub>газ</sub>(P<sub>T</sub>, T<sub>T</sub>, α<sub>ox</sub>, Fuel) = 1190.6

Ср. показатель адиабаты T:  $k = \text{mean}\Big(k_{\Gamma}, k_T\Big) = 1.309$

Ср. теплоемкость T (Дж/кг/К):  $C_p = \frac{k}{k - 1} \cdot R_{\text{газ}}\Big(\alpha_{\text{ox}}, \text{Fuel}\Big) = 1222.3$

Степень понижения давления:  $\pi_T = \frac{P_{\Gamma}^*}{P_T} = 4.84$

Удельный объём перед T (м³/кг):  $\left(\begin{matrix} v_{\Gamma} \\ v_T \end{matrix}\right) = R_{\text{газ}}\Big(\alpha_{\text{ox}}, \text{Fuel}\Big) \cdot \left(\begin{matrix} \frac{T_{\Gamma}}{P_{\Gamma}} \\ \frac{T_T}{P_T} \end{matrix}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0.440 \\ \hline 2 & 1.499 \\ \hline \end{array}$

Площадь кольцевого сечения перед T (м²):  $\left(\begin{matrix} F_{\Gamma} \\ F_T \end{matrix}\right) = \left(\begin{matrix} \frac{G_{\Gamma} \cdot v_{\Gamma}}{c_{\Gamma}} \\ \frac{G_T \cdot v_T}{c_T} \end{matrix}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 86421 \\ \hline 2 & 208684 \\ \hline \end{array} \cdot 10^{-6}$

Площадь кольцевого сечения после T (м²):



Выбранный материал Л:

material\_blade<sub>i</sub> =

"ВКНА-1В" if 1523 ≤ T\*<sub>г</sub>

"ВЖМ7" if 1323 ≤ T\*<sub>г</sub> < 1523

"ЖС-36" if 1123 ≤ T\*<sub>г</sub> < 1323

Плотность материала Л (кг/м^3):

ρ<sub>blade<sub>i</sub></sub> =

7938 if material\_blade<sub>i</sub> = "ВКНА-1В"

8390 if material\_blade<sub>i</sub> = "ВЖМ7"

8760 if material\_blade<sub>i</sub> = "ЖС-36"

NaN otherwise

Предел длительной прочности Л РК (Па):

σ<sub>blade\_long<sub>i</sub></sub> = 10<sup>6</sup> ·

205 if material\_blade<sub>i</sub> = "ВКНА-1В"

120 if material\_blade<sub>i</sub> = "ВЖМ7"

120 if material\_blade<sub>i</sub> = "ЖС-36"

NaN otherwise

material\_blade<sup>T</sup> =

	1	2	3	4
1	"ВЖМ7"	"ВЖМ7"	"ВЖМ7"	"ВЖМ7"

ρ<sub>blade</sub><sup>T</sup> =

	1	2	3	4
1	8390	8390	8390	8390

σ<sub>blade\_long</sub><sup>T</sup> =

	1	2	3	4
1	120	120	120	120

·10<sup>6</sup>

Коэф. формы:

k<sub>n</sub> = 6.8

Модуль Юнга I рода материала Л (Па):

E<sub>blade</sub> = 210·10<sup>9</sup>

Коэф. Пуассона материала Л():

μ<sub>steel</sub> = 0.3



Мах частота вращения ротора на входе (об/мин):

$$\sqrt{\frac{\sigma\_blade\_longZ}{safety \cdot k_n \cdot F_{\Gamma}}} = 12533$$

Мах частота вращения ротора на выходе (об/мин):

$$n_{max} = \sqrt{\frac{\sigma\_blade\_longZ}{safety \cdot k_n \cdot F_T}} = 8065$$

Рекомендуюмая ном. частота вращения (об/мин):

$$n = n_{max} \cdot 0.95 = 7662$$

Ном. частота вращения (рад/с):

$$\omega = \frac{2 \cdot \pi \cdot n}{60} = 555.0$$

$$n_{\omega} = \left\{ \begin{array}{ll} 15000 & \text{if turbine = "ТВД"} \\ 5300 & \text{if turbine = "ТНД"} \end{array} \right. = 5300$$

Ср. диаметр перед Т (м):

$$\left( \begin{array}{c} D_{\Gamma.ср} \\ D_{Т.ср} \end{array} \right) = \frac{2}{\omega} \cdot \left( \begin{array}{c} u_{\Gamma} \\ u_{Т} \end{array} \right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 936.9 \\ \hline 2 & 936.9 \\ \hline \end{array} \cdot 10^{-3}$$

Ср. диаметр после Т (м):

Длина Л первой ступени Т (м):

$$\left( \begin{array}{c} l_{\Gamma} \\ l_{Т} \end{array} \right) = \frac{1}{\pi} \cdot \left( \begin{array}{c} \frac{F_{\Gamma}}{D_{\Gamma.ср}} \\ \frac{F_T}{D_{Т.ср}} \end{array} \right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 29.36 \\ \hline 2 & 70.90 \\ \hline \end{array} \cdot 10^{-3}$$

Длина Л последней ступени Т (м):

Диаметр периферии после Т (м):

$$\left( \begin{array}{c} D_{Т.пер} \\ D_{Т.кор} \end{array} \right) = \left( \begin{array}{c} D_{Т.ср} + l_{\Gamma} \\ D_{Т.ср} - l_{\Gamma} \end{array} \right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1007.8 \\ \hline 2 & 866.0 \\ \hline \end{array} \cdot 10^{-3}$$

Диаметр корня после Т (м):

Равномерное распределение мощности Т по ступеням (Вт):

$$N_{\text{сТ}_i} = \frac{N_{\text{T}}}{Z}$$

$N_{\text{сТ}}^{\text{T}} =$

	1	2	3	4
1	3.80	3.80	3.80	3.80

$\cdot 10^6$

Вид проточной части:  
("const", "кор", "сп", "пер", "доля от предыдущего диаметра периферии")

$ЗППЧ = \left( \begin{array}{l} \left| \begin{array}{llllll} \text{"const"} & \text{if } Z = 1 & \text{"1.07"} & \text{"1.065"} & \text{"1.03"} & \text{"пер"} & \text{"пер"} \end{array} \right. \\ \left| \begin{array}{ll} \text{"кор"} & \text{otherwise} \end{array} \right. \\ \left| \begin{array}{llllll} \text{"пер"} & \text{if } Z = 1 & \text{"1.07"} & \text{"1.05"} & \text{"кор"} & \text{"пер"} & \text{"пер"} \end{array} \right. \\ \left| \begin{array}{ll} \text{"1.055"} & \text{otherwise} \end{array} \right. \end{array} \right)^{\text{T}}$

▼ Определение проточной части ОТ

Линейное распределение кольцевых площадей по сечениям:

$\overset{\text{ww}}{F} =$

for $i \in 1..2Z + 1$
$F_i = \frac{F_{\text{T}} - F_{\text{Г}}}{\text{st}(Z, 3) - 1} \cdot i + \left( F_{\text{Г}} - \frac{F_{\text{T}} - F_{\text{Г}}}{\text{st}(Z, 3) - 1} \right)$
for $i \in 1..Z$
for $a \in 2..3$
$F_{\text{st}(i, a)} = F_{\text{st}(i, a-1)}$ if $ЗППЧ_{i, a-1} = \text{"const"}$
F

$F^{\text{T}} =$

	1	2	3	4	5	6	7	8	9
1	86421	101704	116987	132270	147553	162836	178118	193401	208684

$\cdot 10^{-6}$

D =
for i ∈ 2Z + 1
for r ∈ 1..N<sub>r</sub>
D<sub>i,r</sub> =

D<sub>T.kop</sub> if r = 1
D<sub>T.cp</sub> if r = av(N<sub>r</sub>)
D<sub>T.nep</sub> if r = N<sub>r</sub>

for i ∈ Z..1
for a ∈ 2..1
for r ∈ 1..N<sub>r</sub>
D<sub>st(i,a),r</sub> =

if 3ΠΠΠΨ<sub>i,a</sub> = "const"

D<sub>st(i,a+1),av(N<sub>r</sub>)</sub> −  $\frac{F_{st(i,a)}}{\pi \cdot D_{st(i,a+1),av(N_r)}}$  if r = 1
D<sub>st(i,a+1),av(N<sub>r</sub>)</sub> if r = av(N<sub>r</sub>)
D<sub>st(i,a+1),av(N<sub>r</sub>)</sub> +  $\frac{F_{st(i,a)}}{\pi \cdot D_{st(i,a+1),av(N_r)}}$  if r = N<sub>r</sub>

if 3ΠΠΠΨ<sub>i,a</sub> = "kop"

D<sub>st(i,a+1),1</sub> if r = 1

12⋅[D<sub>st(i,a+1),1</sub> + √((D<sub>st(i,a+1),1</sub>)<sup>2</sup> +  $\frac{4 \cdot F_{st(i,a)}}{\pi}$ )] if r = av(N<sub>r</sub>)
√((D<sub>st(i,a+1),1</sub>)<sup>2</sup> +  $\frac{4 \cdot F_{st(i,a)}}{\pi}$ ) if r = N<sub>r</sub>

if 3ΠΠΠΨ<sub>i,a</sub> = "cp"

D<sub>st(i,a+1),av(N<sub>r</sub>)</sub> −  $\frac{F_{st(i,a)}}{\pi \cdot D_{st(i,a+1),av(N_r)}}$  if r = 1
D<sub>st(i,a+1),av(N<sub>r</sub>)</sub> if r = av(N<sub>r</sub>)
D<sub>st(i,a+1),av(N<sub>r</sub>)</sub> +  $\frac{F_{st(i,a)}}{\pi \cdot D_{st(i,a+1),av(N_r)}}$  if r = N<sub>r</sub>

if 3ΠΠΠΨ<sub>i,a</sub> = "nep"

√((D<sub>st(i,a+1),N<sub>r</sub></sub>)<sup>2</sup> −  $\frac{4 \cdot F_{st(i,a)}}{\pi}$ ) if r = 1

12⋅[√((D<sub>st(i,a+1),N<sub>r</sub></sub>)<sup>2</sup> −  $\frac{4 \cdot F_{st(i,a)}}{\pi}$ ) + D<sub>st(i,a+1),N<sub>r</sub></sub>] if r = av(N<sub>r</sub>)
D<sub>st(i,a+1),N<sub>r</sub></sub> if r = N<sub>r</sub>

D<sup>T</sup> =

	1	2	3	4	5	6	7	8	9
1	620.7	620.7	651.1	698.2	750.4	802.7	843.9	866.0	866.0
2	662.2	669.0	704.0	754.0	808.5	862.8	906.5	932.1	936.9
3	703.7	717.4	756.9	809.9	866.6	922.9	969.0	998.1	1007.8

⋅10<sup>−</sup>

R<sub>ww</sub> =
D2

R<sup>T</sup> =

	1	2	3	4	5	6	7	8	9
1	310.3	310.3	325.6	349.1	375.2	401.4	422.0	433.0	433.0
2	331.1	334.5	352.0	377.0	404.2	431.4	453.2	466.0	468.5
3	351.9	358.7	378.4	404.9	433.3	461.4	484.5	499.1	503.9

⋅10<sup>−3</sup>

d̄ =

for i ∈ 1..Z
for a ∈ 1..3
d̄<sub>st(i,a)</sub> =  $\frac{D_{st(i,a),1}}{D_{st(i,a),N_r}}$

d̄

d̄<sup>T</sup> =

	1	2	3	4	5	6	7	8	9
1	0.8819	0.8651	0.8602	0.8621	0.8659	0.8698	0.8709	0.8677	0.8593

d̄<sup>T</sup> ≤ 0.9 =

	1	2	3	4	5	6	7	8	9
1	1	1	1	1	1	1	1	1	1

h =

for i ∈ 1..2Z + 1
h<sub>i</sub> =  $\frac{F_i}{\pi \cdot D_{i,av(N_r)}}$

h

h<sup>T</sup> =

	1	2	3	4	5	6	7	8	9
1	41.54	48.39	52.90	55.84	58.09	60.07	62.55	66.05	70.90

⋅10<sup>−3</sup>

$$\begin{aligned} & \left| \Psi_{\text{st}(i, a+1), N_r} \right| \\ & \text{if } \left( 3\prod\prod\mathcal{U}_{i, a} \neq \text{"const"} \right) \wedge \left( 3\prod\prod\mathcal{U}_{i, a} \neq \text{"kop"} \right) \wedge \left( 3\prod\prod\mathcal{U}_{i, a} \neq \text{"cp"} \right) \wedge \left( 3\prod\prod\mathcal{U}_{i, a} \neq \text{"nep"} \right) \\ & \left| \sqrt{\left( \frac{D_{\text{st}(i, a+1), N_r}}{\text{str2num}(3\prod\prod\mathcal{U}_{i, a})} \right)^2 - \frac{4 \cdot F_{\text{st}(i, a)}}{\pi}} \right| \text{ if } r = 1 \\ & \frac{1}{2} \cdot \left[ \sqrt{\left( \frac{D_{\text{st}(i, a+1), N_r}}{\text{str2num}(3\prod\prod\mathcal{U}_{i, a})} \right)^2 - \frac{4 \cdot F_{\text{st}(i, a)}}{\pi}} + \frac{D_{\text{st}(i, a+1), N_r}}{\text{str2num}(3\prod\prod\mathcal{U}_{i, a})} \right] \text{ if } r = \text{av}(N_r) \\ & \frac{D_{\text{st}(i, a+1), N_r}}{\text{str2num}(3\prod\prod\mathcal{U}_{i, a})} \text{ if } r = N_r \\ & \text{NaN otherwise} \end{aligned}$$

u =	for i ∈ 1..2·Z + 1 for r ∈ 1..N <sub>r</sub> $u_{i,r} = \frac{\pi \cdot D_{i,r} \cdot n}{60}$
	u

$u^T =$		1	2	3	4	5	6	7	8	9
	1	172.2	172.2	180.7	193.8	208.2	222.8	234.2	240.3	240.3
	2	183.8	185.7	195.4	209.3	224.4	239.4	251.6	258.7	260.0
	3	195.3	199.1	210.0	224.7	240.5	256.1	268.9	277.0	279.7

$F^T =$ 

	1	2	3	4	5	6	7	8	9
1	86421	101704	116987	132270	147553	162836	178118	193401	208684

$\cdot 10^{-6}$

$\overline{d}_1 = 0.8819$

$\overline{d}_1 \leq 0.9 = 1$

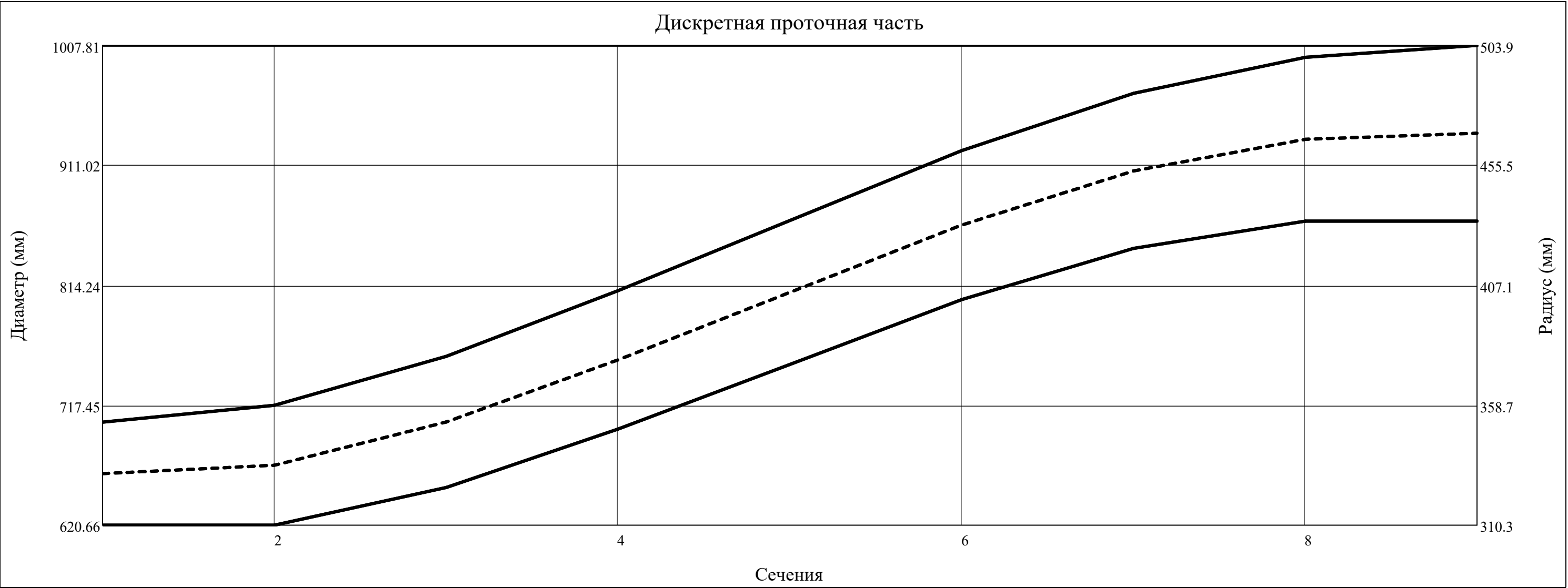
$\overline{d}^T =$ 

	1	2	3	4	5	6	7	8	9
1	0.8819	0.8651	0.8602	0.8621	0.8659	0.8698	0.8709	0.8677	0.8593

$D^T =$ 

	1	2	3	4	5	6	7	8
1	620.7	620.7	651.1	698.2	750.4	802.7	843.9	866.0
2	662.2	669.0	704.0	754.0	808.5	862.8	906.5	932.1
3	703.7	717.4	756.9	809.9	866.6	922.9	969.0	...

 $\cdot 10^{-3}$



$h^T =$ 

	1	2	3	4	5	6	7	8	9
1	41.54	48.39	52.90	55.84	58.09	60.07	62.55	66.05	70.90

 $\cdot 10^{-3}$



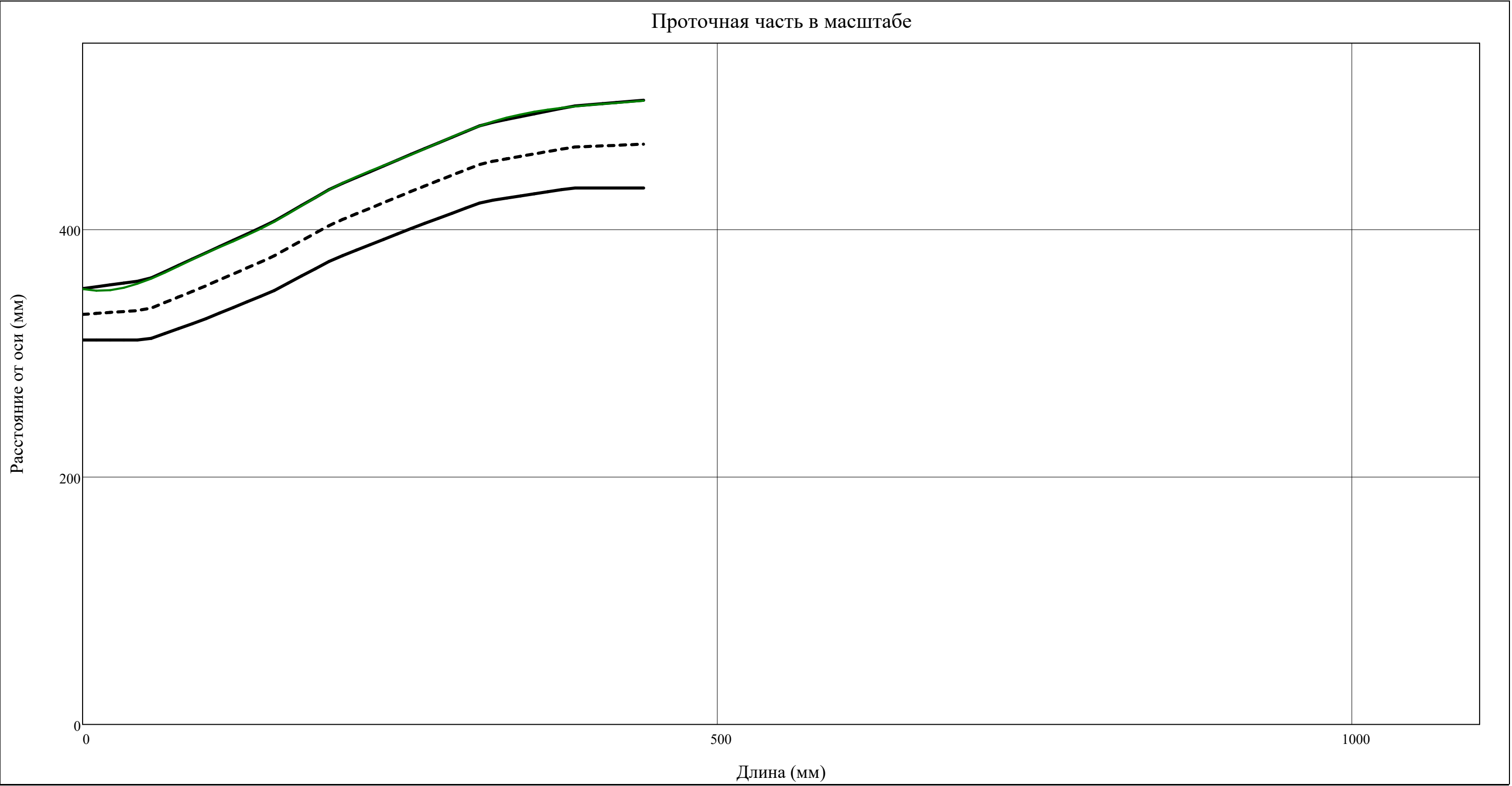






$y_{ПЧпер}(l) = \text{linterp}(x_{ПЧ}, 0.5 \cdot y_{ПЧпер}, 1) \quad y_{ПЧср}(l) = \text{linterp}(x_{ПЧ}, 0.5 \cdot y_{ПЧср}, 1) \quad y_{ПЧкор}(l) = \text{linterp}(x_{ПЧ}, 0.5 \cdot y_{ПЧкор}, 1)$

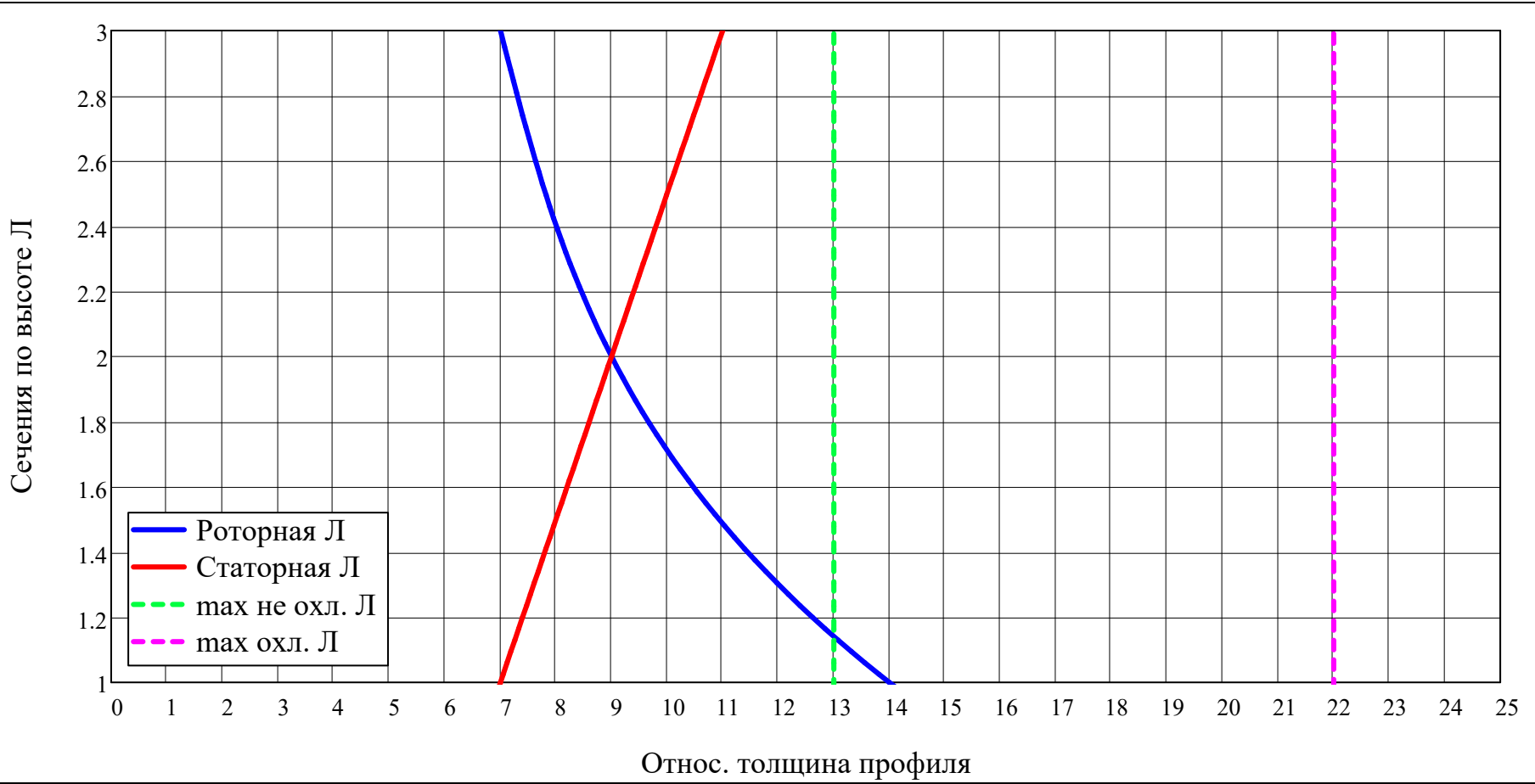
$y_{Лпер}(l) = \text{interp}(\text{cspline}(x_{ПЧ}, 0.5 \cdot y_{Лпер}), x_{ПЧ}, 0.5 \cdot y_{Лпер}, 1)$



Относ. толщины ЛРК и СА:

$$\overline{c}_{\text{stator.}}(r) = \begin{cases} \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 15 \\ 15 \\ 15 \end{pmatrix} \% \right], \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 15 \\ 15 \\ 15 \end{pmatrix} \% , r \right] & \text{if } T_{\text{Л.доп}} < T^*_{\text{г}} \\ \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 7 \\ 9 \\ 11 \end{pmatrix} \% \right], \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 7 \\ 9 \\ 11 \end{pmatrix} \% , r \right] & \text{otherwise} \end{cases}$$

$$\overline{c}_{\text{rotor.}}(r) = \begin{cases} \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 17 \\ 13 \\ 11 \end{pmatrix} \% \right], \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 17 \\ 13 \\ 11 \end{pmatrix} \% , r \right] & \text{if } T_{\text{Л.доп}} < T^*_{\text{г}} \\ \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 14 \\ 9 \\ 7 \end{pmatrix} \% \right], \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 14 \\ 9 \\ 7 \end{pmatrix} \% , r \right] & \text{otherwise} \end{cases}$$



$$\begin{pmatrix} \overline{c}_{\text{stator}} \\ \overline{c}_{\text{rotor}} \end{pmatrix} = \begin{cases} \text{for } i \in 1..Z \\ \text{for } r \in 1..N_r \\ \begin{pmatrix} \overline{c}_{\text{stator}_{i,r}} \\ \overline{c}_{\text{rotor}_{i,r}} \end{pmatrix} = \begin{pmatrix} \overline{c}_{\text{stator.}}(r) \\ \overline{c}_{\text{rotor.}}(r) \end{pmatrix} \end{cases}$$

$\overline{c}_{\text{stator}}^T =$

	1	2	3	4
1	7.00	7.00	7.00	7.00
2	9.00	9.00	9.00	9.00
3	11.00	11.00	11.00	11.00

·%

$\overline{c}_{\text{rotor}}^T =$

	1	2	3	4
1	14.00	14.00	14.00	14.00
2	9.00	9.00	9.00	9.00
3	7.00	7.00	7.00	7.00

·%

$$\begin{pmatrix} \overline{r}_{inlet_{rotor}} & \overline{r}_{inlet_{stator}} \\ \overline{r}_{outlet_{rotor}} & \overline{r}_{outlet_{stator}} \end{pmatrix} =$$

for i ∈ 1..Z

for r ∈ 1..N<sub>r</sub>

$$\begin{pmatrix} \overline{r}_{inlet_{stator}_{i,r}} \\ \overline{r}_{outlet_{stator}_{i,r}} \end{pmatrix} = \overline{c}_{stator.(r)} \cdot \begin{pmatrix} 0.4 \\ 0.2 \end{pmatrix}$$

$$\begin{pmatrix} \overline{r}_{inlet_{rotor}_{i,r}} \\ \overline{r}_{outlet_{rotor}_{i,r}} \end{pmatrix} = \overline{c}_{rotor.(r)} \cdot \begin{pmatrix} 0.35 \\ 0.15 \end{pmatrix}$$

$$\begin{pmatrix} \overline{r}_{inlet_{rotor}} & \overline{r}_{inlet_{stator}} \\ \overline{r}_{outlet_{rotor}} & \overline{r}_{outlet_{stator}} \end{pmatrix}$$

$\overline{r}_{inlet_{stator}}^T$

=

	1	2	3	4
1	2.800	2.800	2.800	2.800
2	3.600	3.600	3.600	3.600
3	4.400	4.400	4.400	4.400

.%

$\overline{r}_{outlet_{stator}}^T$

=

	1	2	3	4
1	1.400	1.400	1.400	1.400
2	1.800	1.800	1.800	1.800
3	2.200	2.200	2.200	2.200

.%

$\overline{r}_{inlet_{rotor}}^T$

=

	1	2	3	4
1	4.900	4.900	4.900	4.900
2	3.150	3.150	3.150	3.150
3	2.450	2.450	2.450	2.450

.%

$\overline{r}_{outlet_{rotor}}^T$

=

	1	2	3	4
1	2.100	2.100	2.100	2.100
2	1.350	1.350	1.350	1.350
3	1.050	1.050	1.050	1.050

.%

$$R_{L.cp} = \left( \begin{array}{l} 0.16 \text{ if turbine} = \text{"ТВД"} \quad 0.15 \quad 0.18 \quad 0.185 \quad 0.5 \quad 0.5 \\ 0.13 \text{ otherwise} \end{array} \right)^T$$

▼ Поступенчатый расчет ОТ

iteration <sub>CA</sub>	iteration <sub>PK</sub>	
$\underline{k}$	$R_L$	
$H^*_{ст}$	$H_{ст}$	
$H_{stator}$	$H_{rotor}$	
$c_{ад}$	$w_{ад}$	
$p^*$	$p$	
$T^*$	$\underline{T}$	
$\underline{G}$	$v$	
$\rho^*$	$\rho$	
$\underline{\alpha_{ox}}$	$\alpha_{ox}$	
$\alpha$	$\beta$	
$\epsilon_{stator}$	$\epsilon_{rotor}$	
$\theta_{CA}$	$\theta_{PK}$	
$g_{охлCA}$	$g_{охлPK}$	
$a^*_c$	$a^*_w$	
$T_{ад}$	$T_{ад}$	
$p^*_w$	$T^*_w$	
$a_{зв}$	$a_{зв}$	
$u$	$u$	
$\underline{c}$	$c$	
$c_a$	$c_u$	
$w$	$w$	
$w_a$	$w_u$	
$\lambda_c$	$M_c$	
$\lambda_w$	$M_w$	
$v_{stator}$	$v_{rotor}$	<div><div>=</div><div><div><math>r = av(N_r)</math></div><div>for <math>i \in 1..Z</math></div><div><math>  trace(concat("ст\text{v}пень i = " . num2str(i)))</math></div></div></div>

chord <sub>stator</sub>	chord <sub>rotor</sub>
$\overline{t}_{\text{оптCA}}$	$\overline{t}_{\text{оптPK}}$
$t_{\text{stator}}$	$t_{\text{rotor}}$
$Z_{\text{stator}}$	$Z_{\text{rotor}}$
$\overline{v}_{\text{stator}}$	$\overline{v}_{\text{rotor}}$
$\xi_{\text{TpCA}}$	$\xi_{\text{TpPK}}$
$\xi_{\text{kpCA}}$	$\xi_{\text{kpPK}}$
$\xi_{\text{ReCA}}$	$\xi_{\text{RePK}}$
$\xi_{\lambda\text{CA}}$	$\xi_{\lambda\text{PK}}$
$\xi_{\text{ппCA}}$	$\xi_{\text{ппPK}}$
$\xi_{\text{BTCA}}$	$\xi_{\text{BTPK}}$
$\xi_{\text{ТДCA}}$	$\xi_{\text{ТДPK}}$
$\xi_{\text{сmCA}}$	$\xi_{\text{сmPK}}$
$\xi_{\Delta\text{r}}$	$\xi_{\text{ВЫХ}}$
$\xi_{\text{Tp.B}}$	$\xi_{\text{Tp.B}}$
$L_{\text{сТ}}$	$Lu_{\text{сТ}}$
$\eta_{\text{МОЩЬ}}$	$\eta_{\text{ЛОП}}$
$\eta^*_{\text{сТ}}$	$\eta^*_{\text{сТ}}$
$\eta_{\text{u1}}$	$\eta_{\text{u2}}$
$\xi_{\text{CA}}$	$\xi_{\text{PK}}$
$(Lu_{\text{нагрузка}} \quad Lu_{\text{нагрузка}})$	

if i = 1

$$\alpha_{\text{ox}_{\text{st}(\text{i},1),\text{r}}} = \alpha_{\text{ox}}$$

$$k_{\text{st}(\text{i},1),\text{r}} = k_{\Gamma}$$

$$P^*_{\text{st}(\text{i},1),\text{r}} = P^*_{\Gamma}$$

$$P^*_{\text{w}_{\text{st}(\text{i},1),\text{r}}} = 0$$

$$P_{\text{st}(\text{i},1),\text{r}} = P_{\Gamma}$$

$$T^*_{\text{st}(\text{i},1),\text{r}} = T^*_{\Gamma}$$

$$T^*_{\text{w}_{\text{st}(\text{i},1),\text{r}}} = 0$$

$$T_{\text{st}(\text{i},1),\text{r}} = T_{\Gamma}$$

$$v_{\text{st}(\text{i},1),\text{r}} = \frac{R_{\text{газ}}\Big(\alpha_{\text{ox}_{\text{st}(\text{i},1)}}^{\text{Fuel}}\Big)\cdot T_{\text{st}(\text{i},1),\text{r}}}{P_{\text{st}(\text{i},1),\text{r}}}$$

$$G_{\text{st}(\text{i},1)} = G_{\Gamma}$$

$$c_{\text{st}(\text{i},1),\text{r}} = c_{\Gamma}$$

$$\alpha_{\text{st}(\text{i},1),\text{r}} = \alpha_{\Gamma}$$

$$\begin{pmatrix} c_{\text{u}_{\text{st}(\text{i},1),\text{r}}} \\ c_{\text{a}_{\text{st}(\text{i},1),\text{r}}} \end{pmatrix} = c_{\text{st}(\text{i},1),\text{r}} \cdot \begin{pmatrix} \cos\Big(\alpha_{\text{st}(\text{i},1),\text{r}}\Big) \\ \sin\Big(\alpha_{\text{st}(\text{i},1),\text{r}}\Big) \end{pmatrix}$$

$$w_{\text{st}(\text{i},1),\text{r}} = 0$$

$$\begin{pmatrix} a_{3\text{B}_{\text{st}(\text{i},1),\text{r}}} \\ a^*c_{\text{st}(\text{i},1),\text{r}} \\ a^*w_{\text{st}(\text{i},1),\text{r}} \end{pmatrix} = \begin{pmatrix} \sqrt{k_{\text{st}(\text{i},1),\text{r}}\cdot R_{\text{газ}}\Big(\alpha_{\text{ox}_{\text{st}(\text{i},1)}}^{\text{Fuel}}\Big)\cdot T_{\text{st}(\text{i},1),\text{r}}} \\ \sqrt{\frac{2\cdot k_{\text{st}(\text{i},1),\text{r}}}{1+k_{\text{st}(\text{i},1),\text{r}}}\cdot R_{\text{газ}}\Big(\alpha_{\text{ox}_{\text{st}(\text{i},1)}}^{\text{Fuel}}\Big)\cdot T^*_{\text{st}(\text{i},1),\text{r}}} \\ \sqrt{\frac{2\cdot k_{\text{st}(\text{i},1),\text{r}}}{1+k_{\text{st}(\text{i},1),\text{r}}}\cdot R_{\text{газ}}\Big(\alpha_{\text{ox}_{\text{st}(\text{i},1)}}^{\text{Fuel}}\Big)\cdot T^*_{\text{w}_{\text{st}(\text{i},1),\text{r}}}} \end{pmatrix}$$

$$\begin{pmatrix} \lambda_{\text{с}_{\text{st}(\text{i},1),\text{r}}} \\ \lambda_{\text{w}_{\text{st}(\text{i},1),\text{r}}} \end{pmatrix} = \begin{pmatrix} \frac{c_{\text{st}(\text{i},1),\text{r}}}{a^*c_{\text{st}(\text{i},1),\text{r}}} \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} M_{\text{с}_{\text{st}(\text{i},1),\text{r}}} \\ M_{\text{w}_{\text{st}(\text{i},1),\text{r}}} \end{pmatrix} = \frac{1}{a_{3\text{B}_{\text{st}(\text{i},1),\text{r}}}} \cdot \begin{pmatrix} c_{\text{st}(\text{i},1),\text{r}} \\ w_{\text{st}(\text{i},1),\text{r}} \end{pmatrix}$$

$$\text{iteration}_{\text{сТ}_i} = 0$$

while 1 > 0

$$\left| \text{iteration}_{\text{сТ}_i} = \text{iteration}_{\text{сТ}_i} + 1 \right.$$

trace(concat(" iteration.ct = ", num2str(iteration<sub>CT<sub>i</sub></sub>))))

$$H_{CT_i} = N_{CT_i} \cdot \begin{cases} \frac{1}{G_{st(i,1)} \cdot 0.9} & \text{if } (iteration_{CT_i} = 1) \\ \frac{1}{\text{mean}(G_{st(i,2)}, G_{st(i,3)}) \cdot \eta_{\text{мощь}_i}} & \text{otherwise} \end{cases}$$

$$R_{L_{i,r}} = R_{L.cp_i}$$

$$c_{a_{st(i,1),r}} = \sqrt{2 \cdot H_{CT_i}}$$

$$H_{stator_i} = H_{CT_i} \cdot (1 - R_{L_{i,r}})$$

$$c_{a_{st(i,2),r}} = \sqrt{2 \cdot H_{stator_i}}$$

$$\bar{v}_{stator_i} = 1$$

$$iteration_{CA_i} = 0$$

while 1 > 0

$$iteration_{CA_i} = iteration_{CA_i} + 1$$

trace(concat(" iteration.CA = ", num2str(iteration<sub>CA<sub>i</sub></sub>))))

$$c_{st(i,2),r} = \bar{v}_{stator_i} \cdot c_{a_{st(i,2),r}}$$

$$\theta_{CA_i} = \theta_{\text{глубина}}(T^*_{st(i,1),r}, T^*_{\text{cooling}}, T_{\text{Л.доп}})$$

$$g_{\text{охл}CA_i} = \begin{cases} \frac{0.035 \cdot \theta_{CA_i}}{1 - \theta_{CA_i}} & \text{if } \frac{0.035 \cdot \theta_{CA_i}}{1 - \theta_{CA_i}} \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$G_{st(i,2)} = G_{st(i,1)} \cdot (1 + g_{\text{охл}CA_i})$$

$$\alpha_{\text{ox}_{st(i,2)}} = \alpha_{\text{ox}_{st(i,1)}} + g_{\text{охл}CA_i}$$

$$\alpha_{\text{ок}CA_i} = \text{mean}(\alpha_{\text{ox}_{st(i,1)}}, \alpha_{\text{ox}_{st(i,2)}})$$

$$k_{st(i,2),r} = k_{st(i,1),r}$$

while 1 > 0

$$k_{CA_i} = \text{mean}(k_{st(i,1),r}, k_{st(i,2),r})$$

$$T_{a_{st(i,2),r}} = T^*_{st(i,1),r} - \frac{H_{stator_i}}{\frac{k_{CA_i}}{k_{CA_i} - 1} \cdot R_{\text{раз.cp}}(\alpha_{\text{ox}_{st(i,1)}}, \alpha_{\text{ox}_{st(i,2)}}, \text{Fuel})}$$

$k_{CA}$ .

$$P_{st(i,2),r} = P_{st(i,1),r}^{*} \cdot \left( \frac{T_{ad_{st(i,2),r}}}{T_{st(i,1),r}^{*}} \right)^{\frac{\gamma_{i,1}}{k_{CA_i}-1}}$$

$$T_{st(i,2),r} = T_{st(i,1),r}^{*} - \frac{H_{stator_i} \cdot \left( \overline{v}_{stator_i} \right)^2}{\frac{k_{CA_i}}{k_{CA_i}-1} \cdot R_{газ.cp} \left( \alpha_{ox_{st(i,1)}}, \alpha_{ox_{st(i,2)}}, Fuel \right)}$$

$$Cp_2 = Cp_{газ} \left( P_{st(i,2),r}, T_{st(i,2),r}, \alpha_{ox_{st(i,2)}}, Fuel \right)$$

$$k' = k_{ад} \left( Cp_2, R_{газ} \left( \alpha_{ox_{st(i,2)}}, Fuel \right) \right)$$

$$\text{if } \left| \text{eps}("rel", k_{st(i,2),r}, k') \right| \leq \text{epsilon}$$

$$\left| \begin{array}{l} k_{st(i,2),r} = k' \\ \text{break} \end{array} \right.$$

$$k_{st(i,2),r} = k'$$

$$T_{ad_{st(i,2),r}}^{*} = T_{st(i,2),r} + \frac{\left( c_{st(i,2),r} \right)^2}{2 \cdot Cp_{газ} \left( P_{st(i,2),r}, T_{st(i,2),r}, \alpha_{ox_{st(i,2)}}, Fuel \right)}$$

$$P_{ad_{st(i,2),r}}^{*} = P_{st(i,2),r} \cdot \left( \frac{T_{ad_{st(i,2),r}}^{*}}{T_{st(i,2),r}} \right)^{\frac{k_{st(i,2),r}}{k_{st(i,2),r}-1}}$$

$$\left( \begin{array}{l} T_{cm_{st(i,2),r}}^{*} \\ P_{cm_{st(i,2),r}}^{*} \end{array} \right) = \left[ \begin{array}{l} T_{смешение} \left[ P_{ad_{st(i,2),r}}^{*}, T_{ad_{st(i,2),r}}^{*}, G_{st(i,1)}, \alpha_{ox_{st(i,1)}}, P_{cooling}^{*}, T_{cooling}^{*}, \left( g_{oxлCA_i} \cdot G_{st(i,1)} \right), \alpha_{ox_{st(i,2)}}, Fuel \right] \\ P_{смешение} \left[ P_{ad_{st(i,2),r}}^{*}, G_{st(i,1)}, P_{cooling}^{*}, \left( g_{oxлCA_i} \cdot G_{st(i,1)} \right) \right] \end{array} \right]$$

$$\left( \begin{array}{l} T_{st(i,2),r}^{*} \\ P_{st(i,2),r}^{*} \end{array} \right) = \left( \begin{array}{l} T_{cm_{st(i,2),r}}^{*} \\ P_{cm_{st(i,2),r}}^{*} \end{array} \right)$$

$$T_{st(i,2),r} = T_{st(i,2),r}^{*} - \frac{\left( c_{st(i,2),r} \right)^2}{2 \cdot Cp_{газ} \left( P_{st(i,2),r}, T_{st(i,2),r}, \alpha_{ox_{st(i,2)}}, Fuel \right)}$$

$$P_{st(i,2),r} = P_{st(i,2),r}^{*} \cdot \left( \frac{T_{st(i,2),r}}{T_{st(i,2),r}^{*}} \right)^{\frac{k_{st(i,2),r}}{k_{st(i,2),r}-1}}$$

$$k_{st(i,2),r} = k_{ад} \left( Cp_{газ} \left( P_{st(i,2),r}, T_{st(i,2),r}, \alpha_{ox_{st(i,2)}}, Fuel \right), R_{газ} \left( \alpha_{ox_{st(i,2)}}, Fuel \right) \right)$$

$$v_{st(i,2),r} = \frac{R_{газ} \left( \alpha_{ox_{st(i,2)}}, Fuel \right) \cdot T_{st(i,2),r}}{P_{st(i,2),r}}$$

$$\alpha_{st(i),r} = \text{asin} \left( \frac{G_{st(i,2)} \cdot v_{st(i,2),r}}{\dots} \right)$$

$$F_{st(i,2),r} = \sqrt{F_{st(i,2)}^2 + c_{st(i,2),r}^2 - 2 \cdot F_{st(i,2)} \cdot c_{st(i,2),r} \cdot \cos(\alpha_{st(i,2),r})}$$

$$\begin{pmatrix} c_{u_{st(i,2),r}} \\ c_{a_{st(i,2),r}} \end{pmatrix} = c_{st(i,2),r} \cdot \begin{pmatrix} \cos(\alpha_{st(i,2),r}) \\ \sin(\alpha_{st(i,2),r}) \end{pmatrix}$$

$$\beta_{st(i,2),r} = \text{triangle}(c_{a_{st(i,2),r}}, c_{u_{st(i,2),r}} - u_{st(i,2),r})$$

$$w_{st(i,2),r} = \sqrt{(c_{st(i,2),r})^2 + (u_{st(i,2),r})^2 - 2 \cdot c_{st(i,2),r} \cdot u_{st(i,2),r} \cdot \cos(\alpha_{st(i,2),r})}$$

$$\begin{pmatrix} w_{u_{st(i,2),r}} \\ w_{a_{st(i,2),r}} \end{pmatrix} = w_{st(i,2),r} \cdot \begin{pmatrix} \cos(\beta_{st(i,2),r}) \\ \sin(\beta_{st(i,2),r}) \end{pmatrix}$$

$$T_{w_{st(i,2),r}}^* = T_{st(i,2),r} + \frac{(w_{st(i,2),r})^2}{2 \cdot C_{p_{\Gamma a3}}(P_{st(i,2),r}, T_{st(i,2),r}, \alpha_{ox_{st(i,2)}} , Fuel)}$$

$$P_{w_{st(i,2),r}}^* = P_{st(i,2),r} \cdot \left( \frac{T_{w_{st(i,2),r}}^*}{T_{st(i,2),r}} \right)^{\frac{k_{st(i,2),r}}{k_{st(i,2),r}-1}}$$

$$\begin{pmatrix} a_{3B_{st(i,2),r}} \\ a_{c_{st(i,2),r}}^* \\ a_{w_{st(i,2),r}}^* \end{pmatrix} = \begin{pmatrix} \sqrt{k_{st(i,2),r} \cdot R_{\Gamma a3}(\alpha_{ox_{st(i,2)}} , Fuel) \cdot T_{st(i,2),r}} \\ \sqrt{\frac{2 \cdot k_{st(i,2),r}}{k_{st(i,2),r} + 1} \cdot R_{\Gamma a3}(\alpha_{ox_{st(i,2)}} , Fuel) \cdot T_{st(i,2),r}^*} \\ \sqrt{\frac{2 \cdot k_{st(i,2),r}}{k_{st(i,2),r} + 1} \cdot R_{\Gamma a3}(\alpha_{ox_{st(i,2)}} , Fuel) \cdot T_{w_{st(i,2),r}}^*} \end{pmatrix}$$

$$\begin{pmatrix} \lambda_{c_{st(i,2),r}} \\ \lambda_{w_{st(i,2),r}} \end{pmatrix} = \begin{pmatrix} \frac{c_{st(i,2),r}}{a_{c_{st(i,2),r}}^*} \\ \frac{w_{st(i,2),r}}{a_{w_{st(i,2),r}}^*} \end{pmatrix}$$

$$\begin{pmatrix} M_{c_{st(i,2),r}} \\ M_{w_{st(i,2),r}} \end{pmatrix} = \frac{1}{a_{3B_{st(i,2),r}}} \cdot \begin{pmatrix} c_{st(i,2),r} \\ w_{st(i,2),r} \end{pmatrix}$$

$$v_{stator_i} = v_{установка}(\alpha_{st(i,1),r}, \alpha_{st(i,2),r})$$

$$chord_{stator_{i,r}} = \frac{B_{CA_i}}{\sin(v_{stator_i})}$$

$$\overline{t}_{оптCA_i} = \overline{t}_{опт}("CA", g_{охлCA_i} > 0, \alpha_{st(i,1),r}, \alpha_{st(i,2),r}, \max(\text{submatrix}(\overline{c}_{stator}, i, i, 1, N_r)))$$

$$Z_{stator_i} = \left\lceil \frac{\pi \cdot \text{mean}(D_{st(i,1),r}, D_{st(i,2),r})}{\overline{t}_{оптCA_i} \cdot chord_{stator_{i,r}}} \right\rceil \text{ if } \text{mod} \left( \left\lceil \frac{\pi \cdot \text{mean}(D_{st(i,1),r}, D_{st(i,2),r})}{\overline{t}_{оптCA_i} \cdot chord_{stator_{i,r}}} \right\rceil, 2 \right) = 0$$

$$Z_{stator_i} = \left\lceil \frac{\pi \cdot \text{mean}(D_{st(i,1),r}, D_{st(i,2),r})}{\overline{t}_{оптCA_i} \cdot chord_{stator_{i,r}}} \right\rceil$$



$$\left\lceil \frac{\pi \cdot \text{mean}(D_{\text{st}(1,1),r}, D_{\text{st}(1,2),r})}{\bar{t}_{\text{оттCA}_i} \cdot \text{chord}_{\text{stator}_i,r}} \right\rceil + 1 \quad \text{otherwise}$$

for  $r \in 1..N_r$

$$t_{\text{stator}_i,r} = \frac{\pi \cdot \text{mean}(D_{\text{st}(i,1),r}, D_{\text{st}(i,2),r})}{Z_{\text{stator}_i}}$$

$$\xi_{\text{трCA}_i} = \xi_{\text{трение}}(\alpha_{\text{st}(i,1),r}, \alpha_{\text{st}(i,2),r})$$

$$\xi_{\text{крCA}_i} = \xi_{\text{кромка}}(\bar{r}_{\text{outlet}_{\text{stator}_i,r}} \cdot \text{chord}_{\text{stator}_i,r}, t_{\text{stator}_i,r}, \alpha_{\text{st}(i,2),r})$$

$$\xi_{\text{РеCA}_i} = \xi_{\text{Ре}}\left(\frac{c_{\text{st}(i,2),r} \cdot \text{chord}_{\text{stator}_i,r}}{\mu_{\text{газ}}(T_{\text{st}(i,2),r}, \alpha_{\text{ox}_{\text{st}(i,2)})} \cdot v_{\text{st}(i,2),r}}\right)$$

$$\xi_{\lambda\text{CA}_i} = \xi_{\text{сжимаемость}}("CA", \lambda_{c_{\text{st}(i,2),r}})$$

$$\xi_{\text{прCA}_i} = \xi_{\text{трCA}_i} + \xi_{\text{крCA}_i} + \xi_{\text{РеCA}_i} + \xi_{\lambda\text{CA}_i}$$

$$\xi_{\text{втCA}_i} = \xi_{\text{вторичные}}(\xi_{\text{трCA}_i}, t_{\text{stator}_i,r}, \alpha_{\text{st}(i,2),r}, h_{\text{st}(i,2)})$$

$$\xi_{\text{тдCA}_i} = \frac{\xi_{\text{тд}}("CA", T_{\text{см}_{\text{st}(i,2),r}}^*, T_{\text{ад}_{\text{st}(i,2),r}}^*, P_{\text{st}(i,2),r}, C_{p_{\text{газ}}}(P_{\text{st}(i,2),r}, T_{\text{st}(i,2),r}, \alpha_{\text{ox}_{\text{st}(i,2)}}^{\text{Fuel}}), R_{\text{газ}}(\alpha_{\text{ox}_{\text{st}(i,2)}}^{\text{Fuel}}), G_{\text{st}(i,2)}, F_{\text{st}(i,2)}, \alpha_{\text{st}(i,2),r}, 0))}{H_{\text{stator}_i}}$$

$$\xi_{\text{смCA}_i} = \xi_{\text{смешение}}("CA", g_{\text{охлCA}_i})$$

$$\text{if } \left| \text{eps}("rel", \sqrt{1 - \xi_{\text{смCA}_i} - \xi_{\text{тдCA}_i} - \xi_{\text{втCA}_i} - \xi_{\text{прCA}_i}}, \bar{v}_{\text{stator}_i}) \right| \leq \text{epsilon}$$

$$\left| \bar{v}_{\text{stator}_i} = \sqrt{1 - \xi_{\text{смCA}_i} - \xi_{\text{тдCA}_i} - \xi_{\text{втCA}_i} - \xi_{\text{прCA}_i}} \right|$$

break

$$\bar{v}_{\text{stator}_i} = \sqrt{1 - \xi_{\text{смCA}_i} - \xi_{\text{тдCA}_i} - \xi_{\text{втCA}_i} - \xi_{\text{прCA}_i}}$$

$$H_{\text{rotor}_i} = H_{\text{ср}_i} \cdot R_{L_{i,\text{av}}(N_r)} \cdot \frac{T_{\text{st}(i,2),r}}{T_{\text{ад}_{\text{st}(i,2),r}}}$$

$$w_{\text{ад}_{\text{st}(i,3),r}} = \sqrt{(w_{\text{st}(i,2),r})^2 + 2 \cdot H_{\text{rotor}_i} + (u_{\text{st}(i,3),r})^2 - (u_{\text{st}(i,2),r})^2}$$

$$\bar{v}_{\text{rotor}_i} = 1$$

$$\text{iteration}_{\text{пК}_i} = 0$$

while  $1 > 0$

$$\text{iteration}_{\text{пК}_i} = \text{iteration}_{\text{пК}_i} + 1$$

$$\text{trace}\left(\text{concat}\left(" \quad \text{iteration.PK} = ", \text{num2str}(\text{iteration}_{\text{пК}_i})\right)\right)$$

$$w_{\text{st}(i,3),r} = \bar{v}_{\text{rotor}_i} \cdot w_{\text{ад}_{\text{st}(i,3),r}}$$

$$\theta_{PK_i} = \theta_{глубина}(T^*_{w_{st(i,2),r}}, T^*_{cooling}, T_{Л.доп})$$

$$g_{охлPK_i} = \begin{cases} \frac{0.035 \cdot \theta_{PK_i}}{1 - \theta_{PK_i}} & \text{if } \frac{0.035 \cdot \theta_{PK_i}}{1 - \theta_{PK_i}} \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$G_{st(i,3)} = G_{st(i,2)} \cdot (1 + g_{охлPK_i})$$

$$\alpha_{ох_{st(i,3)}} = \alpha_{ох_{st(i,2)}} + g_{охлPK_i}$$

$$k_{st(i,3),r} = k_{st(i,2),r}$$

while 1 > 0

$$k_{PK_i} = \text{mean}(k_{st(i,2),r}, k_{st(i,3),r})$$

$$T_{ад_{st(i,3),r}} = T_{st(i,2),r} - \frac{H_{rotor_i}}{\frac{k_{PK_i}}{k_{PK_i} - 1} \cdot R_{газ.cp}(\alpha_{ох_{st(i,2)}}, \alpha_{ох_{st(i,3)}}, Fuel)}$$

$$P_{st(i,3),r} = P_{st(i,2),r} \cdot \left( \frac{T_{ад_{st(i,3),r}}}{T_{st(i,2),r}} \right)^{\frac{k_{PK_i}}{k_{PK_i} - 1}}$$

$$T_{st(i,3),r} = T_{st(i,2),r} - \frac{(w_{st(i,3),r})^2 - (w_{st(i,2),r})^2 - (u_{st(i,3),r})^2 + (u_{st(i,2),r})^2}{2 \cdot \frac{k_{PK_i}}{k_{PK_i} - 1} \cdot R_{газ.cp}(\alpha_{ох_{st(i,2)}}, \alpha_{ох_{st(i,3)}}, Fuel)}$$

$$Cp_3 = Cp_{газ}(P_{st(i,3),r}, T_{st(i,3),r}, \alpha_{ох_{st(i,3)}}, Fuel)$$

$$k' = k_{ад}(Cp_3, R_{газ}(\alpha_{ох_{st(i,3)}}, Fuel))$$

if  $|\text{eps}("rel", k_{st(i,3),r}, k')| \leq \text{epsilon}$

$$\begin{cases} k_{st(i,3),r} = k' \\ \text{break} \end{cases}$$

$$k_{st(i,3)} = k'$$

$$v_{st(i,3),r} = \frac{R_{газ}(\alpha_{ох_{st(i,3)}}, Fuel) \cdot T_{st(i,3),r}}{P_{st(i,3),r}}$$

$$\beta_{st(i,3),r} = \text{asin}\left(\frac{G_{st(i,3)} \cdot v_{st(i,3),r}}{w_{st(i,3),r} \cdot F_{st(i,3)}}\right)$$

$$\begin{pmatrix} c_{u_{st(i,3),r}} \\ c_a \end{pmatrix} = \begin{pmatrix} w_{st(i,3),r} \cdot \cos(\beta_{st(i,3),r}) - u_{st(i,3),r} \\ w_{st(i,3),r} \cdot \sin(\beta_{st(i,3),r}) \end{pmatrix}$$

$$c_{st(i,3),r} = \sqrt{c_{u_{st(i,3),r}}^2 + c_{a_{st(i,3),r}}^2}$$

$$\begin{pmatrix} w_{u_{st(i,3),r}} \\ w_{a_{st(i,3),r}} \end{pmatrix} = \begin{bmatrix} \sqrt{w_{st(i,3),r}^2 - c_{a_{st(i,3),r}}^2} \\ w_{st(i,3),r} \sin(\beta_{st(i,3),r}) \end{bmatrix}$$

$$\alpha_{st(i,3),r} = \text{triangle}(c_{a_{st(i,3),r}}, c_{u_{st(i,3),r}})$$

$$T_{a_{st(i,3),r}}^* = T_{st(i,3),r} + \frac{(c_{st(i,3),r})^2}{2 \cdot Cp_{\Gamma a3}(P_{st(i,3),r}, T_{st(i,3),r}, \alpha_{ox_{st(i,3)}} , Fuel)}$$

$$P_{a_{st(i,3),r}}^* = P_{st(i,3),r} \cdot \left( \frac{T_{a_{st(i,3),r}}^*}{T_{st(i,3),r}} \right)^{\frac{k_{st(i,3),r}}{k_{st(i,3),r}-1}}$$

$$\begin{pmatrix} T_{cm_{st(i,3),r}}^* \\ P_{cm_{st(i,3),r}}^* \end{pmatrix} = \begin{bmatrix} T_{\text{смешение}}[P_{a_{st(i,3),r}}^*, T_{a_{st(i,3),r}}^*, G_{st(i,2)}, \alpha_{ox_{st(i,2)}} , P^*_{cooling}, T^*_{cooling}, (g_{ox_{\text{ЛПК}_i}} \cdot G_{st(i,2)}), \alpha_{ox_{st(i,3)}} , Fuel] \\ P_{\text{смешение}}[P_{a_{st(i,3),r}}^*, G_{st(i,2)}, P^*_{cooling}, (g_{ox_{\text{ЛПК}_i}} \cdot G_{st(i,2)})] \end{bmatrix}$$

$$\begin{pmatrix} T_{st(i,3),r}^* \\ P_{st(i,3),r}^* \end{pmatrix} = \begin{pmatrix} T_{cm_{st(i,3),r}}^* \\ P_{cm_{st(i,3),r}}^* \end{pmatrix}$$

$$T_{st(i,3),r} = T_{st(i,3),r}^* - \frac{(c_{st(i,3),r})^2}{2 \cdot Cp_{\Gamma a3}(P_{st(i,3),r}, T_{st(i,3),r}, \alpha_{ox_{st(i,3)}} , Fuel)}$$

$$P_{st(i,3),r} = P_{st(i,3),r}^* \cdot \left( \frac{T_{st(i,3),r}}{T_{st(i,3),r}^*} \right)^{\frac{k_{st(i,3),r}}{k_{st(i,3),r}-1}}$$

$$k_{st(i,3),r} = k_{a_{st(i,3),r}}(Cp_{\Gamma a3}(P_{st(i,3),r}, T_{st(i,3),r}, \alpha_{ox_{st(i,3)}} , Fuel), R_{\Gamma a3}(\alpha_{ox_{st(i,3)}} , Fuel))$$

$$T_{w_{st(i,3),r}}^* = T_{st(i,3),r} + \frac{(w_{st(i,3),r})^2}{2 \cdot \frac{k_{st(i,3),r}}{k_{st(i,3),r}-1} \cdot R_{\Gamma a3}(\alpha_{ox_{st(i,3)}} , Fuel)}$$

$$\begin{pmatrix} a_{3B_{st(i,3),r}} \\ a_{c_{st(i,3),r}}^* \\ a_{w_{st(i,3),r}}^* \end{pmatrix} = \begin{pmatrix} \sqrt{k_{st(i,3),r} \cdot R_{\Gamma a3}(\alpha_{ox_{st(i,3)}} , Fuel) \cdot T_{st(i,3),r}} \\ \sqrt{\frac{2 \cdot k_{st(i,3),r}}{k_{st(i,3),r}+1} \cdot R_{\Gamma a3}(\alpha_{ox_{st(i,3)}} , Fuel) \cdot T_{st(i,3),r}^*} \\ \sqrt{\frac{2 \cdot k_{st(i,3),r}}{k_{st(i,3),r}+1} \cdot R_{\Gamma a3}(\alpha_{ox_{st(i,3)}} , Fuel) \cdot T_{w_{st(i,3),r}}^*} \end{pmatrix}$$

$$\left( \lambda_{c_{st(i,3),r}} \right) = \left( \frac{c_{st(i,3),r}}{a_{c_{st(i,3),r}}^*} \right)$$

$$\begin{aligned}
& \left( \lambda_{w_{st(i,3),r}} \right) \quad \left( \frac{w_{st(i,3),r}}{a^*_{w_{st(i,3),r}}} \right) \\
& \left( \frac{M_{c_{st(i,3),r}}}{M_{w_{st(i,3),r}}} \right) = \frac{1}{a_{3B_{st(i,3),r}}} \cdot \left( c_{st(i,3),r} \right) \\
& v_{rotor_i} = v_{установка}(\beta_{st(i,2),r}, \beta_{st(i,3),r}) \\
& chord_{rotor_{i,r}} = \frac{B_{PK_i}}{\sin(v_{rotor_i})} \\
& \bar{t}_{оптPK_i} = \bar{t}_{опт} \left( "PK", g_{охлPK_i} > 0, \beta_{st(i,2),r}, \beta_{st(i,3),r}, \max \left( \text{submatrix}(\bar{c}_{rotor}, i, i, 1, N_r) \right) \right) \\
& Z_{rotor_i} = \left| \begin{array}{l} Z_{rotor_i} = \text{ceil} \left( \frac{\pi \cdot \text{mean}(D_{st(i,2),r}, D_{st(i,3),r})}{\bar{t}_{оптPK_i} \cdot chord_{rotor_{i,r}}} \right) \\ \text{while } \gcd(Z_{rotor_i}, Z_{stator_i}) \neq 1 \\ \quad Z_{rotor_i} = Z_{rotor_i} + 1 \end{array} \right. \\
& \text{for } r \in 1..N_r \\
& \quad t_{rotor_{i,r}} = \frac{\pi \cdot \text{mean}(D_{st(i,2),r}, D_{st(i,3),r})}{Z_{rotor_i}} \\
& \xi_{трPK_i} = \xi_{трение}(\beta_{st(i,2),r}, \beta_{st(i,3),r}) \\
& \xi_{крPK_i} = \xi_{кромка} \left( \bar{r}_{outlet_{rotor_{i,r}}} \cdot chord_{rotor_{i,r}}, t_{rotor_{i,r}}, \beta_{st(i,3),r} \right) \\
& \xi_{RePK_i} = \xi_{Re} \left( \frac{w_{st(i,3),r} \cdot chord_{rotor_{i,r}}}{\mu_{газ}(T_{st(i,3),r}, \alpha_{ox_{st(i,3)}}) \cdot v_{st(i,3),r}} \right) \\
& \xi_{\lambda PK_i} = \xi_{сжимаемость}("PK", \lambda_{w_{st(i,3),r}}) \\
& \xi_{прPK_i} = \xi_{трPK_i} + \xi_{крPK_i} + \xi_{RePK_i} + \xi_{\lambda PK_i} \\
& \xi_{втPK_i} = \xi_{вторичные}(\xi_{трPK_i}, t_{rotor_{i,r}}, \beta_{st(i,3),r}, h_{st(i,3)}) \\
& \xi_{ТДPK_i} = \frac{\xi_{ТД} \left( "PK", T^*_{см_{st(i,3),r}}, T^*_{ад_{st(i,3),r}}, P_{st(i,3),r}, C_{p_{газ}} \left( P_{st(i,3),r}, T_{st(i,3),r}, \alpha_{ox_{st(i,3)}}^{Fuel} \right), R_{газ} \left( \alpha_{ox_{st(i,3)}}^{Fuel} \right), G_{st(i,3)}, F_{st(i,3)}, \beta_{st(i,3),r}, u_{st(i,3),r} \right)}{H_{rotor_i}} \\
& \xi_{смPK_i} = \xi_{смешение}("PK", g_{охлPK_i}) \\
& \text{if } \left| \text{eps} \left( "rel", \sqrt{1 - \xi_{смPK_i} - \xi_{ТДPK_i} - \xi_{втPK_i} - \xi_{прPK_i}}, \bar{v}_{rotor_i} \right) \right| \leq \text{epsilon} \\
& \quad \left| \bar{v}_{rotor_i} = \sqrt{1 - \xi_{смPK_i} - \xi_{ТДPK_i} - \xi_{втPK_i} - \xi_{прPK_i}} \right. \\
& \quad \quad \text{break}
\end{aligned}$$

$$\left| \overline{v}_{\text{rotor}_i} = \sqrt{1 - \xi_{\text{смпк}_i} - \xi_{\text{тдпк}_i} - \xi_{\text{втпк}_i} - \xi_{\text{ппк}_i}} \right.$$

$$\text{Lu}_{\text{сТ}_i} = c_{u_{\text{st}(i,2),r}} \cdot u_{\text{st}(i,2),r} + c_{u_{\text{st}(i,3),r}} \cdot u_{\text{st}(i,3),r}$$

$$\begin{pmatrix} \xi_{\text{CA}_i} \\ \xi_{\text{ПК}_i} \\ \xi_{\text{CAиПК}_i} \end{pmatrix} = \frac{1}{H_{\text{сТ}_i}} \cdot \begin{pmatrix} \xi_{\text{Л}}(\overline{v}_{\text{stator}_i}, c_{\text{st}(i,2),r}) \\ \xi_{\text{Л}}(\overline{v}_{\text{rotor}_i}, w_{\text{st}(i,3),r}) \\ \xi_{\text{Л}}(\overline{v}_{\text{stator}_i}, c_{\text{st}(i,2),r}) \cdot \frac{T_{\text{ад}_{\text{st}(i,3),r}}}{T_{\text{st}(i,2),r}} \end{pmatrix}$$

$$\xi_{\text{ВЫХ}_i} = \frac{\xi_{\text{ВЫХОД}}(c_{\text{st}(i,3),r})}{H_{\text{сТ}_i}}$$

$$\xi_{\Delta r_i} = \frac{\xi_{\text{г.зазор}}(\Delta_{r_i}, h_{\text{st}(i,3)}, D_{\text{st}(i,3),r}, R_{L_{i,r}}, \text{Lu}_{\text{сТ}_i})}{H_{\text{сТ}_i}}$$

$$\xi_{\text{тр.в}_i} = \frac{\xi_{\text{трениеИвентиляция}} \left[ D_{\text{st}(i,3),r}, h_{\text{st}(i,3)}, u_{\text{st}(i,3),r}, \left( \frac{v_{\text{st}(i,2),r} + v_{\text{st}(i,3),r}}{2 \cdot v_{\text{st}(i,2),r} \cdot v_{\text{st}(i,3),r}} \right), \text{mean}(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}) \right]}{H_{\text{сТ}_i}}$$

$$\eta_{u1_i} = \frac{\text{Lu}_{\text{сТ}_i}}{H_{\text{сТ}_i}}$$

$$\eta_{\text{лоп}_i} = 1 - \xi_{\text{CAиПК}_i} - \xi_{\text{ПК}_i} - \xi_{\Delta r_i} - \xi_{\text{тр.в}_i}$$

$$\eta_{u2_i} = 1 - \xi_{\text{CAиПК}_i} - \xi_{\text{ПК}_i} - \xi_{\text{ВЫХ}_i}$$

$$\eta_{\text{мощь}_i} = 1 - \xi_{\text{CAиПК}_i} - \xi_{\text{ПК}_i} - \xi_{\text{ВЫХ}_i} - \xi_{\Delta r_i} - \xi_{\text{тр.в}_i}$$

$$L_{\text{сТ}_i} = H_{\text{сТ}_i} \cdot \eta_{\text{мощь}_i}$$

$$\text{trace} \left( \text{concat} \left( \text{"eps(N) = "}, \text{num2str} \left( \text{eps} \left( \text{"rel"}, N_{\text{сТ}_i}, L_{\text{сТ}_i} \cdot \text{mean}(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}) \right) \right) \right) \right)$$

$$\text{break if } \left( \left| \text{eps} \left( \text{"rel"}, N_{\text{сТ}_i}, L_{\text{сТ}_i} \cdot \text{mean}(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}) \right) \right| \leq \text{epsilon} \right) \wedge \left( \text{iteration}_{\text{сТ}_i} = 0 \right)$$

$$\text{iteration}_{\text{сТ}_i} = -1 \text{ if } \left| \text{eps} \left( \text{"rel"}, N_{\text{сТ}_i}, L_{\text{сТ}_i} \cdot \text{mean}(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}) \right) \right| \leq \text{epsilon}$$

$$\text{Lu}_{\text{нагрузка}_i} = \frac{\text{Lu}_{\text{сТ}_i}}{\left( \text{mean}(u_{\text{st}(i,2),r}, u_{\text{st}(i,3),r}) \right)^2}$$

$$\begin{pmatrix} \pi^*_{\text{сТ}_i} \\ \pi_{\text{сТ}_i} \end{pmatrix} = P^*_{\text{st}(i,1),r} \cdot \begin{bmatrix} (P^*_{\text{st}(i,3),r})^{-1} \\ (P_{\text{st}(i,3),r})^{-1} \end{bmatrix}$$

$$k_{\text{ср}} = k_{\text{ад}} \left( C_{\text{гaз.ср}} \left( P_{\text{st}(i,1),r}, P_{\text{st}(i,3),r}, T_{\text{st}(i,1),r}, T_{\text{st}(i,3),r}, \alpha_{\text{ox}_{\text{st}(i,1)}}^{\cdot}, \alpha_{\text{ox}_{\text{st}(i,3)}}^{\cdot}, \text{Fuel} \right), R_{\text{гaз.ср}} \left( \alpha_{\text{ox}_{\text{st}(i,1)}}^{\cdot}, \alpha_{\text{ox}_{\text{st}(i,3)}}^{\cdot}, \text{Fuel} \right) \right) \left[ \frac{\quad}{1 - k_{\text{ср}}} \right]$$

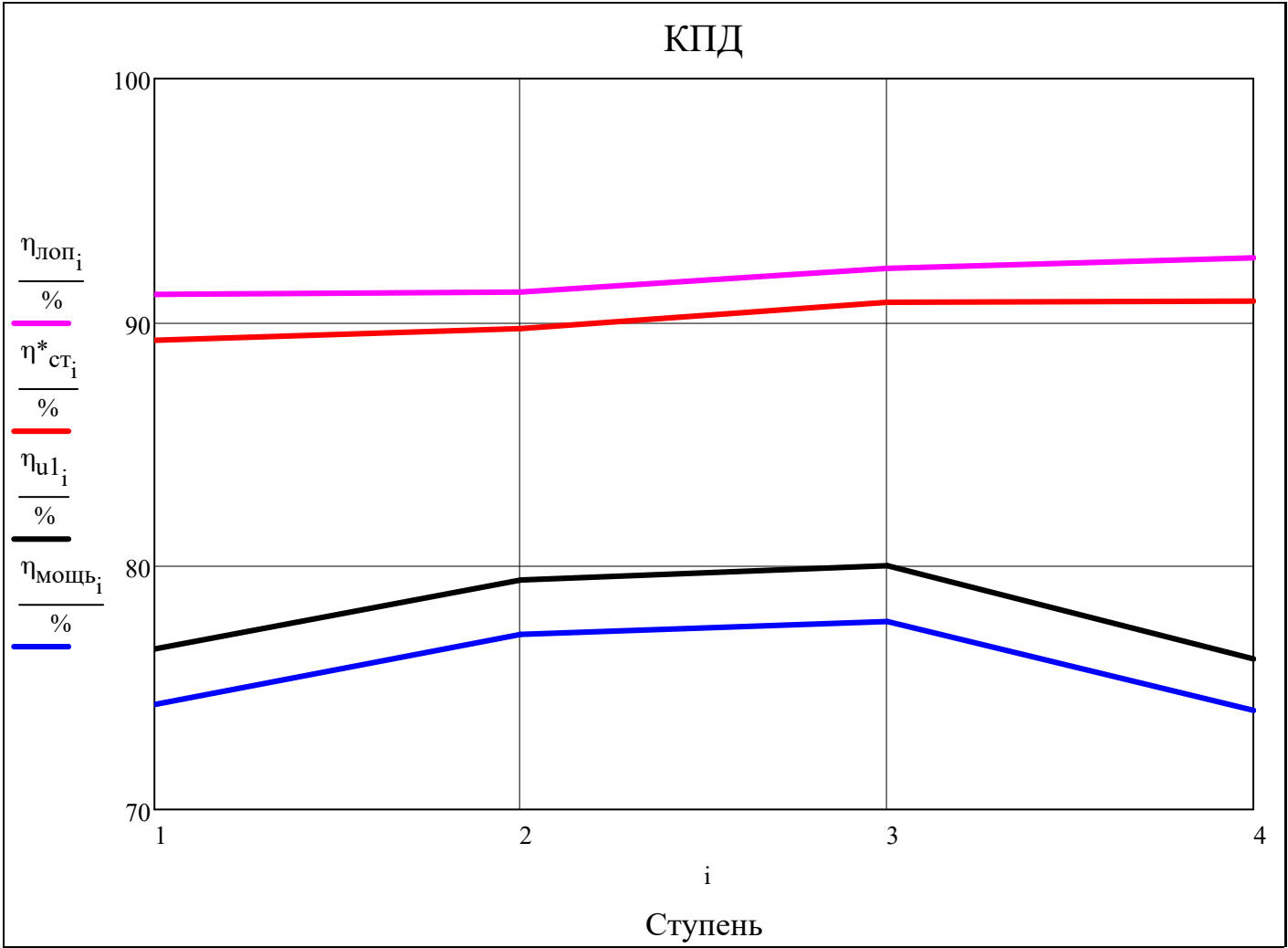
$$\left| \begin{array}{l} H^*_{cT_i} = C_{p_{\Gamma a3, cp}} \left( P_{st(i, 1), r}, P_{st(i, 3), r}, T_{st(i, 1), r}, T_{st(i, 3), r}, \alpha_{ox_{st(i, 1)}} , \alpha_{ox_{st(i, 3)}} , Fuel \right) \cdot T^*_{st(i, 1), r} \cdot \left[ 1 - \left( \pi^*_{cT_i} \right)^{\overline{k_{cp}}} \right] \\ \eta^*_{cT_i} = \frac{L_{cT_i}}{H^*_{cT_i}} \end{array} \right|$$

for i ∈ 1 .. Z

for j ∈ 1 .. 3

$$\left| \begin{array}{l} \rho^*_{st(i, j), r} = \frac{P^*_{st(i, j), r}}{R_{\Gamma a3} \left( \alpha_{ox_{st(i, j)}} , Fuel \right) \cdot T^*_{st(i, j), r}} \\ \rho_{st(i, j), r} = \left( v_{st(i, j), r} \right)^{-1} \\ \left( \begin{array}{l} \varepsilon_{stator_{i, av(N_r)}} \\ \varepsilon_{rotor_{i, av(N_r)}} \end{array} \right) = \left( \begin{array}{l} \alpha_{st(i, 2), av(N_r)} - \alpha_{st(i, 1), av(N_r)} \\ \beta_{st(i, 3), av(N_r)} - \beta_{st(i, 2), av(N_r)} \end{array} \right) \end{array} \right|$$

iteration <sub>CA</sub>	iteration <sub>PK</sub>
k	R <sub>L</sub>
H <sup>*</sup> <sub>cT</sub>	H <sub>cT</sub>
H <sub>stator</sub>	H <sub>rotor</sub>
c <sub>ад</sub>	w <sub>ад</sub>
P <sup>*</sup>	P
T <sup>*</sup>	T
G	v
ρ <sup>*</sup>	ρ
α <sub>ox</sub>	α <sub>ox</sub>
α	β
ε <sub>stator</sub>	ε <sub>rotor</sub>
θ <sub>CA</sub>	θ <sub>PK</sub>
g <sub>охлCA</sub>	g <sub>охлPK</sub>
a <sup>*</sup> <sub>c</sub>	a <sup>*</sup> <sub>w</sub>
T <sub>ад</sub>	T <sub>ад</sub>
P <sup>*</sup> <sub>w</sub>	T <sup>*</sup> <sub>w</sub>
a <sub>3B</sub>	a <sub>3B</sub>
u	u
c	c
c <sub>a</sub>	c <sub>u</sub>



$\eta_{\text{лoп}}^T =$

	1	2	3	4
1	91.14	91.24	92.21	92.64

·%

$\eta^*_{\text{cт}}^T =$

	1	2	3	4
1	89.26	89.74	90.83	90.86

·%

$\text{stack}\left(\eta_{u1}^T, \eta_{u2}^T\right) =$

	1	2	3	4
1	76.58	79.42	80.00	76.17
2	76.26	79.19	79.84	75.97

·%

$\eta_{\text{мoщь}}^T =$

	1	2	3	4
1	74.31	77.19	77.72	74.06

·%

$\eta_{\text{мoщь}_i} \leq \eta_{u1_i} \leq \eta^*_{\text{cт}_i} \leq \eta_{\text{лoп}_i} =$

1
1
1
1

Степень понижения полного давления Т:  
Степень понижения давления Т:

$$\left(\frac{\pi^*_{\text{Т}}}{\pi_{\text{Т}}}\right) = P^*_{\text{st}(1,1),\text{av}\left(N_{\text{r}}\right)} \cdot \left[\frac{\left(P^*_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}\right)^{-1}}{\left(P_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}\right)^{-1}}\right] =$$

	1
1	4.05
2	4.44

Температурный перепад по параметрам торможения (Дж/кг):  
Располагаемый температурный перепад (Дж/кг):

$$\left(\frac{H^*_{\text{Т}}}{H_{\text{Т}}}\right) = \left(\frac{\sum\limits_{i=1}^Z H^*_{\text{сТ}_i}}{\sum\limits_{i=1}^Z H_{\text{сТ}_i}}\right) =$$

	1
1	475.6
2	565.8

 $\cdot 10^3$

Мощность Т (Вт):

$$\sum\limits_{i=1}^Z N_{\text{сТ}_i} = 15.18 \cdot 10^6$$

$$\text{eps}\left(\text{"rel"}, N_{\text{Т}}, \sum\limits_{i=1}^Z N_{\text{сТ}_i}\right) = 0.000\cdot\%$$

Удельная поступенчатая работа Т [Дж/кг]:

$$L_{\text{Т}} = \sum\limits_{i=1}^Z \frac{N_{\text{сТ}_i}}{\text{mean}\left(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}\right)} = 428.9 \cdot 10^3$$

Лопаточный КПД Т:

$$\eta_{\text{Тлоп}} = \frac{\sum\limits_{i=1}^Z \frac{N_{\text{сТ}_i}}{\text{mean}\left(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}\right)} + \frac{\left(c_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}\right)^2}{2}}{H_{\text{Т}}} = 80.55\cdot\%$$

$$k_{\text{Т.ср}} = k_{\text{ад}}\left(C_{\text{рГаз.ср}}\left(P_{\text{st}(1,1),\text{av}\left(N_{\text{r}}\right)}, P_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}, T_{\text{st}(1,1),\text{av}\left(N_{\text{r}}\right)}, T_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}, \alpha_{\text{ox}_{\text{st}(1,1)}}, \alpha_{\text{ox}_{\text{st}(Z,3)}}, \text{Fuel}\right), R_{\text{Газ.ср}}\left(\alpha_{\text{ox}_{\text{st}(1,1)}}, \alpha_{\text{ox}_{\text{st}(Z,3)}}, \text{Fuel}\right)\right) = 1.308$$

Адиабатный КПД Т:

$$\eta^*_{\text{Т}} = \frac{L_{\text{Т}}}{H^*_{\text{Т}}} = 90.18\cdot\%$$

Политропический КПД Т:

$$\eta^*_{\text{Т.п}} = \eta^*_{\text{н}}\left(\text{"расширение"}, \eta^*_{\text{Т}}, \pi^*_{\text{Т}}, k_{\text{Т.ср}}\right) = 88.59\cdot\%$$

Мощностной КПД Т:

$$\eta_{\text{Тмощь}} = \frac{\sum\limits_{i=1}^Z \frac{N_{\text{сТ}_i}}{\text{mean}\left(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}\right)}}{H_{\text{Т}}} = 75.80\cdot\%$$



$$L_{\text{ct}}^{\text{T}} = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 107.1 & 107.2 & 107.2 & 107.2 \\ \hline \end{array} \cdot 10^3$$

$$N_{\text{ct}}^{\text{T}} = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 3.8 & 3.8 & 3.8 & 3.8 \\ \hline \end{array} \cdot 10^6$$

$$Lu_{\text{ct}}^{\text{T}} = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 110.4 & 110.3 & 110.4 & 110.3 \\ \hline \end{array} \cdot 10^3$$

$$Lu_{\text{нагрузка}}^{\text{T}} = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 3.0 & 2.3 & 1.8 & 1.6 \\ \hline \end{array}$$

$$H_{\text{ct}}^{\text{T}} = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 144.2 & 138.9 & 138.0 & 144.8 \\ \hline \end{array} \cdot 10^3$$

$$\text{stack}\Big(H_{\text{stator}}^{\text{T}}, H_{\text{rotor}}^{\text{T}}\Big) = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 125.4 & 118.1 & 113.1 & 118.0 \\ \hline 2 & 18.8 & 20.9 & 24.9 & 26.9 \\ \hline \end{array} \cdot 10^3$$

$$\text{submatrix}\Big(R_{\text{L}}^{\text{T}}, \text{av}\big(N_{\text{r}}\big), \text{av}\big(N_{\text{r}}\big), 1, Z\Big) = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0.1 & 0.2 & 0.2 & 0.2 \\ \hline \end{array}$$

$$G^{\text{T}} = \begin{array}{|c|c|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ \hline 1 & 35.394 & 35.394 & 35.394 & 35.394 & 35.394 & 35.394 & 35.394 & ... \\ \hline \end{array}$$

$$\alpha_{\text{ox}}^{\text{T}} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 2.493 & 2.493 & 2.493 & 2.493 & 2.493 & 2.493 & 2.493 & 2.493 & 2.493 \\ \hline \end{array}$$

$$\text{stack}\Big(\theta_{\text{CA}}^{\text{T}}, \theta_{\text{PK}}^{\text{T}}\Big) = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & -0.005 & -0.112 & -0.246 & -0.420 \\ \hline 2 & -0.066 & -0.192 & -0.354 & -0.568 \\ \hline \end{array}$$

$$\text{stack}\Big(g_{\text{oxлCA}}^{\text{T}}, g_{\text{oxлPK}}^{\text{T}}\Big) = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0.00 & 0.00 & 0.00 & 0.00 \\ \hline 2 & 0.00 & 0.00 & 0.00 & 0.00 \\ \hline \end{array} \cdot 10^{-3}$$

$$G_{\text{oxлCA}_i} = g_{\text{oxлCA}_i} \cdot G_{\text{st}(i, 1)}$$

$$G_{\text{oxлPK}_i} = g_{\text{oxлPK}_i} \cdot G_{\text{st}(i, 2)}$$

$$\text{stack}\Big(G_{\text{oxлCA}}^{\text{T}}, G_{\text{oxлPK}}^{\text{T}}\Big) = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0.0 & 0.0 & 0.0 & 0.0 \\ \hline 2 & 0.0 & 0.0 & 0.0 & 0.0 \\ \hline \end{array}$$

$$G_{\text{cooling}} = 0.8$$

$$\sum_{i = 1}^Z G_{\text{oxлCA}_i} + \sum_{i = 1}^Z G_{\text{oxлCA}_i} \leq G_{\text{cooling}} = 1$$

$$\text{stack}\Big(\text{iteration}_{\text{CA}}^{\text{T}},\text{iteration}_{\text{PK}}^{\text{T}}\Big)=\begin{array}{|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 \\ \hline 1 & 2 & 2 & 2 & 2 \\ \hline 2 & 2 & 2 & 2 & 2 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{k}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 1.298 & 1.302 & 1.303 & 1.306 & 1.307 & 1.312 & 1.313 & 1.319 & 1.320 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{P}^{*\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 927.5 & 915.4 & 676.8 & 666.5 & 483.6 & 476.7 & 338.0 & 332.9 & 229.2 \\ \hline \end{array}\cdot 10^3$$

$$\text{submatrix}\Big(\text{P}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 890.0 & 666.9 & 633.4 & 485.6 & 456.7 & 343.4 & 317.3 & 229.2 & 208.8 \\ \hline \end{array}\cdot 10^3$$

$$\text{submatrix}\Big(\text{T}^{*\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 1368.9 & 1369.9 & 1281.1 & 1282.0 & 1192.3 & 1193.3 & 1102.4 & 1103.7 & 1011.4 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{T}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 1356.0 & 1272.9 & 1261.6 & 1190.2 & 1176.4 & 1103.8 & 1085.9 & 1008.5 & 988.8 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{T}^{*\text{wT}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 0.0 & 1316.2 & 1317.8 & 1225.7 & 1228.4 & 1134.0 & 1136.6 & 1041.5 & 1042.0 \\ \hline \end{array}$$

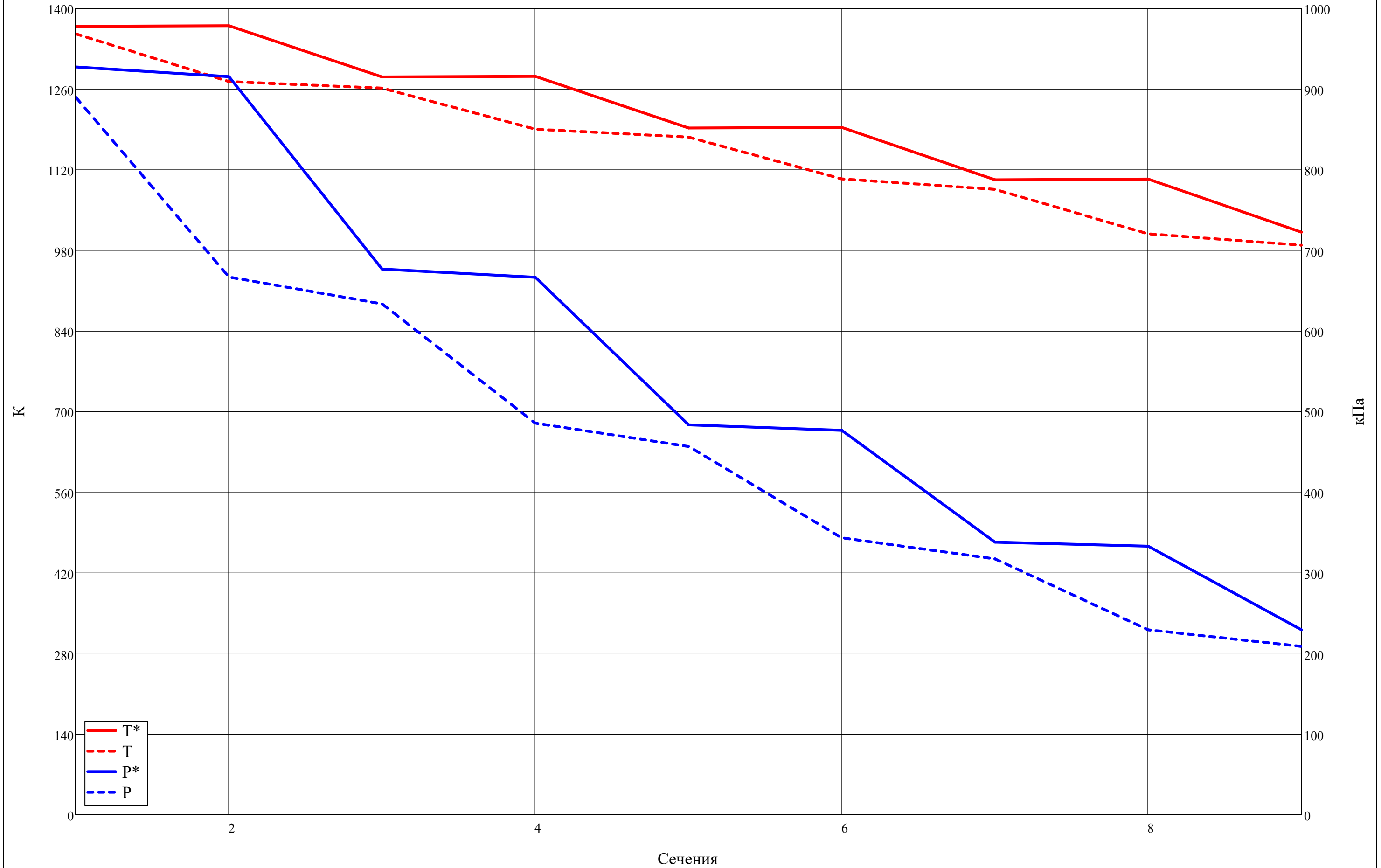
$$\text{submatrix}\Big(\text{T}_{\text{a}\mathcal{A}}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 0.0 & 1269.1 & 1257.7 & 1186.0 & 1173.2 & 1100.2 & 1083.3 & 1004.9 & 986.0 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{v}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 0.440 & 0.551 & 0.575 & 0.707 & 0.743 & 0.927 & 0.987 & 1.269 & 1.366 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\rho^{*\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 2.349 & 2.316 & 1.831 & 1.802 & 1.406 & 1.385 & 1.063 & 1.046 & 0.785 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\rho^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 2.275 & 1.816 & 1.741 & 1.414 & 1.346 & 1.078 & 1.013 & 0.788 & 0.732 \\ \hline \end{array}$$

Термодинамические параметры по тракту Т на ср. сечении



submatrix $\left(\mathbf{a}_{3B}^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	712.6	691.4	688.5	669.8	666.1	646.3	641.3	619.4	613.7

submatrix $\left(\mathbf{a}^*_c^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	667.9	668.6	646.6	647.3	624.3	625.0	600.9	601.8	576.2

submatrix $\left(\mathbf{a}^*_w^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	0.0	655.4	655.8	632.9	633.7	609.3	610.1	584.6	584.9

submatrix $\left(\mathbf{c}^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	180.0	491.2	220.3	475.1	197.6	466.2	200.0	476.7	231.9

submatrix $\left(\mathbf{c}_u^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	0.0	452.3	135.3	435.8	85.3	420.3	38.7	416.3	10.0

submatrix $\left(\mathbf{c}_a^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	180.0	191.6	173.8	189.2	178.3	201.6	196.2	232.3	231.7

submatrix $\left(\mathbf{w}^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	0.0	328.4	373.6	295.2	357.3	270.8	350.4	280.7	355.8

submatrix $\left(\mathbf{w}_u^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	0.0	266.7	330.7	226.5	309.6	180.9	290.3	157.7	270.0

submatrix $\left(\mathbf{w}_a^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	0.0	191.6	173.8	189.2	178.3	201.6	196.2	232.3	231.7

submatrix $\left(\mathbf{c}_{aD}^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z\right) =$

	1	2	3	4	5	6	7	8
1	537.0	500.9	527.1	485.9	525.3	475.7	538.1	485.8

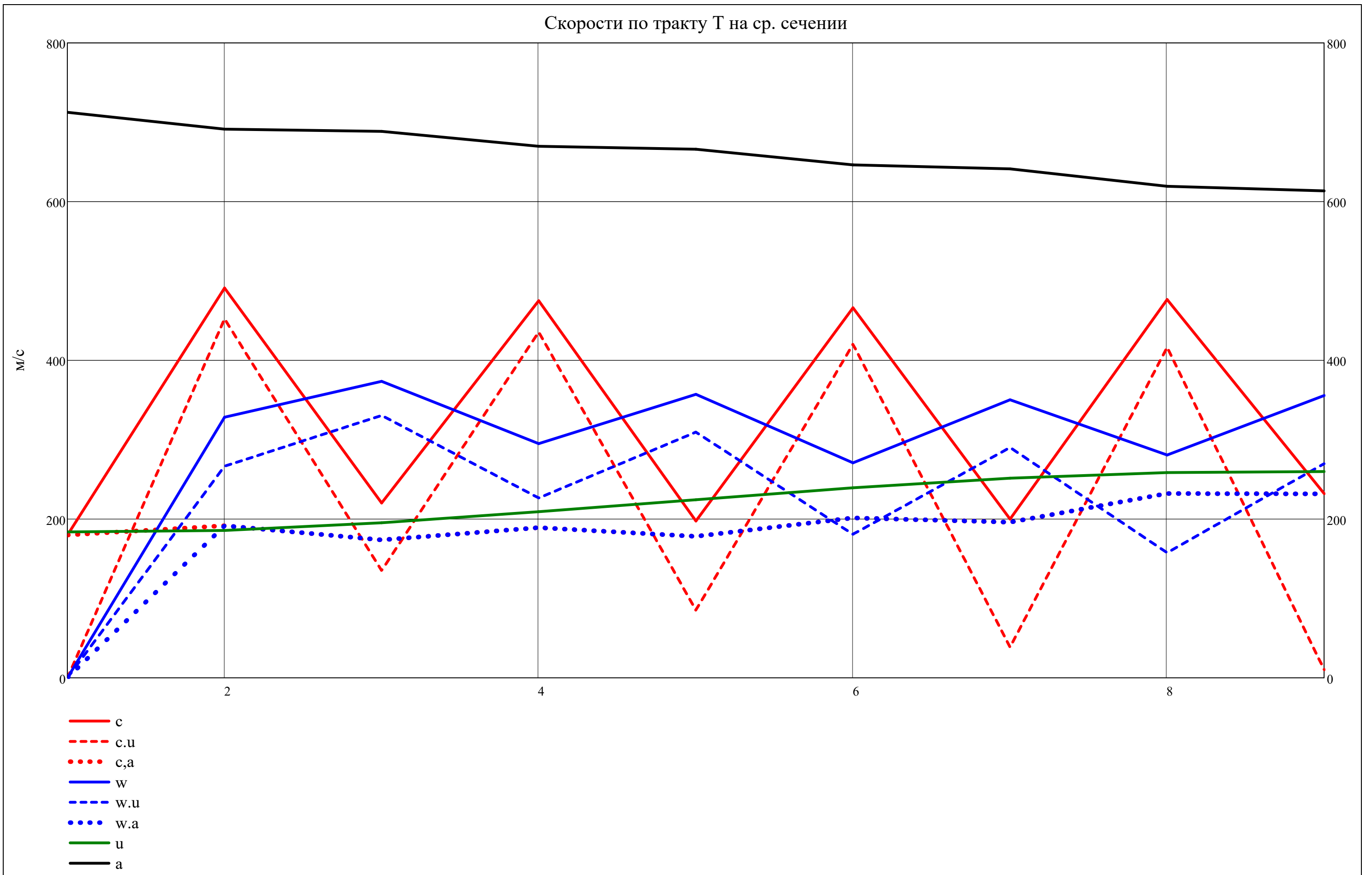
submatrix $\left(\mathbf{w}_{aD}^T, \text{av}\left(\mathbf{N}_r\right), \text{av}\left(\mathbf{N}_r\right), 1, 2Z + 1\right) =$

	1	2	3	4	5	6	7	8	9
1	0.0	0.0	386.2	0.0	368.1	0.0	359.4	0.0	365.1

$\mathbf{u}^T =$

	1	2	3	4	5	6	7	8	9
1	172.2	172.2	180.7	193.8	208.2	222.8	234.2	240.3	240.3
2	183.8	185.7	195.4	209.3	224.4	239.4	251.6	258.7	260.0
3	195.3	199.1	210.0	224.7	240.5	256.1	268.9	277.0	279.7

Скорости по тракту Т на ср. сечении



$$\text{submatrix}\Big(\alpha,1,2\cdot Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 90.00 & 22.96 & 52.10 & 23.47 & 64.44 & 25.62 & 78.83 & 29.16 & 87.53 \\ \hline \end{array} \text{.}^{\circ}$$

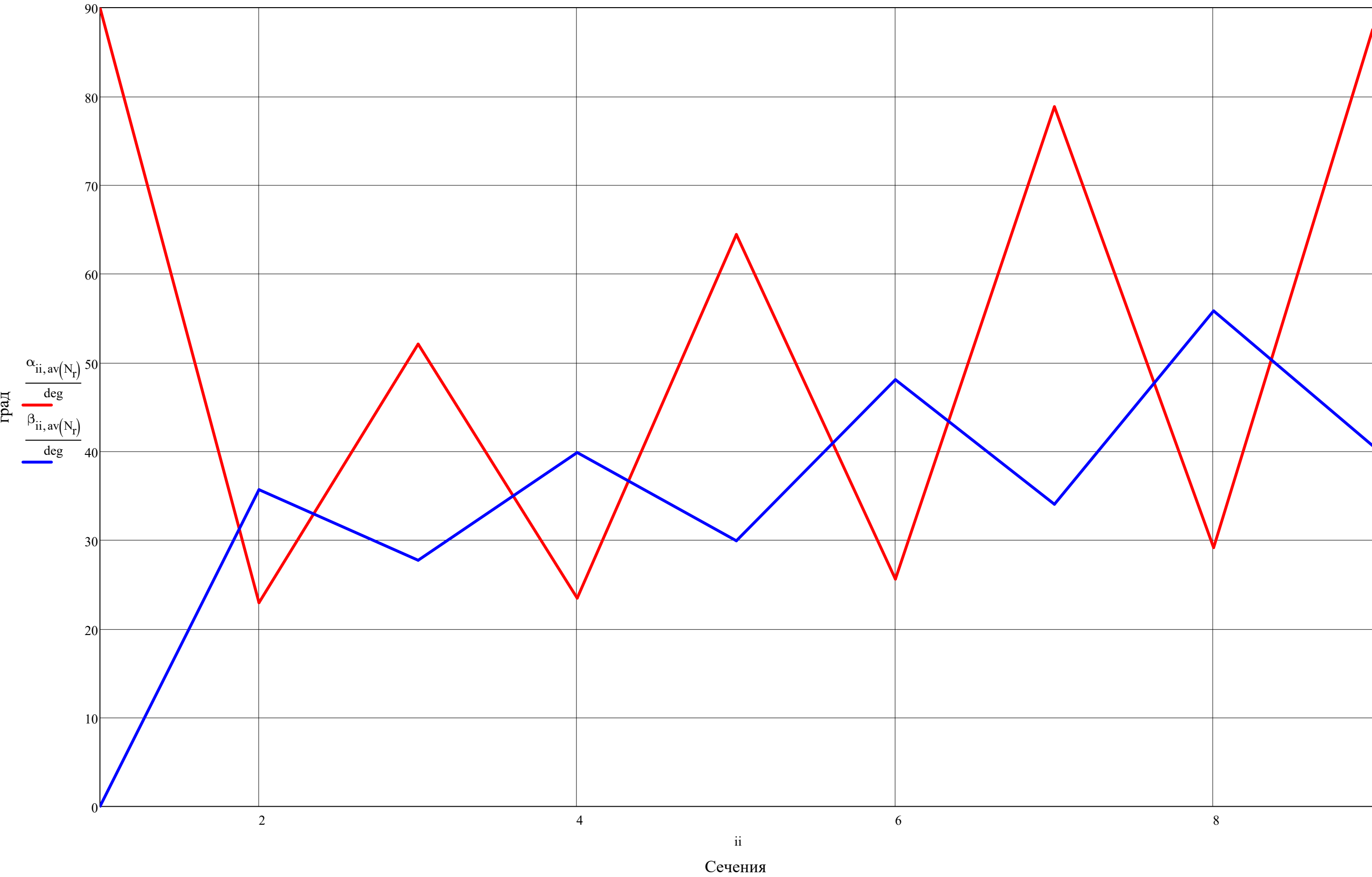
$$\text{submatrix}\Big(\alpha,1,2\cdot Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}\geq 11\text{.}^{\circ}=\begin{array}{|c|c|c|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\beta,1,2\cdot Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 \\ \hline 1 & 0.00 & 35.70 & 27.73 & 39.87 & 29.93 & 48.09 & 34.05 & 55.83 & 40.64 & & & \\ \hline \end{array} \text{.}^{\circ}$$

$$\text{submatrix}\Big(\varepsilon_{\text{stator}},1,Z,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & -67.04 & -28.63 & -38.82 & -49.68 & & \\ \hline \end{array} \text{.}^{\circ}$$

$$\text{submatrix}\Big(\varepsilon_{\text{rotor}},1,Z,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & -7.97 & -9.94 & -14.04 & -15.19 & & \\ \hline \end{array} \text{.}^{\circ}$$

Углы по тракту Т на ср. сечении



$$\text{submatrix}\Big(\lambda_{\text{c}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}=$$

	1	2	3	4	5	6	7	8
1	0.2695	0.7348	0.3407	0.7340	0.3165	0.7458	0.3328	...

$$\text{submatrix}\Big(\lambda_{\text{w}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}=$$

	1	2	3	4	5	6	7	8
1	0.0000	0.5011	0.5697	0.4664	0.5638	0.4445	0.5742	...

$$\text{submatrix}\Big(\text{M}_{\text{c}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}=$$

	1	2	3	4	5	6	7	8
1	0.2526	0.7105	0.3200	0.7093	0.2967	0.7213	0.3118	...

$$\text{submatrix}\Big(\text{M}_{\text{c}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}\leq 1=$$

	1	2	3	4	5	6	7	8	9
1	1	1	1	1	1	1	1	1	1

$$\text{submatrix}\Big(\text{M}_{\text{w}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}=$$

	1	2	3	4	5	6	7	8
1	0.0000	0.4749	0.5426	0.4407	0.5364	0.4191	0.5463	...

$$\text{submatrix}\Big(\text{M}_{\text{w}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}\leq 1=$$

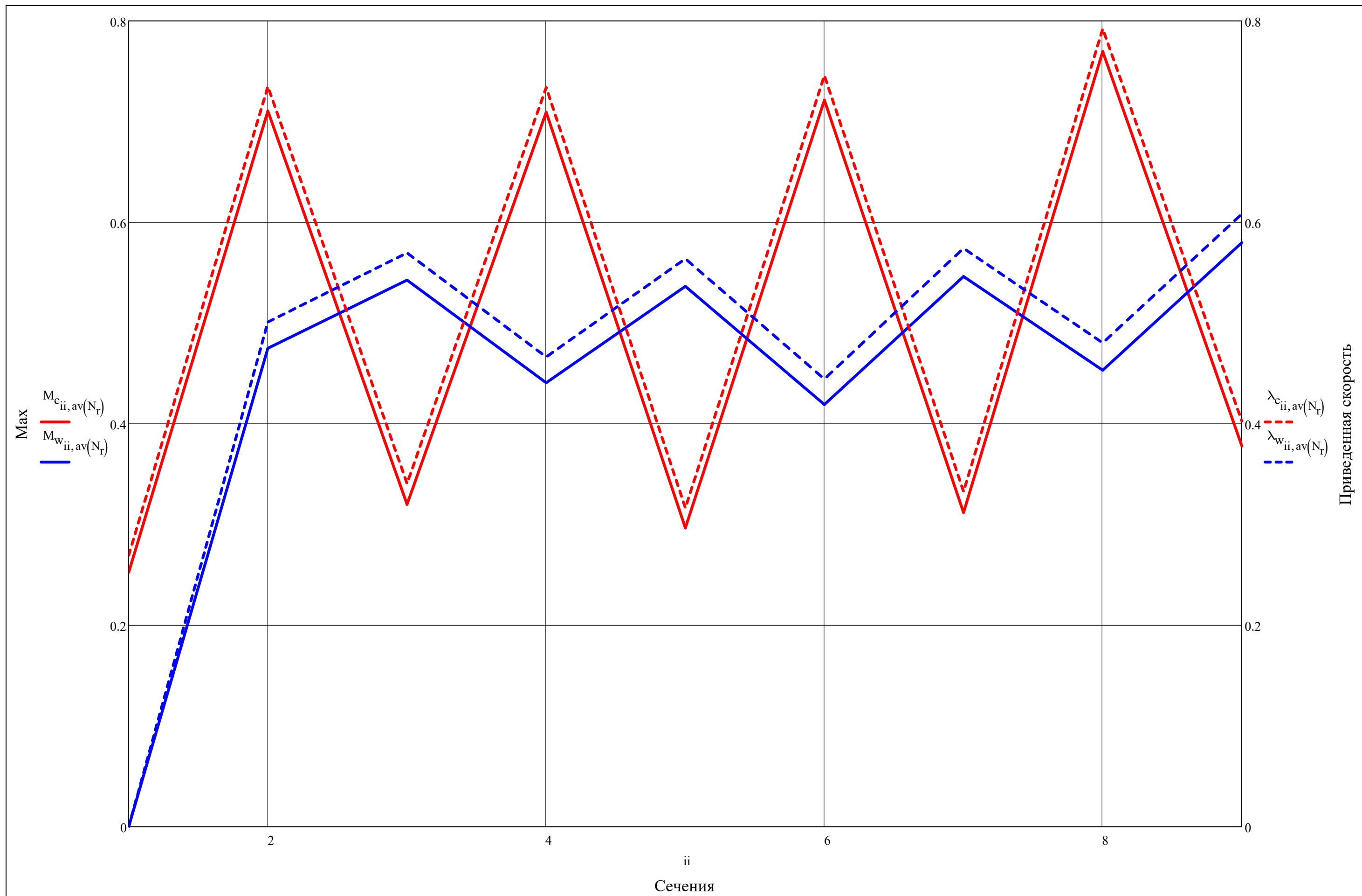
	1	2	3	4	5	6	7	8	9
1	1	1	1	1	1	1	1	1	1

$$\text{stack}\Big(v_{\text{stator}}^{\text{T}},v_{\text{rotor}}^{\text{T}}\Big)=$$

	1	2	3	4
1	43.06	63.00	58.89	53.57
2	68.73	68.33	67.41	67.12

$$.\circ$$





$$\mathbf{t_{stator}}^T = \begin{bmatrix} & 1 & 2 & 3 & 4 \\ 1 & 40.6 & 27.9 & 35.9 & 43.3 \\ 2 & 43.6 & 30.1 & 38.6 & 46.6 \\ 3 & 46.5 & 32.4 & 41.3 & 49.8 \end{bmatrix} \quad \mathbf{t_{rotor}}^T = \begin{bmatrix} & 1 & 2 & 3 & 4 \\ 1 & 19.8 & 23.5 & 28.4 & 30.6 \\ 2 & 21.4 & 25.3 & 30.5 & 33.0 \\ 3 & 22.9 & 27.1 & 32.7 & 35.4 \end{bmatrix} \cdot 10^{-3}$$

$$\text{submatrix}\Big(\text{chord}_{\text{stator}}^T, \text{av}\big(N_r\big), \text{av}\big(N_r\big), 1, Z\Big) = \begin{bmatrix} & 1 & 2 & 3 & 4 \\ 1 & 58.7 & 50.6 & 60.4 & 69.4 \end{bmatrix} \cdot 10^{-3}$$

$$\text{submatrix}\Big(\text{chord}_{\text{rotor}}^T, \text{av}\big(N_r\big), \text{av}\big(N_r\big), 1, Z\Big) = \begin{bmatrix} & 1 & 2 & 3 & 4 \\ 1 & 34.3 & 39.5 & 44.6 & 46.2 \end{bmatrix} \cdot 10^{-3}$$

$$\text{stack}\Big(Z_{\text{stator}}^T, Z_{\text{rotor}}^T\Big) = \begin{bmatrix} & 1 & 2 & 3 & 4 \\ 1 & 48 & 76 & 68 & 62 \\ 2 & 101 & 97 & 91 & 89 \end{bmatrix}$$

$$\text{stack}\Big(\overline{\mathbf{t_{OITCA}}^T}, \overline{\mathbf{t_{OITPK}}^T}\Big) = \begin{bmatrix} & 1 & 2 & 3 & 4 \\ 1 & 0.762 & 0.603 & 0.645 & 0.686 \\ 2 & 0.643 & 0.661 & 0.695 & 0.722 \end{bmatrix}$$

$$\frac{\mathbf{t_{stator}}_{i, \text{av}\big(N_r\big)}}{\text{chord}_{\text{stator}}_{i, \text{av}\big(N_r\big)}} = 0.7 \leq \frac{\mathbf{t_{stator}}_{i, \text{av}\big(N_r\big)}}{\text{chord}_{\text{stator}}_{i, \text{av}\big(N_r\big)}} \leq 1 = \frac{\mathbf{t_{rotor}}_{i, \text{av}\big(N_r\big)}}{\text{chord}_{\text{rotor}}_{i, \text{av}\big(N_r\big)}} = 0.7 \leq \frac{\mathbf{t_{rotor}}_{i, \text{av}\big(N_r\big)}}{\text{chord}_{\text{rotor}}_{i, \text{av}\big(N_r\big)}} \leq 1 =$$

0.743
0.595
0.639
0.671

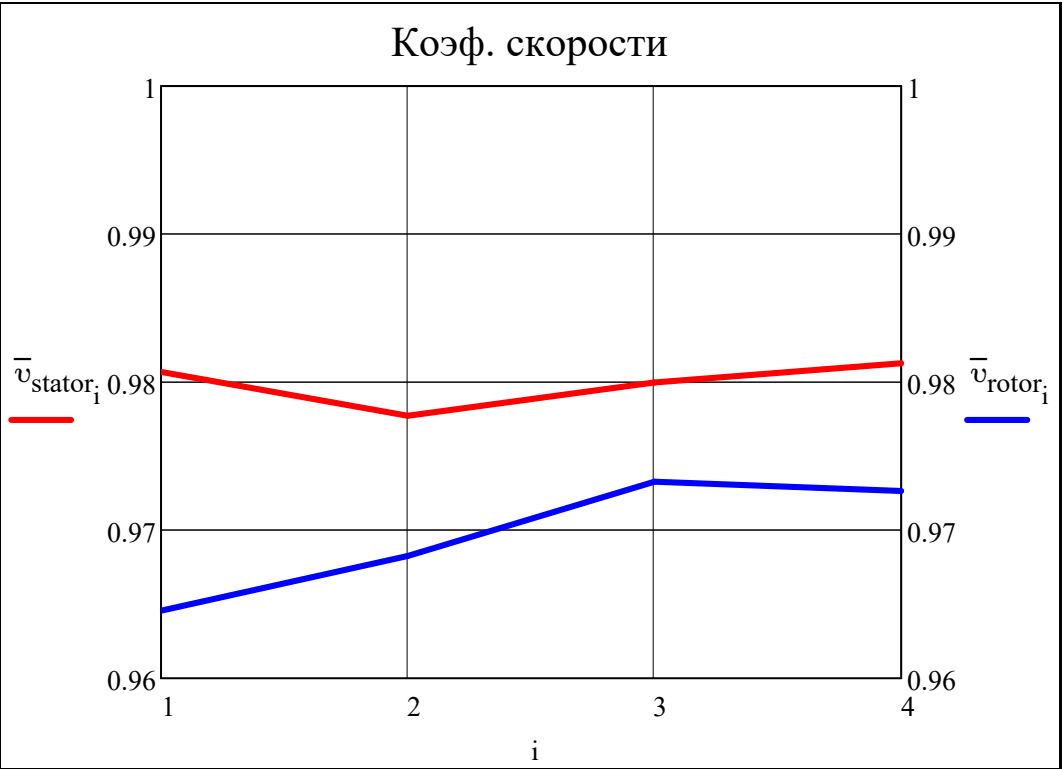
1
0
0
0

0.622
0.640
0.684
0.714

0
0
0
1

$$\text{stack}\left(\overline{v}_{\text{stator}}^T, \overline{v}_{\text{rotor}}^T\right) =$$

	1	2	3	4
1	0.9807	0.9777	0.9800	0.9813
2	0.9646	0.9683	0.9733	0.9727



$$\text{stack}\left(\xi_{\text{TpCA}}^{\text{T}}, \xi_{\text{TpPK}}^{\text{T}}\right) =$$

	1	2	3	4
1	1.396	1.811	1.520	1.394
2	3.932	3.289	2.480	2.497

·%

$$\text{stack}\left(\xi_{\text{KpCA}}^{\text{T}}, \xi_{\text{KpPK}}^{\text{T}}\right) =$$

	1	2	3	4
1	1.243	1.519	1.302	1.101
2	0.933	0.846	0.705	

·%

$$\text{stack}\left(\xi_{\text{ReCA}}^{\text{T}}, \xi_{\text{RePK}}^{\text{T}}\right) =$$

	1	2	3	4
1	-0.014	0.078	0.097	0.126
2	0.246	0.301	0.371	0.507

·%

$$\text{stack}\left(\xi_{\text{IrpCA}}^{\text{T}}, \xi_{\text{IrpPK}}^{\text{T}}\right) =$$

	1	2	3	4
1	2.842	3.626	3.119	2.754
2	5.483	4.819	3.917	3.881

·%

$$\text{stack}\left(\xi_{\lambda\text{CA}}^{\text{T}}, \xi_{\lambda\text{PK}}^{\text{T}}\right) =$$

	1	2	3	4
1	0.217	0.219	0.201	0.134
2	0.371	0.382	0.362	0.297

·%

$$\text{stack}\left(\xi_{\text{BTCA}}^{\text{T}}, \xi_{\text{BTPK}}^{\text{T}}\right) =$$

	1	2	3	4
1	0.980	0.778	0.845	0.958
2	1.477	1.430	1.356	1.513

·%

$$\text{stack}\left(\xi_{\text{TDCA}}^{\text{T}}, \xi_{\text{TDPK}}^{\text{T}}\right) =$$

	1	2	3	4
1	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000

·%

$$\text{stack}\left(\xi_{\text{сmCA}}^{\text{T}}, \xi_{\text{сmPK}}^{\text{T}}\right) =$$

	1	2	3	4
1	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000

·%

$$\text{stack}\left(\xi_{\text{CA}}^{\text{T}}, \xi_{\text{PK}}^{\text{T}}\right) =$$

	1	2	3	4
1	3.326	3.743	3.250	3.026
2	3.621	3.062	2.476	2.493

·%

$$\xi_{\text{ВЫХ}}^{\text{T}} =$$

	1	2	3	4
1	16.829	14.054	14.491	18.579

·%

$$\xi_{\Delta\text{r}}^{\text{T}} =$$

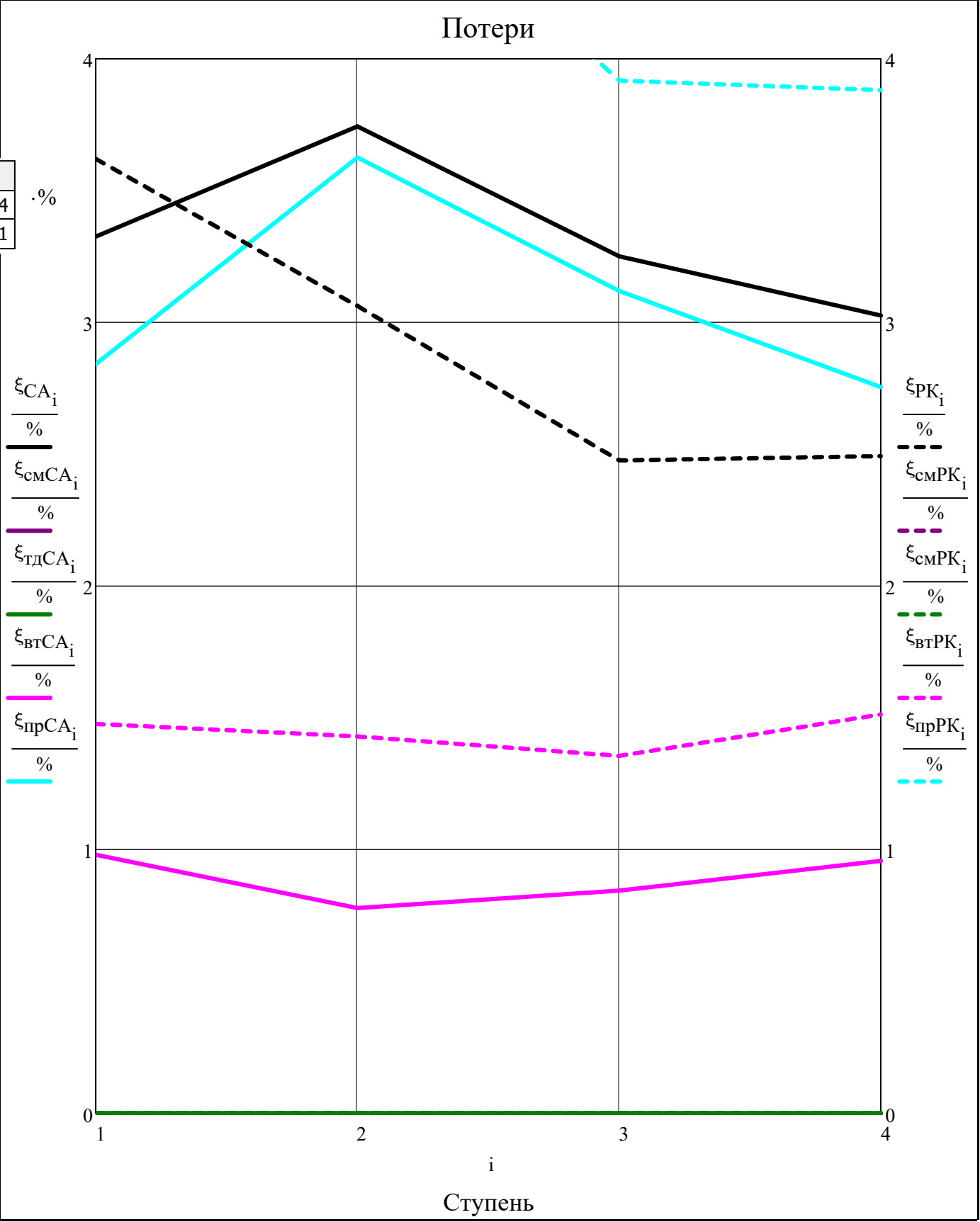
	1	2	3	4
1	1.813	1.786	1.826	1.662

·%

$$\xi_{\text{Tp.в}}^{\text{T}} =$$

	1	2	3	4
1	0.138	0.222	0.300	0.245

·%



$$\overline{m} = \begin{pmatrix} \overline{v}_{\text{stator}_1} \cdot \cos\left(\alpha_{\text{st}(1,2), \text{av}(N_r)}\right)^2 \text{ if } Z = 1 \\ -0.5 \text{ otherwise} \\ -0.25 \\ 0 \\ 0.25 \\ 1 \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} \text{"}\alpha.2=\text{const"}\\ \text{"}\Gamma=\text{const"}\\ \text{"}m=\text{const"}\\ \text{"}R=\text{const"}\end{pmatrix} = \begin{pmatrix} \cos\left(\alpha_{\text{st}(i,2), \text{av}(N_r)}\right)^2 \cdot \overline{v}_{\text{stator}_i} \\ 1 \cdot \overline{v}_{\text{stator}_i} \\ 0.2 \\ -1 \cdot \overline{v}_{\text{stator}_i} \end{pmatrix}$$

m<sup>T</sup> =

	1	2	3	4	5	6
1	-0.5000	-0.2500	0.0000	0.2500	1.0000	1.0000



$$\begin{aligned}
& u_{st(i,2),av(N_r)} = \bar{v}_{stator_i} \cdot \cos(\alpha_{st(i,2),av(N_r)}) \\
& c_{a_{st(i,a),av(N_r)}} = c_{a_{st(i,a),av(N_r)}} \cdot \sqrt{1 + \frac{\left(1 - \frac{\bar{v}_{stator_i}}{m_i}\right) \cdot \left[1 - \frac{1}{\left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)^{2 \cdot m_i}}\right]}{\tan(\alpha_{st(i,2),av(N_r)})^2}} \quad \text{if } a = 2 \\
& \left[ \left(c_{a_{st(i,a),av(N_r)}}\right)^2 \dots \right. \\
& + \left[1 - \left(\bar{v}_{rotor_i}\right)^2\right] \cdot \left(u_{st(i,a),av(N_r)}\right)^2 \cdot \left[1 - \left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)^2\right] - 2 \cdot c_{u_{st(i,a),av(N_r)}} \cdot u_{st(i,a),av(N_r)} \cdot \left[1 - \left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)^{1-m_i}\right] \dots \\
& + \left[1 - \left(\bar{v}_{rotor_i}\right)^2\right] \cdot \left[1 - \frac{1}{\left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)^2}\right] \cdot \left(c_{u_{st(i,a-1),av(N_r)}} + c_{u_{st(i,a),av(N_r)}}\right)^2 \dots \\
& + -2 \cdot c_{u_{st(i,a-1),av(N_r)}} \cdot \left(c_{u_{st(i,a-1),av(N_r)}} + c_{u_{st(i,a),av(N_r)}}\right) \cdot \left[1 - \frac{2}{m_i + 1} \cdot \left(\bar{v}_{rotor_i}\right)^2\right] \cdot \left[1 - \frac{1}{\left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)^{m_i+1}}\right] \dots \\
& + \left(c_{u_{st(i,a-1),av(N_r)}}\right)^2 \cdot \left[1 - \frac{\left(\bar{v}_{stator_i}\right)^2 \cdot \left(\bar{v}_{rotor_i}\right)^2}{m_i}\right] \cdot \left[1 - \frac{1}{\left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)^{2 \cdot m_i}}\right] \\
& \left. \right] \sqrt{\left(c_{a_{st(i,a),av(N_r)}}\right)^2 + \frac{A_{st(i,a)} \cdot (m_i - 1) \cdot \left[-A_{st(i,a)} \cdot (m_i + 1) \cdot \left[\frac{1}{\left(R_{st(i,a),r}\right)^{2 \cdot m_i}} - \frac{1}{\left(R_{st(i,a),av(N_r)}\right)^{2 \cdot m_i}}\right] \dots \right.}{m_i \cdot (m_i + 1)} \left. + 2 \cdot B_{st(i,a)} \cdot m_i \cdot \left[\frac{1}{\left(R_{st(i,a),r}\right)^{m_i+1}} - \frac{1}{\left(R_{st(i,a),av(N_r)}\right)^{m_i+1}}\right] \cdot \begin{cases} -1 & \text{if } a = 2 \\ 1 & \text{otherwise} \end{cases} \right]} \quad \text{otherwise}
\end{aligned}$$

for  $i \in 1..2 \cdot Z + 1$

for  $r \in 1..N_r$

$$\begin{pmatrix} c_{u_{i,r}} \\ c_{a_{i,r}} \end{pmatrix} = c_{i,av(N_r)} \cdot \begin{pmatrix} \cos(\alpha_{i,av(N_r)}) \\ \sin(\alpha_{i,av(N_r)}) \end{pmatrix} \quad \text{if } (i = 1)$$

$$P_{i,r}^* = P_{i,av(N_r)}^*$$

$$T_{i,r}^* = T_{i,av(N_r)}^*$$

$$\rho_{i,r}^* = \frac{P_{i,r}^*}{R_{fa3}(\alpha_{ox_i}, Fuel) \cdot T_{i,r}^*}$$

$$k_{i,r} = k_{ад}\left(Cp_{\text{воздух}}(P^*_{i,r}, T^*_{i,r}), R_{газ}(\alpha_{\text{ox}_i}, \text{Fuel})\right)$$

$$a^*_{c_{i,r}} = \sqrt{\frac{2 \cdot k_{i,r}}{k_{i,r} + 1} \cdot R_{газ}(\alpha_{\text{ox}_i}, \text{Fuel}) \cdot T^*_{i,r}}$$

$$\alpha_{i,r} = \text{triangle}(c_{a_{i,r}}, c_{u_{i,r}})$$

$$c_{i,r} = \frac{c_{a_{i,r}}}{\sin(\alpha_{i,r})}$$

$$\lambda_{c_{i,r}} = \frac{c_{i,r}}{a^*_{c_{i,r}}}$$

$$\begin{pmatrix} T_{i,r} \\ P_{i,r} \\ \rho_{i,r} \end{pmatrix} = \begin{pmatrix} T^*_{i,r} \cdot \Gamma Д \Phi("T", \lambda_{c_{i,r}}, k_{i,r}) \\ P^*_{i,r} \cdot \Gamma Д \Phi("P", \lambda_{c_{i,r}}, k_{i,r}) \\ \rho^*_{i,r} \cdot \Gamma Д \Phi("ρ", \lambda_{c_{i,r}}, k_{i,r}) \end{pmatrix}$$

$$a_{3B_{i,r}} = \sqrt{k_{i,r} \cdot R_{газ}(\alpha_{\text{ox}_i}, \text{Fuel}) \cdot T_{i,r}}$$

$$M_{c_{i,r}} = \frac{c_{i,r}}{a_{3B_{i,r}}}$$

$$\beta_{i,r} = \text{triangle}(c_{a_{i,r}}, u_{i,r} - c_{u_{i,r}})$$

$$w_{i,r} = \frac{c_{a_{i,r}}}{\sin(\beta_{i,r})}$$

$$\begin{pmatrix} w_{u_{i,r}} \\ w_{a_{i,r}} \end{pmatrix} = w_{i,r} \cdot \begin{pmatrix} \cos(\beta_{i,r}) \\ \sin(\beta_{i,r}) \end{pmatrix}$$

$$T^*_{w_{i,r}} = T^*_{i,r} - \frac{(c_{i,r})^2 - (w_{i,r})^2}{2 \cdot \frac{k_{i,r}}{k_{i,r} - 1} \cdot R_{газ}(\alpha_{\text{ox}_i}, \text{Fuel})}$$

$$a^*_{w_{i,r}} = \sqrt{\frac{2 \cdot k_{i,r}}{k_{i,r} + 1} \cdot R_{газ}(\alpha_{\text{ox}_i}, \text{Fuel}) \cdot T^*_{w_{i,r}}}$$

$$\lambda_{w_{i,r}} = \frac{w_{i,r}}{a^*_{w_{i,r}}}$$

$$M_{w_{i,r}} = \frac{w_{i,r}}{a_{3B_{i,r}}}$$

for i ∈ 1..Z

for r ∈ 1..N<sub>r</sub>

$$|(\Delta c_{a_{i,r}}) - (c_{a_{i,r}} - c_{a_{i,r}})|$$



$$\begin{pmatrix} \widetilde{c}_{st(i,1),r} \\ \Delta c_{a_{st(i,2),r}} \end{pmatrix} = \begin{pmatrix} \widetilde{c}_{st(i,2),r} & \widetilde{c}_{st(i,1),r} \\ c_{a_{st(i,3),r}} - c_{a_{st(i,2),r}} \end{pmatrix}$$

$$R_{L_{i,r}} = 1 - \frac{c_{u_{st(i,2),r}} - c_{u_{st(i,3),r}}}{u_{st(i,2),r} + u_{st(i,3),r}}$$

$$\varepsilon_{stator_{i,r}} = \begin{cases} \alpha_{st(i,2),r} - \alpha_{st(i,1),r} & \text{if } \alpha_{st(i,2),r} \geq \frac{\pi}{2} \\ \alpha_{st(i,1),r} - \alpha_{st(i,2),r} & \text{otherwise} \end{cases}$$

$$\varepsilon_{rotor_{i,r}} = \begin{cases} \beta_{st(i,3),r} - \beta_{st(i,2),r} & \text{if } \beta_{st(i,3),r} \geq \frac{\pi}{2} \\ \beta_{st(i,2),r} - \beta_{st(i,3),r} & \text{otherwise} \end{cases}$$

$$\begin{pmatrix} P^* & T^* & T & \rho^* & k & a_c^* & a_{3B} & c & c_u & c_a & \Delta c_a & \alpha & \lambda_c & \lambda_w & \varepsilon_{stator} \\ P & T_w^* & T & \rho & R_L & a_w^* & a_{3B} & w & w_u & w_a & \Delta c_a & \beta & M_c & M_w & \varepsilon_{rotor} \end{pmatrix}^T$$

$$p^{*T} =$$

	1	2	3	4	5	6	7	8	9
1	927.5	915.4	676.8	666.5	483.6	476.7	338.0	332.9	229.2
2	927.5	915.4	676.8	666.5	483.6	476.7	338.0	332.9	229.2
3	927.5	915.4	676.8	666.5	483.6	476.7	338.0	332.9	229.2

$\cdot 10^3$

$$T^{*T} =$$

	1	2	3	4	5	6	7	8	9
1	1368.9	1369.9	1281.1	1282.0	1192.3	1193.3	1102.4	1103.7	1011.4
2	1368.9	1369.9	1281.1	1282.0	1192.3	1193.3	1102.4	1103.7	1011.4
3	1368.9	1369.9	1281.1	1282.0	1192.3	1193.3	1102.4	1103.7	1011.4

$$T^{*T}_w =$$

	1	2	3	4	5	6	7	8	9
1	1381.3	1313.8	1273.2	1222.8	1197.0	1130.2	1120.2	1036.5	1033.9
2	1383.0	1313.1	1278.7	1222.6	1203.2	1130.7	1126.9	1038.0	1041.0
3	1384.8	1312.5	1284.4	1222.5	1209.7	1131.4	1133.9	1039.7	1048.3

$$\rho^{*T} =$$

	1	2	3	4	5	6	7	8	9
1	2.349	2.316	1.831	1.802	1.406	1.385	1.063	1.046	0.785
2	2.349	2.316	1.831	1.802	1.406	1.385	1.063	1.046	0.785
3	2.349	2.316	1.831	1.802	1.406	1.385	1.063	1.046	0.785

$$k^T =$$

	1	2	3	4	5	6	7	8	9
1	1.317	1.317	1.321	1.321	1.326	1.326	1.331	1.331	1.338
2	1.317	1.317	1.321	1.321	1.326	1.326	1.331	1.331	1.338
3	1.317	1.317	1.321	1.321	1.326	1.326	1.331	1.331	1.338

$$R_L^T =$$

	1	2	3	4
1	0.0536	0.0511	0.0925	0.1037
2	0.0913	0.1091	0.1574	0.1829
3	0.1251	0.1592	0.2136	0.2505

$$p^T =$$

	1	2	3	4	5	6	7	8	9
1	890.0	632.0	636.1	460.2	459.1	325.8	317.9	215.9	208.8
2	890.0	661.2	638.3	481.8	459.5	340.2	318.0	226.6	208.8
3	890.0	687.3	639.6	501.1	459.7	353.1	318.0	235.9	208.8

$\cdot 10^3$

$$T^T =$$

	1	2	3	4	5	6	7	8	9
1	1355.4	1252.9	1262.0	1171.6	1177.2	1086.7	1085.7	990.9	987.9
2	1355.4	1266.6	1263.0	1184.8	1177.5	1098.4	1085.7	1002.9	987.9
3	1355.4	1278.5	1263.6	1196.1	1177.6	1108.5	1085.8	1013.1	987.9

$$\rho^T =$$

	1	2	3	4	5	6	7	8	9
1	2.276	1.749	1.747	1.362	1.352	1.039	1.015	0.755	0.733
2	2.276	1.810	1.752	1.410	1.353	1.074	1.015	0.783	0.733
3	2.276	1.864	1.755	1.452	1.353	1.104	1.015	0.807	0.733

$$R_L^T \geq 0.05 =$$

	1	2	3	4
1	1	1	1	1
2	1	1	1	1
3	1	1	1	1



$$\mathbf{a_c^*}^T =$$

	1	2	3	4	5	6	7	8	9
1	670.1	670.3	648.6	648.9	626.2	626.5	602.7	603.0	577.9
2	670.1	670.3	648.6	648.9	626.2	626.5	602.7	603.0	577.9
3	670.1	670.3	648.6	648.9	626.2	626.5	602.7	603.0	577.9

$$\mathbf{u}^T =$$

	1	2	3	4	5	6	7	8	9
1	172.2	172.2	180.7	193.8	208.2	222.8	234.2	240.3	240.3
2	183.8	185.7	195.4	209.3	224.4	239.4	251.6	258.7	260.0
3	195.3	199.1	210.0	224.7	240.5	256.1	268.9	277.0	279.7

$$\mathbf{c}^T =$$

	1	2	3	4	5	6	7	8	9
1	180.0	529.2	213.2	511.7	188.4	500.2	196.8	511.3	231.7
2	180.0	497.3	207.1	480.3	186.6	472.1	196.6	483.5	231.7
3	180.0	467.8	203.6	451.4	185.8	446.3	196.6	458.4	231.7

$$\mathbf{c_u}^T =$$

	1	2	3	4	5	6	7	8	9
1	0.0	476.1	142.1	459.2	77.7	444.1	29.4	444.2	13.3
2	0.0	458.9	112.6	441.5	55.1	426.9	13.1	424.0	0.2
3	0.0	444.6	86.6	426.5	35.3	411.8	-1.0	406.3	-10.9

$$\mathbf{c_a}^T =$$

	1	2	3	4	5	6	7	8	9
1	180.0	231.1	158.9	225.9	171.6	230.1	194.6	253.2	231.4
2	180.0	191.6	173.8	189.2	178.3	201.6	196.2	232.3	231.7
3	180.0	145.5	184.3	148.0	182.4	171.9	196.6	212.2	231.5

$$\Delta \mathbf{c_a}^T =$$

	1	2	3	4	5	6	7	8
1	51.1	-72.2	67.0	-54.4	58.6	-35.6	58.7	-21.9
2	11.6	-17.8	15.4	-11.0	23.3	-5.4	36.1	-0.5
3	-34.5	38.8	-36.3	34.5	-10.5	24.7	15.6	19.2

$$\mathbf{a_w^*}^T =$$

	1	2	3	4	5	6	7	8	9
1	673.1	656.4	646.6	633.7	627.5	609.7	607.5	584.4	584.3
2	673.5	656.3	648.0	633.6	629.1	609.8	609.3	584.8	586.2
3	674.0	656.1	649.5	633.6	630.8	610.0	611.2	585.3	588.3

$$\mathbf{a_{3B}}^T =$$

	1	2	3	4	5	6	7	8	9
1	717.7	690.0	693.6	668.3	671.0	644.7	645.8	616.9	617.5
2	717.7	693.8	693.9	672.0	671.1	648.2	645.8	620.6	617.5
3	717.7	697.0	694.0	675.2	671.2	651.1	645.8	623.8	617.5

$$\mathbf{w}^T =$$

	1	2	3	4	5	6	7	8	9
1	249.1	381.8	163.5	348.6	215.6	319.3	282.5	325.1	324.1
2	257.2	333.7	192.5	299.5	245.8	275.2	308.8	285.1	348.1
3	265.6	285.4	221.8	250.2	274.5	232.0	334.0	248.5	371.5

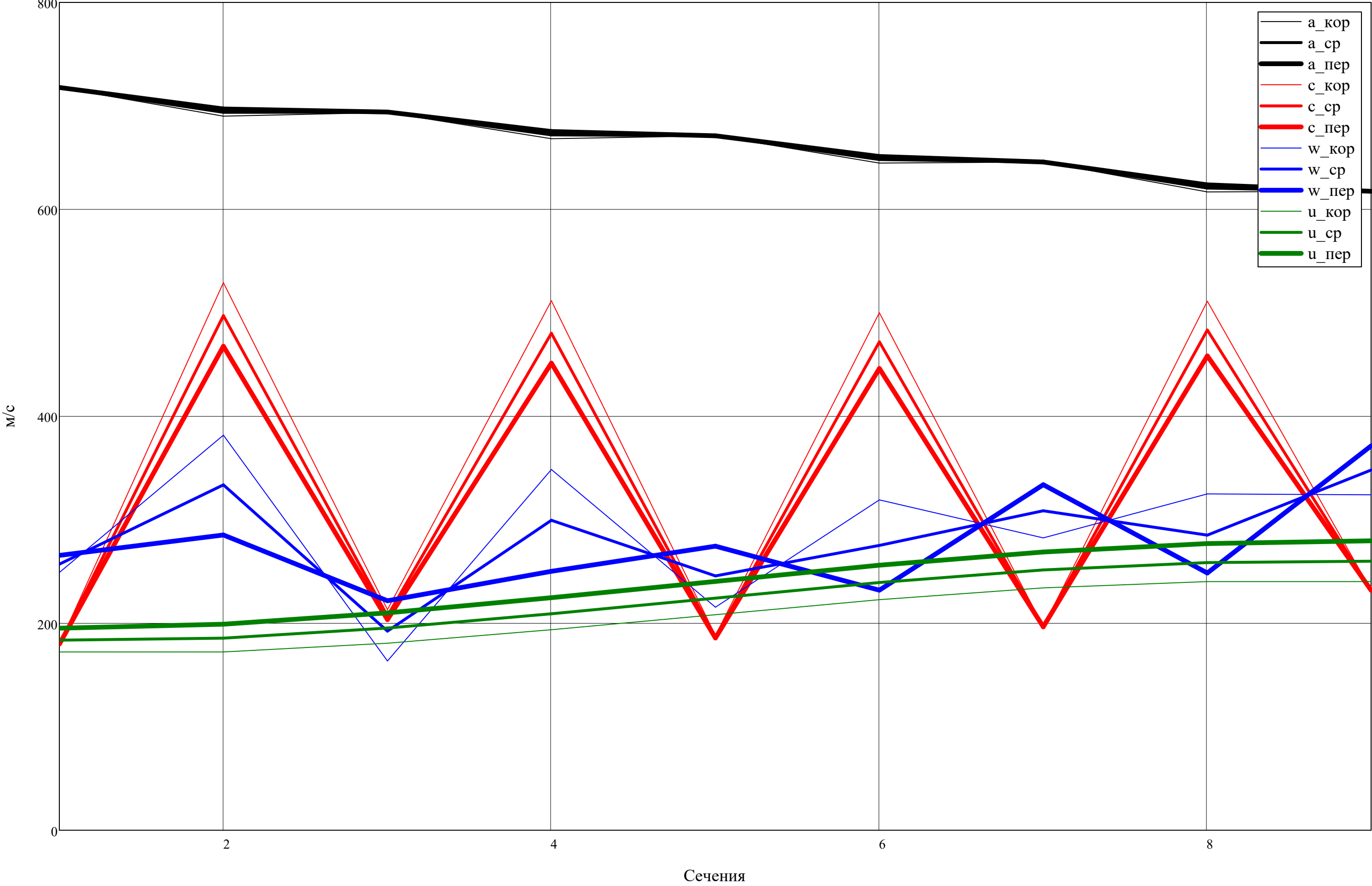
$$\mathbf{w_u}^T =$$

	1	2	3	4	5	6	7	8
1	172.2	-303.9	38.6	-265.4	130.5	-221.3	204.8	-203.8
2	183.8	-273.2	82.7	-232.2	169.2	-187.4	238.4	-165.3
3	195.3	-245.5	123.4	-201.7	205.2	-155.7	269.9	...

$$\mathbf{w_a}^T =$$

	1	2	3	4	5	6	7	8	9
1	180.0	231.1	158.9	225.9	171.6	230.1	194.6	253.2	231.4
2	180.0	191.6	173.8	189.2	178.3	201.6	196.2	232.3	231.7
3	180.0	145.5	184.3	148.0	182.4	171.9	196.6	212.2	231.5

Скорости по тракту Т



$\alpha^T =$ 

	1	2	3	4	5	6	7	8	9
1	90.00	25.89	48.19	26.20	65.64	27.39	81.41	29.69	86.70
2	90.00	22.66	57.06	23.20	72.81	25.28	86.17	28.72	89.95
3	90.00	18.12	64.82	19.13	79.04	22.65	90.30	27.58	92.70

 $\cdot \circ$

$80^\circ \leq \alpha^T =$ 

	1	2	3	4	5	6	7	8	9
1	1	0	0	0	0	0	1	0	1
2	1	0	0	0	0	0	1	0	1
3	1	0	0	0	0	0	1	0	1

 $[1, c.78]$

Угол поворота потока:

$\epsilon_{\text{stator}}^T =$ 

	1	2	3	4
1	64.11	21.99	38.24	51.72
2	67.34	33.86	47.53	57.46
3	71.88	45.69	56.39	62.72

 $\cdot \circ$

$\beta^T =$ 

	1	2	3	4	5	6	7	8
1	46.26	142.75	76.35	139.59	52.74	133.88	43.53	128.83
2	44.41	144.96	64.55	140.83	46.49	132.92	39.45	125.44
3	42.67	149.35	56.19	143.74	41.64	132.18	36.07	...

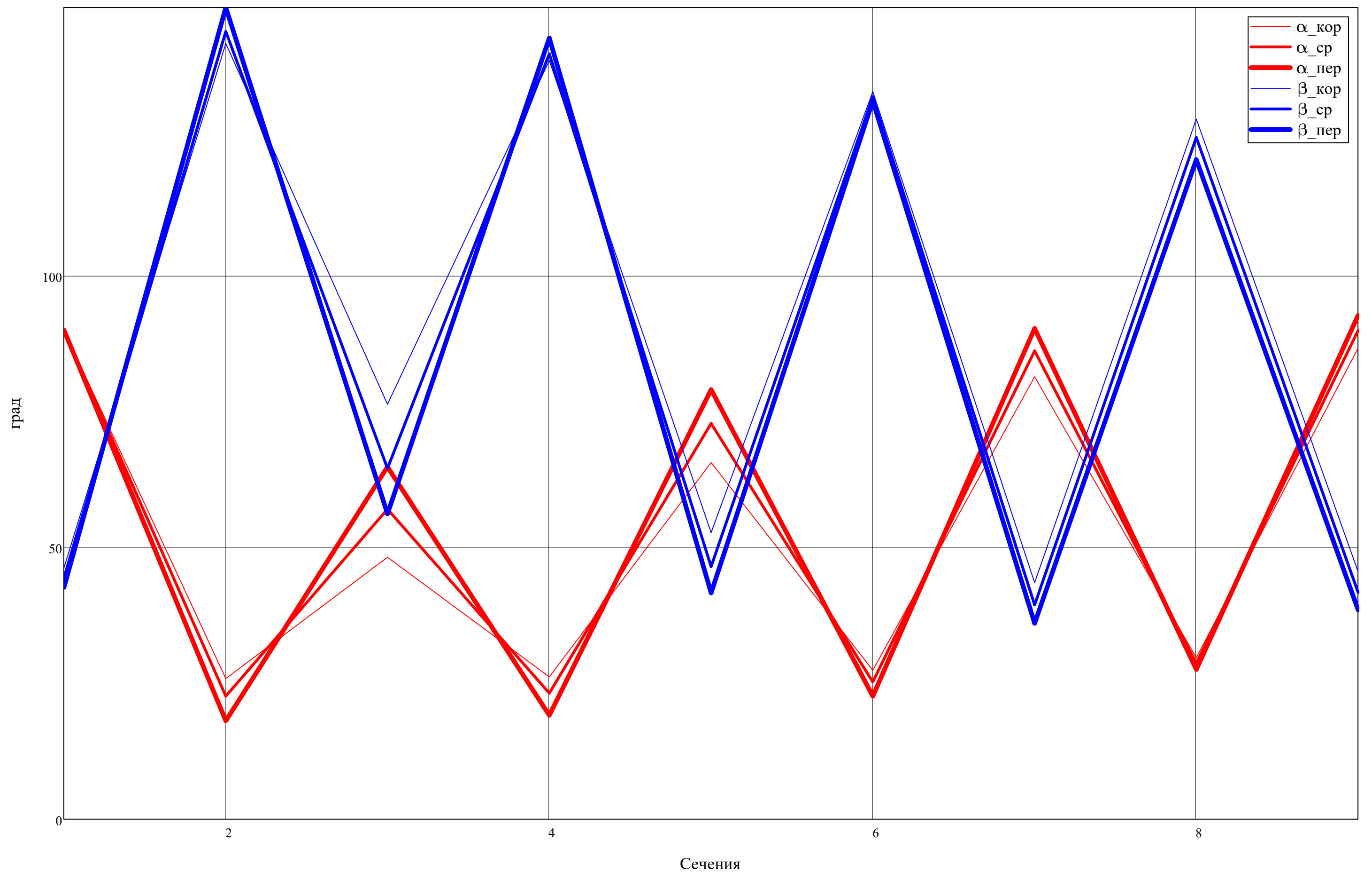
 $\cdot \circ$

$\epsilon_{\text{rotor}}^T =$ 

	1	2	3	4
1	66.40	86.85	90.35	83.28
2	80.41	94.34	93.47	83.71
3	93.16	102.10	96.11	82.82

 $\cdot \circ$

УГЛЫ по тракту К



$\lambda_c^T =$ 

	1	2	3	4	5	6	7	8	9
1	0.269	0.790	0.329	0.789	0.301	0.798	0.327	0.848	0.401
2	0.269	0.742	0.319	0.740	0.298	0.753	0.326	0.802	0.401
3	0.269	0.698	0.314	0.696	0.297	0.712	0.326	0.760	0.401

$M_c^T =$ 

	1	2	3	4	5	6	7	8	9
1	0.251	0.767	0.307	0.766	0.281	0.776	0.305	0.829	0.375
2	0.251	0.717	0.299	0.715	0.278	0.728	0.304	0.779	0.375
3	0.251	0.671	0.293	0.669	0.277	0.685	0.304	0.735	0.375

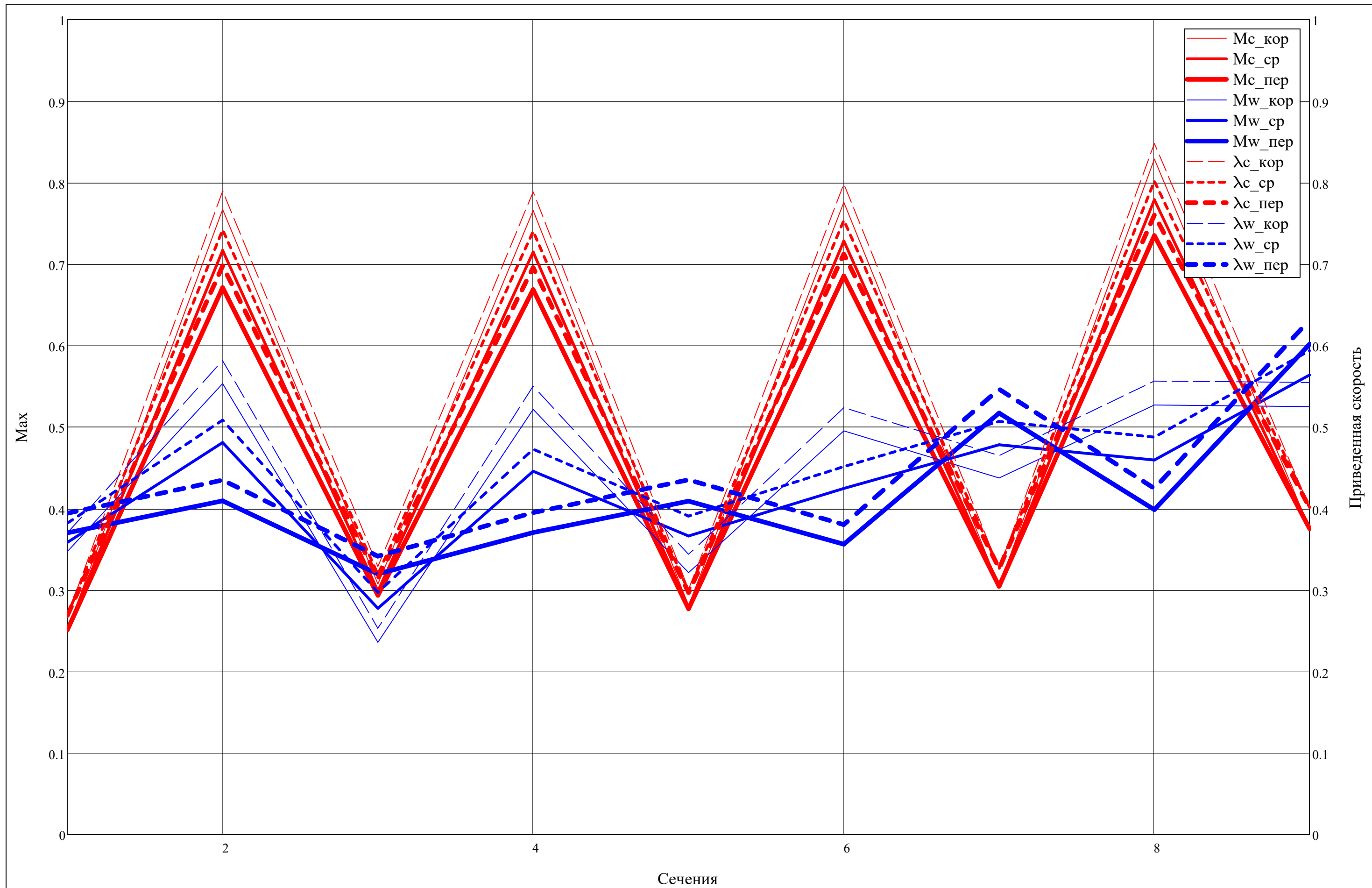
$\lambda_w^T =$ 

	1	2	3	4	5	6	7	8	9
1	0.370	0.582	0.253	0.550	0.344	0.524	0.465	0.556	0.555
2	0.382	0.509	0.297	0.473	0.391	0.451	0.507	0.488	0.594
3	0.394	0.435	0.341	0.395	0.435	0.380	0.546	0.425	0.631

$M_w^T =$ 

	1	2	3	4	5	6	7	8	9
1	0.347	0.553	0.236	0.522	0.321	0.495	0.437	0.527	0.525
2	0.358	0.481	0.277	0.446	0.366	0.425	0.478	0.459	0.564
3	0.370	0.409	0.320	0.371	0.409	0.356	0.517	0.398	0.602





Рассматриваемая ступень:

j =

j = Z

j =

"Такой ступени не существует!" if (j < 1) ∨ (j > Z)

j otherwise

= 4

▼Построение треугольников скоростей в 3х сечениях

Δ<sub>c</sub>(v,i,j,r) =

tan(α<sub>st(i,j),r</sub>)·v if (tan(α<sub>st(i,j),r</sub>) ≥ 0) ∧ (−|c<sub>st(i,j),r</sub>·cos(α<sub>st(i,j),r</sub>)| ≤ v ≤ 0)

tan(α<sub>st(i,j),r</sub>)·v if (tan(α<sub>st(i,j),r</sub>) < 0) ∧ (0 ≤ v ≤ |c<sub>st(i,j),r</sub>·cos(α<sub>st(i,j),r</sub>)|)

Δ<sub>w</sub>(v,i,j,r) =

−tan(β<sub>st(i,j),r</sub>)·v if (−tan(β<sub>st(i,j),r</sub>) ≥ 0) ∧ (−|w<sub>st(i,j),r</sub>·cos(β<sub>st(i,j),r</sub>)| ≤ v ≤ 0) ∧ (j ≠ 1)

−tan(β<sub>st(i,j),r</sub>)·v if (−tan(β<sub>st(i,j),r</sub>) < 0) ∧ (0 ≤ v ≤ |w<sub>st(i,j),r</sub>·cos(β<sub>st(i,j),r</sub>)|) ∧ (j ≠ 1)

Δ<sub>u</sub>(v,i,j,r) =

−c<sub>a<sub>st(i,j),r</sub></sub> if (−c<sub>st(i,j),r</sub>·cos(α<sub>st(i,j),r</sub>) ≤ v ≤ w<sub>st(i,j),r</sub>·cos(β<sub>st(i,j),r</sub>)) ∧ (j ≠ 1)

NaN otherwise

v<sub>lim</sub> =

ceil

⎛

max(c,w,u)

10<sup>2</sup>

⎞

·10<sup>2</sup> = 600.0

v =

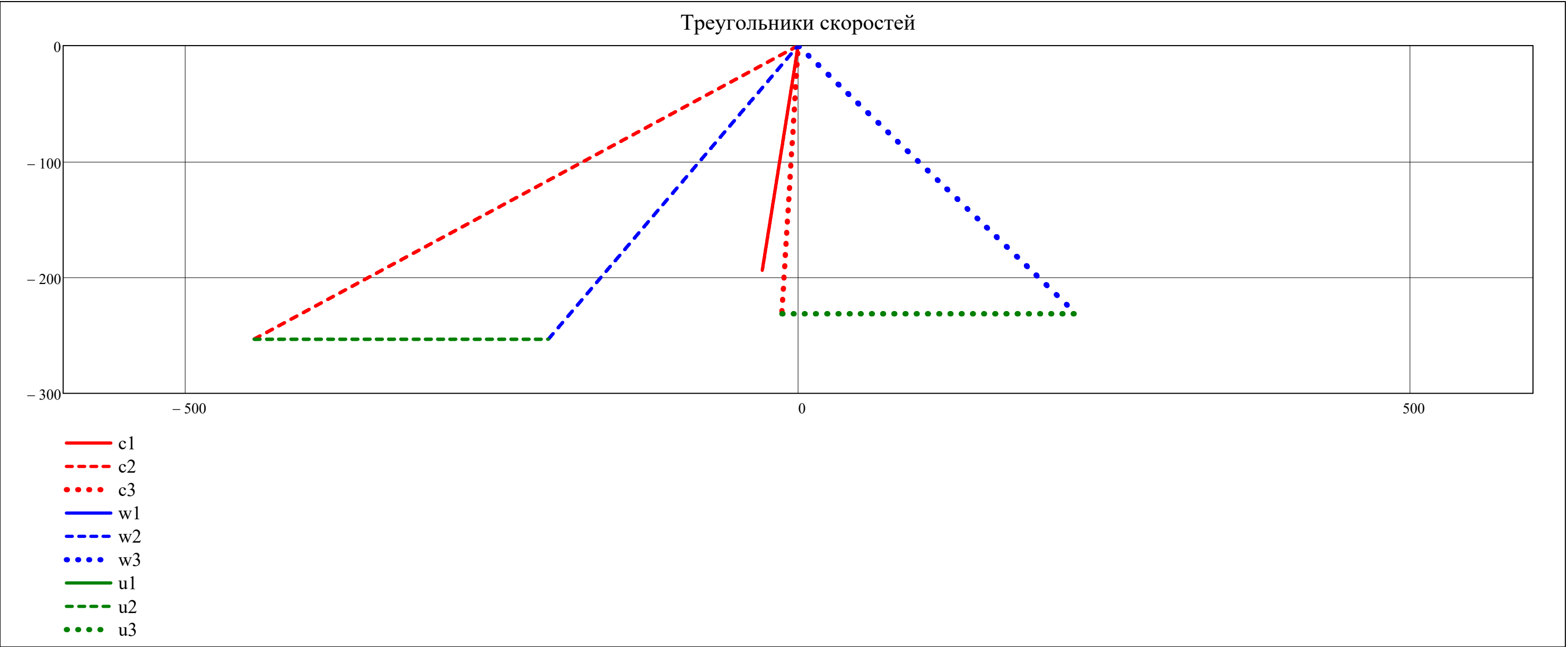
−max(c,w,u), −max(c,w,u) +

max(c,w,u)

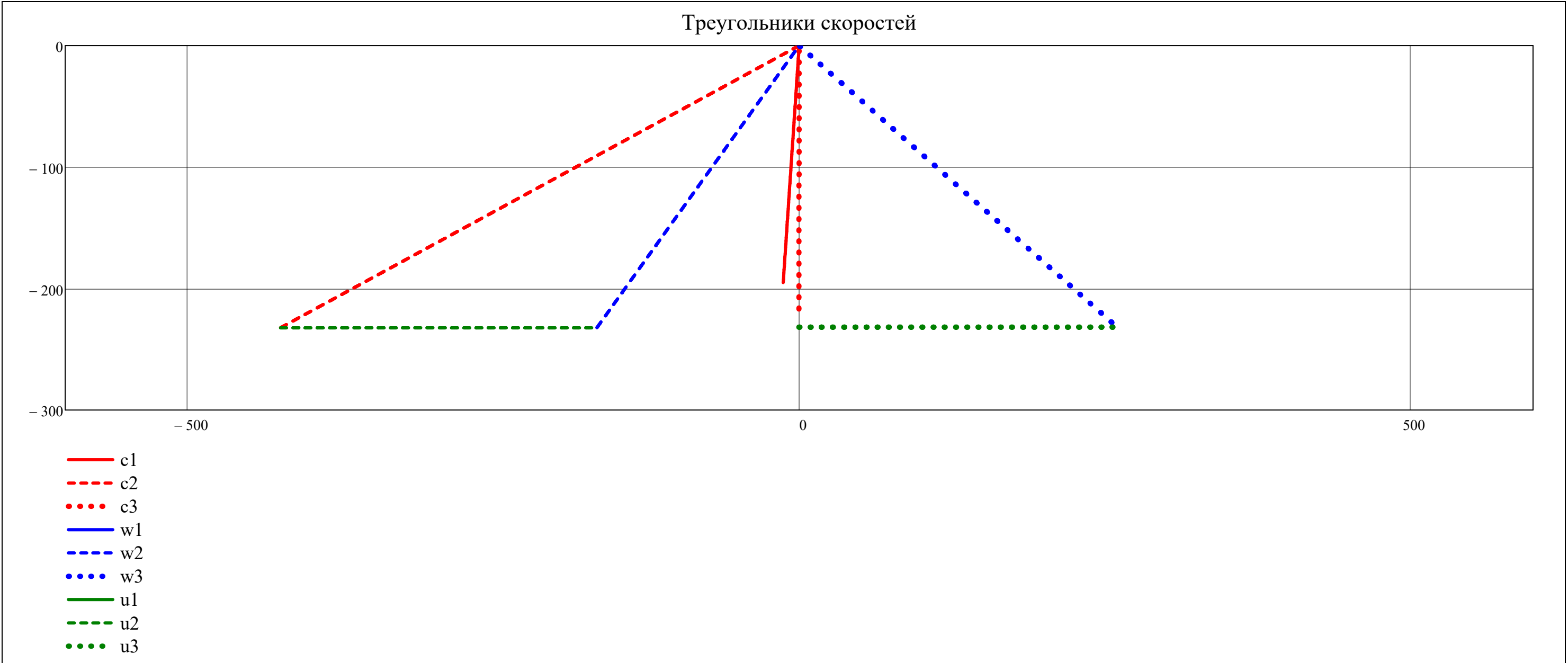
3000

.. max(c,w,u)

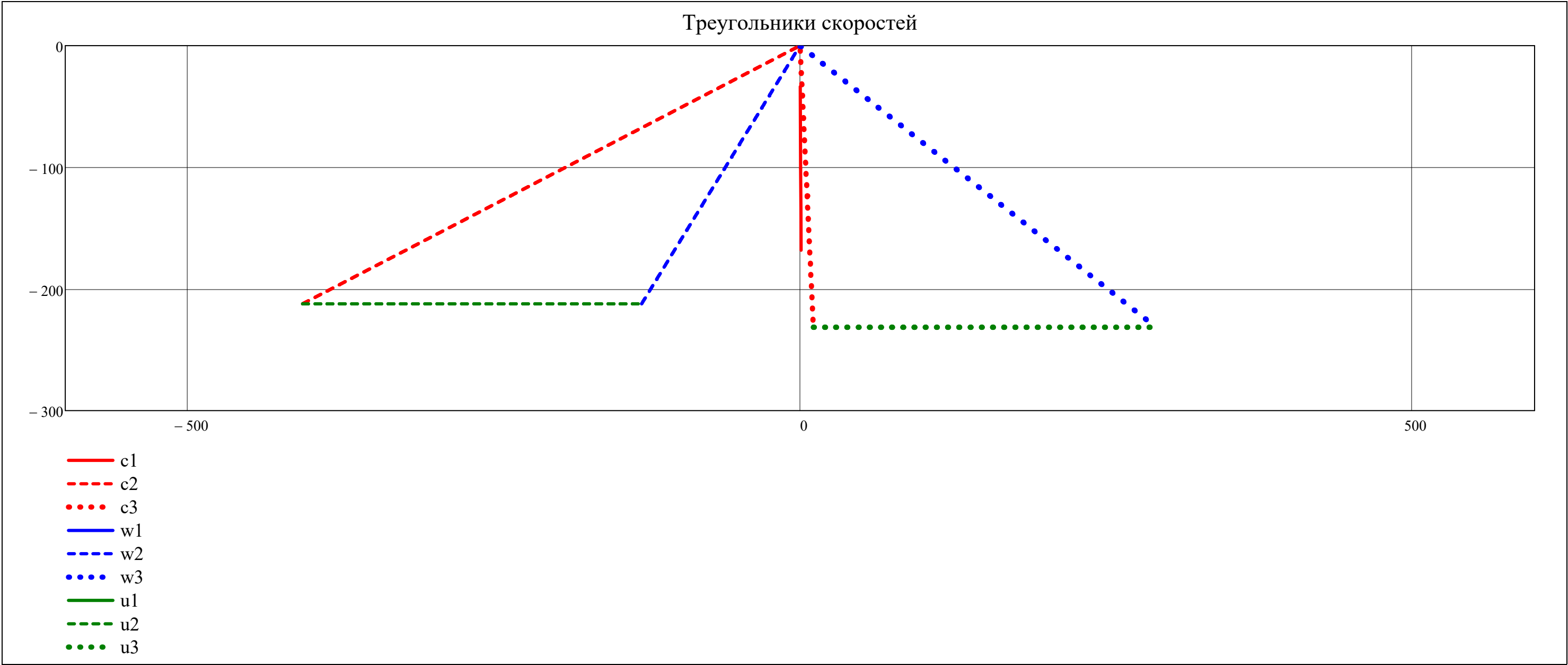
r = 1



$\bar{r}_w = \text{av}(N_r)$



$r_w = N_r$



Парусность:

$$\begin{pmatrix} \text{sail}_{\text{stator}} \\ \text{sail}_{\text{rotor}} \end{pmatrix} = \begin{pmatrix} 1 \\ 0.85 \end{pmatrix}$$

▼ Расчет хорд Л по парусности

$$\begin{pmatrix} \text{chord}_{\text{stator}} \\ \text{chord}_{\text{rotor}} \end{pmatrix} =$$

for i ∈ 1..Z

$$\text{sail} = \frac{R_{\text{st}(i,2),N_r} - R_{\text{st}(i,2),1}}{R_{\text{st}(i,2),\text{av}(N_r)} - R_{\text{st}(i,2),1}}$$

for r ∈ 1..N<sub>r</sub>

$$b_{\text{CAkop}} = \frac{\text{chord}_{\text{stator}_{i,\text{av}(N_r)}} \cdot \text{sail}}{\text{sail}_{\text{stator}} - 1 + \text{sail}}$$

$$b_{\text{PKkop}} = \frac{\text{chord}_{\text{rotor}_{i,\text{av}(N_r)}} \cdot \text{sail}}{\text{sail}_{\text{rotor}} - 1 + \text{sail}}$$

$$\begin{pmatrix} b_{\text{CAпер}} \\ b_{\text{PKпер}} \end{pmatrix} = \begin{pmatrix} b_{\text{CAkop}} \cdot \text{sail}_{\text{stator}} \\ b_{\text{PKkop}} \cdot \text{sail}_{\text{rotor}} \end{pmatrix}$$

$$\text{chord}_{\text{stator.}}(z) = \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} R_{\text{st}(i,2),1} \\ R_{\text{st}(i,2),\text{av}(N_r)} \\ R_{\text{st}(i,2),N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{CAkop}} \\ \text{chord}_{\text{stator}_{i,\text{av}(N_r)}} \\ b_{\text{CAпер}} \end{pmatrix} \right], \begin{pmatrix} R_{\text{st}(i,2),1} \\ R_{\text{st}(i,2),\text{av}(N_r)} \\ R_{\text{st}(i,2),N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{CAkop}} \\ \text{chord}_{\text{stator}_{i,\text{av}(N_r)}} \\ b_{\text{CAпер}} \end{pmatrix}, z \right]$$

$$\text{chord}_{\text{rotor.}}(z) = \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} R_{\text{st}(i,2),1} \\ R_{\text{st}(i,2),\text{av}(N_r)} \\ R_{\text{st}(i,2),N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{PKkop}} \\ \text{chord}_{\text{rotor}_{i,\text{av}(N_r)}} \\ b_{\text{PKпер}} \end{pmatrix} \right], \begin{pmatrix} R_{\text{st}(i,2),1} \\ R_{\text{st}(i,2),\text{av}(N_r)} \\ R_{\text{st}(i,2),N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{PKkop}} \\ \text{chord}_{\text{rotor}_{i,\text{av}(N_r)}} \\ b_{\text{PKпер}} \end{pmatrix}, z \right]$$

$$\begin{pmatrix} \text{chord}_{\text{stator}_{i,r}} \\ \text{chord}_{\text{rotor}_{i,r}} \end{pmatrix} = \begin{pmatrix} \text{chord}_{\text{stator.}}(R_{\text{st}(i,2),r}) \\ \text{chord}_{\text{rotor.}}(R_{\text{st}(i,3),r}) \end{pmatrix}$$

$$\begin{pmatrix} \text{chord}_{\text{stator}} \\ \text{chord}_{\text{rotor}} \end{pmatrix}$$

Длины хорд РК и СА (м):

$$\text{chord}_{\text{stator}}^T =$$

	1	2	3	4
1	58.7	50.6	60.4	69.4
2	58.7	50.6	60.4	69.4
3	58.7	50.6	60.4	69.4

$\cdot 10^{-3}$

$$\text{chord}_{\text{rotor}}^T =$$

	1	2	3	4
1	35.4	39.8	45.8	50.0
2	32.3	36.4	42.0	45.9
3	27.6	30.5	36.0	41.7

$\cdot 10^{-3}$

▲ Расчет хорд Л по парусности

Ср. линия профиля:  
0.5 - дуга окружности  
0.45 - парабола

$\overline{x_f} = 0.45$

$t_{\text{sator}}$  $t_{\text{rotor}}$

$r_{\text{inlet}}_{\text{sator}}$  $r_{\text{inlet}}_{\text{rotor}}$

$r_{\text{outlet}}_{\text{sator}}$  $r_{\text{outlet}}_{\text{rotor}}$

$c_{\text{sator}}$  $c_{\text{rotor}}$

$v_{\text{sator}}$  $v_{\text{rotor}}$

=

for  $i \in 1..Z$

for  $r \in 1..N_r$

$t_{\text{sator}}_{i,r}$  $t_{\text{rotor}}_{i,r}$

$r_{\text{inlet}}_{\text{sator}}_{i,r}$  $r_{\text{inlet}}_{\text{rotor}}_{i,r}$

$r_{\text{outlet}}_{\text{sator}}_{i,r}$  $r_{\text{outlet}}_{\text{rotor}}_{i,r}$

$c_{\text{sator}}_{i,r}$  $c_{\text{rotor}}_{i,r}$

$v_{\text{sator}}_{i,r}$  $v_{\text{rotor}}_{i,r}$

$\left(\begin{array}{l} t_{\text{sator}}_{i,r} \\ t_{\text{rotor}}_{i,r} \end{array}\right) = \pi \cdot \left(\frac{\text{mean}\left(D_{\text{st}}(i,1),r,D_{\text{st}}(i,2),r\right)}{Z_{\text{sator}}_i} \right)$  $\left(\begin{array}{l} r_{\text{inlet}}_{\text{sator}}_{i,r} \quad r_{\text{outlet}}_{\text{sator}}_{i,r} \\ r_{\text{inlet}}_{\text{rotor}}_{i,r} \quad r_{\text{outlet}}_{\text{rotor}}_{i,r} \end{array}\right) = \left(\frac{\overline{r}_{\text{inlet}}_{\text{sator}}_{i,r} \cdot \text{chord}_{\text{sator}}_{i,r} \quad \overline{r}_{\text{outlet}}_{\text{sator}}_{i,r} \cdot \text{chord}_{\text{sator}}_{i,r}}{\overline{r}_{\text{inlet}}_{\text{rotor}}_{i,r} \cdot \text{chord}_{\text{rotor}}_{i,r} \quad \overline{r}_{\text{outlet}}_{\text{rotor}}_{i,r} \cdot \text{chord}_{\text{rotor}}_{i,r}} \right)$  $\left(\begin{array}{l} c_{\text{sator}}_{i,r} \\ c_{\text{rotor}}_{i,r} \end{array}\right) = \left(\frac{\overline{c}_{\text{sator}}_{i,r} \cdot \text{chord}_{\text{sator}}_{i,r}}{\overline{c}_{\text{rotor}}_{i,r} \cdot \text{chord}_{\text{rotor}}_{i,r}} \right)$  $\left(\begin{array}{l} v_{\text{sator}}_{i,r} \\ v_{\text{rotor}}_{i,r} \end{array}\right) = \left(\begin{array}{l} v_{\text{installation}}\left(0.5,\alpha_{\text{st}}(i,1),r,\alpha_{\text{st}}(i,2),r\right) \\ v_{\text{installation}}\left(0.5,\beta_{\text{st}}(i,2),r,\beta_{\text{st}}(i,3),r\right) \end{array}\right) + \frac{\pi}{2}$

$t_{\text{sator}}$  $t_{\text{rotor}}$

$r_{\text{inlet}}_{\text{sator}}$  $r_{\text{inlet}}_{\text{rotor}}$

$r_{\text{outlet}}_{\text{sator}}$  $r_{\text{outlet}}_{\text{rotor}}$

$c_{\text{sator}}$  $c_{\text{rotor}}$

$v_{\text{sator}}$  $v_{\text{rotor}}$

$\left(\begin{array}{l} v_{\text{установки}}\left(\alpha_{\text{st}}(i,1),r,\alpha_{\text{st}}(i,2),r\right) \\ v_{\text{установки}}\left(\beta_{\text{st}}(i,2),r,\beta_{\text{st}}(i,3),r\right) \end{array}\right)$

$\frac{\pi}{2}$  добавляется в виду поворота рисунка на 90 град

Расчет параметров решетки

Относительные радиусы профилей ():

$\overline{r}_{\text{inlet}_{\text{stator}}}^T =$		1	2	3	4	.%
	1	2.800	2.800	2.800	2.800	
	2	3.600	3.600	3.600	3.600	
	3	4.400	4.400	4.400	4.400	
$\overline{r}_{\text{inlet}_{\text{rotor}}}^T =$		1	2	3	4	.%
	1	4.900	4.900	4.900	4.900	
	2	3.150	3.150	3.150	3.150	
	3	2.450	2.450	2.450	2.450	
$\overline{r}_{\text{outlet}_{\text{stator}}}^T =$		1	2	3	4	.%
	1	1.400	1.400	1.400	1.400	
	2	1.800	1.800	1.800	1.800	
	3	2.200	2.200	2.200	2.200	
$\overline{r}_{\text{outlet}_{\text{rotor}}}^T =$		1	2	3	4	.%
	1	2.100	2.100	2.100	2.100	
	2	1.350	1.350	1.350	1.350	
	3	1.050	1.050	1.050	1.050	

Относительная толщина профиля ():

$\overline{c}_{\text{stator}}^T =$		1	2	3	4	.%
	1	7.00	7.00	7.00	7.00	
	2	9.00	9.00	9.00	9.00	
	3	11.00	11.00	11.00	11.00	
$\overline{c}_{\text{rotor}}^T =$		1	2	3	4	.%
	1	14.00	14.00	14.00	14.00	
	2	9.00	9.00	9.00	9.00	
	3	7.00	7.00	7.00	7.00	

Относительный шаг решетки ():

$\left(\frac{t_{\text{stator}}}{\text{chord}_{\text{stator}}}\right)^T =$		1	2	3	4
	1	0.6923	0.5507	0.5942	0.6244
	2	0.7425	0.5950	0.6394	0.6714
	3	0.7927	0.6394	0.6846	0.7183
$\left(\frac{t_{\text{rotor}}}{\text{chord}_{\text{rotor}}}\right)^T =$		1	2	3	4
	1	0.5592	0.5901	0.6211	0.6117
	2	0.6605	0.6948	0.7272	0.7179
	3	0.8317	0.8911	0.9077	0.8495

Относительная густота решетки ():

$\left(\frac{\text{chord}_{\text{stator}}}{t_{\text{stator}}}\right)^T =$		1	2	3	4
	1	1.444	1.816	1.683	1.602
	2	1.347	1.681	1.564	1.490
	3	1.262	1.564	1.461	1.392
$\left(\frac{\text{chord}_{\text{rotor}}}{t_{\text{rotor}}}\right)^T =$		1	2	3	4
	1	1.788	1.695	1.610	1.635
	2	1.514	1.439	1.375	1.393
	3	1.202	1.122	1.102	1.177



Длина хорды профиля [м]:

$$\text{chord}_{\text{stator}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 58.7 & 50.6 & 60.4 & 69.4 \\ \hline 2 & 58.7 & 50.6 & 60.4 & 69.4 \\ \hline 3 & 58.7 & 50.6 & 60.4 & 69.4 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{chord}_{\text{rotor}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 35.4 & 39.8 & 45.8 & 50.0 \\ \hline 2 & 32.3 & 36.4 & 42.0 & 45.9 \\ \hline 3 & 27.6 & 30.5 & 36.0 & 41.7 \\ \hline \end{array} \cdot 10^{-3}$$

Радиусы профилей:

$$\text{r\_inlet}_{\text{stator}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 1.64 & 1.42 & 1.69 & 1.94 \\ \hline 2 & 2.11 & 1.82 & 2.17 & 2.50 \\ \hline 3 & 2.58 & 2.23 & 2.66 & 3.05 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{r\_inlet}_{\text{rotor}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 1.73 & 1.95 & 2.24 & 2.45 \\ \hline 2 & 1.02 & 1.15 & 1.32 & 1.45 \\ \hline 3 & 0.68 & 0.75 & 0.88 & 1.02 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{r\_outlet}_{\text{stator}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0.82 & 0.71 & 0.85 & 0.97 \\ \hline 2 & 1.06 & 0.91 & 1.09 & 1.25 \\ \hline 3 & 1.29 & 1.11 & 1.33 & 1.53 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{r\_outlet}_{\text{rotor}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0.74 & 0.83 & 0.96 & 1.05 \\ \hline 2 & 0.44 & 0.49 & 0.57 & 0.62 \\ \hline 3 & 0.29 & 0.32 & 0.38 & 0.44 \\ \hline \end{array} \cdot 10^{-3}$$

Толщина профиля [м]:

$$\text{c}_{\text{stator}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 4.11 & 3.55 & 4.23 & 4.86 \\ \hline 2 & 5.28 & 4.56 & 5.43 & 6.24 \\ \hline 3 & 6.45 & 5.57 & 6.64 & 7.63 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{c}_{\text{rotor}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 4.95 & 5.57 & 6.41 & 7.00 \\ \hline 2 & 2.91 & 3.28 & 3.78 & 4.14 \\ \hline 3 & 1.93 & 2.13 & 2.52 & 2.92 \\ \hline \end{array} \cdot 10^{-3}$$

Шаг решетки [м]:

$$\text{t}_{\text{stator}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 40.6 & 27.9 & 35.9 & 43.3 \\ \hline 2 & 43.6 & 30.1 & 38.6 & 46.6 \\ \hline 3 & 46.5 & 32.4 & 41.3 & 49.8 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{t}_{\text{rotor}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 19.8 & 23.5 & 28.4 & 30.6 \\ \hline 2 & 21.4 & 25.3 & 30.5 & 33.0 \\ \hline 3 & 22.9 & 27.1 & 32.7 & 35.4 \\ \hline \end{array} \cdot 10^{-3}$$

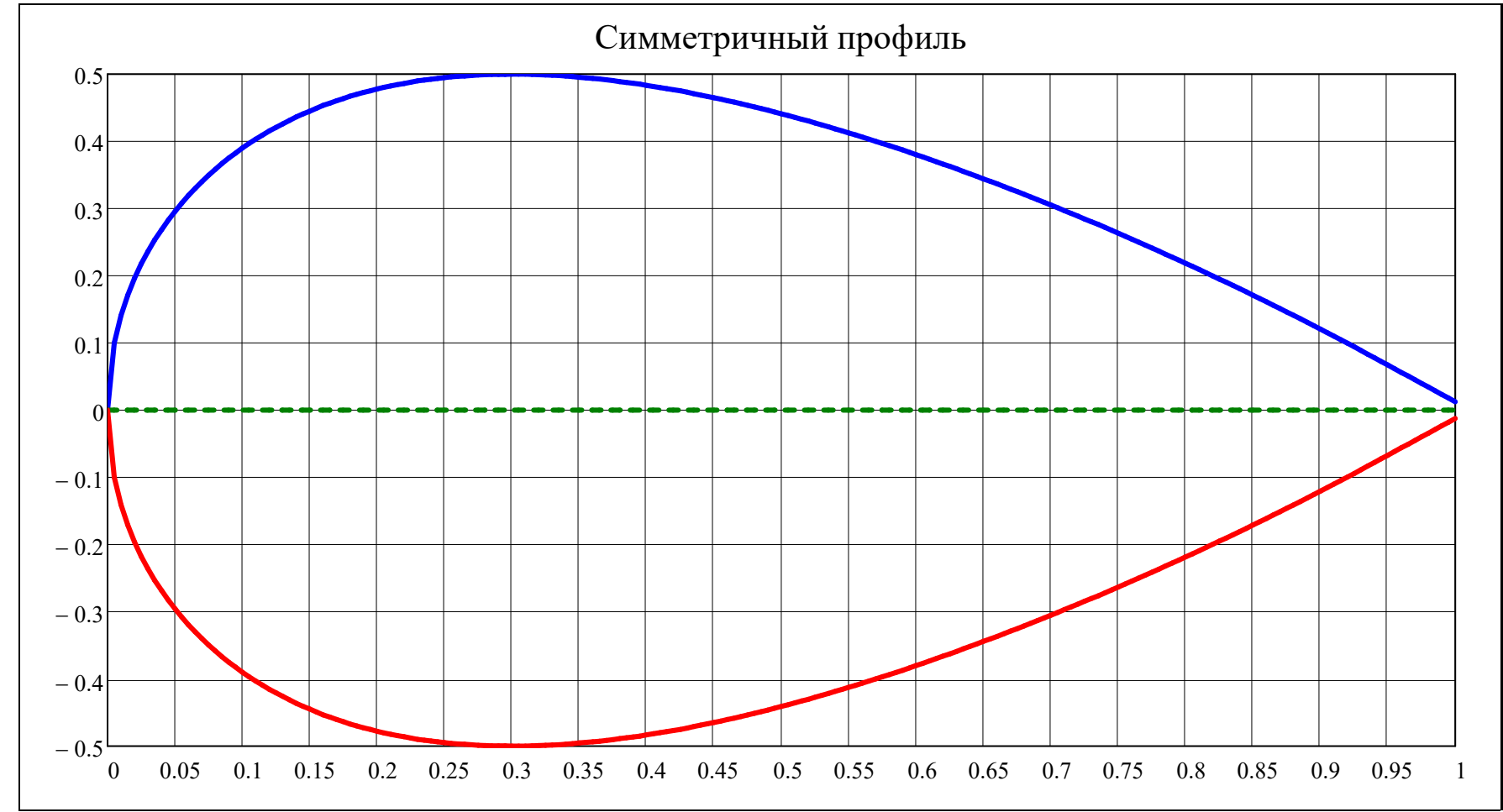
Угол поворота потока:	$\epsilon_{\text{stator}}^T =$		1	2	3	4	.°	$\epsilon_{\text{rotor}}^T =$		1	2	3	4	.°
		1	64.11	21.99	38.24	51.72			1	66.40	86.85	90.35	83.28	
		2	67.34	33.86	47.53	57.46			2	80.41	94.34	93.47	83.71	
		3	71.88	45.69	56.39	62.72			3	93.16	102.10	96.11	82.82	
Угол установки профиля:	$\upsilon_{\text{stator}}^T =$		1	2	3	4	.°	$\upsilon_{\text{rotor}}^T =$		1	2	3	4	.°
		1	134.1	124.4	130.0	136.4			1	142.1	135.9	134.8	138.2	
		2	129.9	123.9	129.5	136.6			2	136.4	132.6	133.0	137.5	
		3	123.2	120.8	127.7	136.2			3	130.3	128.8	131.3	137.0	
Угол изгиба профиля:	$\pi - \epsilon_{\text{stator}}^T =$		1	2	3	4	.°	$\pi - \epsilon_{\text{rotor}}^T =$		1	2	3	4	.°
		1	115.9	158.0	141.8	128.3			1	113.6	93.1	89.7	96.7	
		2	112.7	146.1	132.5	122.5			2	99.6	85.7	86.5	96.3	
		3	108.1	134.3	123.6	117.3			3	86.8	77.9	83.9	97.2	

$$\begin{pmatrix} X_U & Y_U \\ X_L & Y_L \end{pmatrix} = \text{NACA}(0,0,100\%,1)$$

Относ. координаты профиля РК и СА:

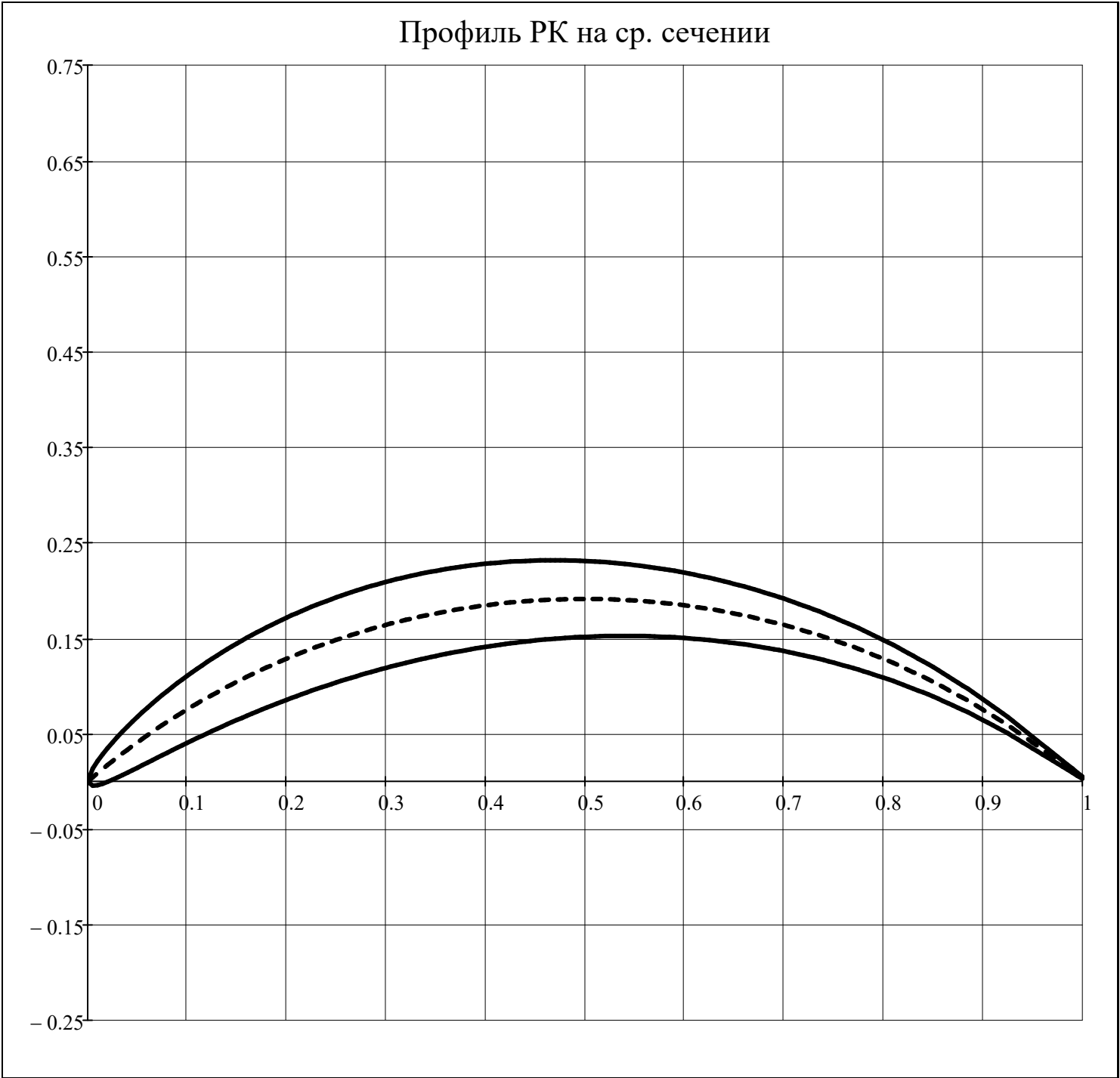
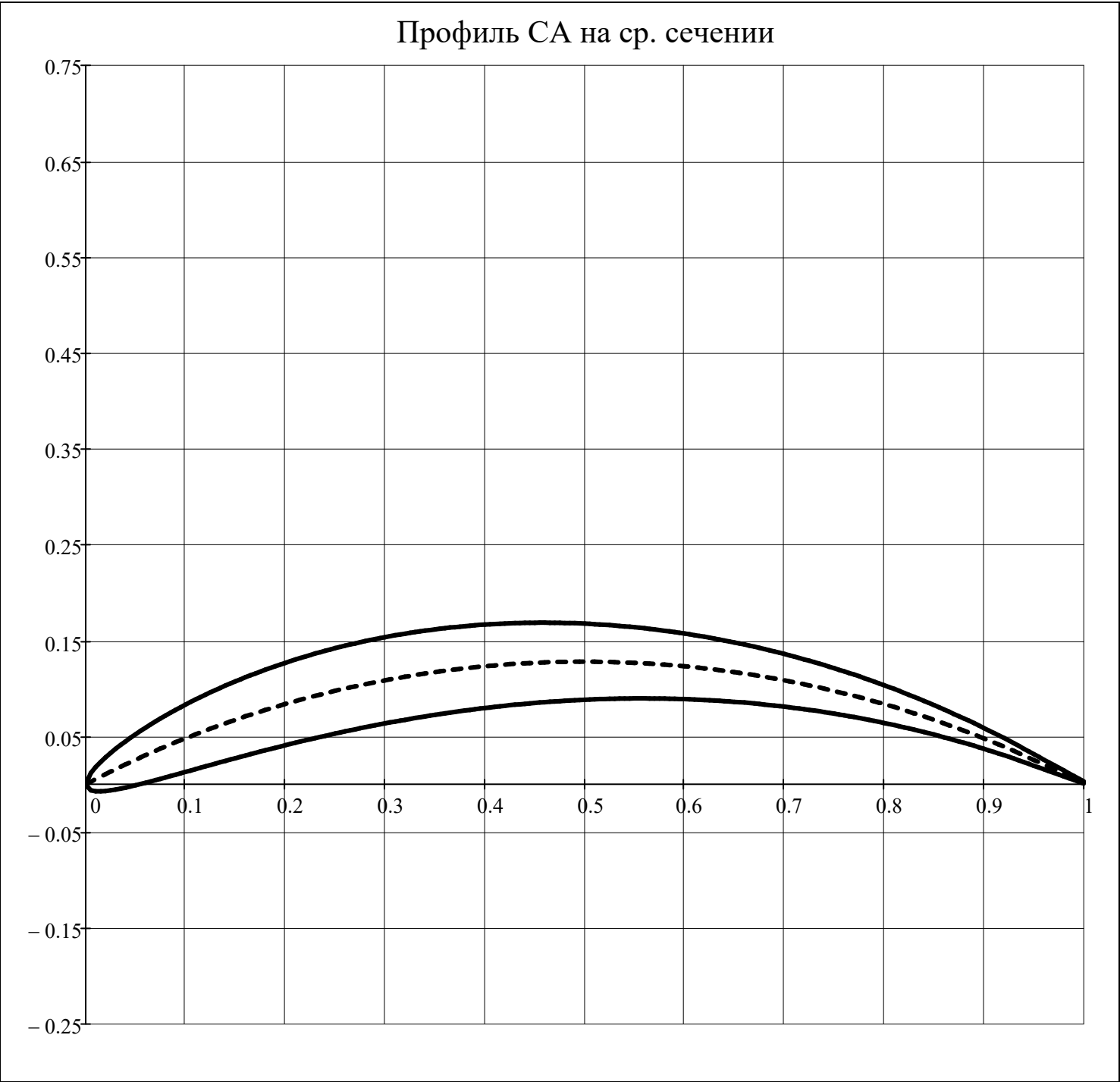
$$\text{AIRFOIL}_0(x, \text{line}, \overline{f}, \overline{x_f}, \overline{c}) = \begin{cases} \text{if } 0 \leq x \leq 1 \\ \left| \begin{array}{ll} \text{linterp}(X_U, Y_U, x) & \text{if line = "+"} \\ \frac{\text{linterp}(X_U, Y_U, x) + \text{linterp}(X_L, Y_L, x)}{2} & \text{if line = "0"} \\ \text{linterp}(X_L, Y_L, x) & \text{if line = "-"} \end{array} \right. \\ \text{NaN otherwise} \end{cases}$$

$x = 0, 0.005 \dots 1$



AIRFOIL(x,line,c\_bar,theta) =

$\text{interp}\left(X_U,y/b_{\text{ср.л}}\left(X_U,\theta\right)+Y_U\cdot\overline{c},x\right)$  if line = "+"  
$$\frac{\text{interp}\left(X_U,y/b_{\text{ср.л}}\left(X_U,\theta\right)+Y_U\cdot\overline{c},x\right)+\text{interp}\left(X_L,y/b_{\text{ср.л}}\left(X_L,\theta\right)+Y_L\cdot\overline{c},x\right)}{2}$$
 if line = "0"  
 $\text{interp}\left(X_L,y/b_{\text{ср.л}}\left(X_L,\theta\right)+Y_L\cdot\overline{c},x\right)$  if line = "-"  
NaN otherwise



$$l_{upper\_stator}^T =$$

	1	2	3	4
1	63.47	51.71	62.74	73.48
2	64.41	52.70	64.03	74.79
3	65.61	53.99	65.52	76.17

$$\cdot 10^{-3}$$

$$l_{lower\_stator}^T =$$

	1	2	3	4
1	60.67	50.86	60.98	70.78
2	60.72	51.07	61.31	71.03
3	60.91	51.38	61.69	71.35

$$\cdot 10^{-3}$$

$$area_{stator}^T =$$

	1	2	3	4
1	164.78	122.77	174.49	230.41
2	211.86	157.85	224.34	296.25
3	258.93	192.93	274.19	362.08

$$\cdot 10^{-6}$$

$$Sx_{stator}^T =$$

	1	2	3	4
1	1061.6	226.1	672.4	1396.3
2	1439.6	450.4	1082.8	2006.5
3	1890.1	749.6	1584.1	2693.9

$$\cdot 10^{-9}$$

$$Sy_{stator}^T =$$

	1	2	3	4
1	4071.3	2618.3	4436.4	6732.1
2	5234.5	3366.4	5703.9	8655.5
3	6397.7	4114.5	6971.5	10579.0

$$\cdot 10^{-9}$$

$$x0_{stator}^T =$$

	1	2	3	4
1	24.7	21.3	25.4	29.2
2	24.7	21.3	25.4	29.2
3	24.7	21.3	25.4	29.2

$$\cdot 10^{-3}$$

$$y0_{stator}^T =$$

	1	2	3	4
1	6.4	1.8	3.9	6.1
2	6.8	2.9	4.8	6.8
3	7.3	3.9	5.8	7.4

$$\cdot 10^{-3}$$

$$l_{upper\_rotor}^T =$$

	1	2	3	4
1	39.66	46.66	54.18	58.15
2	36.48	42.49	48.89	52.24
3	31.76	35.92	41.76	46.84

$$\cdot 10^{-3}$$

$$l_{lower\_rotor}^T =$$

	1	2	3	4
1	36.43	41.97	48.58	52.49
2	34.08	39.38	45.33	48.71
3	29.93	33.74	39.30	44.33

$$\cdot 10^{-3}$$

$$area_{rotor}^T =$$

	1	2	3	4
1	119.78	151.28	200.50	239.04
2	64.32	81.62	108.55	129.92
3	36.38	44.43	61.95	83.13

$$\cdot 10^{-6}$$

$$Sx_{rotor}^T =$$

	1	2	3	4
1	483.2	926.0	1479.2	1752.8
2	293.2	504.1	764.8	881.1
3	167.6	252.5	386.5	505.1

$$\cdot 10^{-9}$$

$$Sy_{rotor}^T =$$

	1	2	3	4
1	1784.1	2532.5	3864.1	5030.0
2	875.6	1251.6	1919.7	2513.8
3	422.4	570.0	938.6	1458.9

$$\cdot 10^{-9}$$

$$x0_{rotor}^T =$$

	1	2	3	4
1	14.9	16.7	19.3	21.0
2	13.6	15.3	17.7	19.3
3	11.6	12.8	15.2	17.5

$$\cdot 10^{-3}$$

$$y0_{rotor}^T =$$

	1	2	3	4
1	4.0	6.1	7.4	7.3
2	4.6	6.2	7.0	6.8
3	4.6	5.7	6.2	6.1

$$\cdot 10^{-3}$$

$$J_{x_{\text{stator}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 7676 & 549 & 3039 & 9634 \\ \hline 2 & 11083 & 1608 & 6143 & 15621 \\ \hline 3 & 15756 & 3556 & 10770 & 23247 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{y_{\text{stator}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 131811 & 73173 & 147804 & 257737 \\ \hline 2 & 169471 & 94079 & 190034 & 331377 \\ \hline 3 & 207131 & 114986 & 232263 & 405016 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{xy_{\text{stator}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 27857 & 5131 & 18182 & 43361 \\ \hline 2 & 37769 & 10217 & 29269 & 62292 \\ \hline 3 & 49570 & 16997 & 42799 & 83602 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{x0_{\text{stator}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 837 & 133 & 448 & 1172 \\ \hline 2 & 1301 & 323 & 916 & 2030 \\ \hline 3 & 1960 & 644 & 1617 & 3204 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{y0_{\text{stator}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 31219 & 17331 & 35007 & 61045 \\ \hline 2 & 40139 & 22283 & 45009 & 78486 \\ \hline 3 & 49059 & 27234 & 55011 & 95928 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{xy0_{\text{stator}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 1628 & 309 & 1086 & 2565 \\ \hline 2 & 2200 & 612 & 1737 & 3666 \\ \hline 3 & 2871 & 1010 & 2522 & 4894 \\ \hline \end{array} \cdot 10^{-12}$$

$$\alpha_{\text{major}_{\text{stator}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 3.06 & 1.03 & 1.80 & 2.45 \\ \hline 2 & 3.23 & 1.59 & 2.25 & 2.74 \\ \hline 3 & 3.48 & 2.17 & 2.70 & 3.01 \\ \hline \end{array} \cdot ^\circ$$

$$J_{x_{\text{rotor}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 2310 & 6463 & 12383 & 14730 \\ \hline 2 & 1494 & 3444 & 5964 & 6663 \\ \hline 3 & 850 & 1571 & 2649 & 3398 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{y_{\text{rotor}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 34823 & 55552 & 97582 & 138694 \\ \hline 2 & 15620 & 25151 & 44488 & 63733 \\ \hline 3 & 6426 & 9583 & 18633 & 33548 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{xy_{\text{rotor}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 7643 & 16433 & 30208 & 39111 \\ \hline 2 & 4234 & 8188 & 14327 & 18078 \\ \hline 3 & 2061 & 3427 & 6201 & 9401 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{x0_{\text{rotor}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 361 & 794 & 1471 & 1878 \\ \hline 2 & 158 & 330 & 575 & 687 \\ \hline 3 & 78 & 136 & 238 & 329 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{y0_{\text{rotor}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 8248 & 13158 & 23112 & 32850 \\ \hline 2 & 3700 & 5957 & 10537 & 15095 \\ \hline 3 & 1522 & 2270 & 4413 & 7946 \\ \hline \end{array} \cdot 10^{-12}$$

$$J_{xy0_{\text{rotor}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 446 & 931 & 1701 & 2229 \\ \hline 2 & 242 & 458 & 802 & 1029 \\ \hline 3 & 115 & 188 & 345 & 536 \\ \hline \end{array} \cdot 10^{-12}$$

$$\alpha_{\text{major}_{\text{rotor}}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 3.22 & 4.28 & 4.47 & 4.09 \\ \hline 2 & 3.90 & 4.62 & 4.57 & 4.07 \\ \hline 3 & 4.54 & 5.01 & 4.70 & 4.01 \\ \hline \end{array} \cdot ^\circ$$

$$J_{u_{stator}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 750 & 127 & 414 & 1063 \\ 2 & 1176 & 306 & 848 & 1855 \\ 3 & 1785 & 605 & 1499 & 2946 \end{array} \cdot 10^{-12}$$

$$J_{v_{stator}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 31306.3 & 17336.5 & 35041.3 & 61154.6 \\ 2 & 40263.3 & 22299.6 & 45077.7 & 78661.7 \\ 3 & 49233.3 & 27272.6 & 55130.2 & 96185.3 \end{array} \cdot 10^{-12}$$

$$J_{uv_{stator}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 0 & 0 & -0 & 0 \\ 2 & 0 & 0 & 0 & -0 \\ 3 & 0 & 0 & 0 & 0 \end{array} \cdot 10^{-12}$$

$$J_{p_{stator}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 32056 & 17464 & 35455 & 62217 \\ 2 & 41440 & 22605 & 45925 & 80516 \\ 3 & 51018 & 27878 & 56629 & 99132 \end{array} \cdot 10^{-12}$$

$$W_{p_{stator}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 927.3 & 594.5 & 1008.3 & 1531.7 \\ 2 & 1196.3 & 767.4 & 1301.6 & 1976.7 \\ 3 & 1468.5 & 942.6 & 1598.5 & 2426.8 \end{array} \cdot 10^{-9}$$

$$stiffness_{stator}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 639.9 & 355.2 & 717.6 & 1251.3 \\ 2 & 1360.1 & 755.0 & 1525.1 & 2659.5 \\ 3 & 2483.2 & 1378.5 & 2784.5 & 4855.6 \end{array} \cdot 10^{-12}$$

$$J_{u_{rotor}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 336 & 725 & 1338 & 1718 \\ 2 & 141 & 293 & 511 & 614 \\ 3 & 68 & 120 & 209 & 291 \end{array} \cdot 10^{-12}$$

$$J_{v_{rotor}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 8273 & 13227 & 23245 & 33009 \\ 2 & 3716 & 5994 & 10601 & 15168 \\ 3 & 1531 & 2286 & 4442 & 7983 \end{array} \cdot 10^{-12}$$

$$J_{uv_{rotor}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & -0 & 0 \\ 3 & 0 & -0 & 0 & 0 \end{array} \cdot 10^{-12}$$

$$J_{p_{rotor}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 8609 & 13952 & 24583 & 34727 \\ 2 & 3857 & 6288 & 11113 & 15782 \\ 3 & 1599 & 2406 & 4651 & 8275 \end{array} \cdot 10^{-12}$$

$$W_{p_{rotor}}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 412.5 & 585.9 & 893.9 & 1163.7 \\ 2 & 200.3 & 286.2 & 439.0 & 575.0 \\ 3 & 96.3 & 129.8 & 213.9 & 332.6 \end{array} \cdot 10^{-9}$$

$$stiffness_{rotor}^T = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & 676.2 & 1078.8 & 1895.0 & 2693.4 \\ 2 & 125.4 & 201.9 & 357.0 & 511.5 \\ 3 & 31.2 & 46.5 & 90.5 & 162.9 \end{array} \cdot 10^{-12}$$

CP<sub>x</sub><sub>stator</sub>

T

=

	1	2	3	4
1	20.536	17.726	21.132	24.284
2	20.536	17.726	21.132	24.284
3	20.536	17.726	21.132	24.284

·10<sup>-3</sup>

CP<sub>y</sub><sub>stator</sub>

T

=

	1	2	3	4
1	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000

·10<sup>-3</sup>

CP<sub>x</sub><sub>rotor</sub>

T

=

	1	2	3	4
1	12.380	13.914	16.018	17.490
2	11.315	12.746	14.699	16.082
3	9.649	10.663	12.592	14.586

·10<sup>-3</sup>

CP<sub>y</sub><sub>rotor</sub>

T

=

	1	2	3	4
1	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000

·10<sup>-3</sup>

▲

Результат расчета абсолютных геометрических характеристик сечений Л



Рассматриваемая ступень:

$$j_v = \begin{cases} j = Z & \\ j = & \text{"Такой ступени не существует!" if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{cases} = 4$$

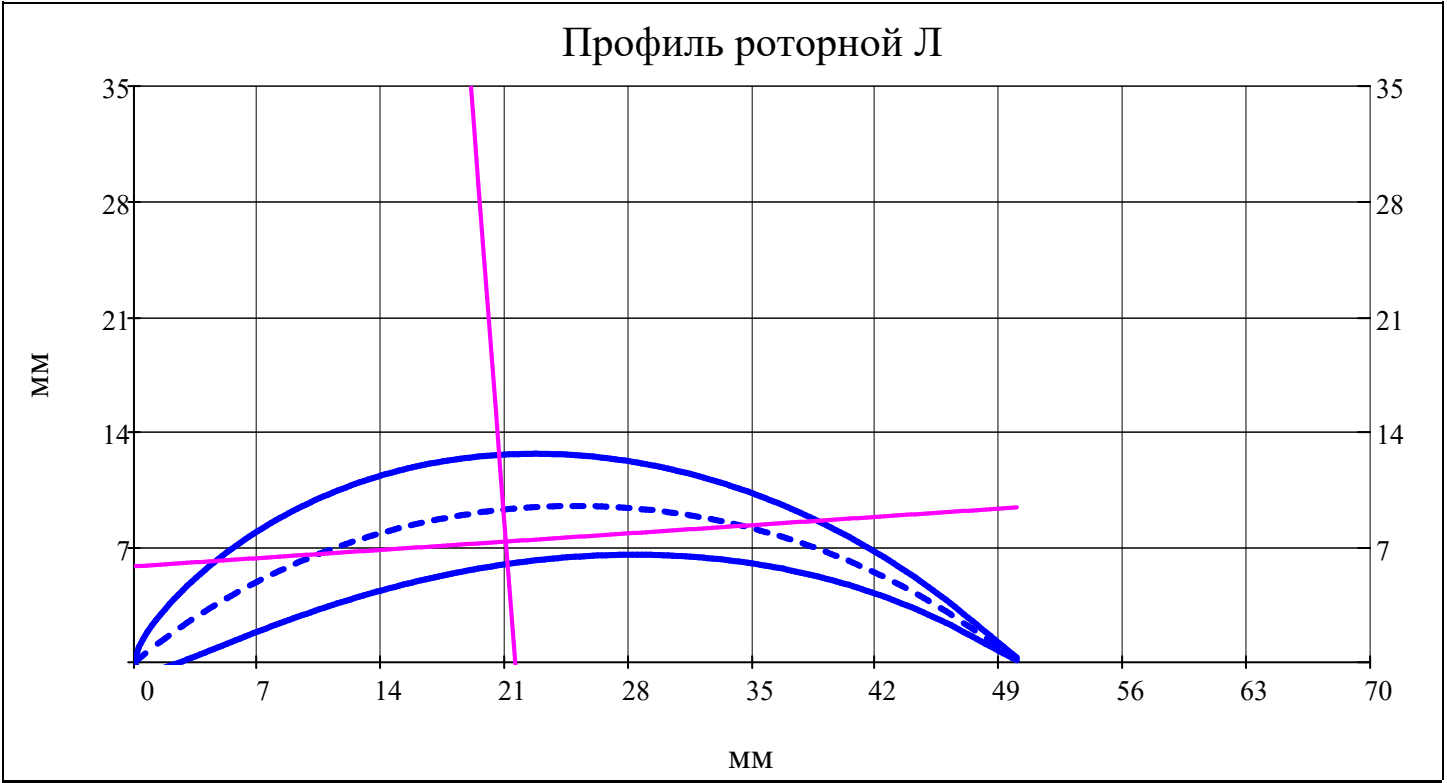
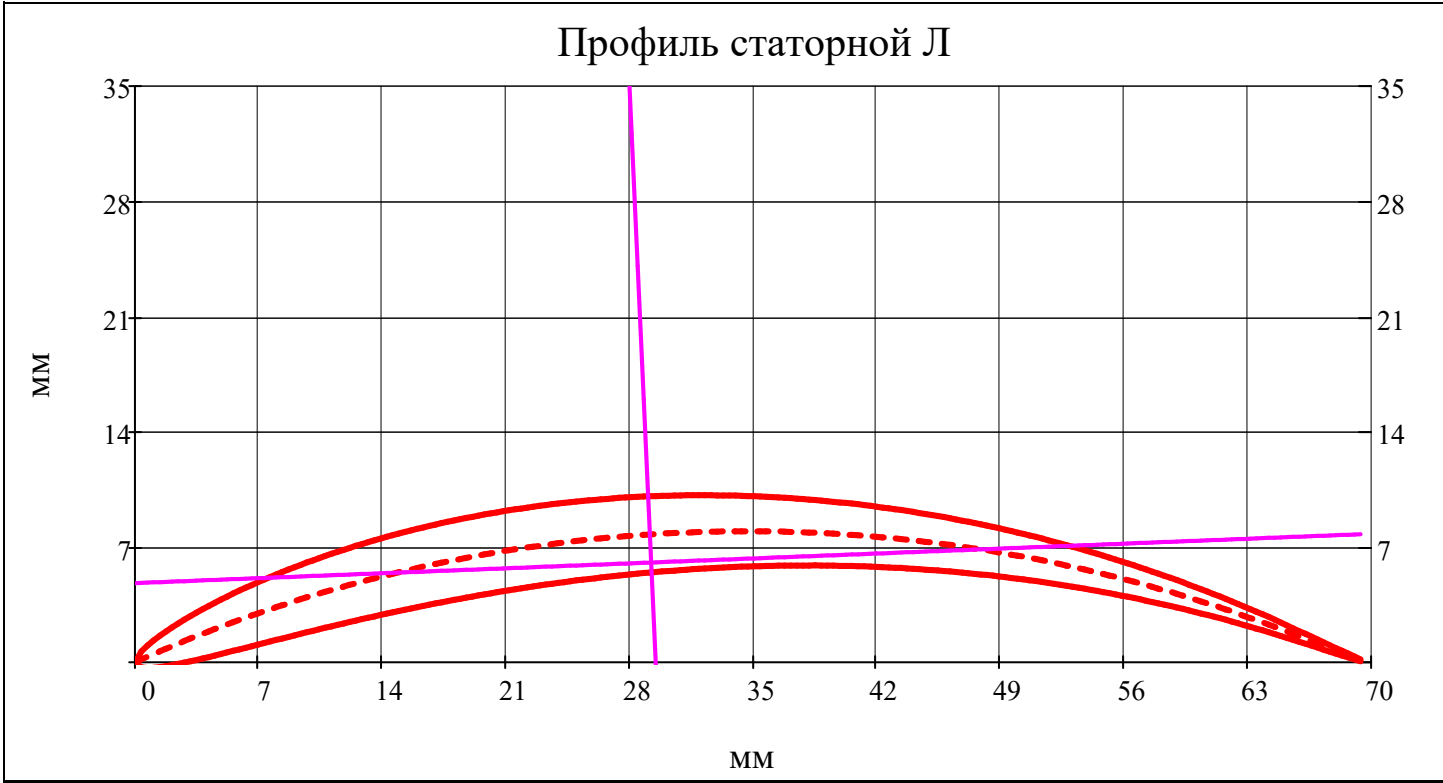
Построение профилей Л РК и НА

$$\text{AXLE0}(\text{type}, x, i, r) = \begin{cases} \frac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \tan\left(\alpha_{\text{major}_{\text{rotor}_{i,r}}}\right) \cdot \left(x - \frac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if type = "rotor"} \\ \frac{y0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}} + \tan\left(\alpha_{\text{major}_{\text{stator}_{i,r}}}\right) \cdot \left(x - \frac{x0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}}\right) & \text{if type = "stator"} \\ \text{NaN} & \text{otherwise} \end{cases}$$

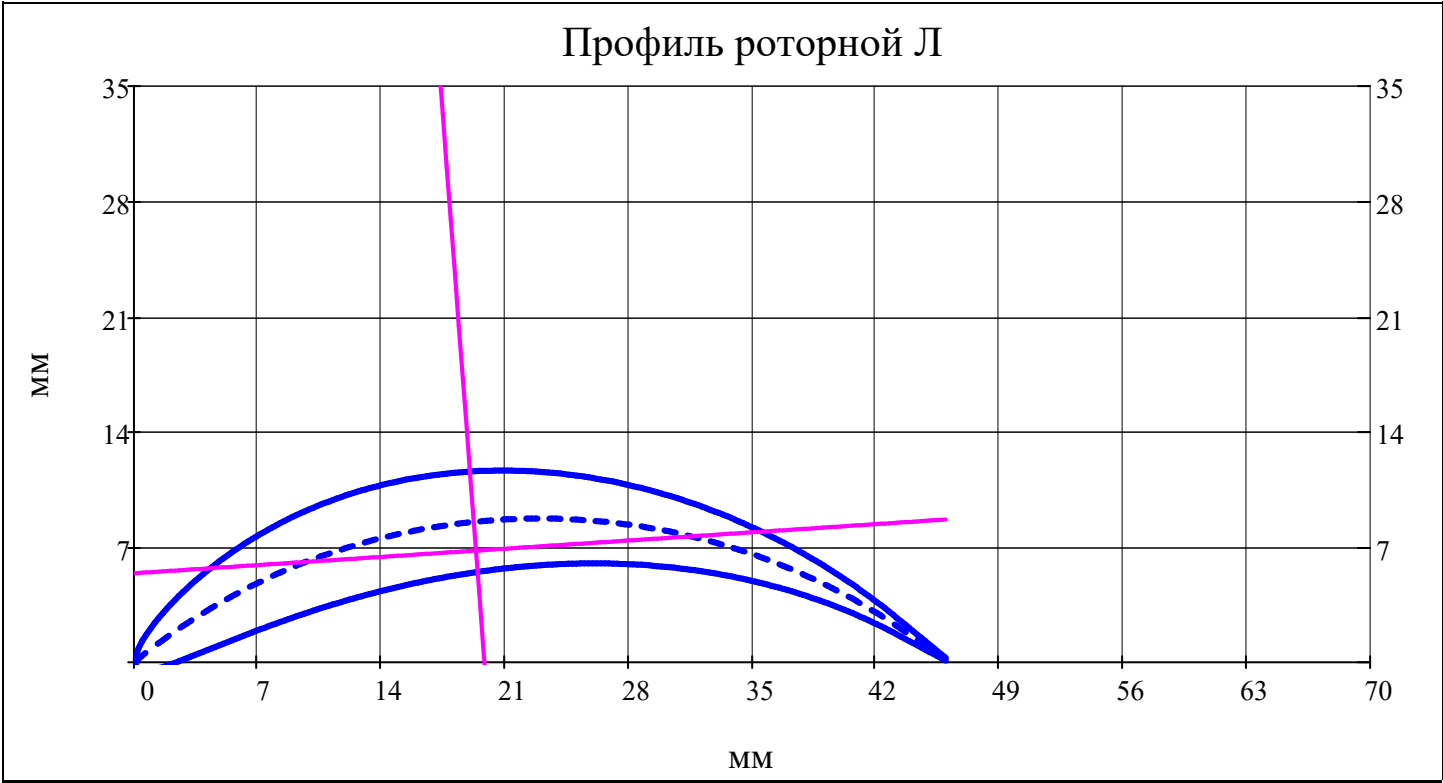
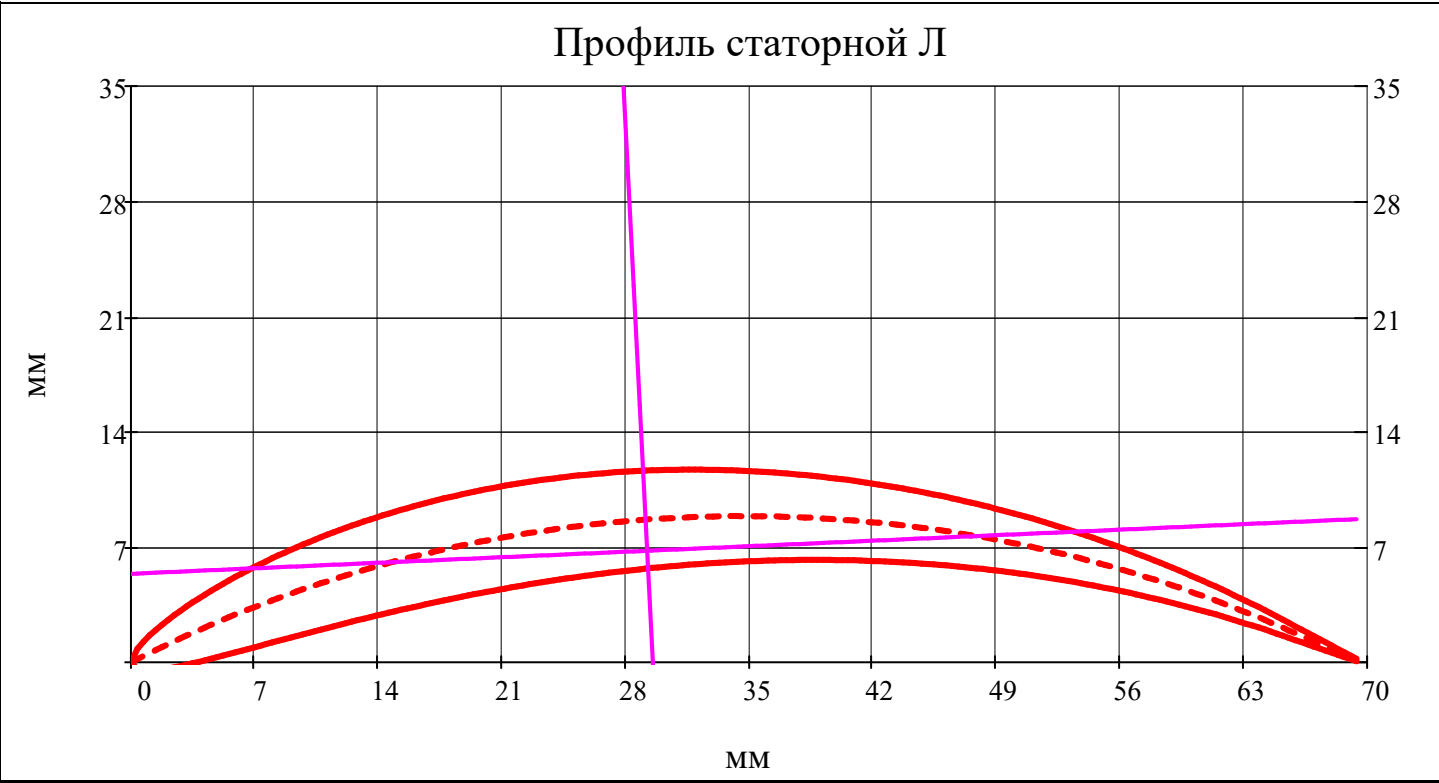
$$\text{AXLE90}(\text{type}, x, i, r) = \begin{cases} \frac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \tan\left(\alpha_{\text{major}_{\text{rotor}_{i,r}}} + \frac{\pi}{2}\right) \cdot \left(x - \frac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if (type = "rotor") } \wedge \left|\alpha_{\text{major}_{\text{rotor}_{i,r}}}\right| \geq 1^\circ \\ \frac{y0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}} + \tan\left(\alpha_{\text{major}_{\text{stator}_{i,r}}} + \frac{\pi}{2}\right) \cdot \left(x - \frac{x0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}}\right) & \text{if (type = "stator") } \wedge \left|\alpha_{\text{major}_{\text{stator}_{i,r}}}\right| \geq 1^\circ \\ \text{NaN} & \text{otherwise} \end{cases}$$

$$b_{\text{lim}} = \frac{\text{ceil}\left(\max\left(\text{chord}_{\text{rotor}_{j,N_r}}, \text{chord}_{\text{stator}_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 70.0 \cdot 10^{-3}$$

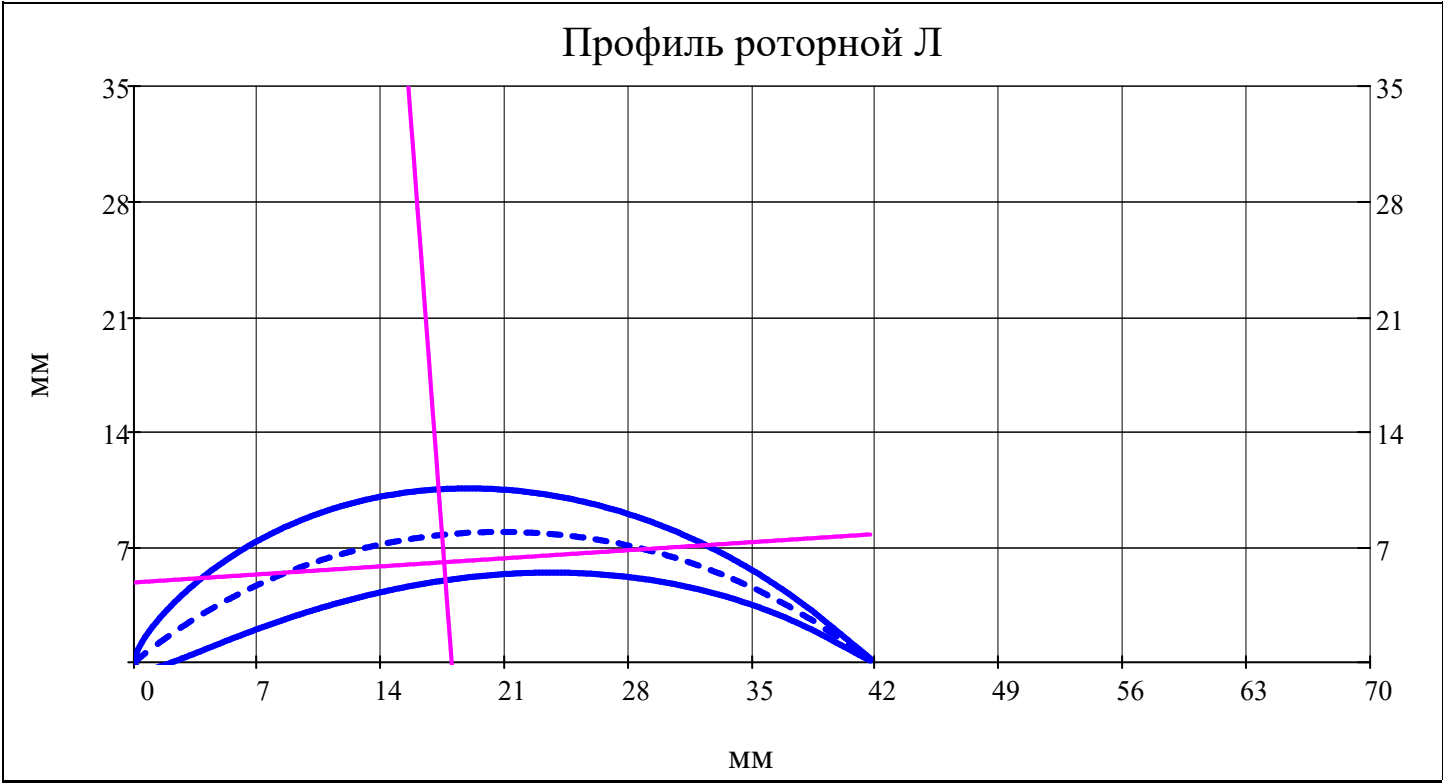
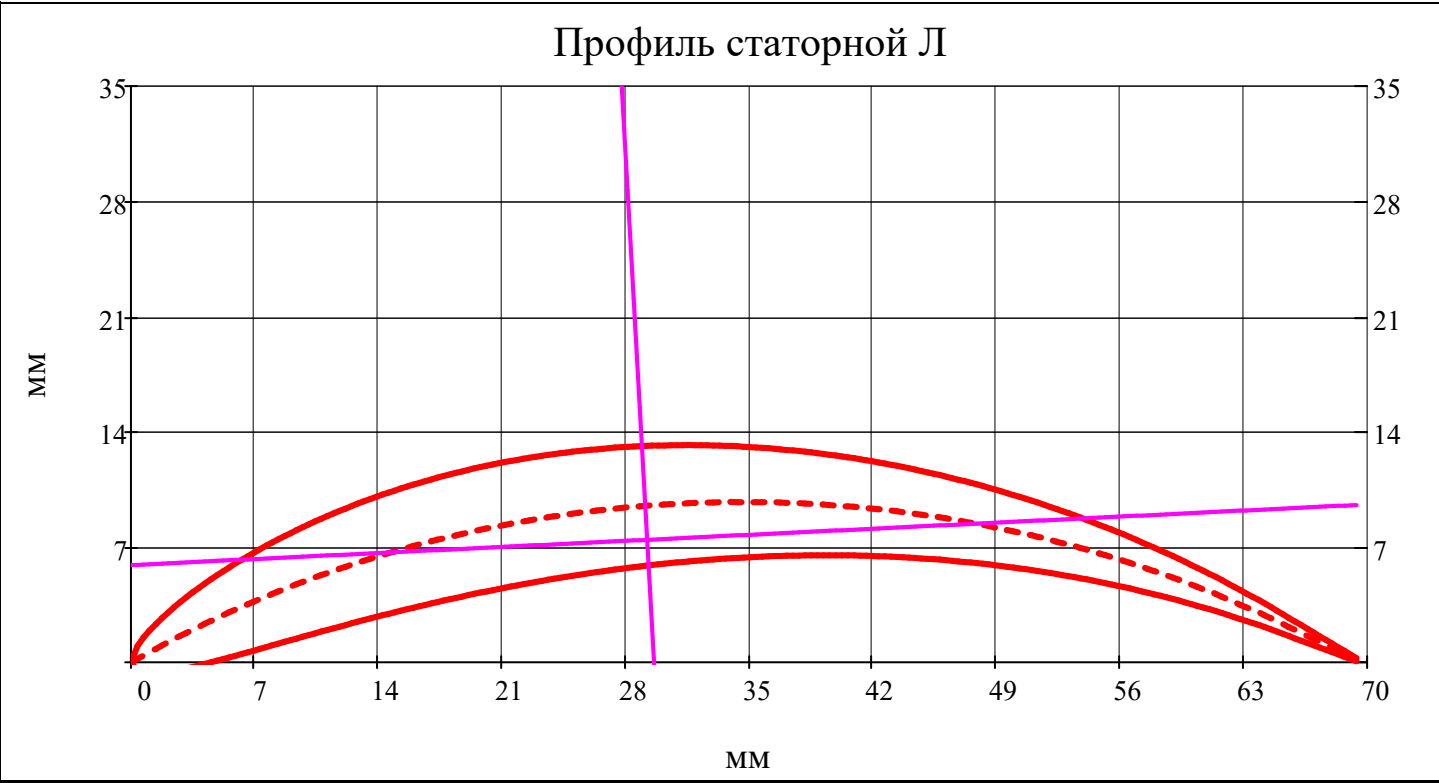
$r_w = 1$



$r_w = av(N_r)$



$r_w = N_r$



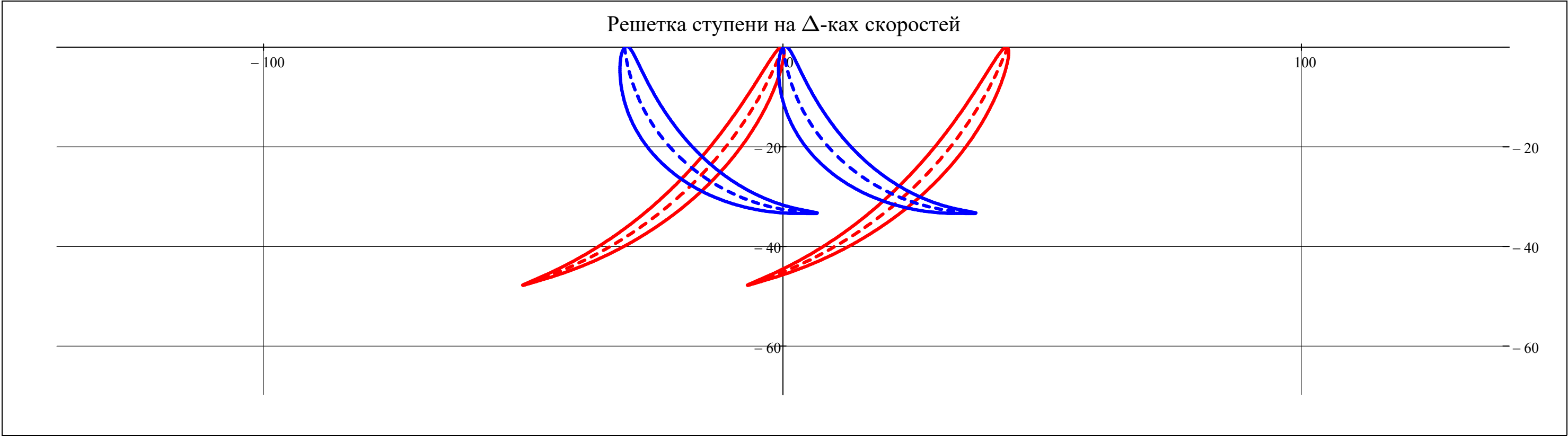
Рассматриваемая ступень:

$$j_w = \begin{cases} j = Z & \\ j = & \begin{cases} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{cases} \end{cases} = 4$$

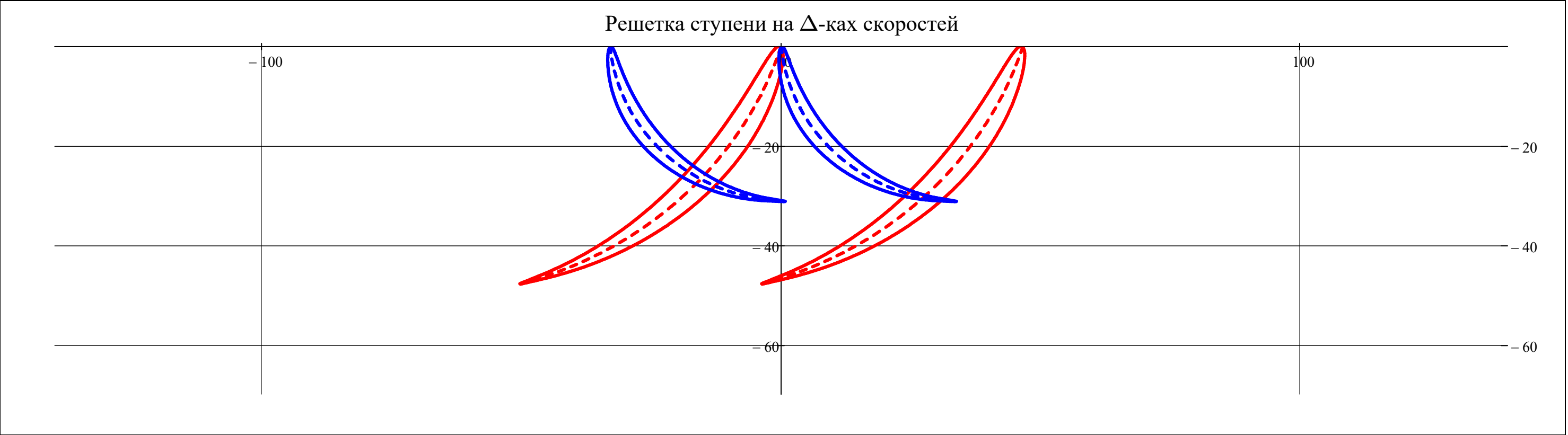
$$b_{lim} = \frac{\text{ceil}\left(\max\left(\text{chord}_{\text{rotor}_{j,N_r}}, \text{chord}_{\text{stator}_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 70.0 \cdot 10^{-3}$$

Построение плоских решеток профилей Л на треугольниках скоростей

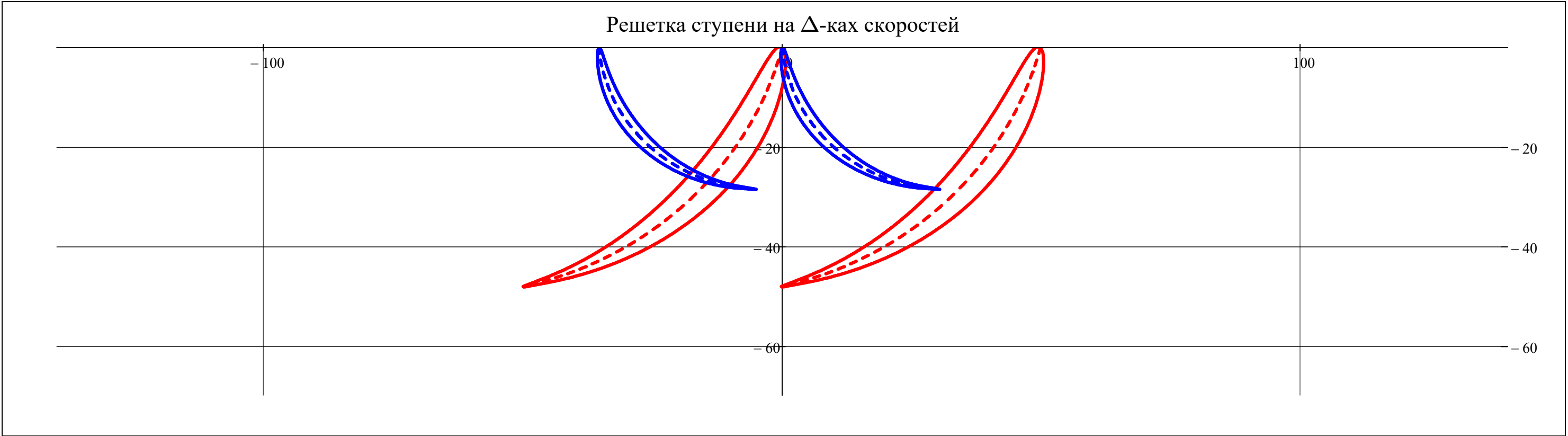
$$r_w = 1$$



$\bar{r}_w = \text{av}(N_r)$



$r_w = N_r$



Рассматриваемая ступень:

$$j_w = \begin{cases} j = Z & \\ j = \begin{cases} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{cases} & \end{cases} = 4$$

▼ Поперечная часть ступени

$$r_w = \min(D), \min(D) + \frac{\max(D) - \min(D)}{N_{\text{dis}}} \dots \max(D)$$

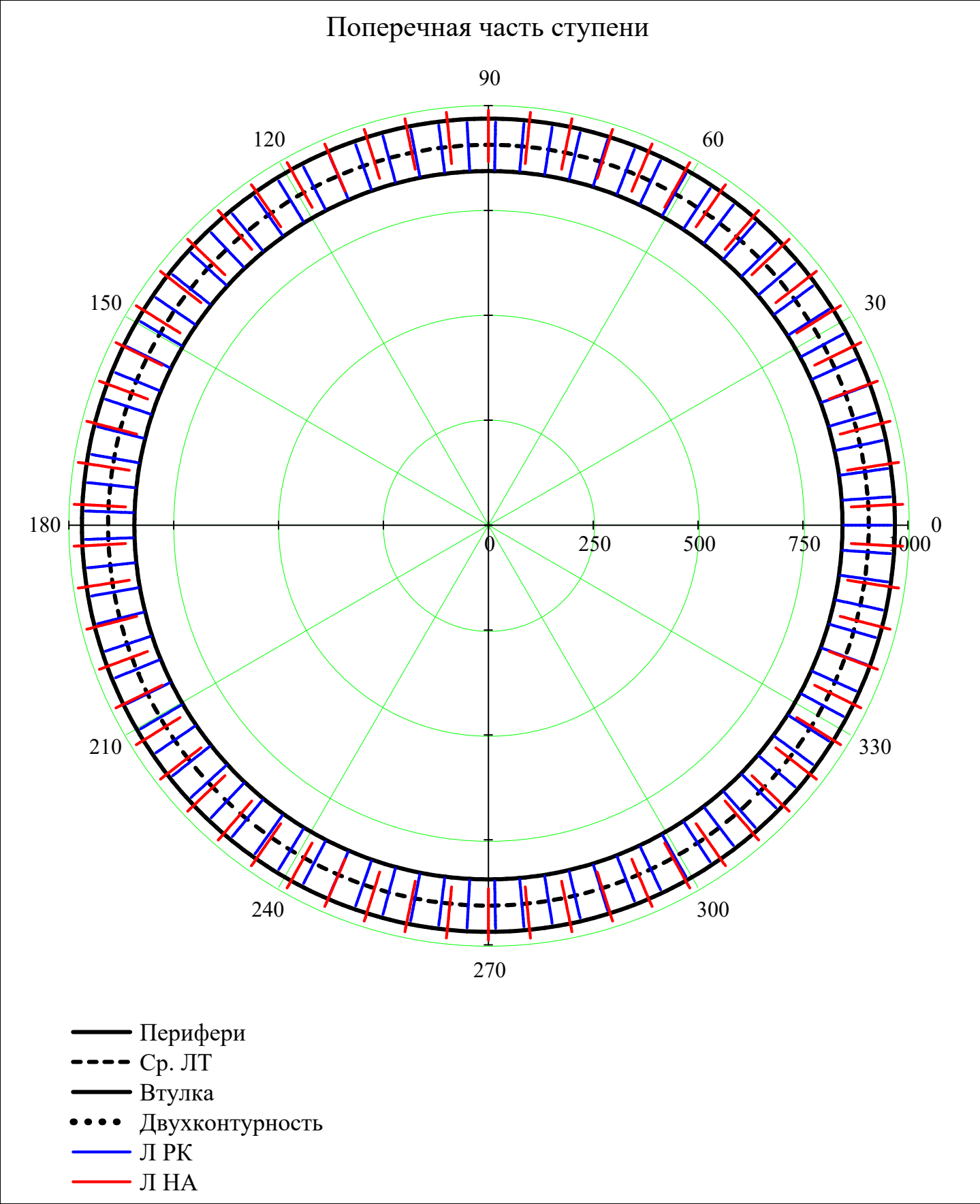
$$\begin{aligned} i_{\text{rotor}} &= 1 \dots Z_{\text{rotor}_j} \\ i_{\text{stator}} &= 1 \dots Z_{\text{stator}_j} \end{aligned}$$

$$\varphi = 0, \frac{2 \cdot \pi}{360} \dots 2 \cdot \pi$$

Л <sub>ПК</sub> (r,j) =	$\frac{2 \cdot \pi}{Z_{\text{rotor}_j}}$ if D <sub>st(j,1)</sub> , 1 < r < D <sub>st(j,1),N<sub>r</sub></sub>
	NaN otherwise

Л <sub>HA</sub> (r,j) =	$\frac{2 \cdot \pi}{Z_{\text{stator}_j}}$ if D <sub>st(j,2)</sub> , 1 < r < D <sub>st(j,2),N<sub>r</sub></sub>
	NaN otherwise





$\nu_{0\text{изГ.stator}}$  $\nu_{0\text{изГ.rotor}}$

$\nu_{0\text{угЛ.stator}}$  $\nu_{0\text{угЛ.rotor}}$

$\nu_{0\text{угЛ.stator\_bondage}}$  $\nu_{0\text{угЛ.rotor\_bondage}}$

=

for i ∈ 1..Z

for r ∈ av(N<sub>r</sub>)

for mode ∈ 1..6

$\nu_{0\text{изГ.stator}_{i,\text{mode}}} = \nu_{0\text{изГИБ}}\Big(\text{mode}, \text{mean}\big(h_{\text{st}}(i, 1), h_{\text{st}}(i, 2)\big), E_{\text{blade}}, \rho_{\text{blade}_i}, \text{area}_{\text{stator}_{i,r}}, J_{\text{u}_{\text{stator}_{i,r}}}\Big)$

$\nu_{0\text{изГ.rotor}_{i,\text{mode}}} = \nu_{0\text{изГИБ}}\Big(\text{mode}, \text{mean}\big(h_{\text{st}}(i, 2), h_{\text{st}}(i, 3)\big), E_{\text{blade}}, \rho_{\text{blade}_i}, \text{area}_{\text{rotor}_{i,r}}, J_{\text{u}_{\text{rotor}_{i,r}}}\Big)$

$\nu_{0\text{угЛ.stator}_{i,\text{mode}}} = \nu_{0\text{угЛ}}\Big(\text{mode}, 0, \text{mean}\big(h_{\text{st}}(i, 1), h_{\text{st}}(i, 2)\big), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{stator}_{i,r}}, J_{\text{p}_{\text{stator}_{i,r}}}\Big)$

$\nu_{0\text{угЛ.rotor}_{i,\text{mode}}} = \nu_{0\text{угЛ}}\Big(\text{mode}, 0, \text{mean}\big(h_{\text{st}}(i, 2), h_{\text{st}}(i, 3)\big), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{rotor}_{i,r}}, J_{\text{p}_{\text{rotor}_{i,r}}}\Big)$

$\nu_{0\text{угЛ.stator\_bondage}_{i,\text{mode}}} = \nu_{0\text{угЛ}}\Big(\text{mode}, 1, \text{mean}\big(h_{\text{st}}(i, 1), h_{\text{st}}(i, 2)\big), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{stator}_{i,r}}, J_{\text{p}_{\text{stator}_{i,r}}}\Big)$

$\nu_{0\text{угЛ.rotor\_bondage}_{i,\text{mode}}} = \nu_{0\text{угЛ}}\Big(\text{mode}, 1, \text{mean}\big(h_{\text{st}}(i, 2), h_{\text{st}}(i, 3)\big), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{rotor}_{i,r}}, J_{\text{p}_{\text{rotor}_{i,r}}}\Big)$

$\nu_{0\text{изГ.stator}}$  $\nu_{0\text{изГ.rotor}}$

$\nu_{0\text{угЛ.stator}}$  $\nu_{0\text{угЛ.rotor}}$

$\nu_{0\text{угЛ.stator\_bondage}}$  $\nu_{0\text{угЛ.rotor\_bondage}}$

Частота собственных изгибных колебаний (Гц) [9, с.240]:

$$\text{stack}\left(\nu_{0_{\text{изг.stator}}}, \nu_{0_{\text{изг.rotor}}}\right)^T =$$

	1	2	3	4	5	6	7	8
1	3263	1318	1559	1694	1618	1636	1616	1298
2	20449	8261	9769	10618	10139	10252	10130	8134
3	57262	23133	27357	29734	28391	28708	28368	22777
4	112296	45365	53649	58311	55677	56299	55632	44667
5	185556	74961	88649	96353	92001	93028	91925	73807
6	277118	111950	132392	143897	137398	138932	137285	110226

Частота собственных угловых колебаний (Гц) [9, с.243] без и с бандажом:

$$\text{stack}\left(\nu_{0_{\text{угл.stator}}}, \nu_{0_{\text{угл.rotor}}}\right)^T =$$

	1	2	3	4	5	6	7	8
1	3125	2608	2392	2193	2761	2440	2268	2039
2	9376	7823	7177	6578	8284	7319	6803	6118
3	15626	13038	11962	10963	13806	12199	11339	10197
4	21877	18253	16747	15348	19329	17078	15875	14275
5	28128	23468	21532	19733	24851	21958	20410	18354
6	34378	28683	26317	24118	30374	26838	24946	22433

$$\text{stack}\left(\nu_{0_{\text{угл.stator\_bondage}}}, \nu_{0_{\text{угл.rotor\_bondage}}}\right)^T =$$

	1	2	3	4	5	6	7	8
1	6251	5215	4785	4385	5523	4880	4536	4079
2	12501	10430	9570	8770	11045	9759	9071	8157
3	18752	15645	14355	13155	16568	14639	13607	12236
4	25002	20860	19140	17540	22090	19518	18143	16315
5	31253	26076	23924	21925	27613	24398	22678	20394
6	37503	31291	28709	26310	33135	29277	27214	24472

Расчетный узел: type = "turbine"

Объем бандажной полки (м³):  $V_{\text{бп}} = 0$

Радиус положения ЦМ бандажной полки (м):  $R_{\text{бп}} = 0$

$$\text{neutral\_line}(\text{type},\text{x},\text{i},\text{r}) = \left\{ \begin{array}{l} \frac{y0_{\text{rotor}_{\text{i},\text{r}}}}{\text{chord}_{\text{rotor}_{\text{i},\text{r}}}} + \tan\left(\left(\alpha_{\text{major}_{\text{rotor}_{\text{i},\text{r}}}} + \varphi_{\text{neutral}_{\text{rotor}}}\left(\text{i},\text{Rst}(\text{i},2),\text{r}\right)\right)\right) \cdot \left(\text{x} - \frac{x0_{\text{rotor}_{\text{i},\text{r}}}}{\text{chord}_{\text{rotor}_{\text{i},\text{r}}}}\right) \quad \text{if type = "rotor"} \\ \\ \frac{y0_{\text{stator}_{\text{i},\text{r}}}}{\text{chord}_{\text{stator}_{\text{i},\text{r}}}} + \tan\left(\left(\alpha_{\text{major}_{\text{stator}_{\text{i},\text{r}}}} + \varphi_{\text{neutral}_{\text{stator}}}\left(\text{i},\text{Rst}(\text{i},2),\text{r}\right)\right)\right) \cdot \left(\text{x} - \frac{x0_{\text{stator}_{\text{i},\text{r}}}}{\text{chord}_{\text{stator}_{\text{i},\text{r}}}}\right) \quad \text{if type = "stator"} \end{array} \right.$$

$$\text{epure}(\text{type},\text{x},\text{i},\text{r}) = \left\{ \begin{array}{l} \frac{y0_{\text{rotor}_{\text{i},\text{r}}}}{\text{chord}_{\text{rotor}_{\text{i},\text{r}}}} + \frac{-1}{\tan\left(\alpha_{\text{major}_{\text{rotor}_{\text{i},\text{r}}}} + \varphi_{\text{neutral}_{\text{rotor}}}\left(\text{i},\text{Rst}(\text{i},2),\text{r}\right) - \frac{\pi}{4}\right)} \cdot \left(\text{x} - \frac{x0_{\text{rotor}_{\text{i},\text{r}}}}{\text{chord}_{\text{rotor}_{\text{i},\text{r}}}}\right) \quad \text{if type = "rotor"} \\ \\ \frac{y0_{\text{stator}_{\text{i},\text{r}}}}{\text{chord}_{\text{stator}_{\text{i},\text{r}}}} + \frac{-1}{\tan\left(\alpha_{\text{major}_{\text{stator}_{\text{i},\text{r}}}} + \varphi_{\text{neutral}_{\text{stator}}}\left(\text{i},\text{Rst}(\text{i},2),\text{r}\right) - \frac{\pi}{4}\right)} \cdot \left(\text{x} - \frac{x0_{\text{stator}_{\text{i},\text{r}}}}{\text{chord}_{\text{stator}_{\text{i},\text{r}}}}\right) \quad \text{if type = "stator"} \end{array} \right.$$

Наиболее удаленные точки от НЛ (мм):

$$u_{-u_{\text{rotor}}}^T =$$

	1	2	3	4
1	-1.160	-1.024	-0.986	-1.003
2	0.261	0.336	0.342	-0.616
3	0.241	0.281	0.268	0.223

$$\cdot 10^{-3}$$

$$u_{-l_{\text{rotor}}}^T =$$

	1	2	3	4
1	28.375	28.028	27.933	28.008
2	25.969	25.738	25.725	25.849
3	23.420	23.278	23.334	23.497

$$\cdot 10^{-3}$$

$$u_{-u_{\text{stator}}}^T =$$

	1	2	3	4
1	-6.048	18.972	16.627	15.685
2	14.809	34.565	38.064	22.591
3	-11.210	-18.804	-18.046	37.611

$$\cdot 10^{-3}$$

$$u_{-l_{\text{stator}}}^T =$$

	1	2	3	4
1	-9.648	-27.201	-27.296	-26.659
2	2.702	-20.244	-22.418	-24.751
3	34.492	34.701	10.465	-19.527

$$\cdot 10^{-3}$$

$$v_{-u_{\text{rotor}}}^T =$$

	1	2	3	4
1	4.927	5.365	5.441	5.299
2	3.698	3.973	3.956	3.765
3	3.189	3.344	3.240	3.002

$$\cdot 10^{-3}$$

$$v_{-l_{\text{rotor}}}^T =$$

	1	2	3	4
1	-7.980	-10.413	-10.906	-10.223
2	-8.576	-10.135	-10.108	-9.138
3	-8.916	-9.837	-9.322	-8.081

$$\cdot 10^{-3}$$

$$v_{-u_{\text{stator}}}^T =$$

	1	2	3	4
1	29.582	4.200	5.221	6.027
2	38.137	20.800	13.898	8.774
3	7.817	9.146	23.918	15.820

$$\cdot 10^{-3}$$

$$v_{-l_{\text{stator}}}^T =$$

	1	2	3	4
1	-39.707	-6.703	-9.605	-12.000
2	-30.181	-20.609	-18.668	-15.935
3	-22.276	-20.913	-39.336	-22.312

$$\cdot 10^{-3}$$

$$\begin{pmatrix} \sigma_{\text{p\_rotor}} & \sigma_{\text{n\_rotor}} \\ \sigma_{\text{p\_stator}} & \sigma_{\text{n\_stator}} \end{pmatrix} = \begin{array}{l} \text{for } i \in 1..Z \\ \text{for } r \in 1..N_r \\ \begin{pmatrix} \sigma_{\text{p\_rotor}_{i,r}} & \sigma_{\text{n\_rotor}_{i,r}} \\ \sigma_{\text{p\_stator}_{i,r}} & \sigma_{\text{n\_stator}_{i,r}} \end{pmatrix} = \begin{pmatrix} \frac{\text{Mu}_{\text{rotor}}(i, \text{Rst}(i, 2), r)}{\text{Ju}_{\text{rotor}_{i,r}}} \cdot \text{v\_u}_{\text{rotor}_{i,r}} - \frac{\text{Mv}_{\text{rotor}}(i, \text{Rst}(i, 2), r)}{\text{Jv}_{\text{rotor}_{i,r}}} \cdot \text{u\_u}_{\text{rotor}_{i,r}} & \frac{\text{Mu}_{\text{rotor}}(i, \text{Rst}(i, 2), r)}{\text{Ju}_{\text{rotor}_{i,r}}} \cdot \text{v\_l}_{\text{rotor}_{i,r}} - \frac{\text{Mv}_{\text{rotor}}(i, \text{Rst}(i, 2), r)}{\text{Jv}_{\text{rotor}_{i,r}}} \cdot \text{u\_l}_{\text{rotor}_{i,r}} \\ \frac{\text{Mu}_{\text{stator}}(i, \text{Rst}(i, 2), r)}{\text{Ju}_{\text{stator}_{i,r}}} \cdot \text{v\_u}_{\text{stator}_{i,r}} - \frac{\text{Mv}_{\text{stator}}(i, \text{Rst}(i, 2), r)}{\text{Jv}_{\text{stator}_{i,r}}} \cdot \text{u\_u}_{\text{stator}_{i,r}} & \frac{\text{Mu}_{\text{stator}}(i, \text{Rst}(i, 2), r)}{\text{Ju}_{\text{stator}_{i,r}}} \cdot \text{v\_l}_{\text{stator}_{i,r}} - \frac{\text{Mv}_{\text{stator}}(i, \text{Rst}(i, 2), r)}{\text{Jv}_{\text{stator}_{i,r}}} \cdot \text{u\_l}_{\text{stator}_{i,r}} \end{pmatrix} \end{array} \\ \begin{pmatrix} \sigma_{\text{p\_rotor}} & \sigma_{\text{n\_rotor}} \\ \sigma_{\text{p\_stator}} & \sigma_{\text{n\_stator}} \end{pmatrix} \end{pmatrix}$$

$$\begin{pmatrix} \sigma_{\text{p\_rotor.}} & \sigma_{\text{p\_stator.}} \\ \sigma_{\text{n\_rotor.}} & \sigma_{\text{n\_stator.}} \end{pmatrix} = \begin{array}{l} \text{for } i \in 1..Z \\ \begin{array}{l} \sigma_{\text{p\_rotor.}}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{p\_rotor}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{p\_rotor}}, i, i, 1, N_r\right)^T, z\right) \\ \sigma_{\text{p\_stator.}}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{p\_stator}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{p\_stator}}, i, i, 1, N_r\right)^T, z\right) \\ \sigma_{\text{n\_rotor.}}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{n\_rotor}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{n\_rotor}}, i, i, 1, N_r\right)^T, z\right) \\ \sigma_{\text{n\_stator.}}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{n\_stator}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(\text{R}, \text{st}(i, 1), \text{st}(i, 1), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{n\_stator}}, i, i, 1, N_r\right)^T, z\right) \end{array} \end{array} \\ \begin{pmatrix} \sigma_{\text{p\_rotor.}} & \sigma_{\text{p\_stator.}} \\ \sigma_{\text{n\_rotor.}} & \sigma_{\text{n\_stator.}} \end{pmatrix} \end{pmatrix}$$

$$\sigma_{\text{p\_rotor}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & -49.58 & -38.69 & -24.96 & -15.94 \\ \hline 2 & -31.38 & -25.94 & -16.28 & -8.77 \\ \hline 3 & -4.79 & -6.12 & -2.55 & -0.07 \\ \hline \end{array} \cdot 10^6$$

$$\sigma_{\text{p\_rotor}}^T \leq 70 \cdot 10^6 = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 1 & 1 & 1 & 1 \\ \hline 2 & 1 & 1 & 1 & 1 \\ \hline 3 & 1 & 1 & 1 & 1 \\ \hline \end{array}$$

$$\sigma_{\text{n\_rotor}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 86.83 & 79.81 & 53.31 & 33.39 \\ \hline 2 & 76.42 & 69.01 & 43.71 & 22.64 \\ \hline 3 & 13.77 & 18.44 & 7.63 & 0.20 \\ \hline \end{array} \cdot 10^6$$

$$\sigma_{\text{n\_rotor}}^T \leq 70 \cdot 10^6 = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0 & 0 & 1 & 1 \\ \hline 2 & 0 & 1 & 1 & 1 \\ \hline 3 & 1 & 1 & 1 & 1 \\ \hline \end{array}$$

$$\sigma_{\text{p\_stator}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0.00 & 1.03 & 0.58 & 0.05 \\ \hline 2 & 1.78 & 12.03 & 7.28 & 2.32 \\ \hline 3 & -10.85 & -20.23 & -8.47 & 8.70 \\ \hline \end{array} \cdot 10^6$$

$$\sigma_{\text{p\_stator}}^T \leq 70 \cdot 10^6 = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 1 & 1 & 1 & 1 \\ \hline 2 & 1 & 1 & 1 & 1 \\ \hline 3 & 1 & 1 & 1 & 1 \\ \hline \end{array}$$

$$\sigma_{\text{n\_stator}}^T = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 0.00 & -1.58 & -1.01 & -0.10 \\ \hline 2 & -0.09 & -9.17 & -6.42 & -3.38 \\ \hline 3 & 31.68 & 42.27 & 8.54 & -7.36 \\ \hline \end{array} \cdot 10^6$$

$$\sigma_{\text{n\_stator}}^T \leq 70 \cdot 10^6 = \begin{array}{|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 \\ \hline 1 & 1 & 1 & 1 & 1 \\ \hline 2 & 1 & 1 & 1 & 1 \\ \hline 3 & 1 & 1 & 1 & 1 \\ \hline \end{array}$$



$$\begin{pmatrix} \sigma_{\text{rotor}} \\ \sigma_{\text{stator}} \end{pmatrix} = \begin{cases} \text{for } i \in 1..Z \\ \text{for } r \in 1..N_r \\ \left| \begin{aligned} \sigma_{\text{rotor}_{i,r}} &= \sqrt{\left(\sigma_{\text{Zrotor}}(i, R_{\text{st}}(i, 2), r) + \max(\sigma_{\text{Protor}_{i,r}}, \sigma_{\text{nrotor}_{i,r}})\right)^2 + \tau_{\text{rotor}}(i, R_{\text{st}}(i, 2), r)^2} \\ \sigma_{\text{stator}_{i,r}} &= \sqrt{\left(0 + \max(\sigma_{\text{Pstator}_{i,r}}, \sigma_{\text{nstator}_{i,r}})\right)^2 + \tau_{\text{stator}}(i, R_{\text{st}}(i, 2), r)^2} \end{aligned} \right. \\ \begin{pmatrix} \sigma_{\text{rotor}} \\ \sigma_{\text{stator}} \end{pmatrix} \end{cases}$$

$$\begin{pmatrix} \sigma_{\text{rotor.}} \\ \sigma_{\text{stator.}} \end{pmatrix} = \begin{cases} \text{for } i \in 1..Z \\ \left| \begin{aligned} \sigma_{\text{rotor.}}(i, z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, \text{st}(i, 2), \text{st}(i, 2), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{rotor}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, \text{st}(i, 2), \text{st}(i, 2), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{rotor}}, i, i, 1, N_r\right)^T, z\right) \\ \sigma_{\text{stator.}}(i, z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, \text{st}(i, 2), \text{st}(i, 2), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{stator}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, \text{st}(i, 2), \text{st}(i, 2), 1, N_r\right)^T, \text{submatrix}\left(\sigma_{\text{stator}}, i, i, 1, N_r\right)^T, z\right) \end{aligned} \right. \\ \begin{pmatrix} \sigma_{\text{rotor.}} \\ \sigma_{\text{stator.}} \end{pmatrix} \end{cases}$$

$\sigma_{\text{rotor}}^T =$ 

	1	2	3	4
1	113.20	114.67	95.63	80.56
2	97.50	97.27	77.14	56.67
3	22.50	32.20	20.77	3.32

$\cdot 10^6$

$\sigma_{\text{stator}}^T =$ 

	1	2	3	4
1	0.00	1.09	0.70	0.16
2	2.67	12.08	7.36	2.47
3	31.86	42.31	8.71	8.81

$\cdot 10^6$

$$\begin{pmatrix} \text{safety}_{\text{rotor}} \\ \text{safety}_{\text{stator}} \end{pmatrix} = \begin{cases} \text{for } i \in 1..Z \\ \text{for } r \in 1..N_r \\ \left| \begin{aligned} \text{safety}_{\text{rotor}_{i,r}} &= \begin{cases} \frac{\sigma_{\text{blade\_long}i}}{\sigma_{\text{rotor}_{i,r}}} & \text{if } \sigma_{\text{rotor}_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{cases} \\ \text{safety}_{\text{stator}_{i,r}} &= \begin{cases} \frac{\sigma_{\text{blade\_long}i}}{\sigma_{\text{stator}_{i,r}}} & \text{if } \sigma_{\text{stator}_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{cases} \end{aligned} \right. \\ \begin{pmatrix} \text{safety}_{\text{rotor}} \\ \text{safety}_{\text{stator}} \end{pmatrix} \end{cases}$$

$\text{safety}_{\text{rotor}}^T =$ 

	1	2	3	4
1	1.06	1.05	1.25	1.49
2	1.23	1.23	1.56	2.12
3	5.33	3.73	5.78	36.17

$\text{safety}_{\text{stator}}^T =$ 

	1	2
1	00000000000000000000000000000000	
2		44.88
3		3.77

$\text{safety}_{\text{rotor}}^T \geq \text{safety} =$ 

	1	2	3	4
1	0	0	0	1
2	0	0	1	1
3	1	1	1	1

$\text{safety}_{\text{stator}}^T \geq \text{safety} =$ 

	1	2	3	4
1	1	1	1	1
2	1	1	1	1
3	1	1	1	1

Рассматриваемая ступень:

$$j = \begin{cases} j = 1 & \text{if type = "compressor"} \\ Z & \text{if type = "turbine"} \\ j = \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{cases} = 4$$

$$b_{lim} = \frac{ceil\left(\max\left(chord_{rotor,j,N_r},chord_{stator,j,N_r}\right)\cdot 10^2\right)}{10^2} = 70.0\cdot 10^{-3}$$

Расстояния от оси ЛМ до рассматриваемой ступени (м):

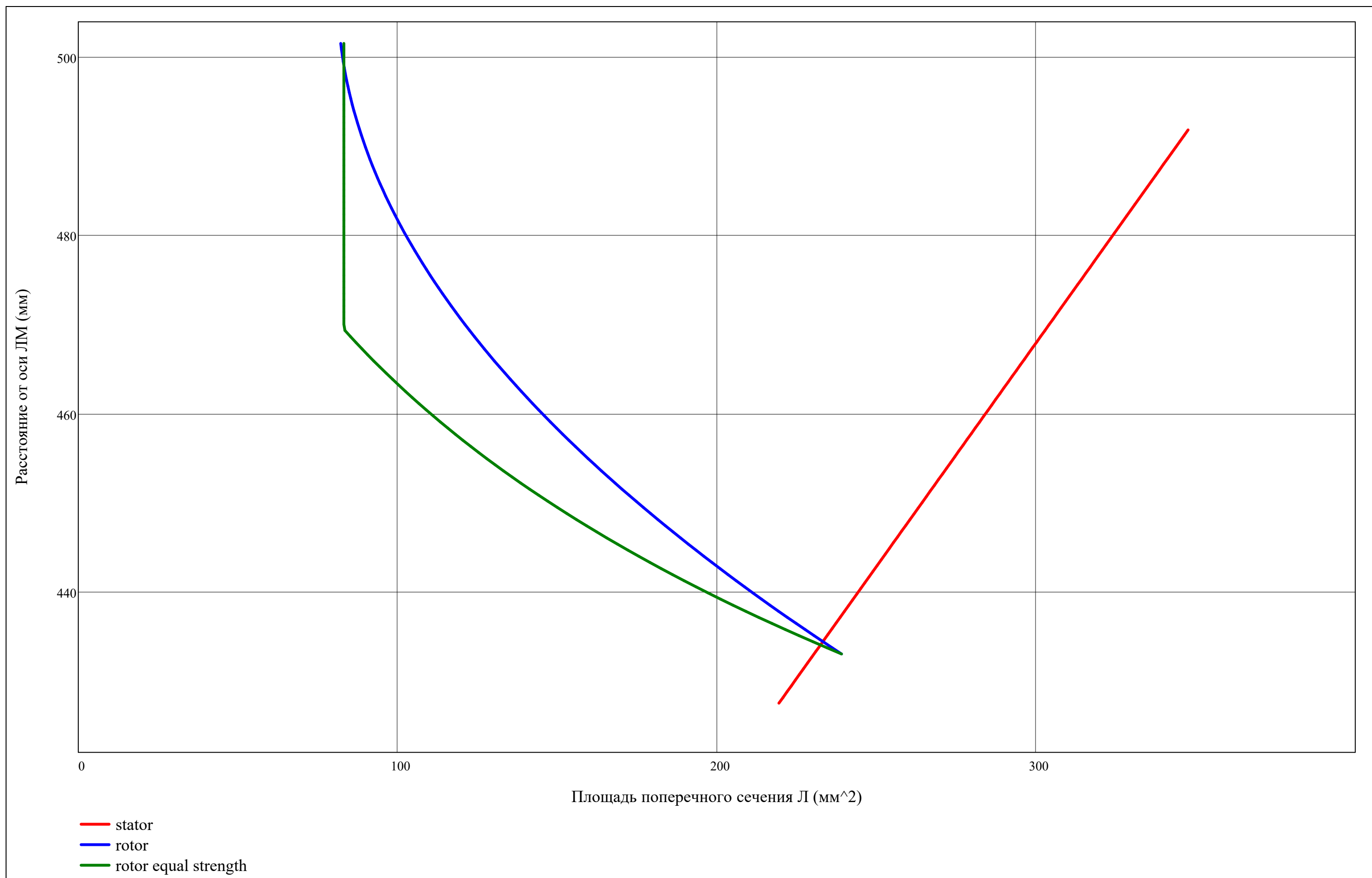
$$R_j = \text{submatrix}\Big(R,2\cdot j-1,2\cdot j+1,1,N_r\Big) = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 422.0 & 453.2 & 484.5 \\ 2 & 433.0 & 466.0 & 499.1 \\ 3 & 433.0 & 468.5 & 503.9 \\ \hline \end{array} \cdot 10^{-3}$$

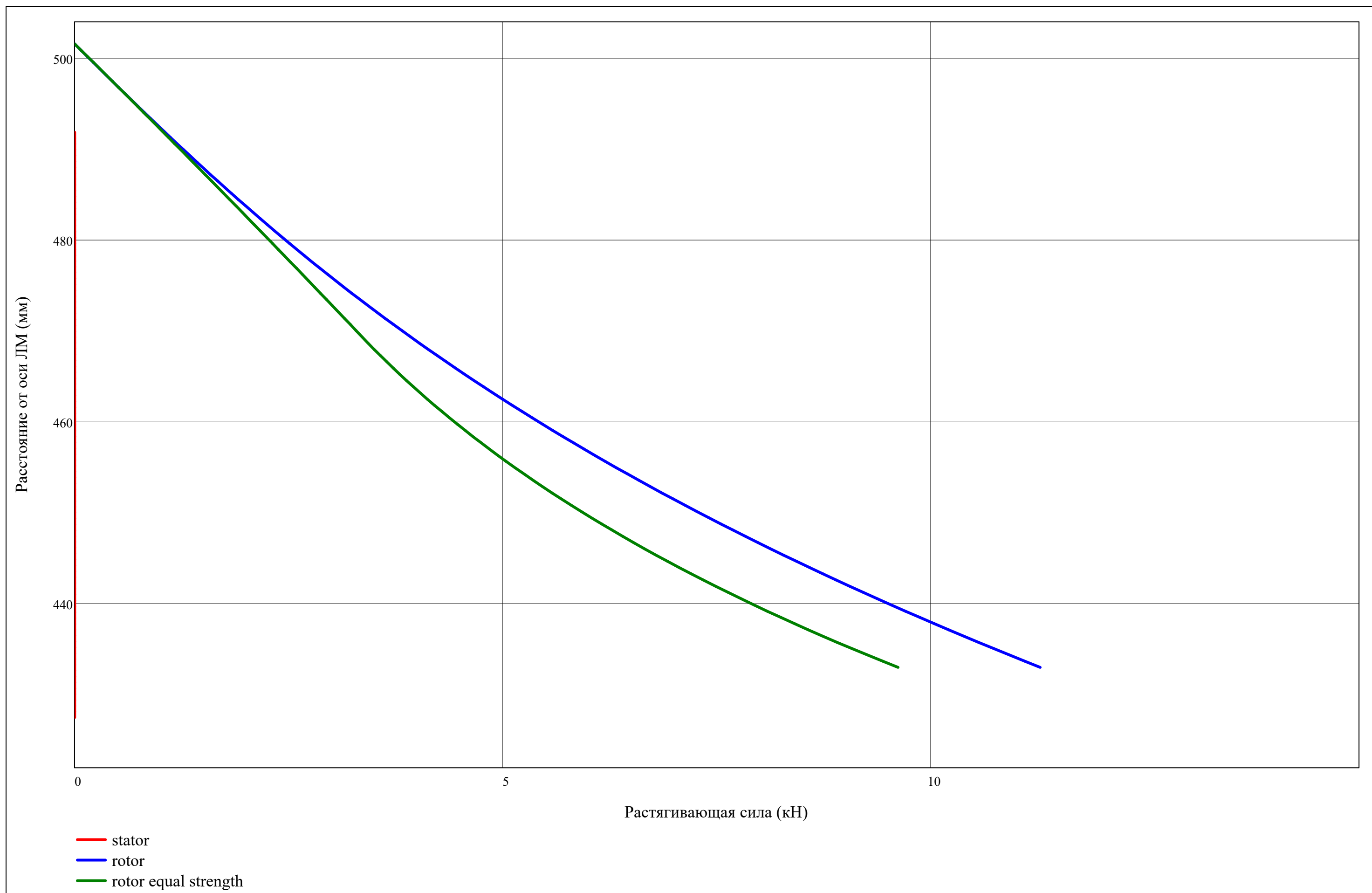
Дискретизация по высоте Л:

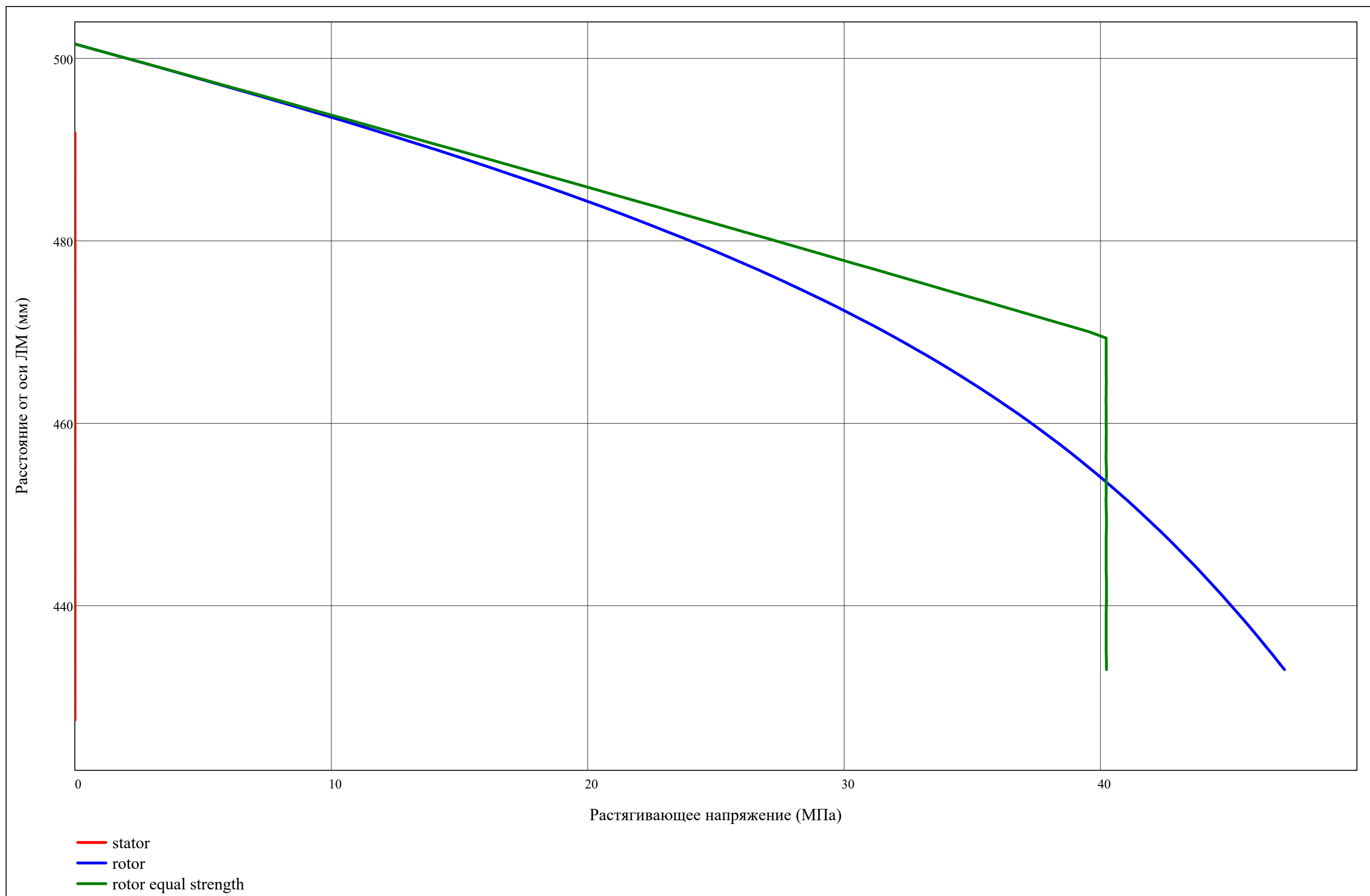
$$z = \min(R_j), \min(R_j) + \frac{\max(R_j) - \min(R_j)}{100} .. \max(R_j)$$

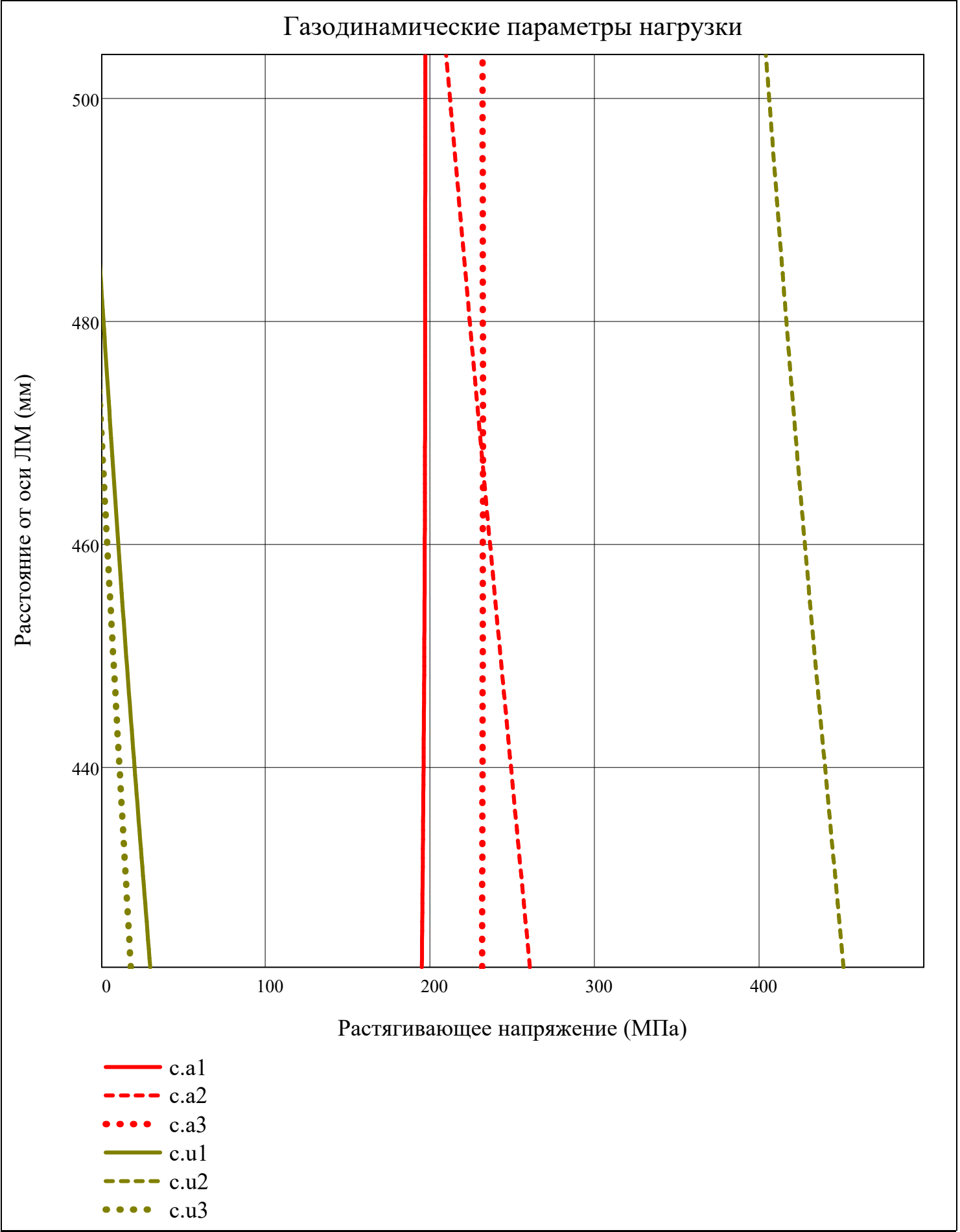
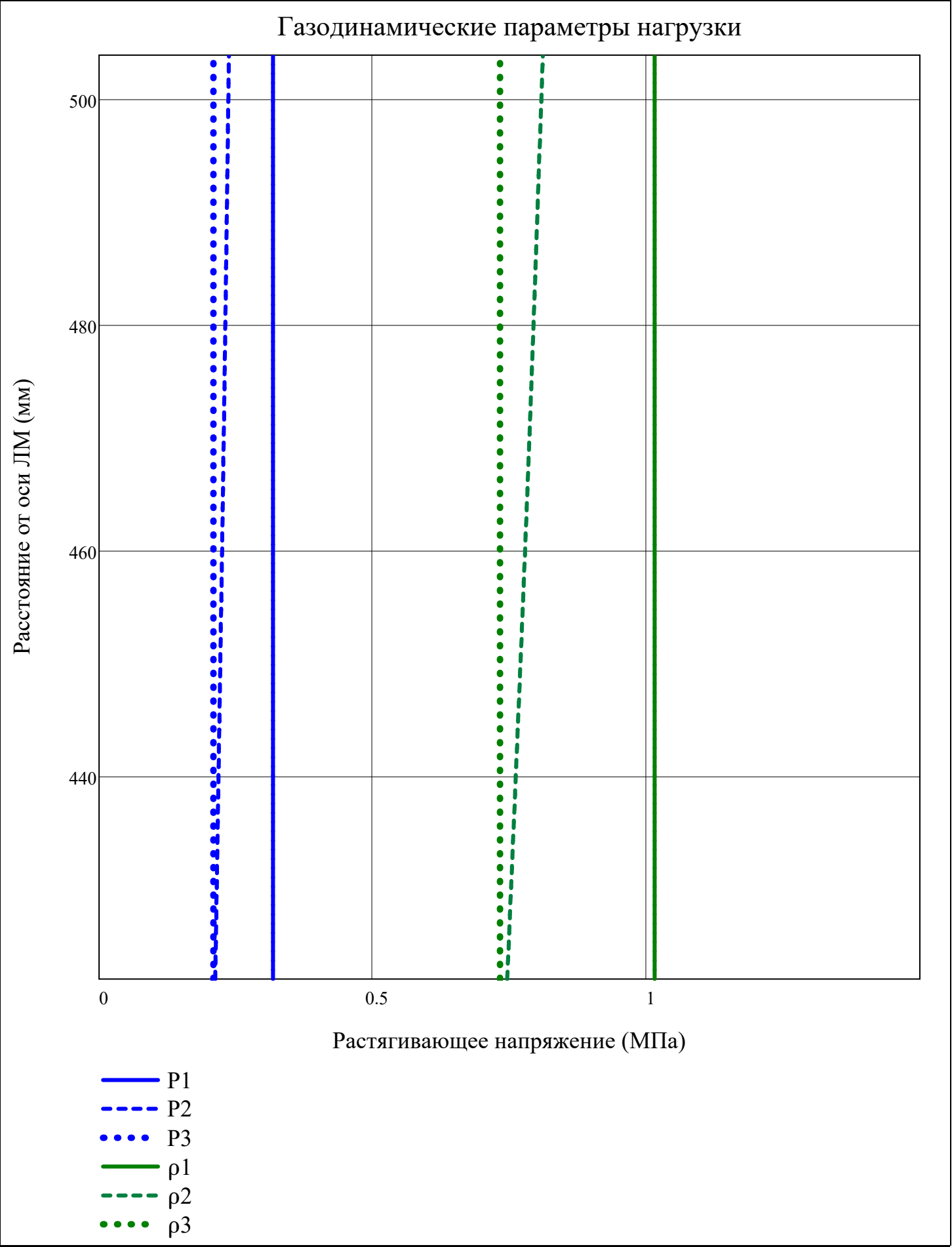
$$z_{rotor} = \begin{cases} \text{mean}\Big(R_{j1,1},R_{j2,1}\Big), \text{mean}\Big(R_{j1,1},R_{j2,1}\Big) + \frac{\text{mean}\Big(R_{j1,N_r},R_{j2,N_r}\Big) - \text{mean}\Big(R_{j1,1},R_{j2,1}\Big)}{100} .. \text{mean}\Big(R_{j1,N_r},R_{j2,N_r}\Big) & \text{if type = "compressor"} \\ \text{mean}\Big(R_{j2,1},R_{j3,1}\Big), \text{mean}\Big(R_{j2,1},R_{j3,1}\Big) + \frac{\text{mean}\Big(R_{j2,N_r},R_{j3,N_r}\Big) - \text{mean}\Big(R_{j2,1},R_{j3,1}\Big)}{100} .. \text{mean}\Big(R_{j2,N_r},R_{j3,N_r}\Big) & \text{if type = "turbine"} \end{cases}$$

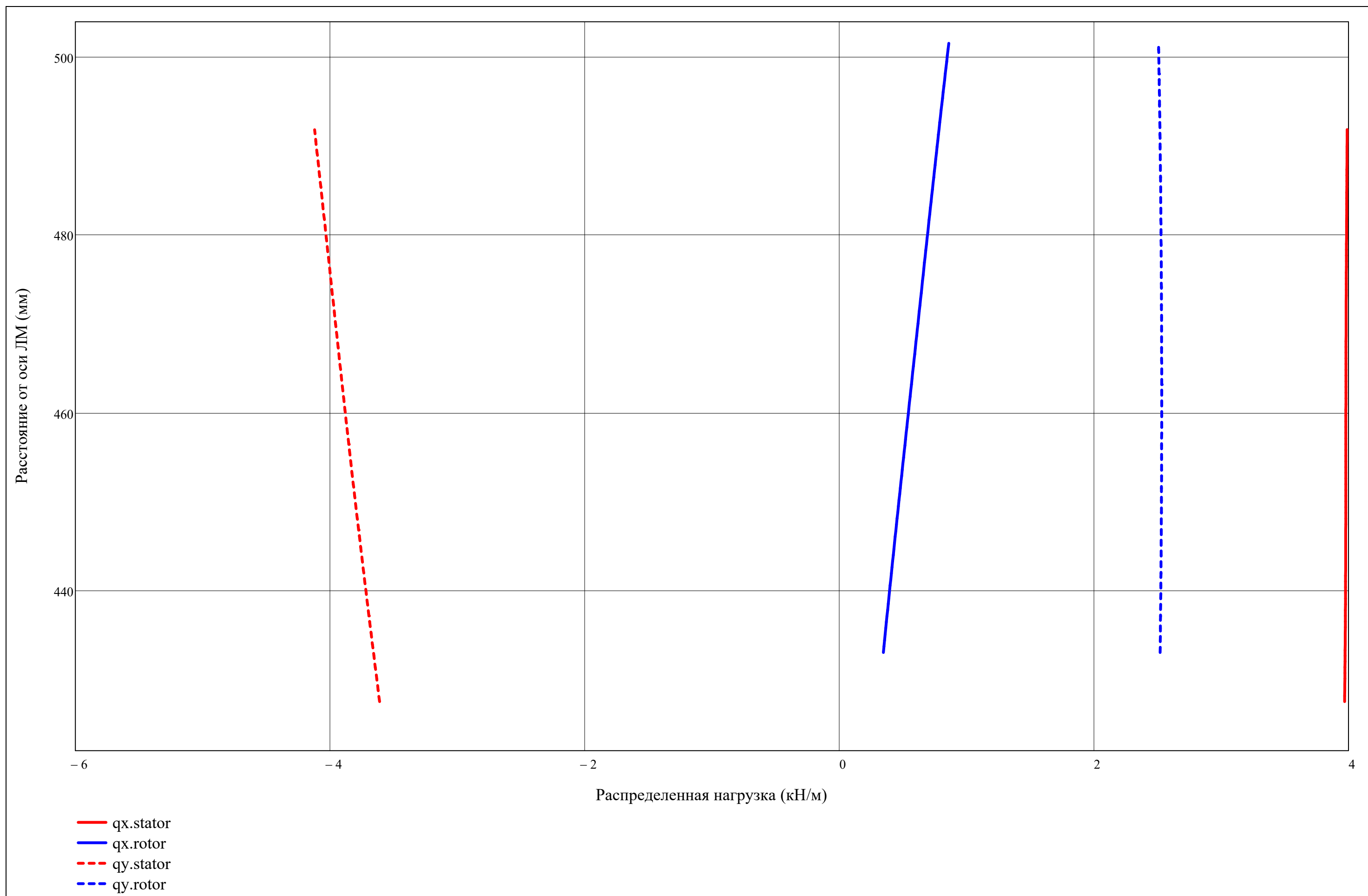
$$z_{stator} = \begin{cases} \text{mean}\Big(R_{j2,1},R_{j3,1}\Big), \text{mean}\Big(R_{j2,1},R_{j3,1}\Big) + \frac{\text{mean}\Big(R_{j2,N_r},R_{j3,N_r}\Big) - \text{mean}\Big(R_{j2,1},R_{j3,1}\Big)}{100} .. \text{mean}\Big(R_{j2,N_r},R_{j3,N_r}\Big) & \text{if type = "compressor"} \\ \text{mean}\Big(R_{j1,1},R_{j2,1}\Big), \text{mean}\Big(R_{j1,1},R_{j2,1}\Big) + \frac{\text{mean}\Big(R_{j1,N_r},R_{j2,N_r}\Big) - \text{mean}\Big(R_{j1,1},R_{j2,1}\Big)}{100} .. \text{mean}\Big(R_{j1,N_r},R_{j2,N_r}\Big) & \text{if type = "turbine"} \end{cases}$$

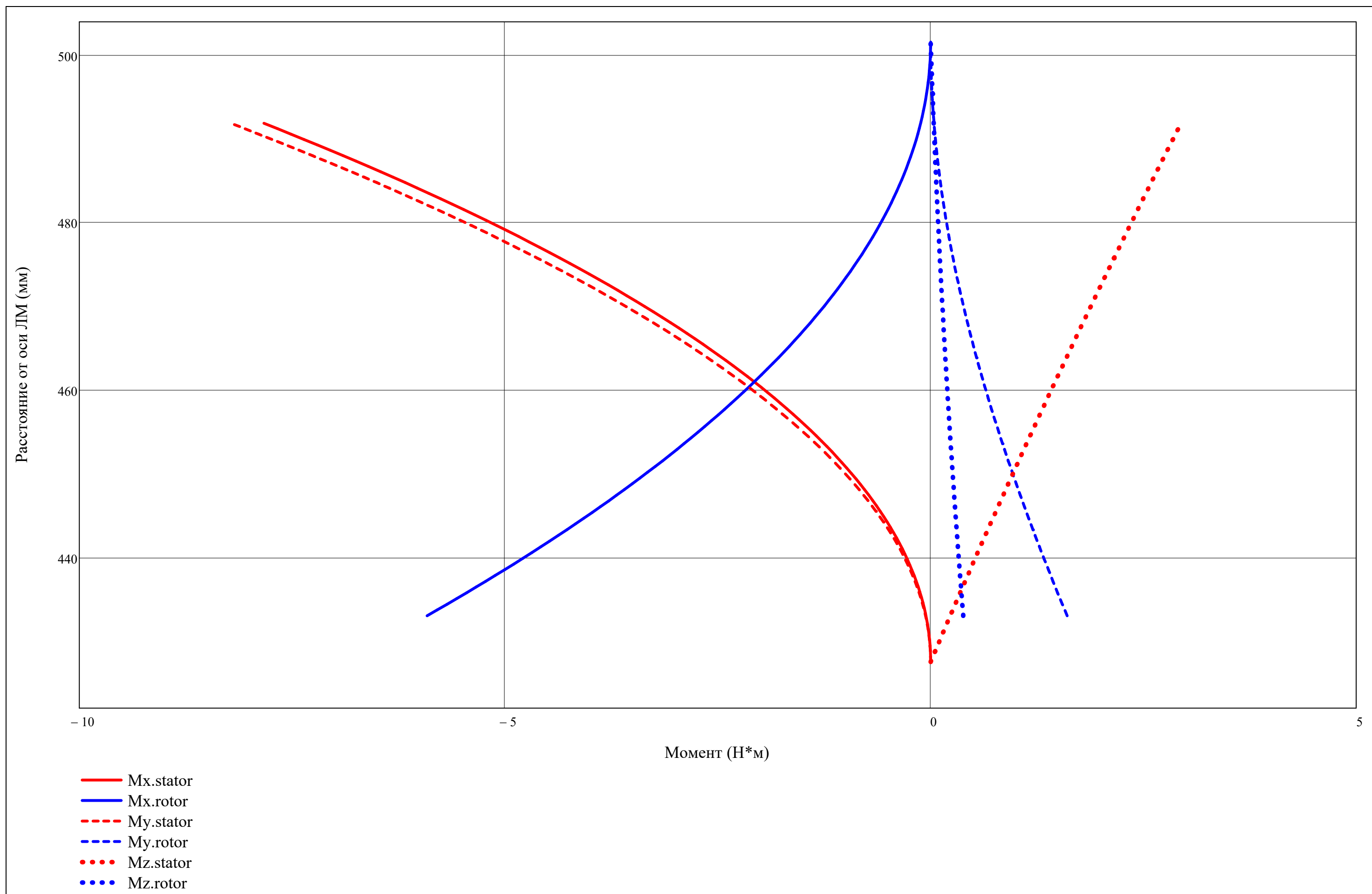




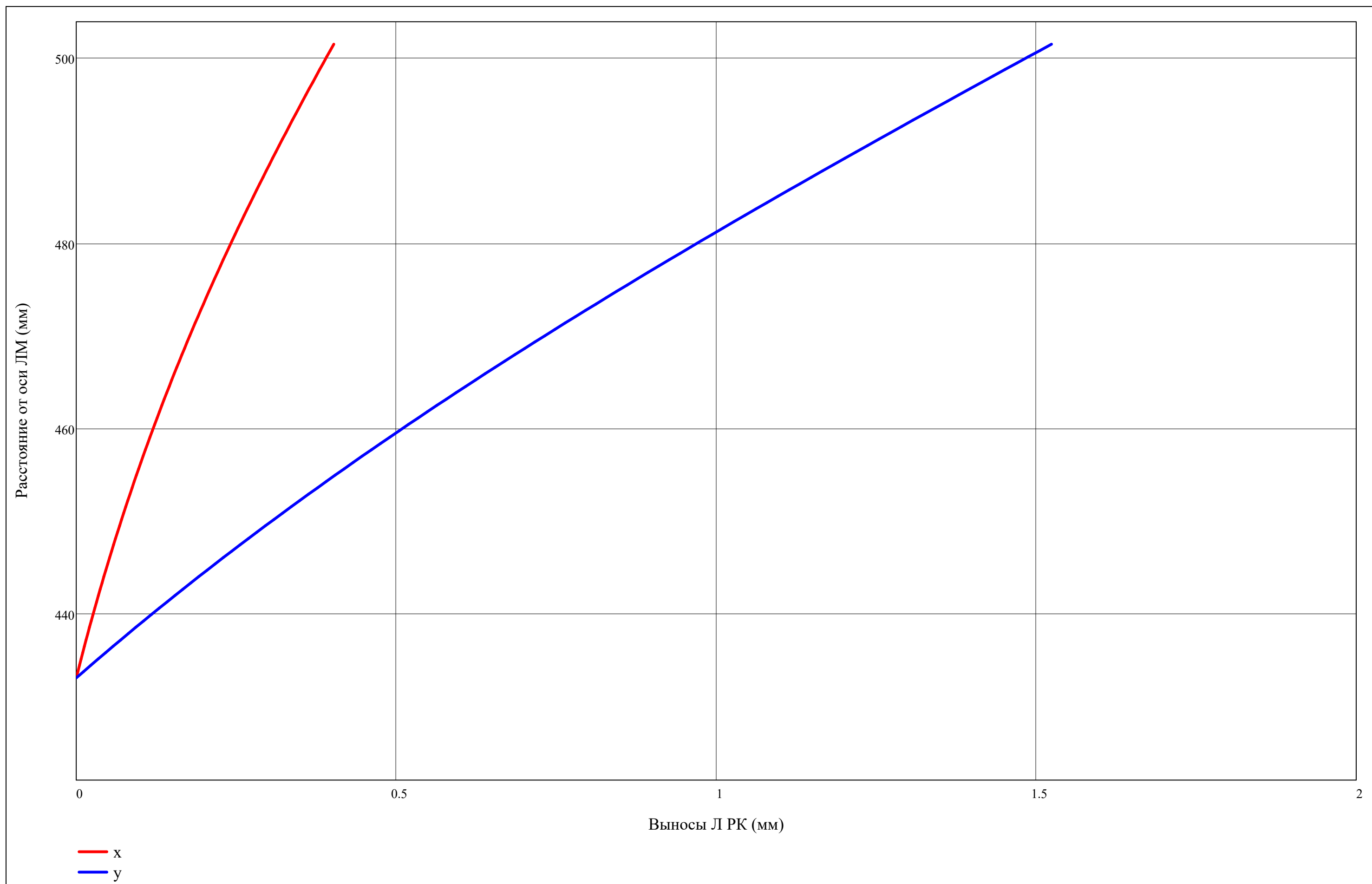


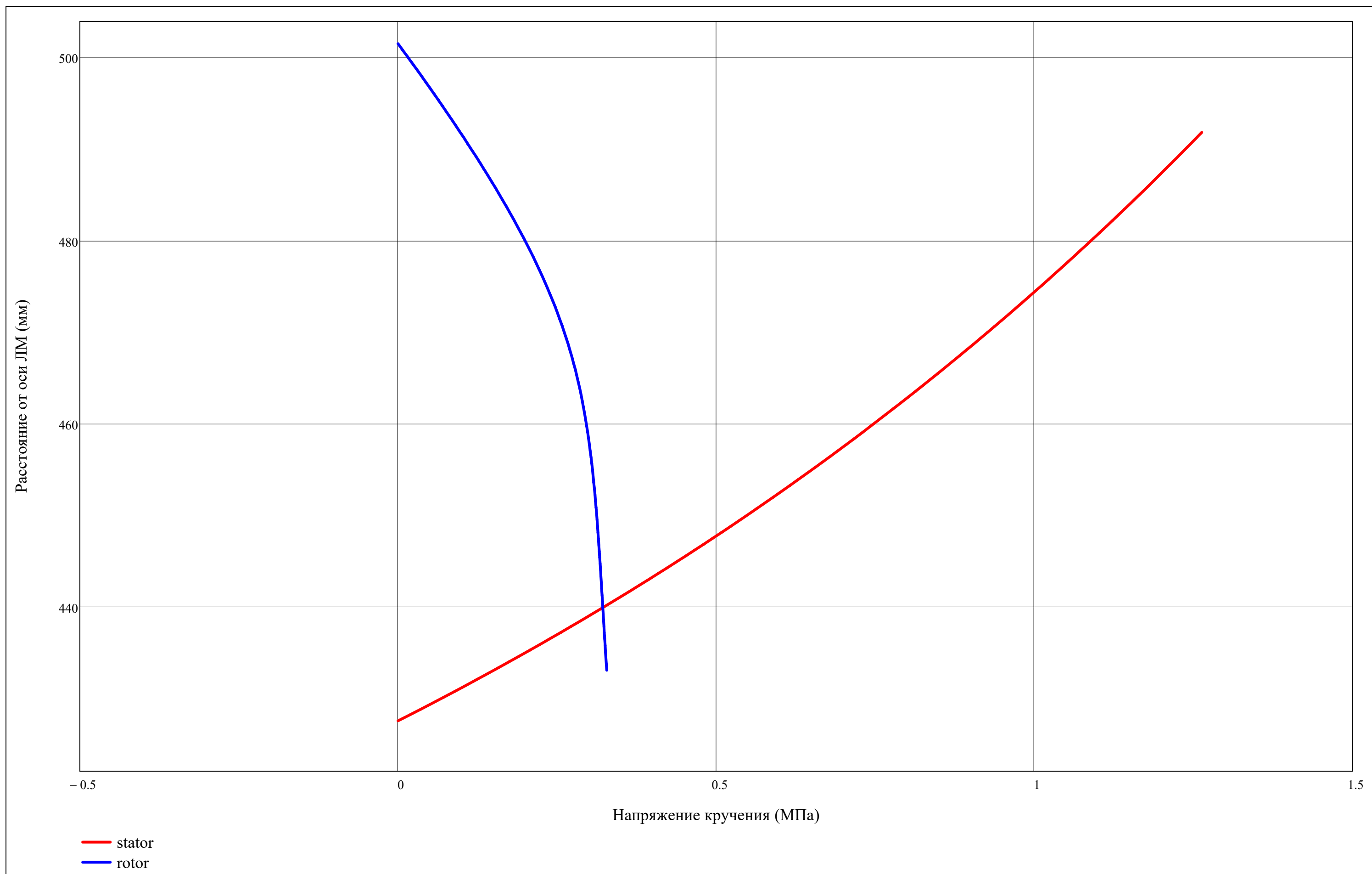


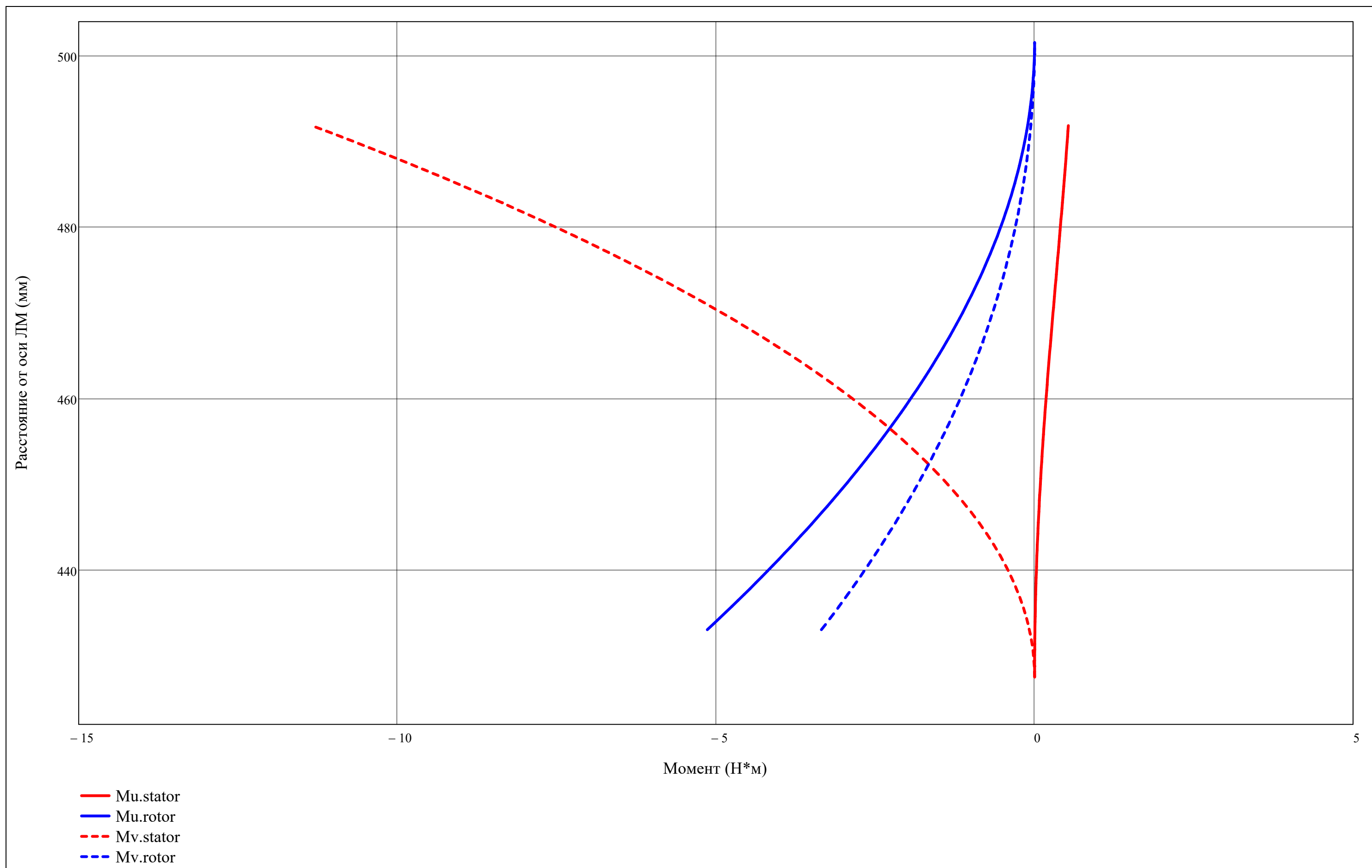


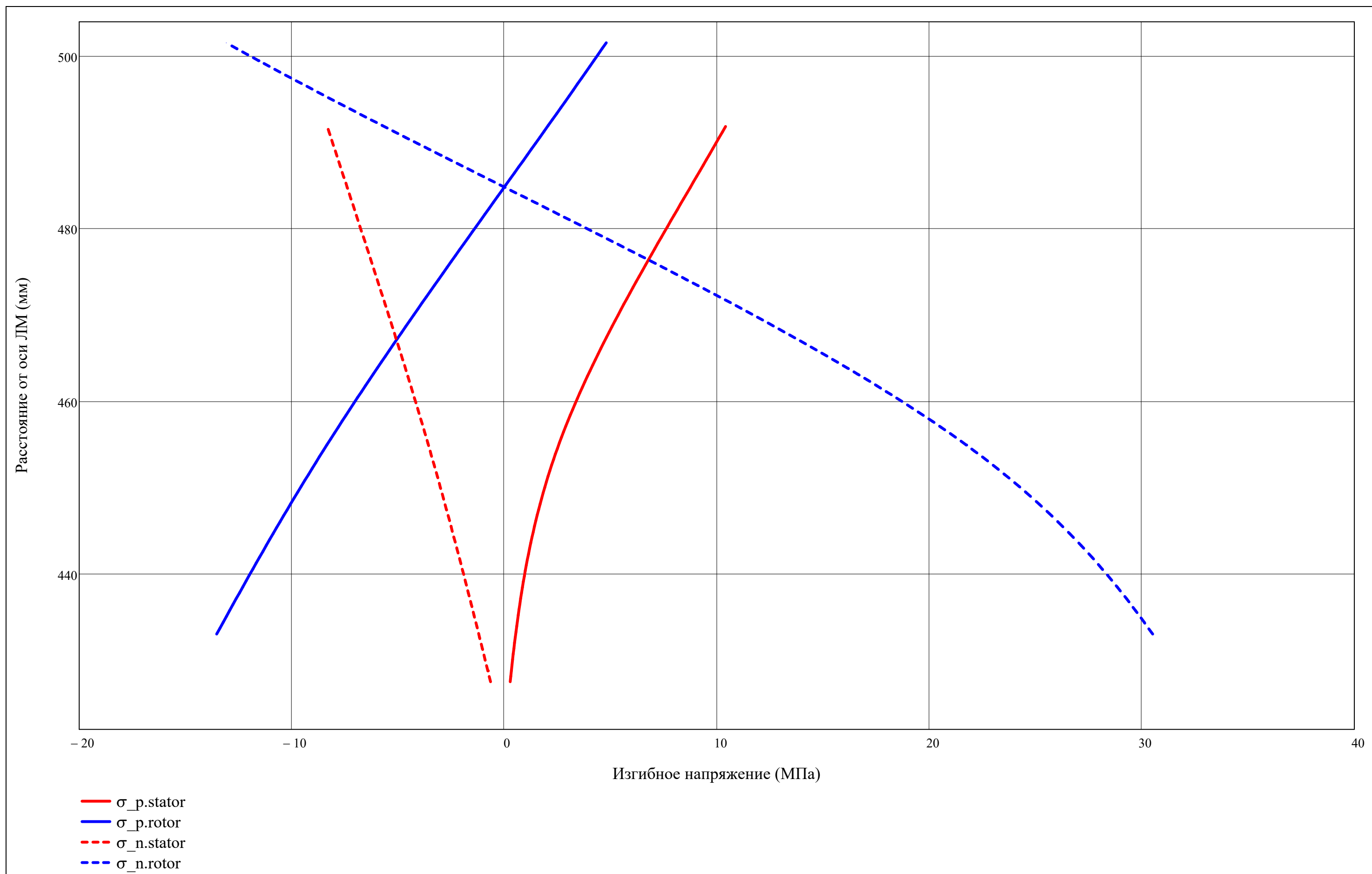


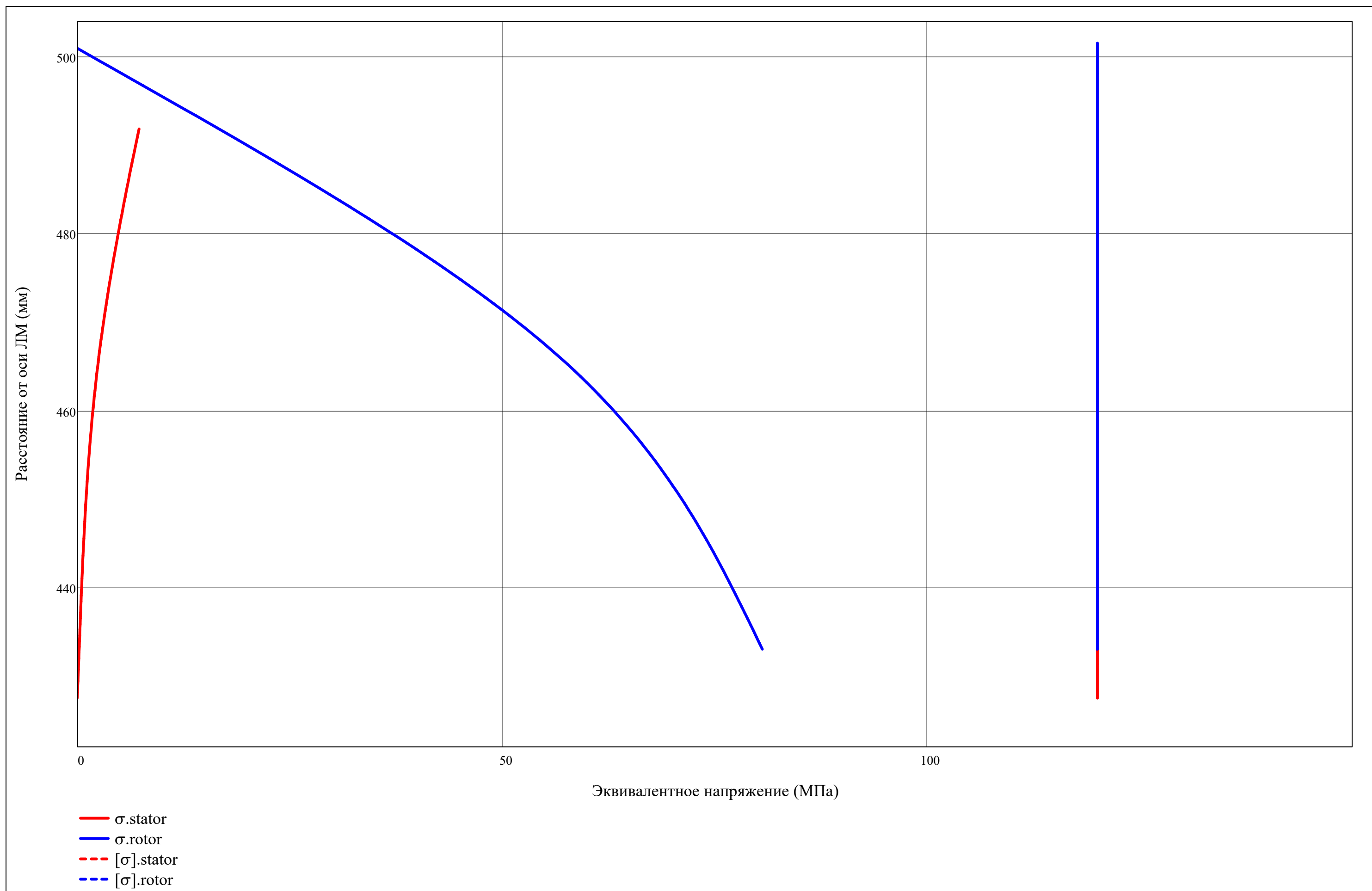












blade

r

=

"stator"

2

Наиболее удаленные точки от НЛ (мм):

u\_urotor<sub>j,r</sub>

v\_urotor<sub>j,r</sub>

u\_lrotor<sub>j,r</sub>

v\_lrotor<sub>j,r</sub>

u\_u<sub>stator<sub>j,r</sub></sub>

v\_u<sub>stator<sub>j,r</sub></sub>

u\_l<sub>stator<sub>j,r</sub></sub>

v\_l<sub>stator<sub>j,r</sub></sub>

=

	1	2
1	-0.62	3.77
2	25.85	-9.14
3	22.59	8.77
4	-24.75	-15.93

·10<sup>-3</sup>

Изгибные напряжения (Па):

σ\_protor<sub>j,r</sub>

σ\_pstator<sub>j,r</sub>

σ\_nrotor<sub>j,r</sub>

σ\_nstator<sub>j,r</sub>

=

	1	2
1	-8.8	2.3
2	22.6	-3.4

·10<sup>6</sup>

Эквивалентные напряжения (Па):

σ<sub>stator<sub>j,r</sub></sub>

σ<sub>rotor<sub>j,r</sub></sub>

=

	1
1	2.5
2	56.7

·10<sup>6</sup>

Коэф. запаса:

safety<sub>stator<sub>j,r</sub></sub>

safety<sub>rotor<sub>j,r</sub></sub>

=

	1
1	48.515
2	2.117

v\_urotor<sub>j,r</sub>

v\_lrotor<sub>j,r</sub>

v\_u<sub>stator<sub>j,r</sub></sub>

v\_l<sub>stator<sub>j,r</sub></sub>

if blade = "rotor"

=

	1
1	8.774
2	-15.935

·10<sup>-3</sup>

otherwise

x0rotor<sub>j,r</sub>

y0rotor<sub>j,r</sub>

x0<sub>stator<sub>j,r</sub></sub>

y0<sub>stator<sub>j,r</sub></sub>

if blade = "rotor"

=

	1
1	29.217
2	6.773

·10<sup>-3</sup>

otherwise

chord =

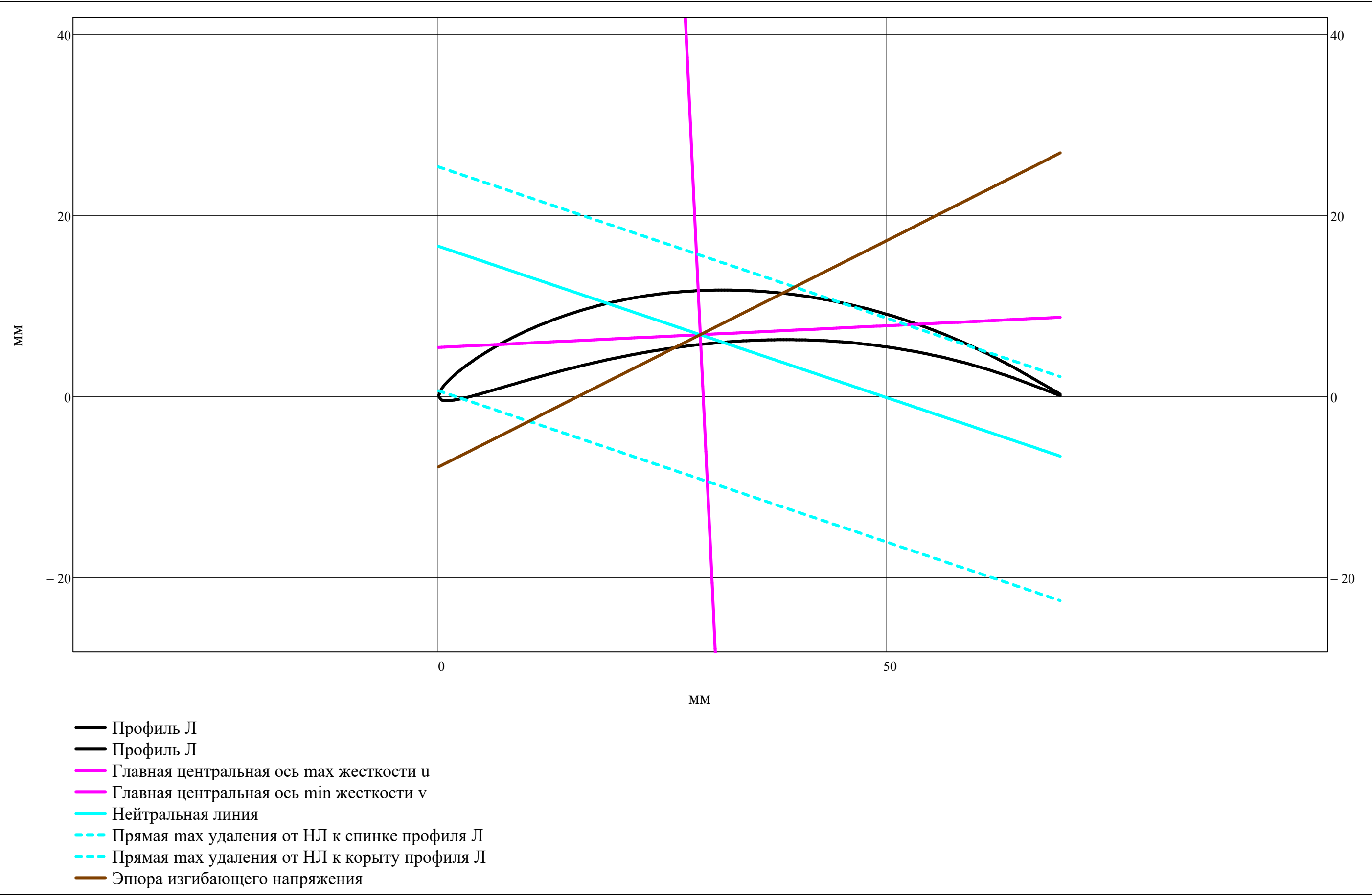
chord<sub>rotor<sub>j,r</sub></sub>

chord<sub>stator<sub>j,r</sub></sub>

if blade = "rotor"

if blade = "stator"

= 69.4·10<sup>-3</sup>



$$\begin{pmatrix} \text{blade} \\ \text{r} \end{pmatrix} = \begin{pmatrix} \text{"stator"} \\ 3 \end{pmatrix}$$

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u_{u_{\text{rotor}_{j,r}}} & v_{u_{\text{rotor}_{j,r}}} \\ u_{l_{\text{rotor}_{j,r}}} & v_{l_{\text{rotor}_{j,r}}} \\ u_{u_{\text{stator}_{j,r}}} & v_{u_{\text{stator}_{j,r}}} \\ u_{l_{\text{stator}_{j,r}}} & v_{l_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{table}
	1	2
1	0.22	3.00
2	23.50	-8.08
3	37.61	15.82
4	-19.53	-22.31

$$\text{Коэф. запаса: } \begin{pmatrix} \text{safety}_{\text{stator}_{j,r}} \\ \text{safety}_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{table}
	1
1	13.626
2	36.173

Изгибные напряжения (Па):

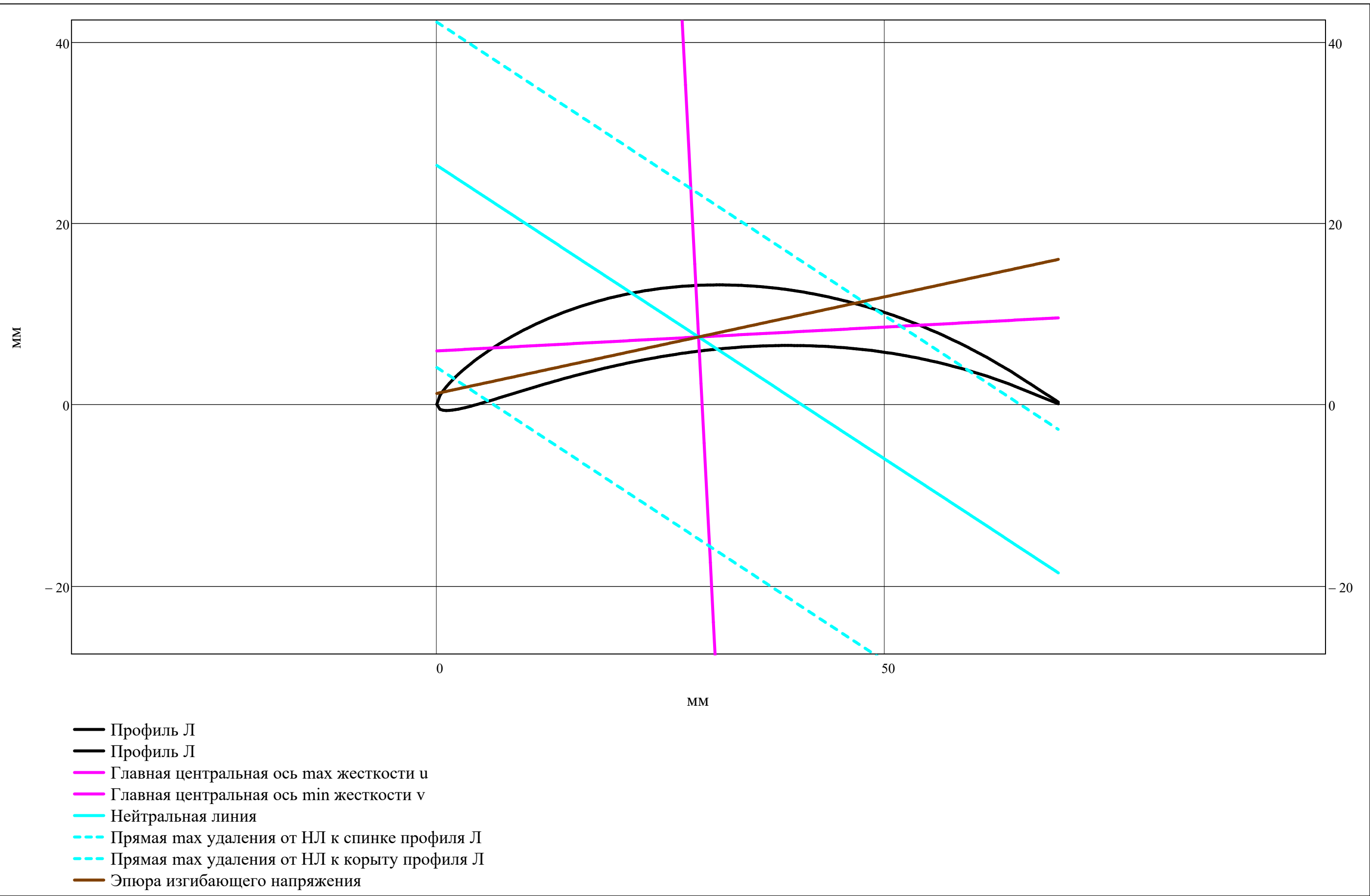
$$\begin{pmatrix} \sigma_{p_{\text{rotor}_{j,r}}} & \sigma_{p_{\text{stator}_{j,r}}} \\ \sigma_{n_{\text{rotor}_{j,r}}} & \sigma_{n_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{table}
	1	2
1	-0.1	8.7
2	0.2	-7.4

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{\text{stator}_{j,r}} \\ \sigma_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{table}
	1
1	8.8
2	3.3

$$\begin{pmatrix} v_p \\ v_n \end{pmatrix} = \begin{cases} \begin{pmatrix} v_{u_{\text{rotor}_{j,r}}} \\ v_{l_{\text{rotor}_{j,r}}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v_{u_{\text{stator}_{j,r}}} \\ v_{l_{\text{stator}_{j,r}}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{table}
	1
1	15.820
2	-22.312
$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0_{\text{rotor}_{j,r}} \\ y0_{\text{rotor}_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{\text{stator}_{j,r}} \\ y0_{\text{stator}_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{table}	
---	---
	1
1	29.217
2	7.440
$$\text{chord} = \begin{cases} \text{chord}_{\text{rotor}_{j,r}} & \text{if blade = "rotor"} \\ \text{chord}_{\text{stator}_{j,r}} & \text{if blade = "stator"} \end{cases} = 69.4 \cdot 10^{-3}$$$$$$





$$\begin{pmatrix} \text{blade} \\ \text{r} \end{pmatrix} = \begin{pmatrix} \text{"rotor"} \\ 1 \end{pmatrix}$$

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u_{u_{\text{rotor}_{j,r}}} & v_{u_{\text{rotor}_{j,r}}} \\ u_{l_{\text{rotor}_{j,r}}} & v_{l_{\text{rotor}_{j,r}}} \\ u_{u_{\text{stator}_{j,r}}} & v_{u_{\text{stator}_{j,r}}} \\ u_{l_{\text{stator}_{j,r}}} & v_{l_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & -1.00 & 5.30 \\ \hline 2 & 28.01 & -10.22 \\ \hline 3 & 15.69 & 6.03 \\ \hline 4 & -26.66 & -12.00 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{Коэф. запаса: } \begin{pmatrix} \text{safety}_{\text{stator}_{j,r}} \\ \text{safety}_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 751.571 \\ \hline 2 & 1.490 \\ \hline \end{array}$$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma_{p_{\text{rotor}_{j,r}}} & \sigma_{p_{\text{stator}_{j,r}}} \\ \sigma_{n_{\text{rotor}_{j,r}}} & \sigma_{n_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & -15.9 & 0.1 \\ \hline 2 & 33.4 & -0.1 \\ \hline \end{array} \cdot 10^6$$

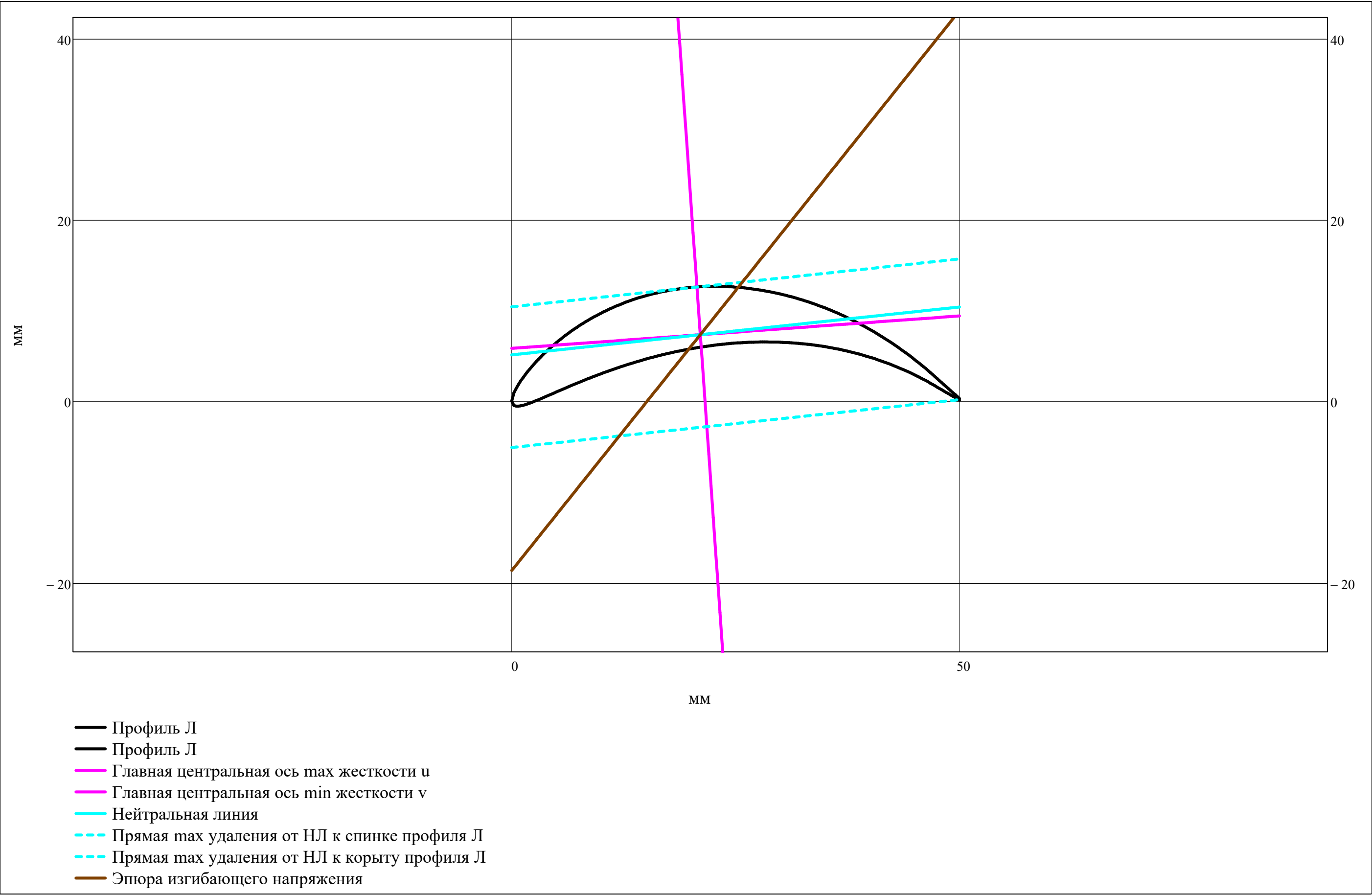
Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{\text{stator}_{j,r}} \\ \sigma_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0.2 \\ \hline 2 & 80.6 \\ \hline \end{array} \cdot 10^6$$

$$\begin{pmatrix} v_{p} \\ v_{n} \end{pmatrix} = \begin{cases} \begin{pmatrix} v_{u_{\text{rotor}_{j,r}}} \\ v_{l_{\text{rotor}_{j,r}}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v_{u_{\text{stator}_{j,r}}} \\ v_{l_{\text{stator}_{j,r}}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 5.299 \\ \hline 2 & -10.223 \\ \hline \end{array} \cdot 10^{-3}$$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0_{\text{rotor}_{j,r}} \\ y0_{\text{rotor}_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{\text{stator}_{j,r}} \\ y0_{\text{stator}_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 21.043 \\ \hline 2 & 7.333 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{chord} = \begin{cases} \text{chord}_{\text{rotor}_{j,r}} & \text{if blade = "rotor"} \\ \text{chord}_{\text{stator}_{j,r}} & \text{if blade = "stator"} \end{cases} = 50.0 \cdot 10^{-3}$$



blade

rw

=

"rotor"

2

Наиболее удаленные точки от НЛ (мм):

u\_urotorj,r

v\_urotorj,r

u\_lrotorj,r

v\_lrotorj,r

u\_ustatorj,r

v\_ustatorj,r

u\_lstatorj,r

v\_lstatorj,r

=

	1	2
1	-0.62	3.77
2	25.85	-9.14
3	22.59	8.77
4	-24.75	-15.93

·10<sup>-3</sup>

Изгибные напряжения (Па):

σ\_protorj,r

σ\_pstatorj,r

σ\_nrotorj,r

σ\_nstatorj,r

=

	1	2
1	-8.8	2.3
2	22.6	-3.4

·10<sup>6</sup>

Эквивалентные напряжения (Па):

σ\_statorj,r

σ\_rotorj,r

=

	1
1	2.5
2	56.7

·10<sup>6</sup>

Коэф. запаса:

safety\_statorj,r

safety\_rotorj,r

=

	1
1	48.515
2	2.117

v\_p

v\_n

=

v\_urotorj,r

v\_lrotorj,r

v\_ustatorj,r

v\_lstatorj,r

if blade = "rotor"

=

	1
1	3.765
2	-9.138

·10<sup>-3</sup>

otherwise

x0

y0

=

x0\_rotorj,r

y0\_rotorj,r

x0\_statorj,r

y0\_statorj,r

if blade = "rotor"

=

	1
1	19.349
2	6.782

·10<sup>-3</sup>

otherwise

chord

=

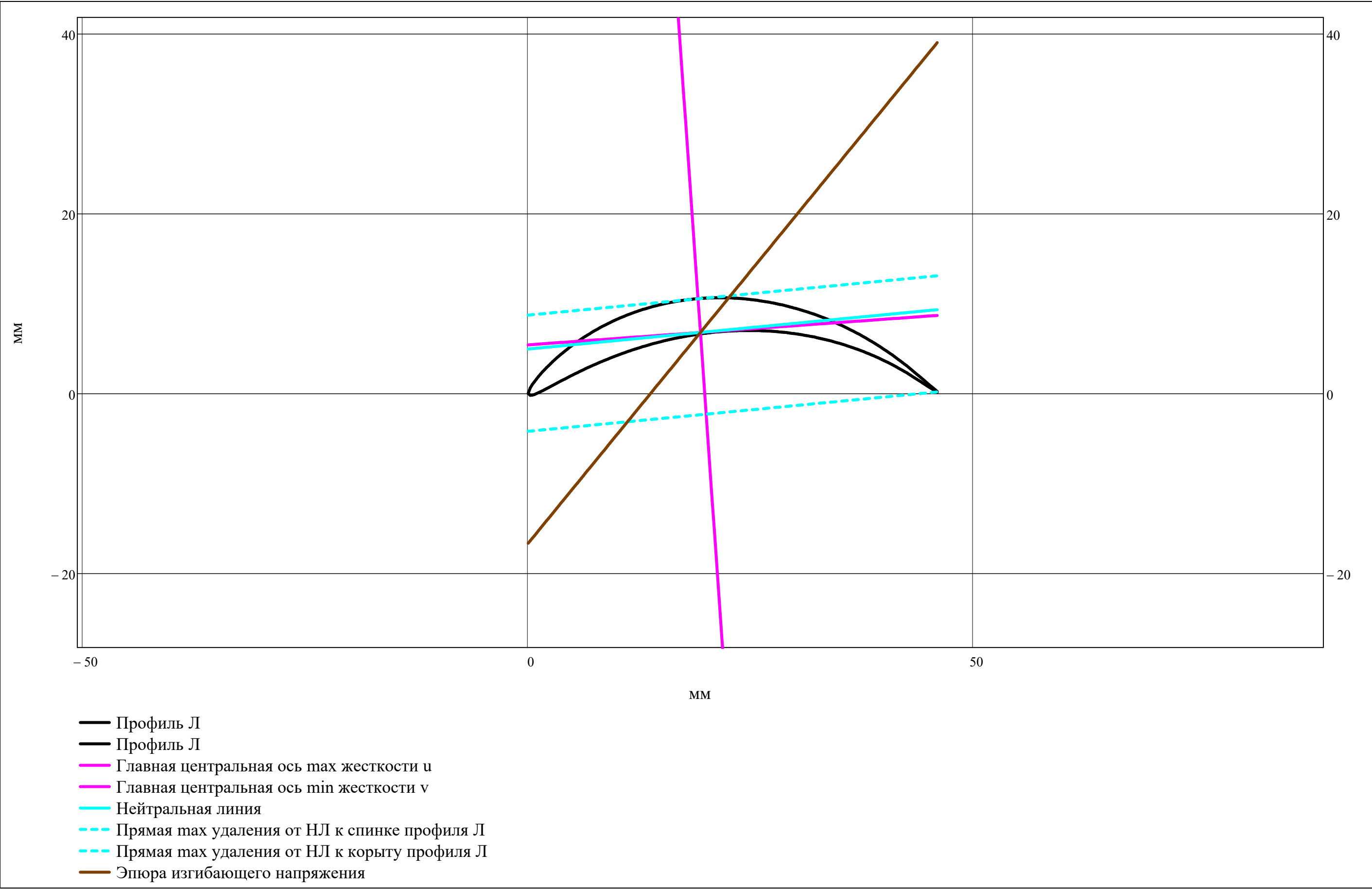
chord\_rotorj,r

chord\_statorj,r

if blade = "rotor"

if blade = "stator"

= 45.9 · 10<sup>-3</sup>



Запас по температуре (K):

$\Delta T_{\text{safety}} = 0$

Выбранный материал Д:

$\text{material\_disk}_i = \begin{cases} \text{"ВЖ175"} & \text{if turbine = "ТВД"} \\ \text{"ЭП742"} & \text{if turbine = "ТНД"} \end{cases}$

Плотность материала Д (кг/м^3):

$\rho_{\text{disk}}_i = \begin{cases} 8266 & \text{if material\_disk}_i = \text{"ВЖ175"} \\ 8320 & \text{if material\_disk}_i = \text{"ЭП742"} \\ 8393 & \text{if material\_disk}_i = \text{"ЖС-6К"} \\ 7900 & \text{if material\_disk}_i = \text{"BT41"} \\ 4500 & \text{if material\_disk}_i = \text{"BT25"} \\ 4570 & \text{if material\_disk}_i = \text{"BT23"} \\ 4510 & \text{if material\_disk}_i = \text{"BT9"} \\ 4430 & \text{if material\_disk}_i = \text{"BT6"} \\ \text{NaN} & \text{otherwise} \end{cases}$

Предел длительной прочности Д (Па):

$\sigma_{\text{disk\_long}}_i = 10^6 \cdot \begin{cases} 620 & \text{if material\_disk}_i = \text{"ВЖ175"} \\ 680 & \text{if material\_disk}_i = \text{"ЭП742"} \\ 125 & \text{if material\_disk}_i = \text{"ЖС-6К"} \\ 123 & \text{if material\_disk}_i = \text{"BT41"} \\ 150 & \text{if material\_disk}_i = \text{"BT25"} \\ 230 & \text{if material\_disk}_i = \text{"BT23"} \\ 200 & \text{if material\_disk}_i = \text{"BT9"} \\ 210 & \text{if material\_disk}_i = \text{"BT6"} \\ \text{NaN} & \text{otherwise} \end{cases}$

$\text{material\_disk}^T =$

	1	2	3	4
1	"ЭП742"	"ЭП742"	"ЭП742"	"ЭП742"

$\rho_{\text{disk}}^T =$

	1	2	3	4
1	8320	8320	8320	8320

$\sigma_{\text{disk\_long}}^T =$

	1	2	3	4
1	680	680	680	680

$\cdot 10^6$

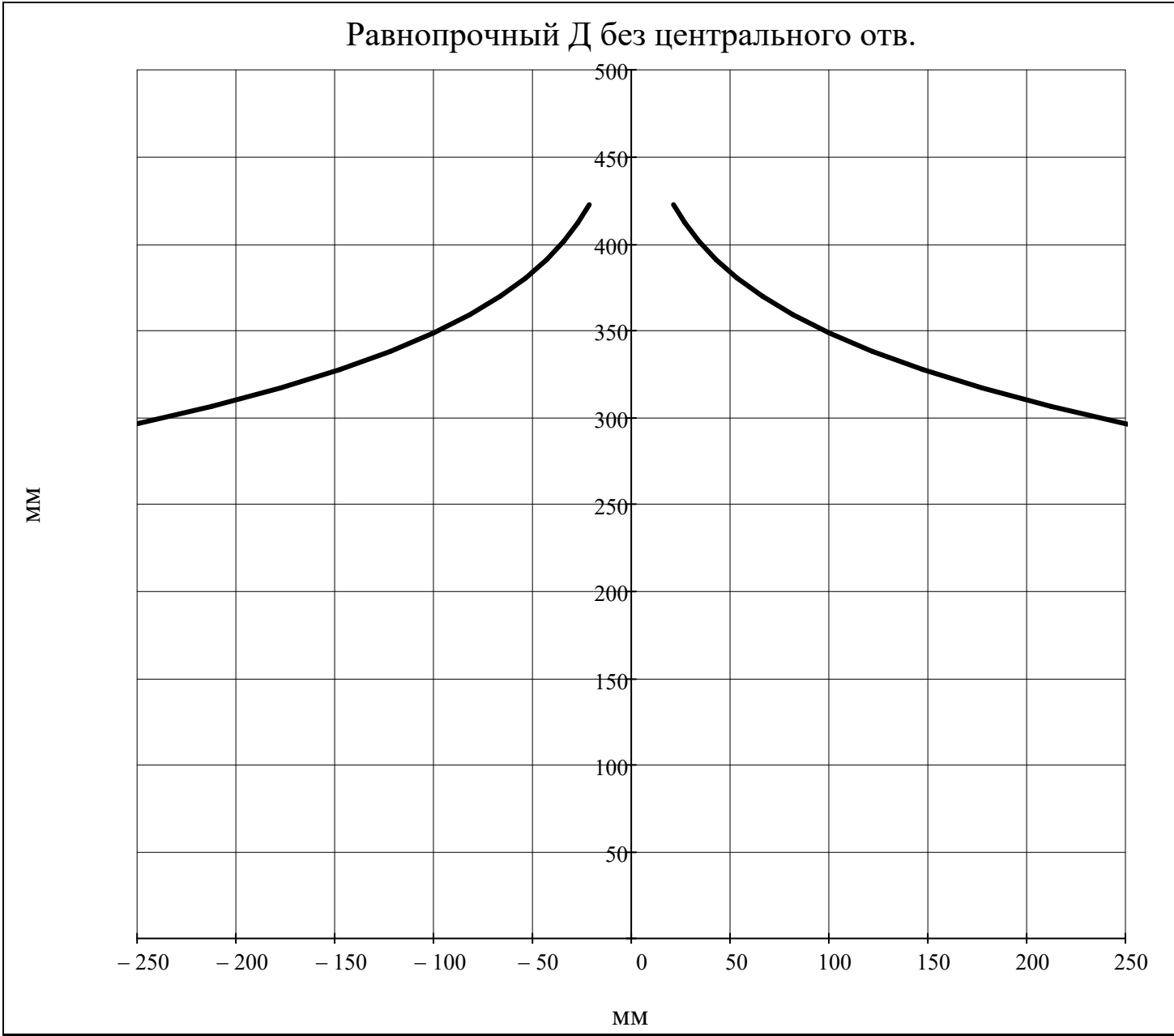
Рассматриваемая ступень:

$$j_w = \begin{cases} j = Z & \\ j = \begin{cases} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{cases} & \end{cases} = 4$$

Профилирование равнопрочного Д без центрального отв.

$$h(i,z) = \begin{cases} \left( \text{chord}_{\text{rotor}_i, \text{ORIGIN}} \cdot \sin\left(v_{\text{rotor}_i, \text{ORIGIN}}\right) \right) \cdot e^{\frac{\rho_{\text{disk}_i} \cdot \omega^2}{2} \cdot \frac{1}{\sigma_{z_{\text{rotor}}(i, R_{\text{st}(i,2), \text{ORIGIN}})}} \cdot \left[ \left( R_{\text{st}(i,2), \text{ORIGIN}} \right)^2 - z^2 \right]} & \text{if } z \leq R_{\text{st}(i,2), \text{ORIGIN}} \\ \text{NaN} & \text{otherwise} \end{cases}$$

$$z = 0, \frac{R_{\text{st}(j,2), \text{ORIGIN}}}{N_{\text{dis}}} \dots R_{\text{st}(j,2), \text{ORIGIN}}$$



Профилирование равнопрочного Д без центрального отв.