







Исходные данные

Коэф. запаса:

safety = 1.3

Горючее:

Fuel = "Керосин"

turbine = "ТВД"

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	32.30
2	0.11
3	3.24

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"

 = 14.893·10<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"

 = 2731.8·10<sup>3</sup>

Полная температура перед Т (К):

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

1773 if turbine = "ТВД"

1368.9 if turbine = "ТНД"

 = 1773.0

Коэф. избытка воздуха в Т:

α<sub>ох</sub> = 

2.267 if turbine = "ТВД"

2.493 if turbine = "ТНД"

 = 2.267

Полное давление отбора охлаждающего воздуха (К):

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

2845.6 if turbine = "ТВД"

319.4 if turbine = "ТНД"

 = 2845.6·10<sup>3</sup>

Полная температура отбора охлаждающего воздуха (К):

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

806.9 if turbine = "ТВД"

418.2 if turbine = "ТНД"

 = 806.9

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:

$\eta_{\text{Л}} = 88\%$

$88\% \leq \eta_{\text{Л}} \leq 95\% = 1$

Угол входа в Т:

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

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

$$\begin{pmatrix} c_{\Gamma} \\ c_T \end{pmatrix} = \begin{cases} \begin{pmatrix} 100 \\ 180 \end{pmatrix} & \text{if turbine = "ТВД"} \\ \begin{pmatrix} 180 \\ 260 \end{pmatrix} & \text{if turbine = "ТНД"} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 100.0 \\ \hline 2 & 180.0 \\ \hline \end{array}$$

$$u_T = \begin{cases} 520 & \text{if turbine = "ТВД"} \\ 260 & \text{if turbine = "ТНД"} \end{cases} = 520.0$$

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

Полное давление отбора охлаждающего воздуха (K):  
 $P_{cooling}^* = P_{cooling}^* \cdot \sigma_{cooling} = 2760.2 \cdot 10^3$

Полная температура отбора охлаждающего воздуха (K):  
 $T_{cooling}^* = T_{cooling}^* + \Delta T_{\text{охл.подогрев}} = 846.9$

Массовый расход перед Т (кг/с):  
 $G_{T_{in}} = G_T - G_{leak} = 32.2$

Массовый расход после Т (кг/с):  
 $G_T = G_T + G_{cooling} = 35.4$

Удельная работа Т (Дж/кг):  
 $L_T^* = \frac{N_T}{\text{mean}(G_T, G_T)} = 440.4 \cdot 10^3$

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

Располагаемый теплоперепад в Т (Дж/кг):  
 $H_T = \frac{L_T^* + 0.5c_T^2}{\eta_{\text{л}}} = 518.9 \cdot 10^3$

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> =  $\frac{k_{\Gamma}}{k_{\Gamma} - 1} \cdot R_{\text{Газ}}(\alpha_{\text{ox}}, \text{Fuel})$

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

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

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	2705198.4
4	1769.2

Количество итераций: iteration = 1

Показатель адиабаты перед Т: k<sub>Г</sub> = 1.283

Статическое давление перед Т (Па): P<sub>Г</sub> = 2705.2·10<sup>3</sup>

Статическая температура перед Т (K): T<sub>Г</sub> = 1769.2

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) = 1309

iteration		
k <sub>T</sub>		
P <sub>T</sub>		
T <sub>T</sub>		
=	iteration = 0	=
	k <sub>T</sub> = k <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	1
2	1.293
3	866477.23
4	1424.088

Количество итераций: iteration = 1

Показатель адиабаты после T: k<sub>T</sub> = 1.293

Статическое давление после T (Па): P<sub>T</sub> = 866.5·10<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> = 1424.1

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) = 1271.6



Ср. показатель адиабаты T:  $k = \text{mean}\Big(k_\Gamma,k_T\Big) = 1.288$

Ср. теплоемкость T (Дж/кг/К):  $C_p = \frac{k}{k-1}\cdot R_{\text{газ}}\Big(\alpha_{\text{ox}},\text{Fuel}\Big) = 1289.8$

Степень понижения давления:  $\pi_T = \frac{P_\Gamma^*}{P_T} = 3.15$

Удельный объём перед T (м³/кг):

Удельный объём после T (м³/кг):

$\left(\begin{array}{c} v_\Gamma \\ v_T \end{array}\right)$

$= R_{\text{газ}}\Big(\alpha_{\text{ox}},\text{Fuel}\Big)\cdot$

$\left(\begin{array}{c} \frac{T_\Gamma}{P_\Gamma} \\ \frac{T_T}{P_T} \end{array}\right)$

	1
1	0.189
2	0.474

$=$

Площадь кольцевого сечения перед T (м²):

Площадь кольцевого сечения после T (м²):

$\left(\begin{array}{c} F_\Gamma \\ F_T \end{array}\right)$

$=$

$\left(\begin{array}{c} \frac{G_\Gamma\cdot v_\Gamma}{c_\Gamma} \\ \frac{G_T\cdot v_T}{c_T} \end{array}\right)$

$=$

	1
1	60741
2	93341

$\cdot 10^{-6}$

$$y_0 = 0.55$$

Коэф. использования скорости:

$$\mu_c = \text{mean}(0.7, 1) = 0.9$$

$$0.7 \leq \mu_c \leq 1 = 1$$

▼ Определение количества ступеней T

$$\begin{pmatrix} Z_{\text{recomend}} \\ \alpha_{\text{ВОЗВ}} \end{pmatrix} =$$

$$c_{cp} = \text{mean}(c_T, c_T)$$

$$\alpha_{\text{ВОЗВ}} = 0.025$$
while 1 > 0

$$Z = \text{round} \left[ \frac{2 \cdot H_T \cdot \frac{(1 + \alpha_{\text{ВОЗВ}})}{(\mu_c \cdot c_{cp})^2} - 1}{\frac{u_T^2}{(\mu_c \cdot c_{cp})^2 \cdot y_0^2} - 1} \right]$$

break if  $\left| \text{eps} \left[ \text{"rel"}, \alpha_{\text{ВОЗВ}}, \frac{Z - 1}{2 \cdot Z} \cdot \left( \pi_T^{\frac{k-1}{k}} - 1 \right) \cdot (1 - \eta_{\text{л}}) \right] \right| < \text{epsilon}$

$$\alpha_{\text{ВОЗВ}} = \frac{Z - 1}{2 \cdot Z} \cdot \left( \pi_T^{\frac{k-1}{k}} - 1 \right) \cdot (1 - \eta_{\text{л}})$$

if  $\alpha_{\text{ВОЗВ}} = 0$ 

$$\begin{pmatrix} Z \\ \alpha_{\text{ВОЗВ}} \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

break

$$\begin{pmatrix} Z \\ \alpha_{\text{ВОЗВ}} \end{pmatrix}$$

	1
1	1.000
2	0.000

Рекомендуемое количество ступеней:  $Z_{\text{recomend}} = 1$

Количество ступеней:

$$Z = \begin{cases} 1 & \text{if turbine = "ТВД"} \\ 4 & \text{if turbine = "ТНД"} \end{cases} = 1$$

Дискретизация ступеней:  $i = 1 \dots Z$

Дискретизация сечений:  $ii = 1 \dots 2 \cdot Z + 1$

▲ Определение количества ступеней T

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
1	"ВКНА-1В"

ρ<sub>blade</sub><sup>T</sup> =

	1
1	7938

σ<sub>blade\_long</sub><sup>T</sup> =

	1
1	205

· 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):

$$\sqrt{\frac{\sigma\_blade\_longZ}{safety \cdot k_n \cdot F_{\Gamma}}} = 19539$$

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

$$n_{max} = \sqrt{\frac{\sigma\_blade\_longZ}{safety \cdot k_n \cdot F_T}} = 15762$$

Рекомендукмая ном. частота вращения (об/мин):

$$n = n_{max} \cdot 0.95 = 14974$$

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

Ном. частота вращения (рад/с):

$$\omega = \frac{2 \cdot \pi \cdot n}{60} = 1570.8$$

Ср. диаметр перед Т (м):

$$\left( \begin{array}{c} D_{\Gamma.cp} \\ D_{T.cp} \end{array} \right) = \frac{2}{\omega} \cdot \left( \begin{array}{c} u_T \\ u_T \end{array} \right) = \left( \begin{array}{cc} & 1 \\ 1 & 662.1 \\ 2 & 662.1 \end{array} \right) \cdot 10^{-3}$$

Ср. диаметр после Т (м):

Длина Л первой ступени Т (м):

$$\left( \begin{array}{c} l_{\Gamma} \\ l_T \end{array} \right) = \frac{1}{\pi} \cdot \left( \begin{array}{c} \frac{F_{\Gamma}}{D_{\Gamma.cp}} \\ \frac{F_T}{D_{T.cp}} \end{array} \right) = \left( \begin{array}{cc} & 1 \\ 1 & 29.20 \\ 2 & 44.88 \end{array} \right) \cdot 10^{-3}$$

Длина Л последней ступени Т (м):

$$\frac{l_{\Gamma}}{D_{\Gamma.cp}} = \frac{1}{22}$$

$$\frac{l_T}{D_{T.cp}} = \frac{1}{14}$$

Диаметр периферии после Т (м):

$$\left( \begin{array}{c} D_{T.пер} \\ D_{T.кор} \end{array} \right) = \left( \begin{array}{c} D_{T.cp} + l_T \\ D_{T.cp} - l_T \end{array} \right) = \left( \begin{array}{cc} & 1 \\ 1 & 707.0 \\ 2 & 617.2 \end{array} \right) \cdot 10^{-3}$$

Диаметр корня после Т (м):

Равномерное распределение мощности Т по ступеням (Вт):  
 $N_{\text{сТ}_i} = \frac{N_{\text{T}}}{Z}$

$N_{\text{сТ}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 14.89 \\ \hline \end{array} \cdot 10^6$

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

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

▼ Определение проточной части ОТ

Линейное распределение кольцевых площадей по сечениям:

$$\begin{array}{|l} F_{\text{ww}} = \text{for } i \in 1..2Z + 1 \\ \\ F_i = \frac{F_{\text{T}} - F_{\text{Г}}}{\text{st}(Z, 3) - 1} \cdot i + \left( F_{\text{Г}} - \frac{F_{\text{T}} - F_{\text{Г}}}{\text{st}(Z, 3) - 1} \right) \\ \\ \text{for } i \in 1..Z \\ \\ \text{for } a \in 2..3 \\ \\ F_{\text{st}(i, a)} = F_{\text{st}(i, a-1)} \text{ if } \text{ЗППЧ}_{i, a-1} = \text{"const"} \\ \\ F \end{array}$$

$F^{\text{T}} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 60741 & 60741 & 93341 & & & & & & \\ \hline \end{array} \cdot 10^{-6}$

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

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

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

if 3ΠΠΠΨ<sub>i,a</sub> = "kop"

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

$\frac{1}{2} \cdot \left[ D_{st(i,a+1),1} + \sqrt{\left( D_{st(i,a+1),1} \right)^2 + \frac{4 \cdot F_{st(i,a)}}{\pi}} \right]$  if r = av(N<sub>r</sub>)

$\sqrt{\left( D_{st(i,a+1),1} \right)^2 + \frac{4 \cdot F_{st(i,a)}}{\pi}}$  if r = N<sub>r</sub>

if 3ΠΠΠΨ<sub>i,a</sub> = "cp"

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

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

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

if 3ΠΠΠΨ<sub>i,a</sub> = "nep"

$\sqrt{\left( D_{st(i,a+1),N_r} \right)^2 - \frac{4 \cdot F_{st(i,a)}}{\pi}}$  if r = 1

$\frac{1}{2} \cdot \left[ \sqrt{\left( D_{st(i,a+1),N_r} \right)^2 - \frac{4 \cdot F_{st(i,a)}}{\pi}} + D_{st(i,a+1),N_r} \right]$  if r = av(N<sub>r</sub>)

D if r = N<sub>r</sub>

D<sup>T</sup> =

	1	2	3	4	5	6	7	8	9
1	650.0	650.0	617.2						
2	678.5	678.5	662.1						
3	707.0	707.0	707.0						

·10<sup>-3</sup>

R

=

D

2

R<sup>T</sup> =

	1	2	3	4	5	6	7	8	9
1	325.0	325.0	308.6						
2	339.2	339.2	331.0						
3	353.5	353.5	353.5						

·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	0.9194	0.9194	0.8730						

d̄<sup>T</sup> ≤ 0.9 =

	1	2	3
1	0	0	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
1	28.50	28.50	44.88

·10<sup>-3</sup>

$$D_{\text{st}(i,a+1),N_r}^{u_i - v_r}$$
if  $\left(3\Pi\Pi\Pi_{i,a} \neq \text{"const"}\right) \wedge \left(3\Pi\Pi\Pi_{i,a} \neq \text{"kop"}\right) \wedge \left(3\Pi\Pi\Pi_{i,a} \neq \text{"cp"}\right) \wedge \left(3\Pi\Pi\Pi_{i,a} \neq \text{"nep"}\right)$ 

$$\sqrt{\left(\frac{D_{\text{st}(i,a+1),N_r}}{\text{str2num}\left(3\Pi\Pi\Pi_{i,a}\right)}\right)^2 - \frac{4\cdot F_{\text{st}(i,a)}}{\pi}}$$
if  $r = 1$ 

$$\frac{1}{2}\cdot\left[\sqrt{\left(\frac{D_{\text{st}(i,a+1),N_r}}{\text{str2num}\left(3\Pi\Pi\Pi_{i,a}\right)}\right)^2 - \frac{4\cdot F_{\text{st}(i,a)}}{\pi}} + \frac{D_{\text{st}(i,a+1),N_r}}{\text{str2num}\left(3\Pi\Pi\Pi_{i,a}\right)}\right]$$
if  $r = \text{av}\left(N_r\right)$ 

$$\frac{D_{\text{st}(i,a+1),N_r}}{\text{str2num}\left(3\Pi\Pi\Pi_{i,a}\right)}$$
if  $r = N_r$ 
NaN otherwise

D

$$u = \begin{cases} \text{for } i \in 1..2\cdot Z + 1 \\ \text{for } r \in 1..N_r \\ u_{i,r} = \frac{\pi\cdot D_{i,r}\cdot n}{60} \end{cases}$$

u

$$u^T =$$

	1	2	3	4	5	6	7	8	9
1	510.5	510.5	484.8						
2	532.9	532.9	520.0						
3	555.2	555.2	555.2						

$F^T =$ 

	1	2	3	4	5	6	7	8	9
1	60741	60741	93341						

$\cdot 10^{-6}$

$\overline{d}_1 = 0.9194$

$\overline{d}_1 \leq 0.9 = 0$

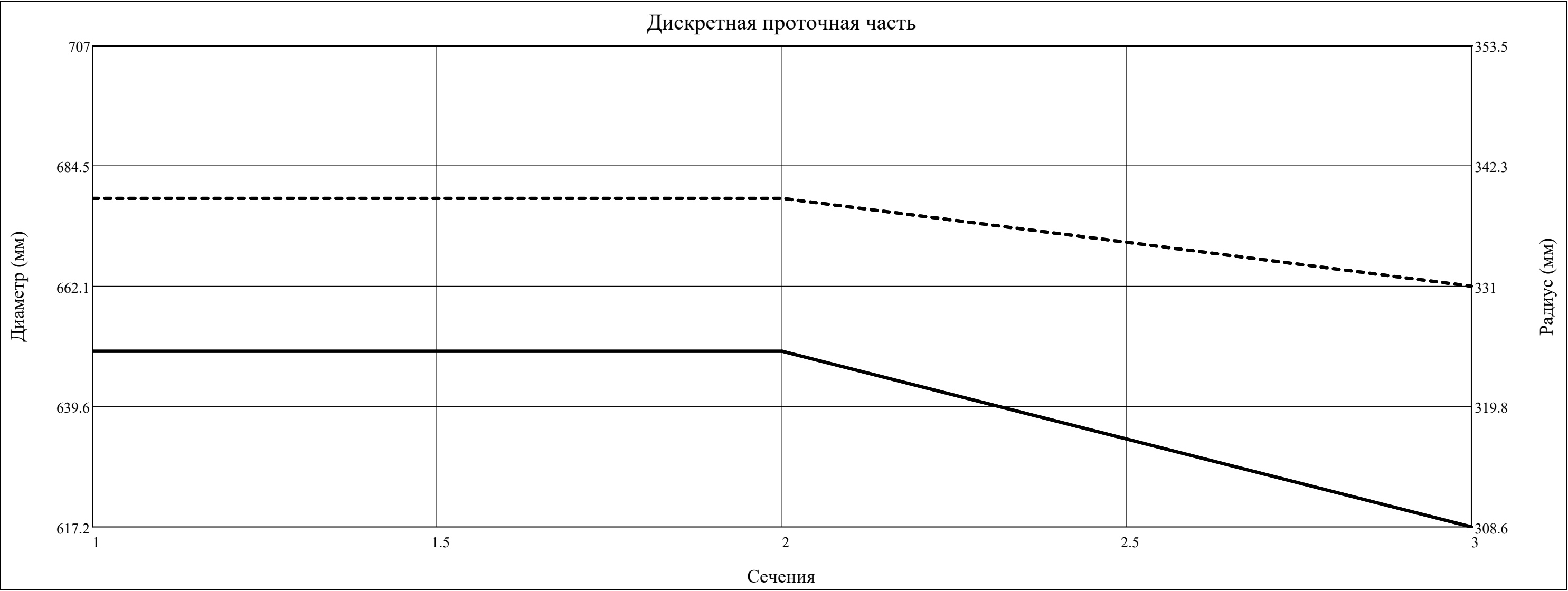
$\overline{d}^T =$ 

	1	2	3	4	5	6	7	8	9
1	0.9194	0.9194	0.8730						

$D^T =$ 

	1	2	3
1	650.0	650.0	617.2
2	678.5	678.5	662.1
3	707.0	707.0	707.0

$\cdot 10^{-3}$



$h^T =$ 

	1	2	3
1	28.50	28.50	44.88

$\cdot 10^{-3}$





$$\begin{pmatrix} \gamma_{\Pi\Upsilon_{\text{пер}}} \\ \gamma_{\Pi\Upsilon} \\ \gamma_{\Pi\Upsilon_{\text{кор}}} \end{pmatrix} = \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } a \in 1..2 \\ \quad \quad \text{for } r \in N_r \\ \quad \quad \left| \begin{array}{l} \begin{pmatrix} k_2 \\ k_1 \end{pmatrix} = \frac{0.5}{B_{CA_i}} \cdot \begin{pmatrix} D_{\text{st}(i,2),r} - D_{\text{st}(i,1),r} \\ 0 \end{pmatrix} \text{ if } a = 1 \\ \begin{pmatrix} k_2 \\ k_1 \end{pmatrix} = \frac{0.5}{B_{PK_i}} \cdot \begin{pmatrix} D_{\text{st}(i,3),r} - D_{\text{st}(i,2),r} \\ 0 \end{pmatrix} \text{ if } a = 2 \\ \gamma_{\Pi\Upsilon_{\text{пер}}_{\text{st}(i,a)}} = \text{atan}\left(\frac{k_2 - k_1}{1 + k_2 \cdot k_1}\right) \end{array} \right. \\ \text{for } i \in 1..Z \\ \quad \text{for } a \in 1..2 \\ \quad \quad \left| \begin{array}{l} \begin{pmatrix} k_2 \\ k_1 \end{pmatrix} = \frac{0.5}{B_{CA_i}} \cdot \begin{pmatrix} D_{\text{st}(i,2),N_r} - D_{\text{st}(i,1),N_r} \\ D_{\text{st}(i,2),1} - D_{\text{st}(i,1),1} \end{pmatrix} \text{ if } a = 1 \\ \begin{pmatrix} k_2 \\ k_1 \end{pmatrix} = \frac{0.5}{B_{PK_i}} \cdot \begin{pmatrix} D_{\text{st}(i,3),N_r} - D_{\text{st}(i,2),N_r} \\ D_{\text{st}(i,3),1} - D_{\text{st}(i,2),1} \end{pmatrix} \text{ if } a = 2 \\ \gamma_{\Pi\Upsilon_{\text{st}(i,a)}} = \text{atan}\left(\frac{k_2 - k_1}{1 + k_2 \cdot k_1}\right) \end{array} \right. \\ \text{for } i \in 1..Z \\ \quad \text{for } a \in 1..2 \\ \quad \quad \text{for } r \in 1 \\ \quad \quad \left| \begin{array}{l} \begin{pmatrix} k_2 \\ k_1 \end{pmatrix} = \frac{0.5}{B_{CA_i}} \cdot \begin{pmatrix} D_{\text{st}(i,2),r} - D_{\text{st}(i,1),r} \\ 0 \end{pmatrix} \text{ if } a = 1 \\ \begin{pmatrix} k_2 \\ k_1 \end{pmatrix} = \frac{0.5}{B_{PK_i}} \cdot \begin{pmatrix} D_{\text{st}(i,3),r} - D_{\text{st}(i,2),r} \\ 0 \end{pmatrix} \text{ if } a = 2 \\ \gamma_{\Pi\Upsilon_{\text{кор}}_{\text{st}(i,a)}} = \text{atan}\left(\frac{k_2 - k_1}{1 + k_2 \cdot k_1}\right) \end{array} \right. \\ \begin{pmatrix} \gamma_{\Pi\Upsilon_{\text{пер}}} \\ \gamma_{\Pi\Upsilon} \\ \gamma_{\Pi\Upsilon_{\text{кор}}} \end{pmatrix} \end{array}$$

$$\text{stack}\Big(\gamma_{\Pi\Upsilon_{\text{кор}}}^T, \gamma_{\Pi\Upsilon}^T, \gamma_{\Pi\Upsilon_{\text{пер}}}^T\Big) = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & 0.00 & -28.56 \\ \hline 2 & -0.00 & 28.56 \\ \hline 3 & 0.00 & 0.00 \\ \hline \end{array} .^{\circ}$$

$$\gamma_{\Pi\Upsilon}^T \leq 20.^{\circ} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$\gamma_{\Pi\Upsilon}^T \leq 25.^{\circ} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

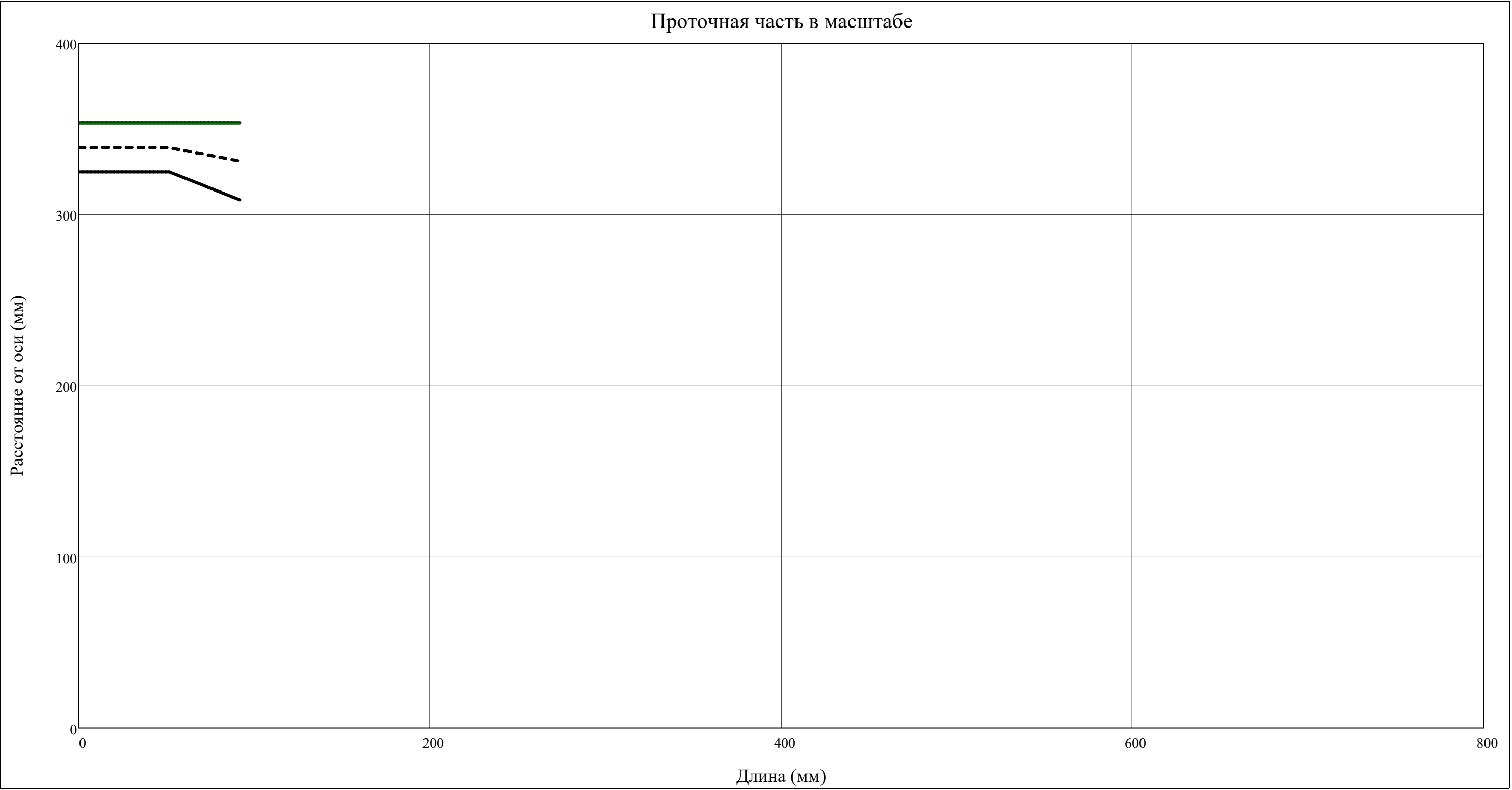
$$\gamma_{\Pi\Upsilon_{\text{кор}}}^T > -12.^{\circ} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$

$$\gamma_{\Pi\Upsilon_{\text{кор}}}^T > -15.^{\circ} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & 1 & 0 \\ \hline \end{array}$$



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

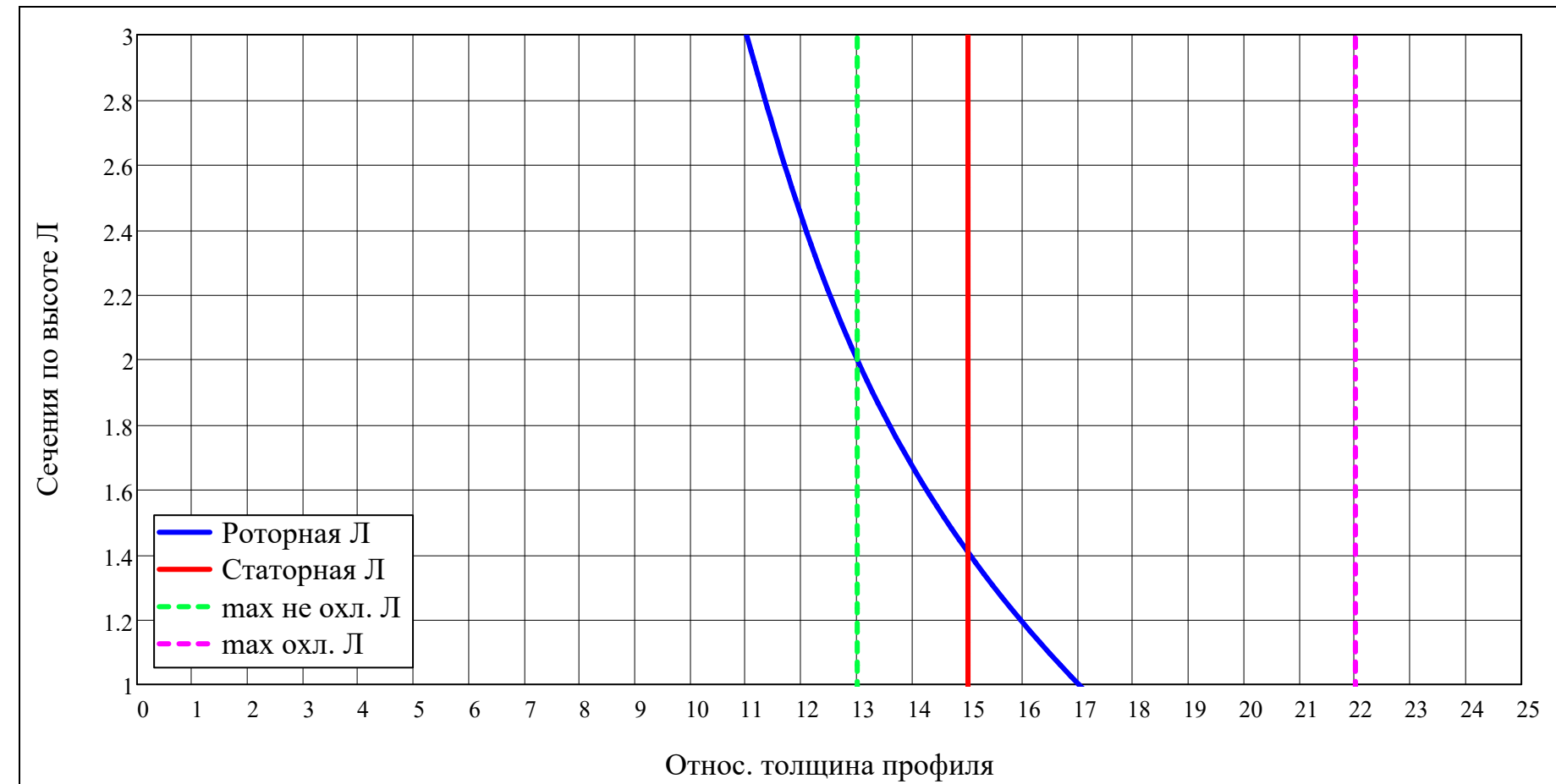
$y_{Лпер}(l) = \text{interp}(\text{cspline}(x_{ПЧ}, 0.5 \cdot y_{Лпер}), x_{ПЧ}, 0.5 \cdot y_{Лпер}, l)$



Относ. толщины ЛРК и СА:

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

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



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

		1
$\overline{c}_{\text{stator}}^T$	1	15.00
	2	15.00
	3	15.00

·%

		1
$\overline{c}_{\text{rotor}}^T$	1	17.00
	2	13.00
	3	11.00

·%

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

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
1	6.000
2	6.000
3	6.000

·%

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

	1
1	3.000
2	3.000
3	3.000

·%

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

	1
1	5.950
2	4.550
3	3.850

·%

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

	1
1	2.550
2	1.950
3	1.650

·%

▶ Вывод результатов поступенчатого расчета продольной геометрии ОТ в EXCEL:

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

▼ 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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

iteration<sub>сТ<sub>i</sub></sub> = 0

while 1 > 0

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

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

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

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

$k_{CA}$ .

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

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

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

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

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

$$\left| k_{st(i,2),r} = k' \right.$$

$$\left| \text{break} \right.$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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  $1 > 0$

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

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

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

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

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

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

$$\alpha_{\text{ox}_{st(i,3)}} = \alpha_{\text{ox}_{st(i,2)}} + g_{\text{охл}PK_i}$$

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

while 1 > 0

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

$$T_{a_{st(i,3),r}} = T_{st(i,2),r} - \frac{H_{\text{rotor}_i}}{\frac{k_{PK_i}}{k_{PK_i} - 1} \cdot R_{\text{газ.ср}}(\alpha_{\text{ox}_{st(i,2)}}, \alpha_{\text{ox}_{st(i,3)}}, \text{Fuel})}$$

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

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

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

$$k' = k_{a_{\text{д}}} (Cp_3, R_{\text{газ}}(\alpha_{\text{ox}_{st(i,3)}}, \text{Fuel}))$$

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

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

break

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\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_{pгаз} \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 \text{break}
\end{aligned}$$



$$\begin{aligned} \overline{v}_{\text{rotor}_i} &= \sqrt{1 - \xi_{\text{смпк}_i} - \xi_{\text{тдпк}_i} - \xi_{\text{втпк}_i} - \xi_{\text{ппк}_i}} \\ \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_{\text{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_{\text{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} \Big( \text{concat} \Big( \text{"eps(N) = "}, \text{num2str} \Big( \text{eps} \Big( \text{"rel"}, N_{\text{сТ}_i}, L_{\text{сТ}_i} \cdot \text{mean}(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}) \Big) \Big) \Big) \Big) \\ \text{break if } \Big( \left| \text{eps} \Big( \text{"rel"}, N_{\text{сТ}_i}, L_{\text{сТ}_i} \cdot \text{mean}(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}) \Big) \right| \leq \text{epsilon} \Big) \wedge \Big( \text{iteration}_{\text{сТ}_i} = 0 \Big) \\ \text{iteration}_{\text{сТ}_i} &= -1 \text{ if } \left| \text{eps} \Big( \text{"rel"}, N_{\text{сТ}_i}, L_{\text{сТ}_i} \cdot \text{mean}(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}) \Big) \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}} \Big( C_{\text{гaз.ср}} \Big( 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} \Big), R_{\text{гaз.ср}} \Big( \alpha_{\text{ox}_{\text{st}(i,1)}}^{\cdot}, \alpha_{\text{ox}_{\text{st}(i,3)}}^{\cdot}, \text{Fuel} \Big) \Big) \\ &\quad \Big[ \quad \quad \quad 1 - k_{\text{ср}} \quad \Big] \end{aligned}$$

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

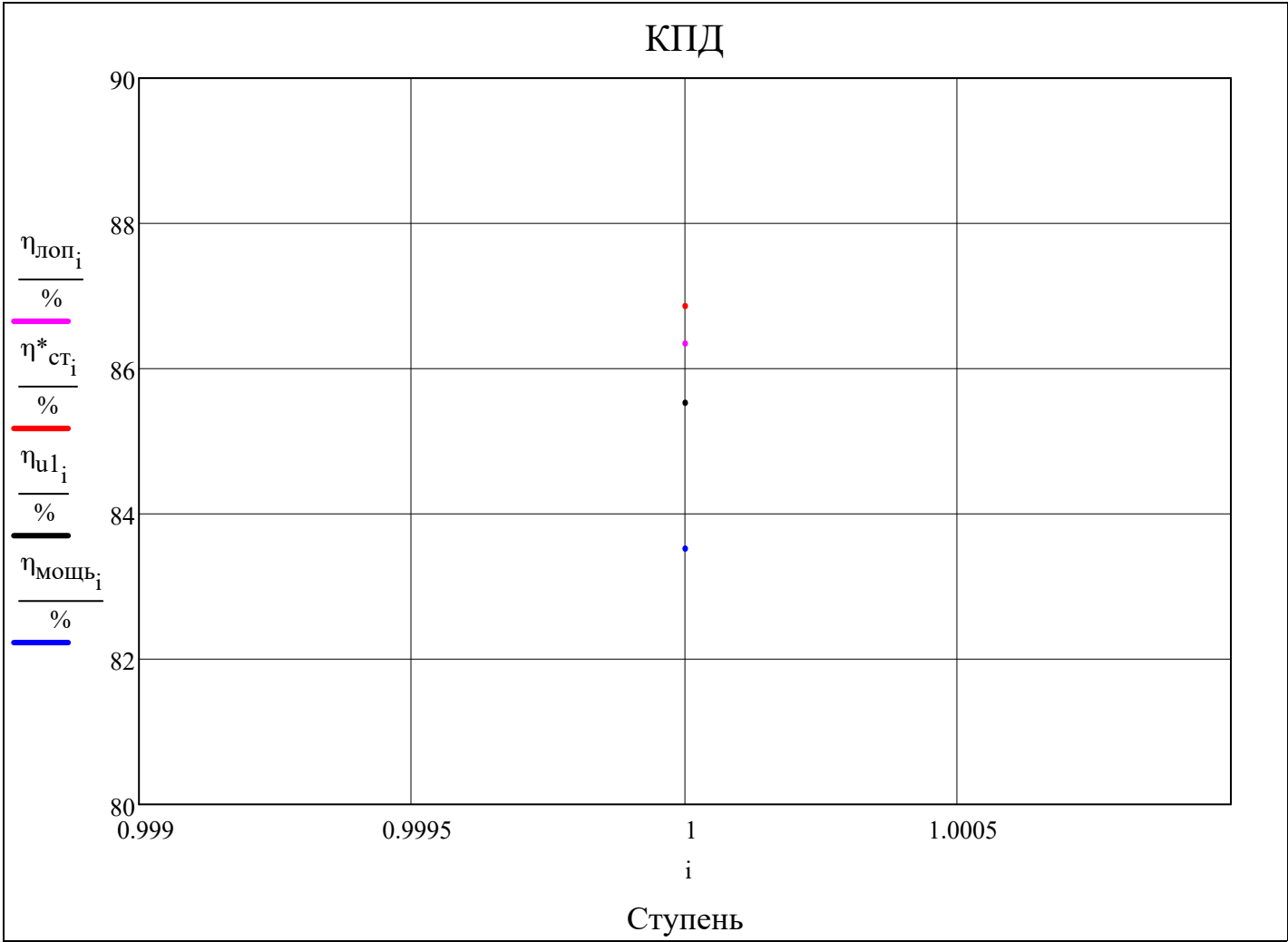
for i ∈ 1 .. Z

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 <sub>cT</sub> <sup>*</sup>	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 <sub>c</sub> <sup>*</sup>	a <sub>w</sub> <sup>*</sup>
T <sub>ад</sub>	T <sub>ад</sub>
P <sub>w</sub> <sup>*</sup>	T <sub>w</sub> <sup>*</sup>
a <sub>3B</sub>	a <sub>3B</sub>
u	u
c	c
c <sub>a</sub>	c <sub>u</sub>

	$w$	$w$
	$w_a$	$w_u$
	$\lambda_c$	$M_c$
	$\lambda_w$	$M_w$
	$v_{\text{stator}}$	$v_{\text{rotor}}$
	$\text{chord}_{\text{stator}}$	$\text{chord}_{\text{rotor}}$
	$\overline{t}_{\text{оптCA}}$	$\overline{t}_{\text{оптPK}}$
	$t_{\text{stator}}$	$t_{\text{rotor}}$
	$Z_{\text{stator}}$	$Z_{\text{rotor}}$
	$\overline{v}_{\text{stator}}$	$\overline{v}_{\text{rotor}}$
	$\xi_{\text{трCA}}$	$\xi_{\text{трPK}}$
	$\xi_{\text{крCA}}$	$\xi_{\text{крPK}}$
	$\xi_{\text{РеCA}}$	$\xi_{\text{РеPK}}$
	$\xi_{\lambda\text{CA}}$	$\xi_{\lambda\text{PK}}$
	$\xi_{\text{прCA}}$	$\xi_{\text{прPK}}$
	$\xi_{\text{втCA}}$	$\xi_{\text{втPK}}$
	$\xi_{\text{тдCA}}$	$\xi_{\text{тдPK}}$
	$\xi_{\text{смCA}}$	$\xi_{\text{смPK}}$
	$\xi_{\Delta\Gamma}$	$\xi_{\text{вых}}$
	$\xi_{\text{тр.в}}$	$\xi_{\text{тр.в}}$
	$L_{\text{ст}}$	$L_u_{\text{ст}}$
	$\eta_{\text{мощь}}$	$\eta_{\text{лоп}}$
	$\eta^*_{\text{ст}}$	$\eta^*_{\text{ст}}$
	$\eta_{u1}$	$\eta_{u2}$
	$\xi_{\text{CA}}$	$\xi_{\text{PK}}$
	$L_{u\text{нагрузка}}$	$L_{u\text{нагрузка}}$



$$\eta_{\text{лoп}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 86.35 \\ \hline \end{array} \cdot \%$$

$$\eta^*_{\text{cт}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 86.87 \\ \hline \end{array} \cdot \%$$

$$\text{stack}\left(\eta_{\text{у1}}^{\text{T}}, \eta_{\text{у2}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 85.54 \\ \hline 2 & 86.83 \\ \hline \end{array} \cdot \%$$

$$\eta_{\text{мoщ}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 83.53 \\ \hline \end{array} \cdot \%$$

$$\eta_{\text{мoщ}_i} \leq \eta_{\text{у1}_i} \leq \eta^*_{\text{cт}_i} \leq \eta_{\text{лoп}_i} =$$

0

Степень понижения полного давления Т:  
Степень понижения давления Т:

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

	1
1	3.14
2	3.26

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

$$\left(\begin{matrix} H^*_{\text{T}} \\ H_{\text{T}} \end{matrix}\right) = \left(\begin{matrix} \sum\limits_{i=1}^Z H^*_{\text{сТ}_i} \\ \sum\limits_{i=1}^Z H_{\text{сТ}_i} \end{matrix}\right) =$$

	1
1	516.1
2	536.7

 $\cdot 10^3$

Мощность Т (Вт):

$$\sum\limits_{i=1}^Z N_{\text{сТ}_i} = 14.89 \cdot 10^6$$

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

Удельная поступенчатая работа Т [Дж/кг]:

$$L_{\text{T}} = \sum\limits_{i=1}^Z \frac{N_{\text{сТ}_i}}{\text{mean}\left(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}\right)} = 448.6 \cdot 10^3$$

Лопаточный КПД Т:

$$\eta_{\text{Тлоп}} = \frac{\sum\limits_{i=1}^Z \frac{N_{\text{сТ}_i}}{\text{mean}\left(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}\right)} + \frac{\left(c_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}\right)^2}{2}}{H_{\text{T}}} = 86.4\cdot\%$$

$$k_{\text{T.ср}} = k_{\text{ад}}\left(\text{Cp}_{\text{Газ.ср}}\left(P_{\text{st}(1,1),\text{av}\left(N_{\text{r}}\right)}, P_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}, T_{\text{st}(1,1),\text{av}\left(N_{\text{r}}\right)}, T_{\text{st}(Z,3),\text{av}\left(N_{\text{r}}\right)}, \alpha_{\text{ox}_{\text{st}(1,1)}}, \alpha_{\text{ox}_{\text{st}(Z,3)}}, \text{Fuel}\right), R_{\text{Газ.ср}}\left(\alpha_{\text{ox}_{\text{st}(1,1)}}, \alpha_{\text{ox}_{\text{st}(Z,3)}}, \text{Fuel}\right)\right) = 1.289$$

Адиабатный КПД Т:

$$\eta^*_{\text{T}} = \frac{L_{\text{T}}}{H^*_{\text{T}}} = 86.92\cdot\%$$

Политропический КПД Т:

$$\eta^*_{\text{T.п}} = \eta^*_{\text{n}}\left(\text{"расширение"}, \eta^*_{\text{T}}, \pi^*_{\text{T}}, k_{\text{T.ср}}\right) = 85.37\cdot\%$$

Мощностной КПД Т:

$$\eta_{\text{Тмощь}} = \frac{\sum\limits_{i=1}^Z \frac{N_{\text{сТ}_i}}{\text{mean}\left(G_{\text{st}(i,2)}, G_{\text{st}(i,3)}\right)}}{H_{\text{T}}} = 83.58\cdot\%$$

$$L_{\text{сТ}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 448.3 \\ \hline \end{array} \cdot 10^3$$

$$N_{\text{сТ}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 14.89 \\ \hline \end{array} \cdot 10^6$$

$$Lu_{\text{сТ}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 459.1 \\ \hline \end{array} \cdot 10^3$$

$$Lu_{\text{нагрузка}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.7 \\ \hline \end{array}$$

$$H_{\text{сТ}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 536.7 \\ \hline \end{array} \cdot 10^3$$

$$\text{stack}\Big(H_{\text{stator}}^{\text{T}},H_{\text{rotor}}^{\text{T}}\Big) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 450.9 \\ \hline 2 & 87.0 \\ \hline \end{array} \cdot 10^3$$

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

$$G^{\text{T}} = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 32.193 & 33.050 & 33.350 \\ \hline \end{array}$$

$$\alpha_{\text{ox}}^{\text{T}} = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 2.267 & 2.294 & 2.303 \\ \hline \end{array}$$

$$\text{stack}\Big(\theta_{\text{CA}}^{\text{T}},\theta_{\text{PK}}^{\text{T}}\Big) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0.432 \\ \hline 2 & 0.206 \\ \hline \end{array}$$

$$\text{stack}\Big(g_{\text{oxлCA}}^{\text{T}},g_{\text{oxлPK}}^{\text{T}}\Big) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 26.61 \\ \hline 2 & 9.09 \\ \hline \end{array} \cdot 10^{-3}$$

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

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

$$\text{stack}\Big(G_{\text{oxлCA}}^{\text{T}},G_{\text{oxлPK}}^{\text{T}}\Big) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0.9 \\ \hline 2 & 0.3 \\ \hline \end{array}$$

$$G_{\text{cooling}} = 3.2$$

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

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

$$\text{submatrix}\Big(\text{k}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3\\\hline 1 & 1.283 & 1.293 & 1.295\\\hline\end{array}$$

$$\text{submatrix}\Big(\text{P}^{*\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3\\\hline 1 & 2731.8 & 2413.7 & 870.5\\\hline\end{array}\cdot10^3$$

$$\text{submatrix}\Big(\text{P}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3\\\hline 1 & 2705.2 & 1017.3 & 838.1\\\hline\end{array}\cdot10^3$$

$$\text{submatrix}\Big(\text{T}^{*\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9\\\hline 1 & 1773.0 & 1759.0 & 1394.2 & & & & & & \\ \hline\end{array}$$

$$\text{submatrix}\Big(\text{T}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9\\\hline 1 & 1769.2 & 1447.0 & 1382.2 & & & & & & \\ \hline\end{array}$$

$$\text{submatrix}\Big(\text{T}^{*\text{wT}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9\\\hline 1 & 0.0 & 1509.6 & 1500.0 & & & & & & \\ \hline\end{array}$$

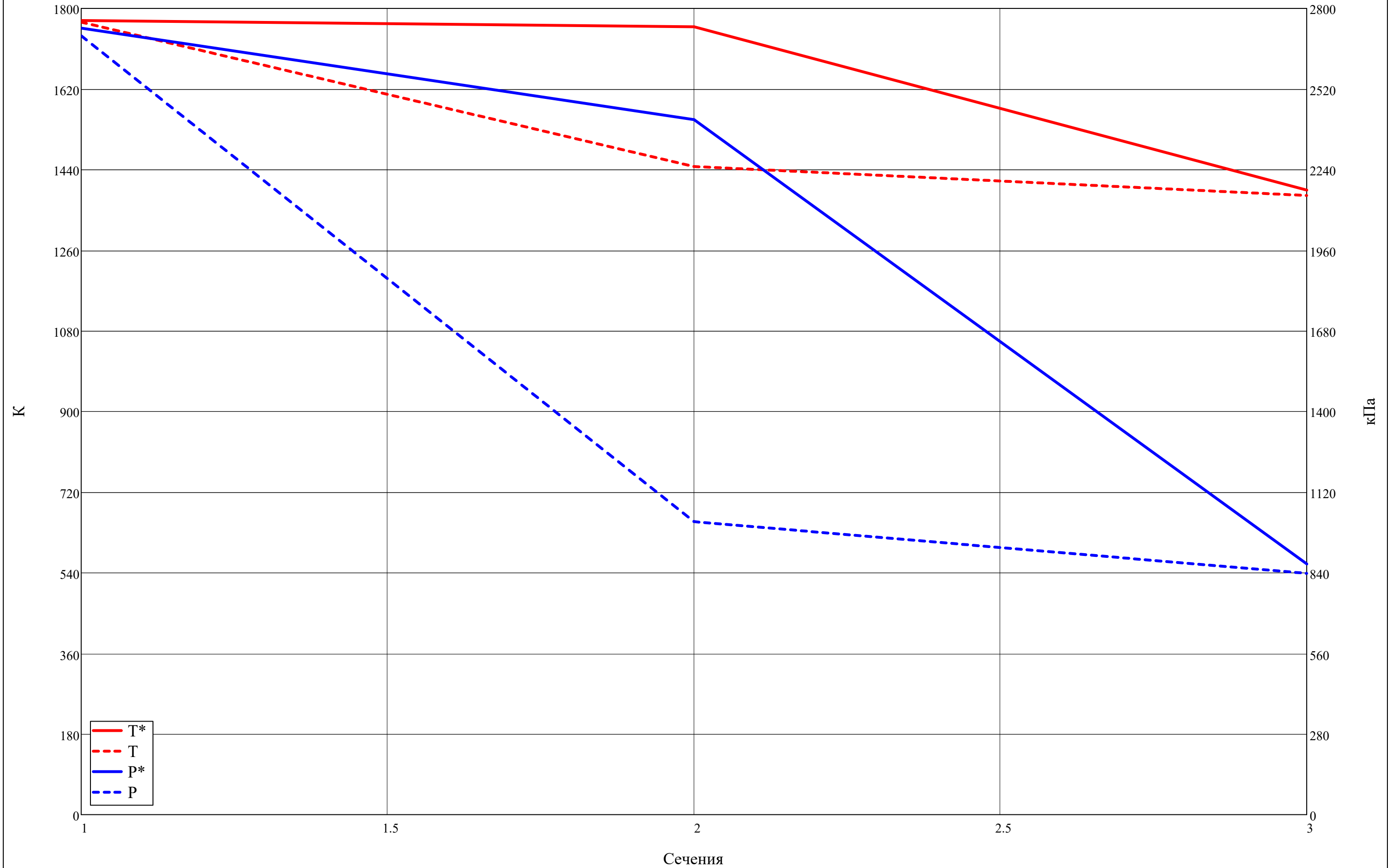
$$\text{submatrix}\Big(\text{T}_{\text{a}\mathcal{A}}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9\\\hline 1 & 0.0 & 1428.5 & 1378.7 & & & & & & \\ \hline\end{array}$$

$$\text{submatrix}\Big(\text{v}^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3\\\hline 1 & 0.189 & 0.410 & 0.487\\\hline\end{array}$$

$$\text{submatrix}\Big(\rho^{*\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3\\\hline 1 & 5.341 & 4.756 & 2.164\\\hline\end{array}$$

$$\text{submatrix}\Big(\rho^{\text{T}},\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big),1,2\text{Z}+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3\\\hline 1 & 5.300 & 2.437 & 2.053\\\hline\end{array}$$

Термодинамические параметры по тракту Т на ср. сечении





$$\text{submatrix}\Big(a_{3B}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 809.2 & 734.6 & 718.7 \\\hline\end{array}$$

$$\text{submatrix}\Big(a^*_{\text{c}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 758.2 & 756.5 & 673.8 \\\hline\end{array}$$

$$\text{submatrix}\Big(a^*_{\text{w}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 0.0 & 700.8 & 698.9 \\\hline\end{array}$$

$$\text{submatrix}\Big(\text{c}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 100.0 & 892.5 & 174.1 \\\hline\end{array}$$

$$\text{submatrix}\Big(\text{c}_{\text{u}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 0.0 & 864.2 & -2.7 \\\hline\end{array}$$

$$\text{submatrix}\Big(\text{c}_{\text{a}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 100.0 & 223.3 & 174.0 \\\hline\end{array}$$

$$\text{submatrix}\Big(\text{w}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 0.0 & 399.5 & 545.8 \\\hline\end{array}$$

$$\text{submatrix}\Big(\text{w}_{\text{u}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 0.0 & 331.3 & 517.3 \\\hline\end{array}$$

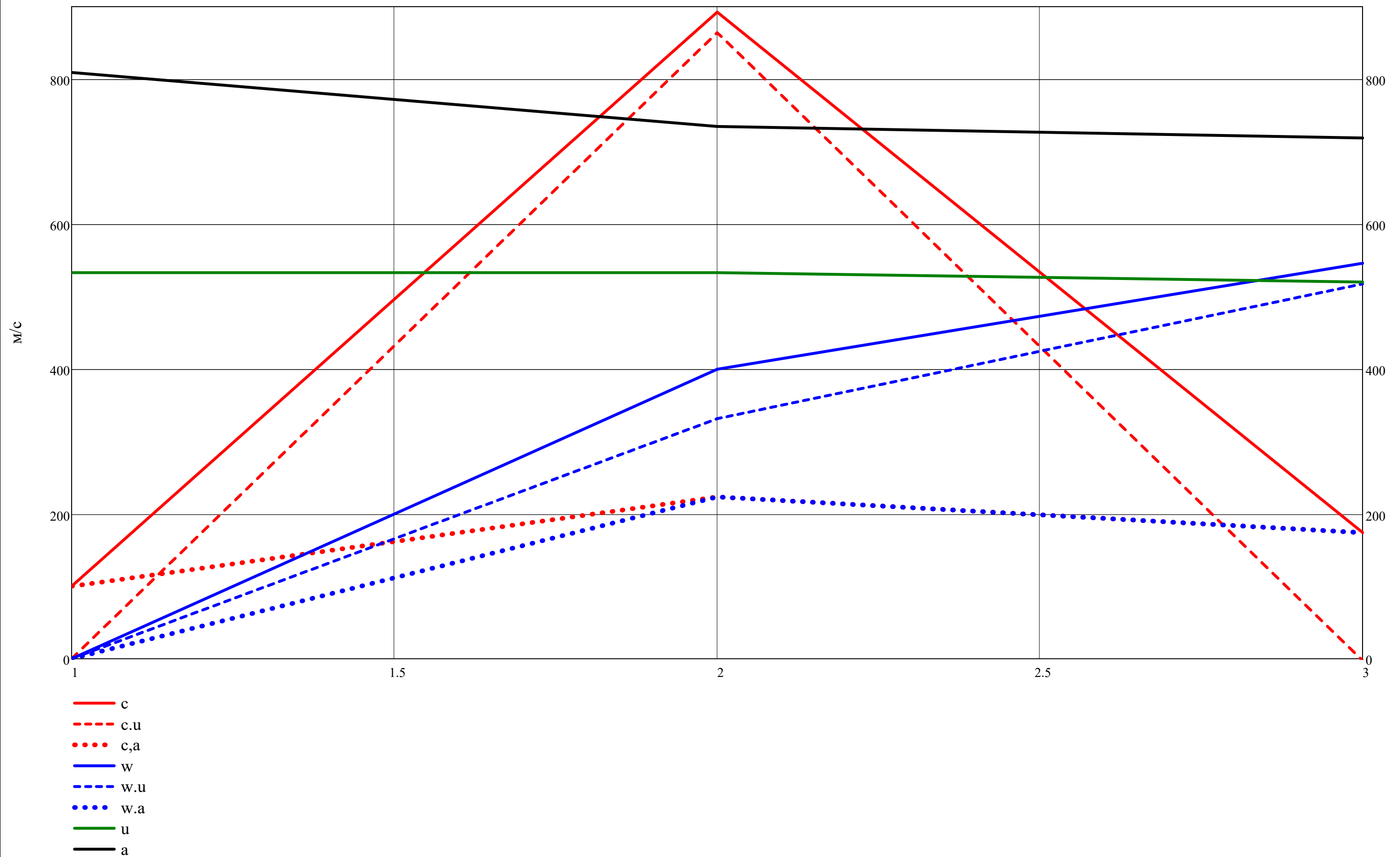
$$\text{submatrix}\Big(\text{w}_{\text{a}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 0.0 & 223.3 & 174.0 \\\hline\end{array}$$

$$\text{submatrix}\Big(\text{c}_{\text{a}\text{d}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z\Big)=\begin{array}{|c|c|c|}\hline & 1 & 2 \\\hline 1 & 1036.1 & 949.6 \\\hline\end{array}$$

$$\text{submatrix}\Big(\text{w}_{\text{a}\text{d}}^{\text{T}},\text{av}\Big(N_{\text{r}}\Big),\text{av}\Big(N_{\text{r}}\Big),1,2Z+1\Big)=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 0.0 & 0.0 & 565.7 \\\hline\end{array}$$

$$\text{u}^{\text{T}}=\begin{array}{|c|c|c|c|}\hline & 1 & 2 & 3 \\\hline 1 & 510.5 & 510.5 & 484.8 \\\hline 2 & 532.9 & 532.9 & 520.0 \\\hline 3 & 555.2 & 555.2 & 555.2 \\\hline\end{array}$$

Скорости по тракту Т на ср. сечении



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

	1	2	3	4	5	6	7	8	9
1	90.00	14.49	90.87						

 $\cdot^{\circ}$

$\text{submatrix}\Big(\alpha,1,2\cdot Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}\geq 11\cdot^{\circ}=$ 

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

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

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	33.98	18.59									

 $\cdot^{\circ}$

$\text{submatrix}\Big(\varepsilon_{\text{stator}},1,Z,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}=$ 

	1	2	3	4	5	6
1	-75.51					

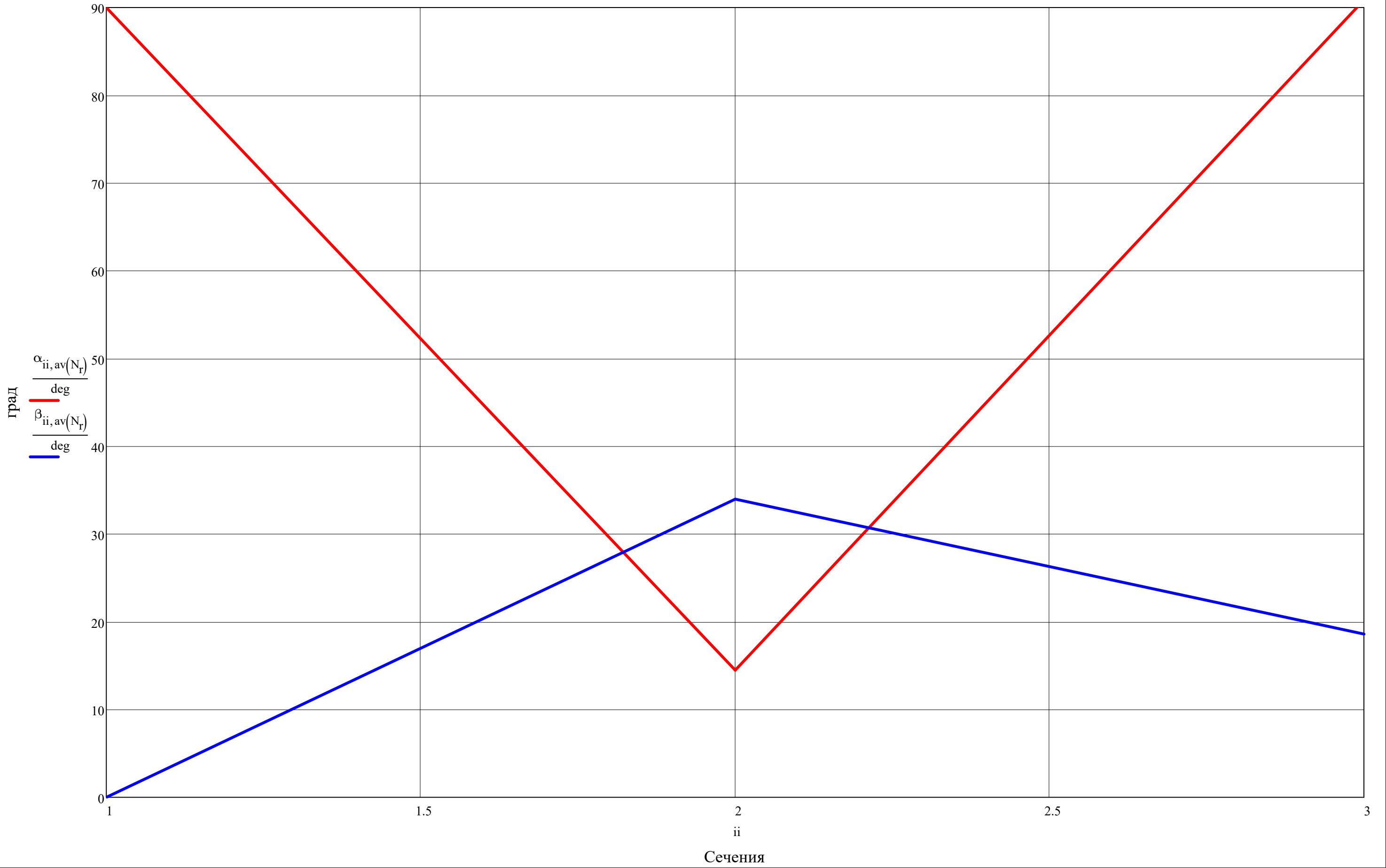
 $\cdot^{\circ}$

$\text{submatrix}\Big(\varepsilon_{\text{rotor}},1,Z,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}=$ 

	1	2	3	4	5	6
1	-15.39					

 $\cdot^{\circ}$

Углы по тракту Т на ср. сечении



$$\text{submatrix}\Big(\lambda_{\text{c}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 0.1319 & 1.1799 & 0.2583 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\lambda_{\text{w}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 0.0000 & 0.5701 & 0.7810 \\ \hline \end{array}$$

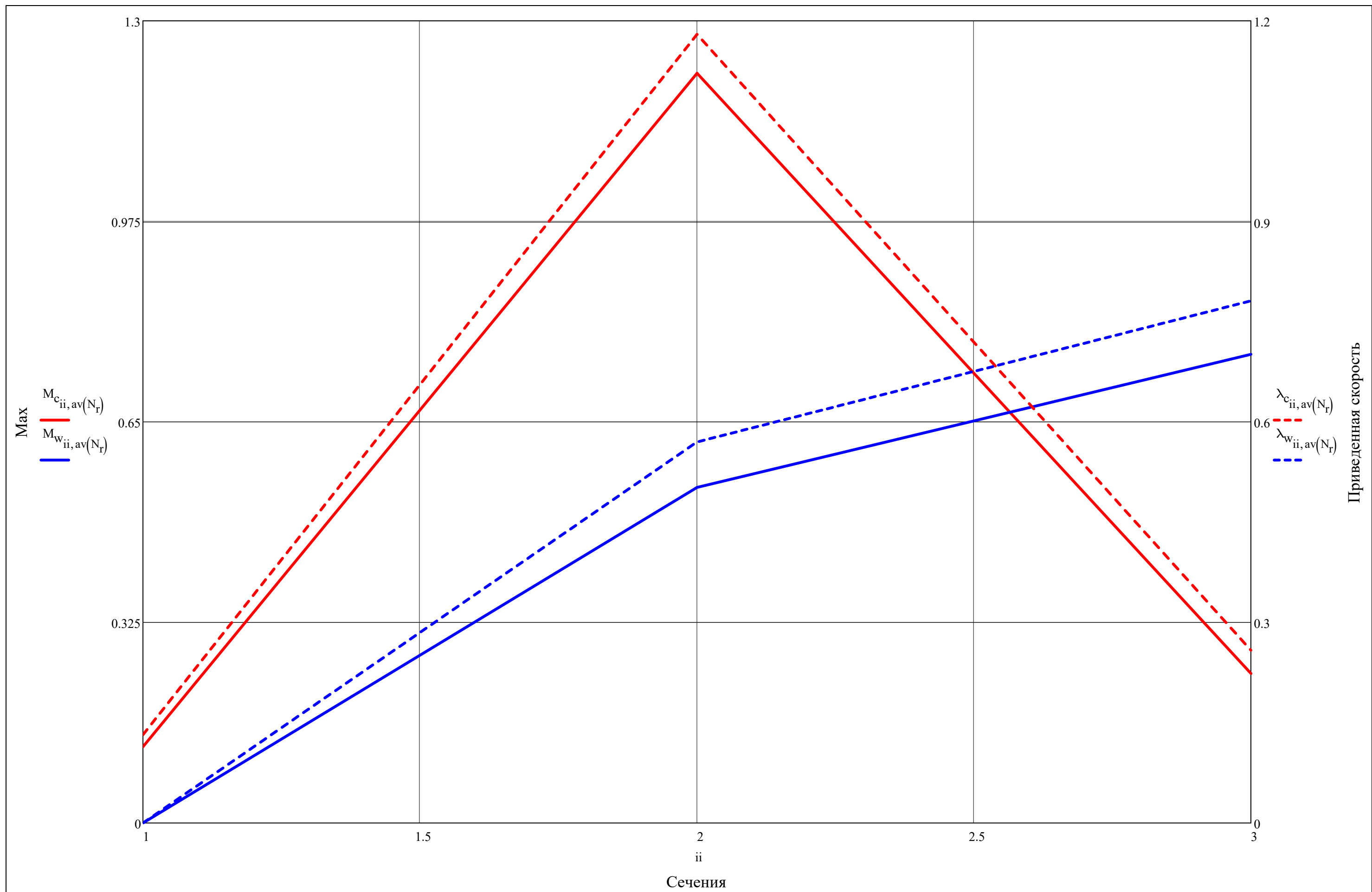
$$\text{submatrix}\Big(\text{M}_{\text{c}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 0.1236 & 1.2150 & 0.2422 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{M}_{\text{c}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}\leq 1= \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 1 & 0 & 1 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{M}_{\text{w}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}= \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 0.0000 & 0.5438 & 0.7594 \\ \hline \end{array}$$

$$\text{submatrix}\Big(\text{M}_{\text{w}},1,2Z+1,\text{av}\Big(\text{N}_{\text{r}}\Big),\text{av}\Big(\text{N}_{\text{r}}\Big)\Big)^{\text{T}}\leq 1= \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 1 & 1 & 1 \\ \hline \end{array}$$

$$\text{stack}\Big(v_{\text{stator}}^{\text{T}},v_{\text{rotor}}^{\text{T}}\Big)= \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 37.03 \\ \hline 2 & 67.08 \\ \hline \end{array} .^{\circ}$$



$$\mathbf{t_{stator}}^T = \begin{bmatrix} & 1 \\ 1 & 56.7 \\ 2 & 59.2 \\ 3 & 61.7 \end{bmatrix} \cdot 10^{-3}$$

$$\mathbf{t_{rotor}}^T = \begin{bmatrix} & 1 \\ 1 & 22.4 \\ 2 & 23.7 \\ 3 & 25.0 \end{bmatrix} \cdot 10^{-3}$$

$$\text{submatrix}\Big(\text{chord}_{\text{stator}}^T, \text{av}\big(\text{N}_{\text{r}}\big), \text{av}\big(\text{N}_{\text{r}}\big), 1, Z\Big) = \begin{bmatrix} & 1 \\ 1 & 68.0 \end{bmatrix} \cdot 10^{-3}$$

$$\text{submatrix}\Big(\text{chord}_{\text{rotor}}^T, \text{av}\big(\text{N}_{\text{r}}\big), \text{av}\big(\text{N}_{\text{r}}\big), 1, Z\Big) = \begin{bmatrix} & 1 \\ 1 & 32.7 \end{bmatrix} \cdot 10^{-3}$$

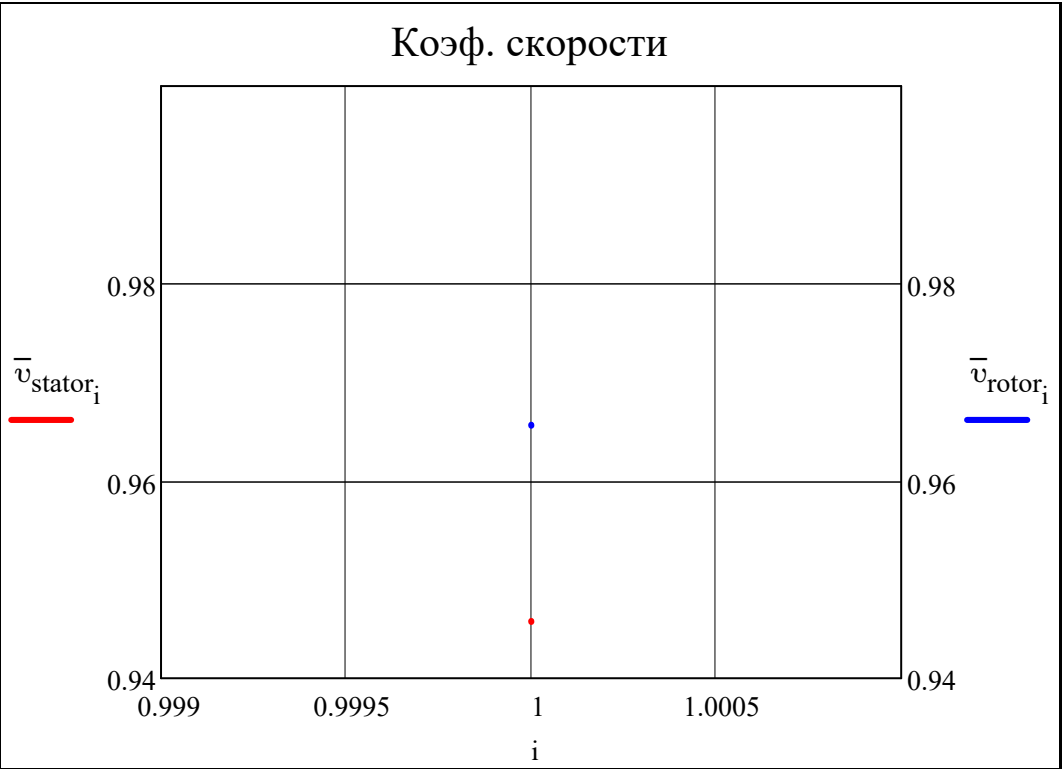
$$\text{stack}\Big(\text{Z}_{\text{stator}}^T, \text{Z}_{\text{rotor}}^T\Big) = \begin{bmatrix} & 1 \\ 1 & 36 \\ 2 & 89 \end{bmatrix}$$

$$\text{stack}\Big(\overline{\text{t}}_{\text{OITCA}}^T, \overline{\text{t}}_{\text{OITPK}}^T\Big) = \begin{bmatrix} & 1 \\ 1 & 0.872 \\ 2 & 0.724 \end{bmatrix}$$

$$\frac{\mathbf{t_{stator}}_{\text{i}, \text{av}\big(\text{N}_{\text{r}}\big)}}{\text{chord}_{\text{stator}}_{\text{i}, \text{av}\big(\text{N}_{\text{r}}\big)}} = \boxed{0.871} \leq \frac{\mathbf{t_{stator}}_{\text{i}, \text{av}\big(\text{N}_{\text{r}}\big)}}{\boxed{1}} \leq 1 = \frac{\mathbf{t_{rotor}}_{\text{i}, \text{av}\big(\text{N}_{\text{r}}\big)}}{\text{chord}_{\text{rotor}}_{\text{i}, \text{av}\big(\text{N}_{\text{r}}\big)}} = \boxed{0.724} \leq \frac{\mathbf{t_{rotor}}_{\text{i}, \text{av}\big(\text{N}_{\text{r}}\big)}}{\boxed{1}} \leq 1 =$$

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

	1
1	0.9458
2	0.9657





$$\text{stack}\left(\xi_{\text{TpCA}}^{\text{T}}, \xi_{\text{TpPK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.398 \\ \hline 2 & 2.620 \\ \hline \end{array} \cdot\%$$

$$\text{stack}\left(\xi_{\text{KpCA}}^{\text{T}}, \xi_{\text{KpPK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 2.753 \\ \hline 2 & 1.689 \\ \hline \end{array} \cdot\%$$

$$\text{stack}\left(\xi_{\text{ReCA}}^{\text{T}}, \xi_{\text{RePK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & -0.135 \\ \hline 2 & 0.085 \\ \hline \end{array} \cdot\%$$

$$\text{stack}\left(\xi_{\lambda\text{CA}}^{\text{T}}, \xi_{\lambda\text{PK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 2.434 \\ \hline 2 & 0.024 \\ \hline \end{array} \cdot\%$$

$$\text{stack}\left(\xi_{\text{BTCA}}^{\text{T}}, \xi_{\text{BTPK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.453 \\ \hline 2 & 0.881 \\ \hline \end{array} \cdot\%$$

$$\text{stack}\left(\xi_{\text{TDCA}}^{\text{T}}, \xi_{\text{TDPK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.856 \\ \hline 2 & 1.200 \\ \hline \end{array} \cdot\%$$

$$\text{stack}\left(\xi_{\text{сmCA}}^{\text{T}}, \xi_{\text{сmPK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0.784 \\ \hline 2 & 0.248 \\ \hline \end{array} \cdot\%$$

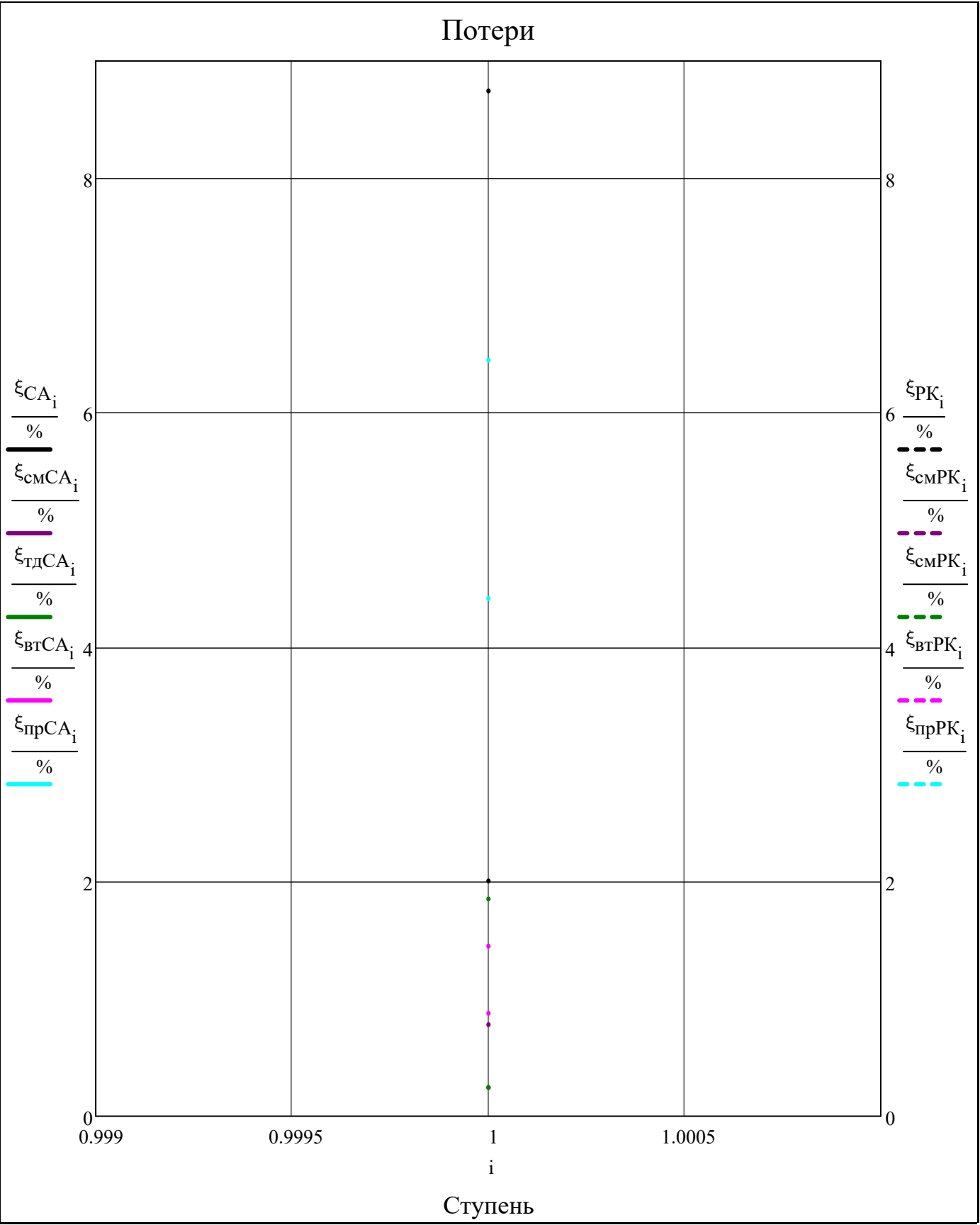
$$\text{stack}\left(\xi_{\text{CA}}^{\text{T}}, \xi_{\text{PK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 8.748 \\ \hline 2 & 2.008 \\ \hline \end{array} \cdot\%$$

$$\xi_{\text{ВЫХ}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 2.822 \\ \hline \end{array} \cdot\%$$

$$\xi_{\Delta\text{r}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 2.476 \\ \hline \end{array} \cdot\%$$

$$\xi_{\text{Гр.В}}^{\text{T}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0.831 \\ \hline \end{array} \cdot\%$$

$$\text{stack}\left(\xi_{\text{ппCA}}^{\text{T}}, \xi_{\text{ппPK}}^{\text{T}}\right) = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 6.451 \\ \hline 2 & 4.418 \\ \hline \end{array} \cdot\%$$





Вывод результатов поступенчатого расчета по ср. сечению ОТ в EXCEL:

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

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

m<sup>T</sup> =

	1	2	3	4	5	6
1	0.8866	-0.2500	0.0000	0.2500	1.0000	1.0000



$$\begin{aligned}
& u_{st(i,2),av(N_r)} = 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 - (\bar{v}_{rotor,i})^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 - (\bar{v}_{rotor,i})^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 (\bar{v}_{rotor,i})^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{(\bar{v}_{stator,i})^2 \cdot (\bar{v}_{rotor,i})^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}{(R_{st(i,a),r})^{2 \cdot m_i}} - \frac{1}{(R_{st(i,a),av(N_r)})^{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}{(R_{st(i,a),r})^{m_i+1}} - \frac{1}{(R_{st(i,a),av(N_r)})^{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
1	2731.8	2413.7	870.5
2	2731.8	2413.7	870.5
3	2731.8	2413.7	870.5

$$\cdot 10^3$$

$$T^{*T} =$$

	1	2	3	4	5	6	7	8	9
1	1773.0	1759.0	1394.2						
2	1773.0	1759.0	1394.2						
3	1773.0	1759.0	1394.2						

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

	1	2	3	4	5	6	7	8	9
1	1878.6	1493.1	1491.4						
2	1888.0	1500.7	1508.0						
3	1897.9	1508.9	1525.6						

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

	1	2	3
1	5.341	4.756	2.164
2	5.341	4.756	2.164
3	5.341	4.756	2.164

$$k^T =$$

	1	2	3
1	1.305	1.305	1.316
2	1.305	1.305	1.316
3	1.305	1.305	1.316

$$R_L^T =$$

	1
1	0.0998
2	0.1767
3	0.2440

$$p^T =$$

	1	2	3
1	2705.2	939.2	847.2
2	2705.2	1014.0	838.1
3	2705.2	1084.4	831.3

$$\cdot 10^3$$

$$T^T =$$

	1	2	3	4	5	6	7	8	9
1	1768.9	1410.5	1385.1						
2	1768.9	1436.0	1381.6						
3	1768.9	1458.8	1378.9						

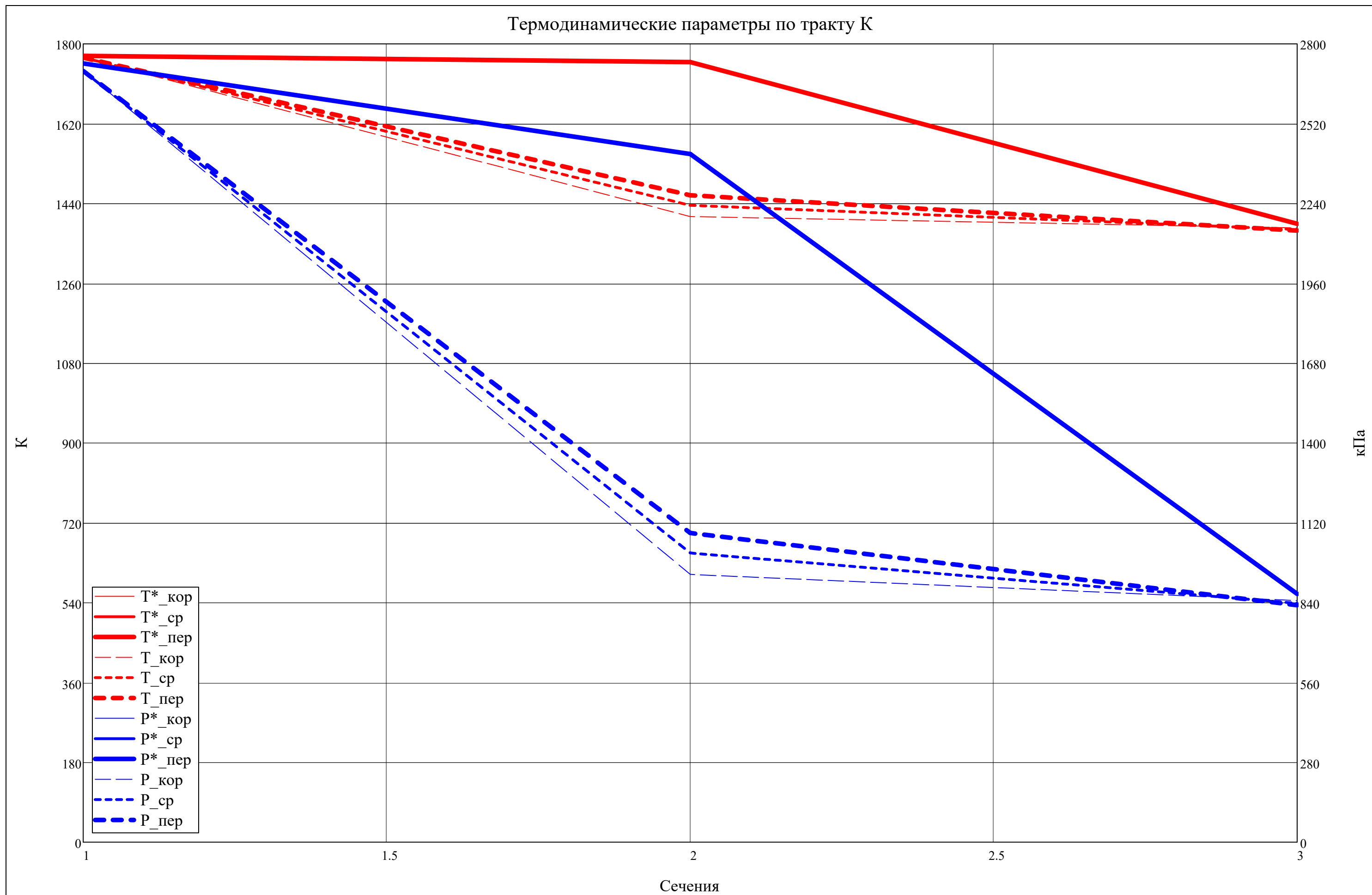
$$\rho^T =$$

	1	2	3
1	5.301	2.308	2.120
2	5.301	2.448	2.103
3	5.301	2.577	2.090

$$R_L^T \geq 0.05 =$$

	1
1	1
2	1
3	1





$$a^*_c{}^T =$$

	1	2	3
1	761.0	758.1	676.1
2	761.0	758.1	676.1
3	761.0	758.1	676.1

$$u^T =$$

	1	2	3
1	510.5	510.5	484.8
2	532.9	532.9	520.0
3	555.2	555.2	555.2

$$c^T =$$

	1	2	3
1	100.0	927.2	147.3
2	100.0	892.5	174.1
3	100.0	860.6	191.8

$$c_u{}^T =$$

	1	2	3
1	0.0	897.7	1.8
2	0.0	864.2	-2.7
3	0.0	833.2	-6.4

$$c_a{}^T =$$

	1	2	3
1	100.0	231.9	147.3
2	100.0	223.3	174.0
3	100.0	215.3	191.7

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

	1	2
1	131.9	-84.7
2	123.3	-49.3
3	115.3	-23.6

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

	1	2	3
1	783.4	698.4	699.3
2	785.3	700.2	703.2
3	787.4	702.1	707.3

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

	1	2	3
1	816.1	728.8	725.3
2	816.1	735.4	724.4
3	816.1	741.2	723.7

$$w^T =$$

	1	2	3
1	520.2	451.4	504.9
2	542.2	399.5	550.9
3	564.2	351.6	593.4

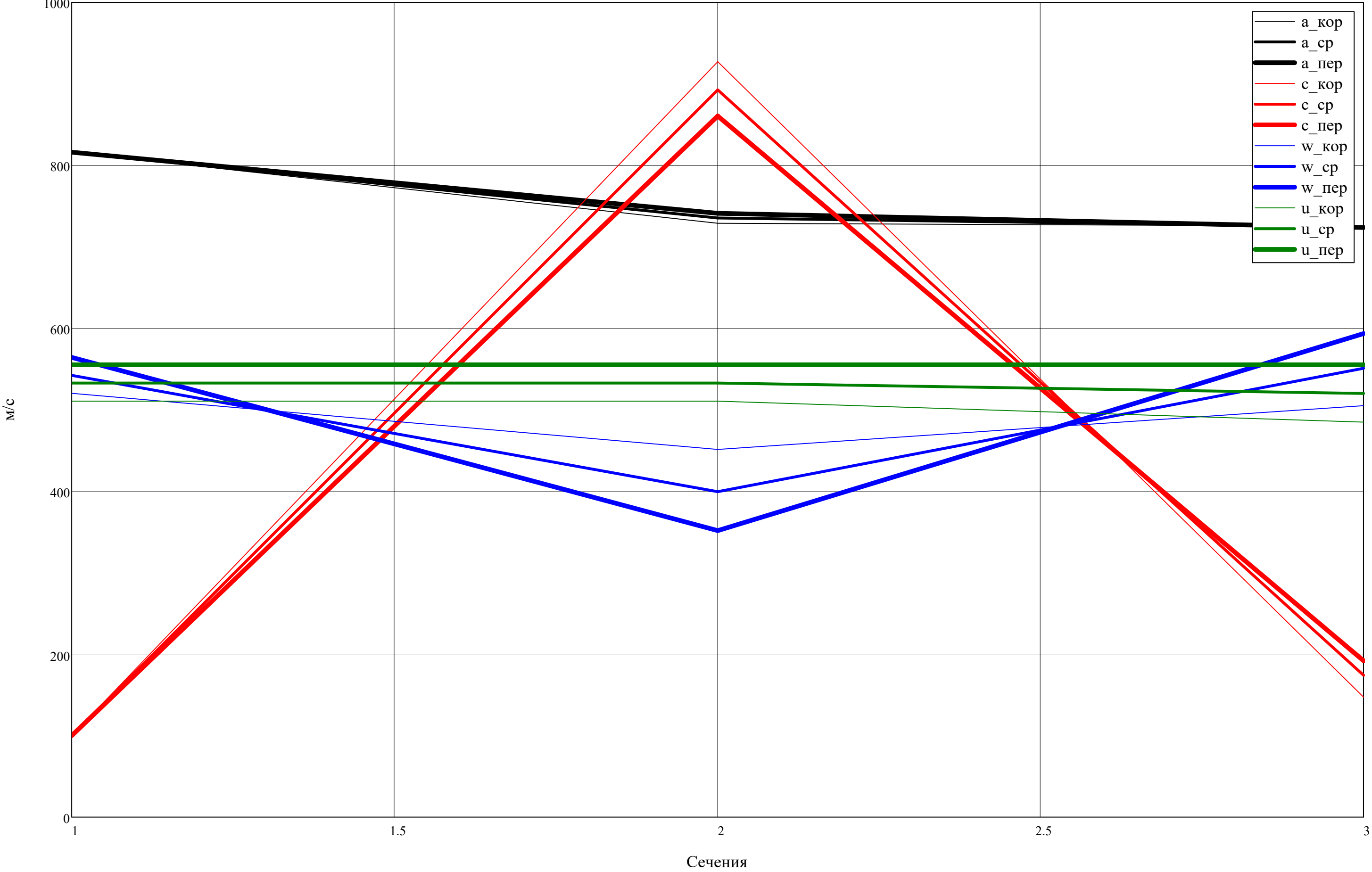
$$w_u{}^T =$$

	1	2	3
1	510.5	-387.2	483.0
2	532.9	-331.3	522.7
3	555.2	-278.0	561.6

$$w_a{}^T =$$

	1	2	3
1	100.0	231.9	147.3
2	100.0	223.3	174.0
3	100.0	215.3	191.7

Скорости по тракту Т



$\alpha^T =$ 

	1	2	3
1	90.00	14.49	89.31
2	90.00	14.49	90.87
3	90.00	14.49	91.90

 $^{\circ}$

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

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

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

	1
1	75.51
2	75.51
3	75.51

 $^{\circ}$

Угол поворота потока:

[1, с.78]

$\beta^T =$ 

	1	2	3
1	11.08	149.08	16.96
2	10.63	146.02	18.42
3	10.21	142.24	18.85

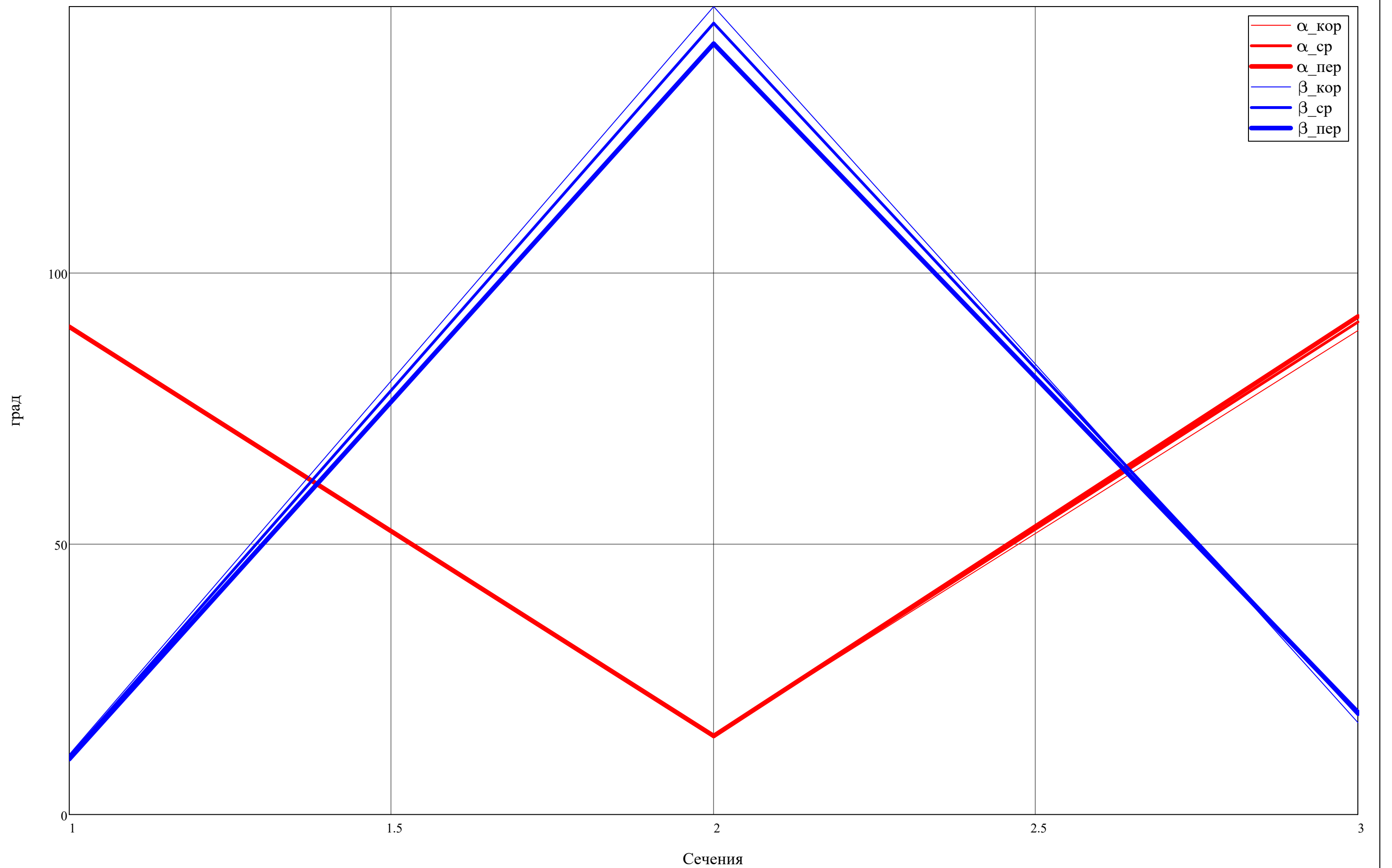
 $^{\circ}$

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

	1
1	132.12
2	127.61
3	123.40

 $^{\circ}$

Углы по тракту К



$\lambda_c^T =$ 

	1	2	3
1	0.131	1.223	0.218
2	0.131	1.177	0.257
3	0.131	1.135	0.284

$M_c^T =$ 

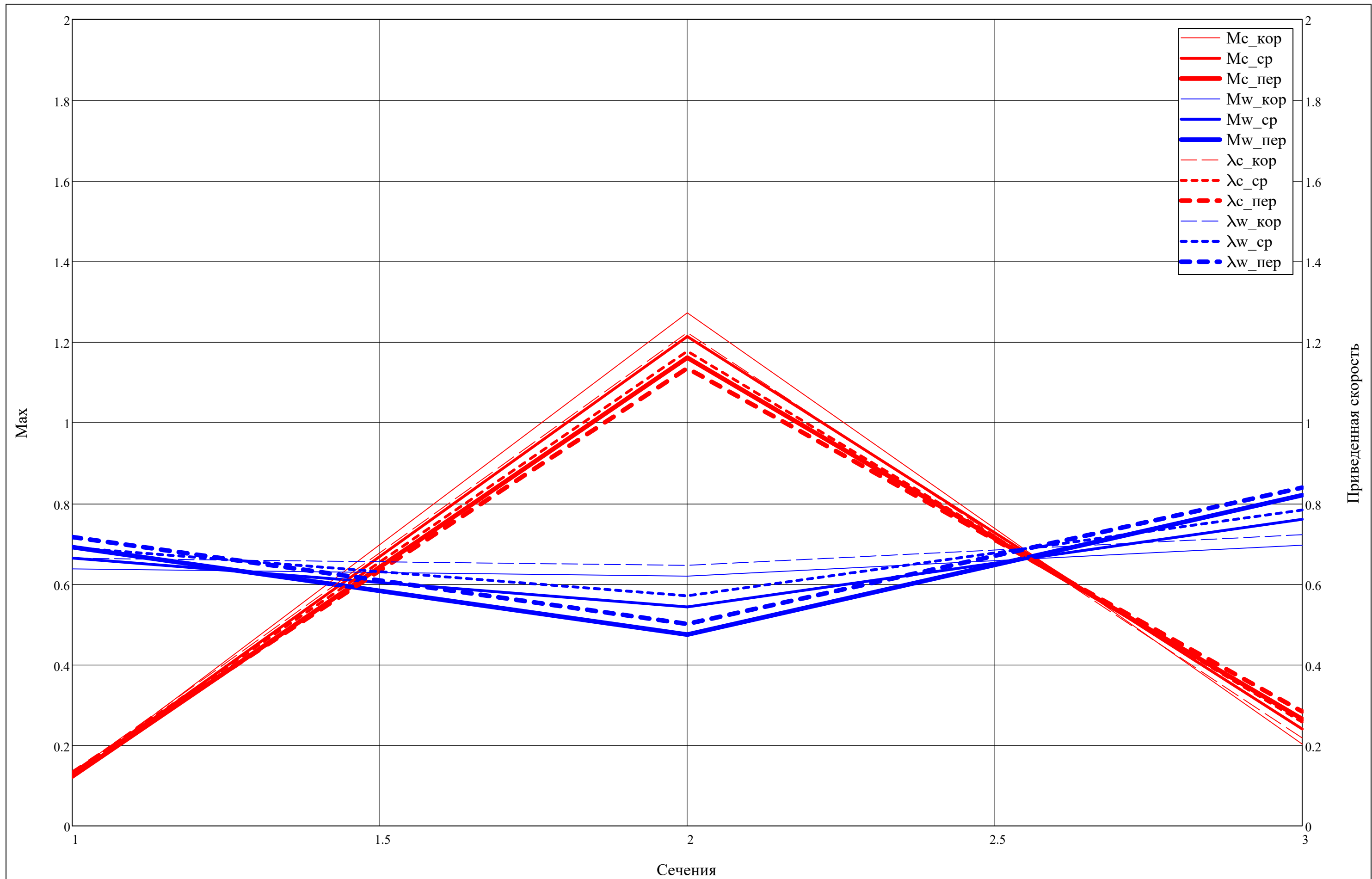
	1	2	3
1	0.123	1.272	0.203
2	0.123	1.214	0.240
3	0.123	1.161	0.265

$\lambda_w^T =$ 

	1	2	3
1	0.664	0.646	0.722
2	0.690	0.571	0.783
3	0.717	0.501	0.839

$M_w^T =$ 

	1	2	3
1	0.637	0.619	0.696
2	0.664	0.543	0.760
3	0.691	0.474	0.820







Рассматриваемая ступень:

j =

j = Z

j =

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

j otherwise

= 1

▼

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> = 1000.0

v =

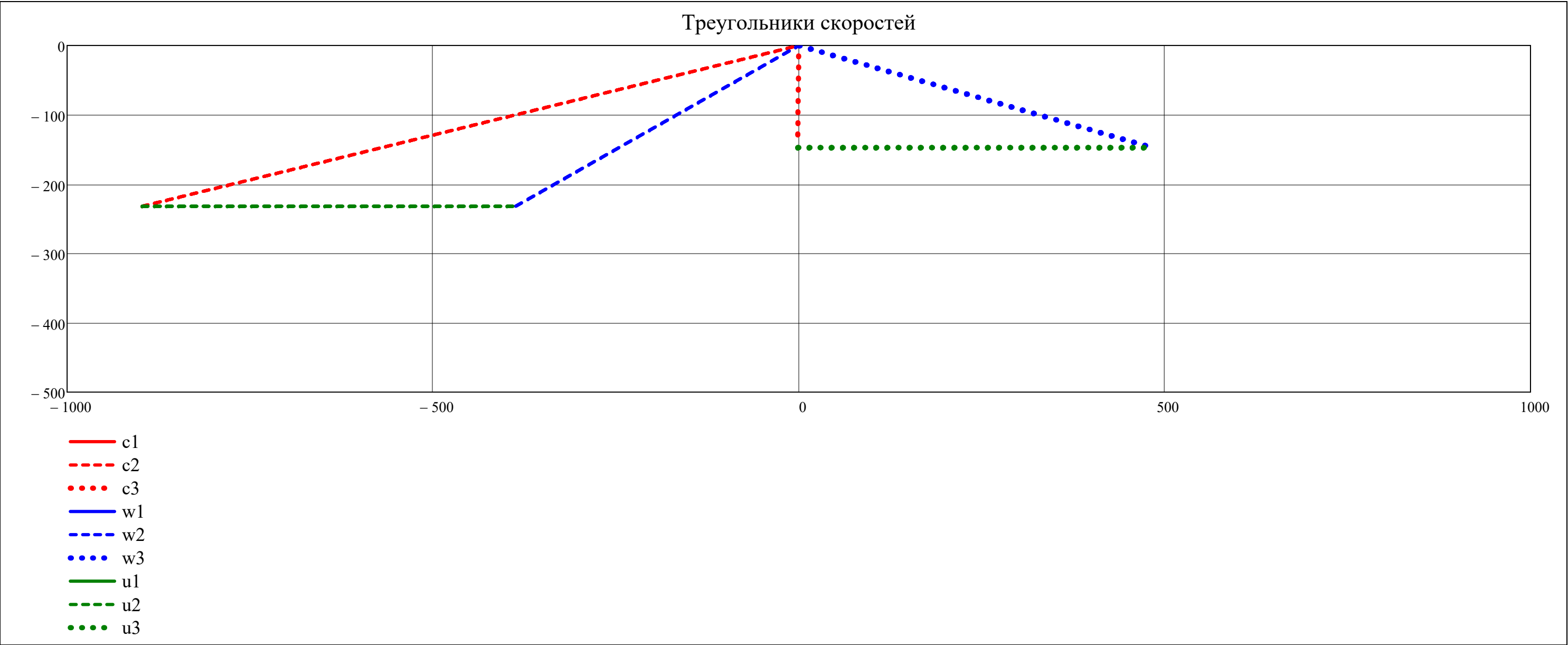
−max(c,w,u), −max(c,w,u) +

max(c,w,u)

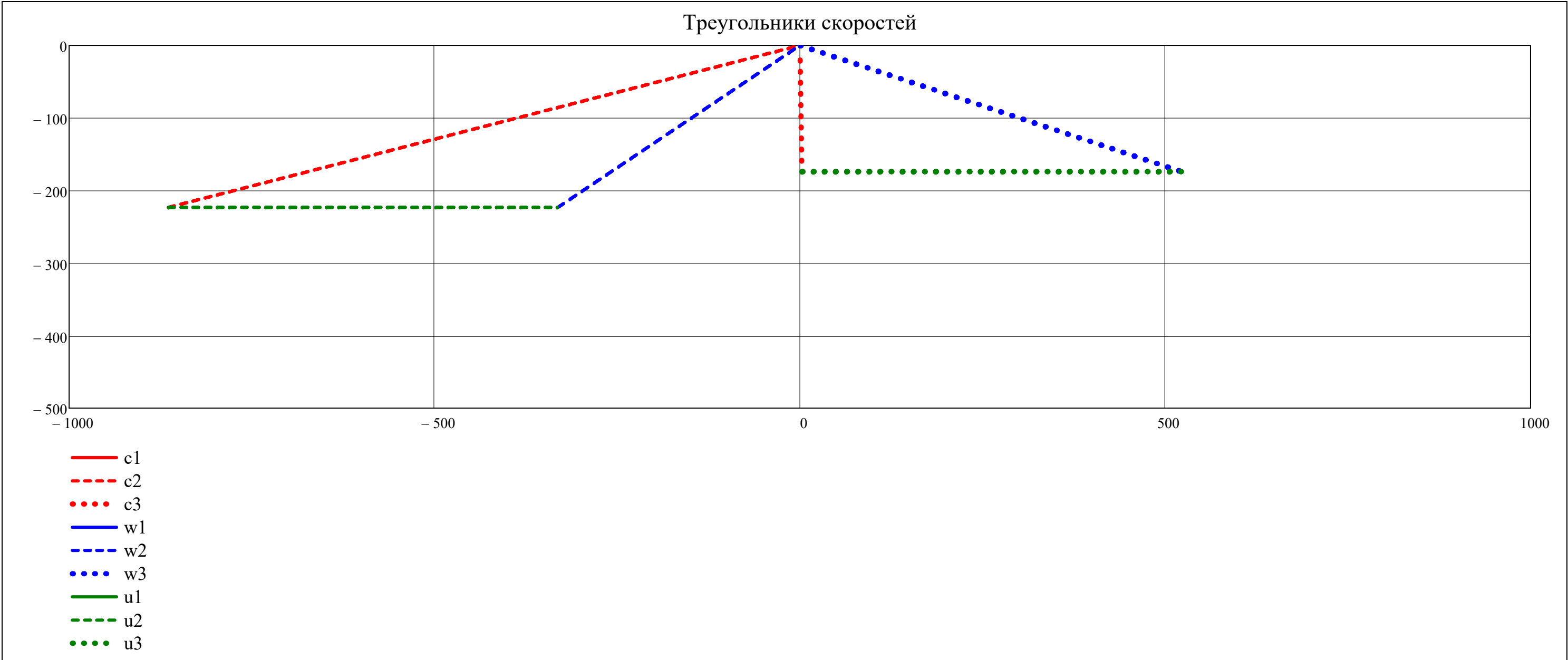
3000

.. max(c,w,u)

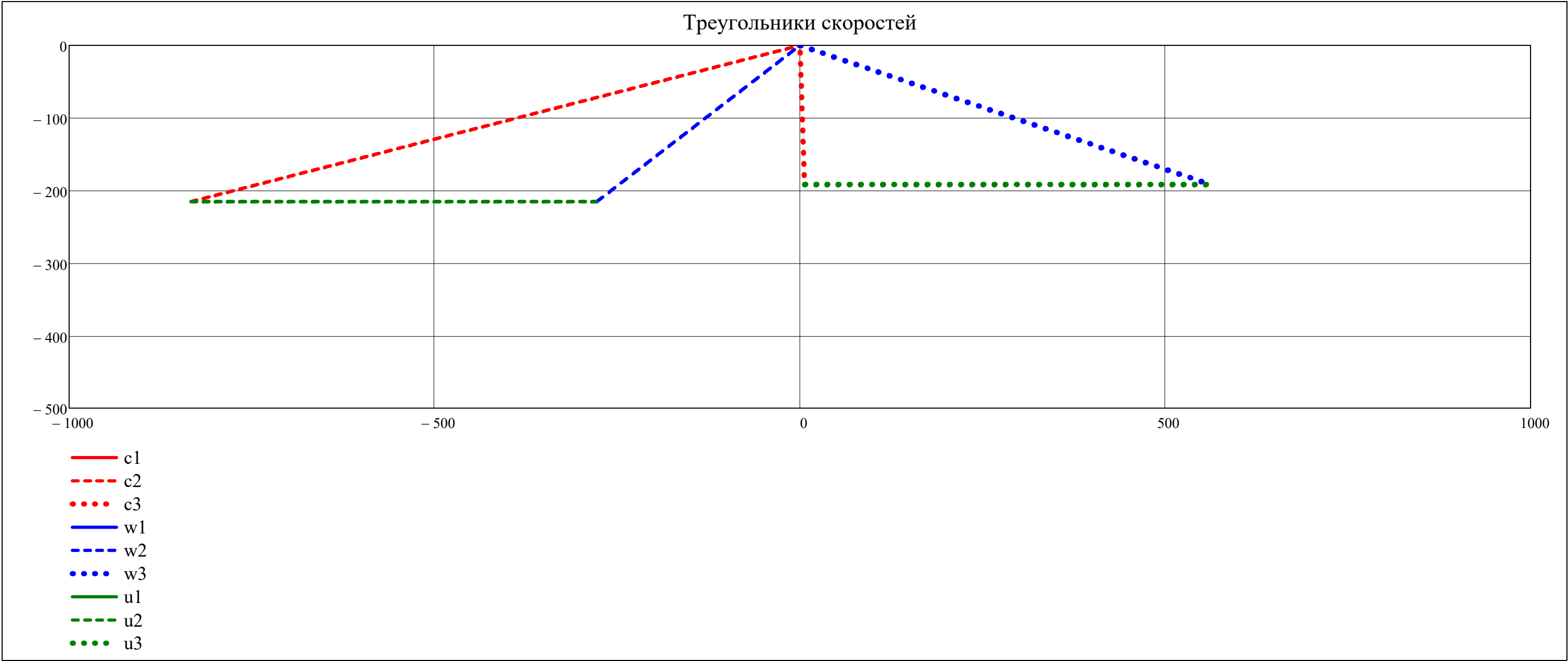
r = 1



$r_w = \text{av}(N_r)$



$r_w = N_r$



Парусность:

sail<sub>stator</sub>

sail<sub>rotor</sub>

=

1

0.85

▼ Расчет хорд Л по парусности

chord<sub>stator</sub>

chord<sub>rotor</sub>

=

for i ∈ 1..Z

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

for r ∈ 1..N<sub>r</sub>

chord<sub>stator</sub><sub>i,av(N<sub>r</sub>)</sub> · sail

b<sub>CAkop</sub> =  $\frac{\hspace{1.5cm}}{sail_{stator} - 1 + sail}$

chord<sub>rotor</sub><sub>i,av(N<sub>r</sub>)</sub> · sail

b<sub>PKkop</sub> =  $\frac{\hspace{1.5cm}}{sail_{rotor} - 1 + sail}$

(b<sub>CAпер</sub>)

(b<sub>PKпер</sub>)

=

b<sub>CAkop</sub> · sail<sub>stator</sub>

b<sub>PKkop</sub> · sail<sub>rotor</sub>

chord<sub>stator</sub>.(z) = interp

cspline

R<sub>st(i,2),1</sub>

R<sub>st(i,2),av(N<sub>r</sub>)</sub>

R<sub>st(i,2),N<sub>r</sub></sub>

b<sub>CAkop</sub>

chord<sub>stator</sub><sub>i,av(N<sub>r</sub>)</sub>

b<sub>CAпер</sub>

R<sub>st(i,2),1</sub>

R<sub>st(i,2),av(N<sub>r</sub>)</sub>

R<sub>st(i,2),N<sub>r</sub></sub>

b<sub>CAkop</sub>

chord<sub>stator</sub><sub>i,av(N<sub>r</sub>)</sub>

b<sub>CAпер</sub>

,z

chord<sub>rotor</sub>.(z) = interp

cspline

R<sub>st(i,2),1</sub>

R<sub>st(i,2),av(N<sub>r</sub>)</sub>

R<sub>st(i,2),N<sub>r</sub></sub>

b<sub>PKkop</sub>

chord<sub>rotor</sub><sub>i,av(N<sub>r</sub>)</sub>

b<sub>PKпер</sub>

R<sub>st(i,2),1</sub>

R<sub>st(i,2),av(N<sub>r</sub>)</sub>

R<sub>st(i,2),N<sub>r</sub></sub>

b<sub>PKkop</sub>

chord<sub>rotor</sub><sub>i,av(N<sub>r</sub>)</sub>

b<sub>PKпер</sub>

,z

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

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

=

chord<sub>stator</sub>.(R<sub>st(i,2),r</sub>)

chord<sub>rotor</sub>.(R<sub>st(i,3),r</sub>)

chord<sub>stator</sub>

chord<sub>rotor</sub>

Длины хорд РК и СА (м):

chord<sub>stator</sub><sup>T</sup>

=

1

68.0

68.0

· 10<sup>−3</sup>

chord<sub>rotor</sub><sup>T</sup>

=

1

38.4

34.2

31.4

· 10<sup>−3</sup>

▲ Расчет хорд Л по парусности

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

$\overline{x_f} = 0.45$

Расчет параметров решетки

$t_{\text{sator}}$

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

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

$c_{\text{sator}}$

$v_{\text{sator}}$

$t_{\text{rotor}}$

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

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

$c_{\text{rotor}}$

$v_{\text{rotor}}$

=

for i ∈ 1..Z

for r ∈ 1..N<sub>r</sub>

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

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

$= \pi \cdot \frac{\frac{\text{mean}(D_{\text{st}(i,1)},r,D_{\text{st}(i,2)},r)}{Z_{\text{sator}_i}}}{\frac{\text{mean}(D_{\text{st}(i,2)},r,D_{\text{st}(i,3)},r)}{Z_{\text{rotor}_i}}}$

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

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

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

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

$= \left( \frac{\overline{r}_{\text{inlet}}_{\text{sator}_{i,r}} \cdot \text{chord}_{\text{sator}_{i,r}}}{\overline{r}_{\text{inlet}}_{\text{rotor}_{i,r}} \cdot \text{chord}_{\text{rotor}_{i,r}}} \cdot \frac{\overline{r}_{\text{outlet}}_{\text{sator}_{i,r}} \cdot \text{chord}_{\text{sator}_{i,r}}}{\overline{r}_{\text{outlet}}_{\text{rotor}_{i,r}} \cdot \text{chord}_{\text{rotor}_{i,r}}} \right)$

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

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

$= \left( \frac{\overline{c}_{\text{sator}_{i,r}} \cdot \text{chord}_{\text{sator}_{i,r}}}{\overline{c}_{\text{rotor}_{i,r}} \cdot \text{chord}_{\text{rotor}_{i,r}}} \right)$

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

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

$= \left( \frac{v_{\text{installation}}(0.5,\alpha_{\text{st}(i,1)},r,\alpha_{\text{st}(i,2)},r)}{v_{\text{installation}}(0.5,\beta_{\text{st}(i,2)},r,\beta_{\text{st}(i,3)},r)} \right) + \frac{\pi}{2}$

$t_{\text{sator}}$

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

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

$c_{\text{sator}}$

$v_{\text{sator}}$

$t_{\text{rotor}}$

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

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

$c_{\text{rotor}}$

$v_{\text{rotor}}$

$v_{\text{установки}}(\alpha_{\text{st}(i,1)},r,\alpha_{\text{st}(i,2)},r)$

$v_{\text{установки}}(\beta_{\text{st}(i,2)},r,\beta_{\text{st}(i,3)},r)$

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

Расчет параметров решетки

Относительные радиусы профилей (°):

1

16.000

1

6.000

2

6.000

3

6.000

$\overline{r}_{\text{inlet}_{\text{stator}}}$

<sup>T</sup>

=

·%

1

5.950

1

4.550

2

3.850

3

$\overline{r}_{\text{inlet}_{\text{rotor}}}$

<sup>T</sup>

=

·%

1

3.000

1

3.000

2

3.000

3

3.000

$\overline{r}_{\text{outlet}_{\text{stator}}}$

<sup>T</sup>

=

·%

1

2.550

1

1.950

2

1.650

3

$\overline{r}_{\text{outlet}_{\text{rotor}}}$

<sup>T</sup>

=

·%

Относительная толщина профиля (°):

1

15.00

1

15.00

2

15.00

3

15.00

$\overline{c}_{\text{stator}}$

<sup>T</sup>

=

·%

1

17.00

1

13.00

2

11.00

3

$\overline{c}_{\text{rotor}}$

<sup>T</sup>

=

·%

Относительный шаг решетки (°):

1

0.8345

1

0.8711

2

0.9076

3

$\left(\frac{t_{\text{stator}}}{\text{chord}_{\text{stator}}}\right)$

<sup>T</sup>

=

1

0.5829

1

0.6918

2

0.7941

3

$\left(\frac{t_{\text{rotor}}}{\text{chord}_{\text{rotor}}}\right)$

<sup>T</sup>

=

Относительная густота решетки (°):

1

1.198

1

1.148

2

1.102

3

$\left(\frac{\text{chord}_{\text{stator}}}{t_{\text{stator}}}\right)$

<sup>T</sup>

=

1

1.716

1

1.445

2

1.259

3

$\left(\frac{\text{chord}_{\text{rotor}}}{t_{\text{rotor}}}\right)$

<sup>T</sup>

=

Длина хорды профиля [м]:

1

1

68.0

2

68.0

3

68.0

$\cdot 10^{-3}$

chord<sub>stator</sub><sup>T</sup> =

1

1

38.4

2

34.2

3

31.4

$\cdot 10^{-3}$

chord<sub>rotor</sub><sup>T</sup> =

Радиусы профилей:

1

1

4.08

2

4.08

3

4.08

$\cdot 10^{-3}$

r\_inlet<sub>stator</sub><sup>T</sup> =

1

1

2.28

2

1.56

3

1.21

$\cdot 10^{-3}$

r\_inlet<sub>rotor</sub><sup>T</sup> =

1

1

2.04

2

2.04

3

2.04

$\cdot 10^{-3}$

r\_outlet<sub>stator</sub><sup>T</sup> =

1

1

0.98

2

0.67

3

0.52

$\cdot 10^{-3}$

r\_outlet<sub>rotor</sub><sup>T</sup> =

Толщина профиля [м]:

1

1

10.20

2

10.20

3

10.20

$\cdot 10^{-3}$

c<sub>stator</sub><sup>T</sup> =

1

1

6.52

2

4.45

3

3.46

$\cdot 10^{-3}$

c<sub>rotor</sub><sup>T</sup> =

Шаг решетки [м]:

1

1

56.7

2

59.2

3

61.7

$\cdot 10^{-3}$

t<sub>stator</sub><sup>T</sup> =

1

1

22.4

2

23.7

3

25.0

$\cdot 10^{-3}$

t<sub>rotor</sub><sup>T</sup> =



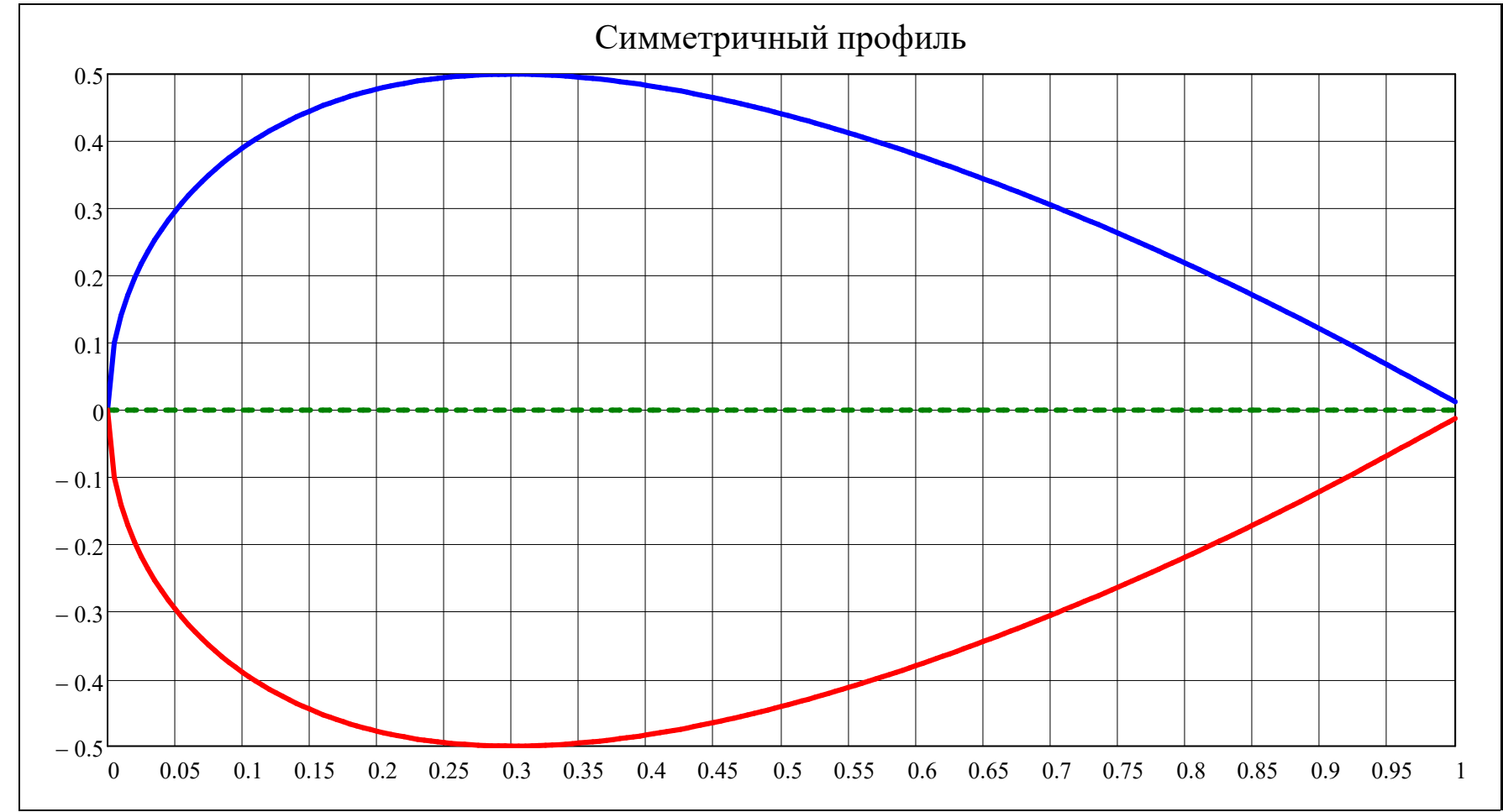
Угол поворота потока:	$\epsilon_{\text{stator}}^T =$	<table><tr><td></td><td>1</td></tr><tr><td>1</td><td>75.51</td></tr><tr><td>2</td><td>75.51</td></tr><tr><td>3</td><td>75.51</td></tr></table>		1	1	75.51	2	75.51	3	75.51	$^{\circ}$	$\epsilon_{\text{rotor}}^T =$	<table><tr><td></td><td>1</td></tr><tr><td>1</td><td>132.12</td></tr><tr><td>2</td><td>127.61</td></tr><tr><td>3</td><td>123.40</td></tr></table>		1	1	132.12	2	127.61	3	123.40	$^{\circ}$
	1																					
1	75.51																					
2	75.51																					
3	75.51																					
	1																					
1	132.12																					
2	127.61																					
3	123.40																					
Угол установки профиля:	$\upsilon_{\text{stator}}^T =$	<table><tr><td></td><td>1</td></tr><tr><td>1</td><td>117.3</td></tr><tr><td>2</td><td>117.3</td></tr><tr><td>3</td><td>117.3</td></tr></table>		1	1	117.3	2	117.3	3	117.3	$^{\circ}$	$\upsilon_{\text{rotor}}^T =$	<table><tr><td></td><td>1</td></tr><tr><td>1</td><td>112.0</td></tr><tr><td>2</td><td>114.0</td></tr><tr><td>3</td><td>115.4</td></tr></table>		1	1	112.0	2	114.0	3	115.4	$^{\circ}$
	1																					
1	117.3																					
2	117.3																					
3	117.3																					
	1																					
1	112.0																					
2	114.0																					
3	115.4																					
Угол изгиба профиля:	$\pi - \epsilon_{\text{stator}}^T =$	<table><tr><td></td><td>1</td></tr><tr><td>1</td><td>104.5</td></tr><tr><td>2</td><td>104.5</td></tr><tr><td>3</td><td>104.5</td></tr></table>		1	1	104.5	2	104.5	3	104.5	$^{\circ}$	$\pi - \epsilon_{\text{rotor}}^T =$	<table><tr><td></td><td>1</td></tr><tr><td>1</td><td>47.9</td></tr><tr><td>2</td><td>52.4</td></tr><tr><td>3</td><td>56.6</td></tr></table>		1	1	47.9	2	52.4	3	56.6	$^{\circ}$
	1																					
1	104.5																					
2	104.5																					
3	104.5																					
	1																					
1	47.9																					
2	52.4																					
3	56.6																					

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

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,c̄,θ) =

linterp(X<sub>U</sub>,y/b<sub>ср.л</sub>(X<sub>U</sub>,θ) + Y<sub>U</sub>·c̄,x)

if line = "+"

linterp(X<sub>U</sub>,y/b<sub>ср.л</sub>(X<sub>U</sub>,θ) + Y<sub>U</sub>·c̄,x)

+ linterp(X<sub>L</sub>,y/b<sub>ср.л</sub>(X<sub>L</sub>,θ) + Y<sub>L</sub>·c̄,x)

2

if line = "0"

linterp(X<sub>L</sub>,y/b<sub>ср.л</sub>(X<sub>L</sub>,θ) + Y<sub>L</sub>·c̄,x)

if line = "-"

NaN otherwise

Профиль СА на ср. сечении

Профиль РК на ср. сечении

Подключение симметричного профиля







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

	1
1	78.07
2	78.07
3	78.07

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

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

	1
1	70.64
2	70.64
3	70.64

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

$$area_{stator}^T =$$

	1
1	473.87
2	473.87
3	473.87

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

$$Sx_{stator}^T =$$

	1
1	4232.2
2	4232.2
3	4232.2

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

$$Sy_{stator}^T =$$

	1
1	13563.5
2	13563.5
3	13563.5

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

$$x0_{stator}^T =$$

	1
1	28.6
2	28.6
3	28.6

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

$$y0_{stator}^T =$$

	1
1	8.9
2	8.9
3	8.9

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

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

	1
1	52.01
2	44.78
3	40.21

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

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

	1
1	44.26
2	39.55
3	36.21

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

$$area_{rotor}^T =$$

	1
1	171.14
2	103.96
3	74.28

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

$$Sx_{rotor}^T =$$

	1
1	1711.6
2	883.3
3	554.2

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

$$Sy_{rotor}^T =$$

	1
1	2765.3
2	1497.1
3	983.0

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

$$x0_{rotor}^T =$$

	1
1	16.2
2	14.4
3	13.2

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

$$y0_{rotor}^T =$$

	1
1	10.0
2	8.5
3	7.5

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

$J_{x_{\text{stator}}}$ <sup>T</sup>

	1
1	44264
2	44264
3	44264

$\cdot 10^{-12}$

$J_{y_{\text{stator}}}$ <sup>T</sup>

	1
1	508717
2	508717
3	508717

$\cdot 10^{-12}$

$J_{xy_{\text{stator}}}$ <sup>T</sup>

	1
1	128548
2	128548
3	128548

$\cdot 10^{-12}$

$J_{x0_{\text{stator}}}$ <sup>T</sup>

	1
1	6465
2	6465
3	6465

$\cdot 10^{-12}$

$J_{y0_{\text{stator}}}$ <sup>T</sup>

	1
1	120489
2	120489
3	120489

$\cdot 10^{-12}$

$J_{xy0_{\text{stator}}}$ <sup>T</sup>

	1
1	7409
2	7409
3	7409

$\cdot 10^{-12}$

$\alpha_{\text{major}_{\text{stator}}}$ <sup>T</sup>

	1
1	3.70
2	3.70
3	3.70

$\cdot \circ$

$J_{x_{\text{rotor}}}$ <sup>T</sup>

	1
1	18774
2	8184
3	4505

$\cdot 10^{-12}$

$J_{y_{\text{rotor}}}$ <sup>T</sup>

	1
1	58548
2	28251
3	17045

$\cdot 10^{-12}$

$J_{xy_{\text{rotor}}}$ <sup>T</sup>

	1
1	29122
2	13406
3	7736

$\cdot 10^{-12}$

$J_{x0_{\text{rotor}}}$ <sup>T</sup>

	1
1	1656
2	679
3	370

$\cdot 10^{-12}$

$J_{y0_{\text{rotor}}}$ <sup>T</sup>

	1
1	13867
2	6691
3	4037

$\cdot 10^{-12}$

$J_{xy0_{\text{rotor}}}$ <sup>T</sup>

	1
1	1466
2	686
3	402

$\cdot 10^{-12}$

$\alpha_{\text{major}_{\text{rotor}}}$ <sup>T</sup>

	1
1	6.75
2	6.43
3	6.18

$\cdot \circ$



$$\mathbf{J_{u_{stator}}}^T = \begin{bmatrix} & 1 \\ 1 & 5986 \\ 2 & 5986 \\ 3 & 5986 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{J_{v_{stator}}}^T = \begin{bmatrix} & 1 \\ 1 & 120968.8 \\ 2 & 120968.8 \\ 3 & 120968.8 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{J_{uv_{stator}}}^T = \begin{bmatrix} & 1 \\ 1 & -0 \\ 2 & -0 \\ 3 & -0 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{J_{p_{stator}}}^T = \begin{bmatrix} & 1 \\ 1 & 126955 \\ 2 & 126955 \\ 3 & 126955 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{W_{p_{stator}}}^T = \begin{bmatrix} & 1 \\ 1 & 3146.4 \\ 2 & 3146.4 \\ 3 & 3146.4 \end{bmatrix} \cdot 10^{-9}$$

$$\mathbf{stiffness_{stator}}^T = \begin{bmatrix} & 1 \\ 1 & 11340.9 \\ 2 & 11340.9 \\ 3 & 11340.9 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{J_{u_{rotor}}}^T = \begin{bmatrix} & 1 \\ 1 & 1482 \\ 2 & 602 \\ 3 & 326 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{J_{v_{rotor}}}^T = \begin{bmatrix} & 1 \\ 1 & 14041 \\ 2 & 6769 \\ 3 & 4081 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{J_{uv_{rotor}}}^T = \begin{bmatrix} & 1 \\ 1 & 0 \\ 2 & 0 \\ 3 & 0 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{J_{p_{rotor}}}^T = \begin{bmatrix} & 1 \\ 1 & 15522 \\ 2 & 7371 \\ 3 & 4407 \end{bmatrix} \cdot 10^{-12}$$

$$\mathbf{W_{p_{rotor}}}^T = \begin{bmatrix} & 1 \\ 1 & 637.2 \\ 2 & 342.1 \\ 3 & 224.1 \end{bmatrix} \cdot 10^{-9}$$

$$\mathbf{stiffness_{rotor}}^T = \begin{bmatrix} & 1 \\ 1 & 1676.5 \\ 2 & 473.1 \\ 3 & 204.3 \end{bmatrix} \cdot 10^{-12}$$

CP<sub>x</sub><sub>stator</sub><sup>T</sup>

=

	1
1	23.790
2	23.790
3	23.790

·10<sup>-3</sup>

CP<sub>y</sub><sub>stator</sub><sup>T</sup>

=

	1
1	0.0000
2	0.0000
3	0.0000

·10<sup>-3</sup>

CP<sub>x</sub><sub>rotor</sub><sup>T</sup>

=

	1
1	13.430
2	11.969
3	10.999

·10<sup>-3</sup>

CP<sub>y</sub><sub>rotor</sub><sup>T</sup>

=

	1
1	0.0000
2	0.0000
3	0.0000

·10<sup>-3</sup>



Абс. координаты профиля:

Airfoil(type,x,line,i,r) =	<div><div><math>AIRFOIL\left(x,line,\overline{c}_{stator_{i,r}},\varepsilon_{stator_{i,r}}\right)</math></div><div>if type = "stator"</div></div> <div><div><math>AIRFOIL\left(x,line,\overline{c}_{rotor_{i,r}},\varepsilon_{rotor_{i,r}}\right)</math></div><div>if type = "rotor"</div></div>
----------------------------	--

Рассматриваемая ступень:

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

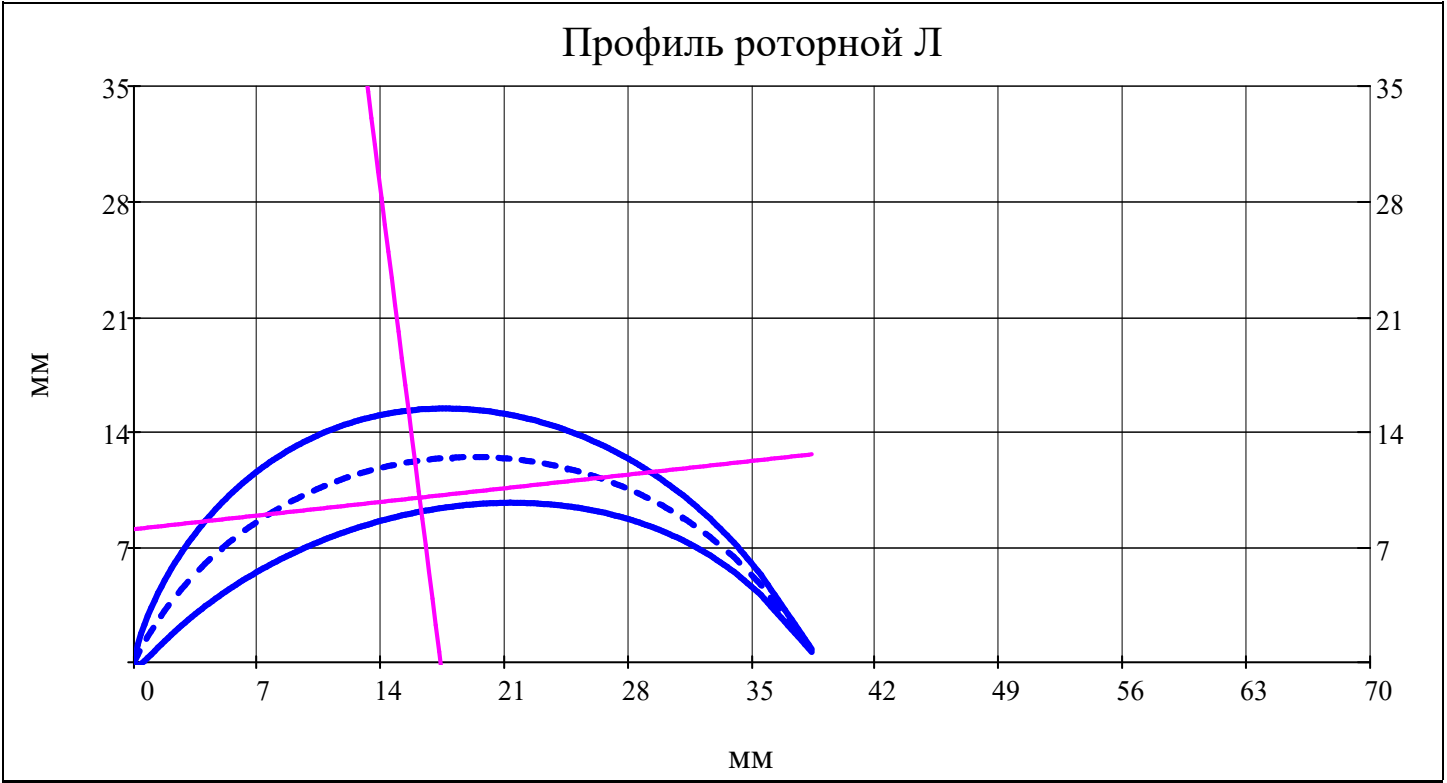
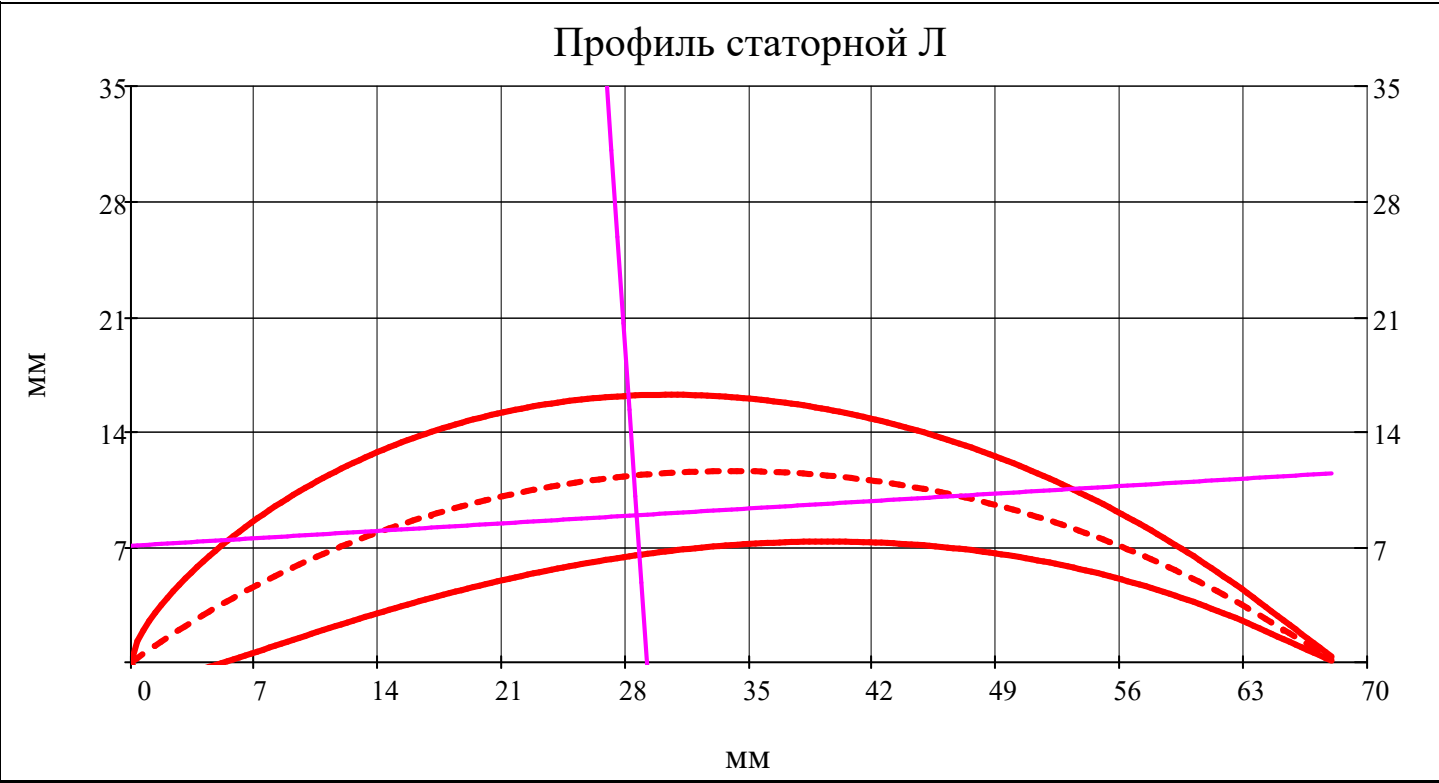
Построение профилей Л РК и НА

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

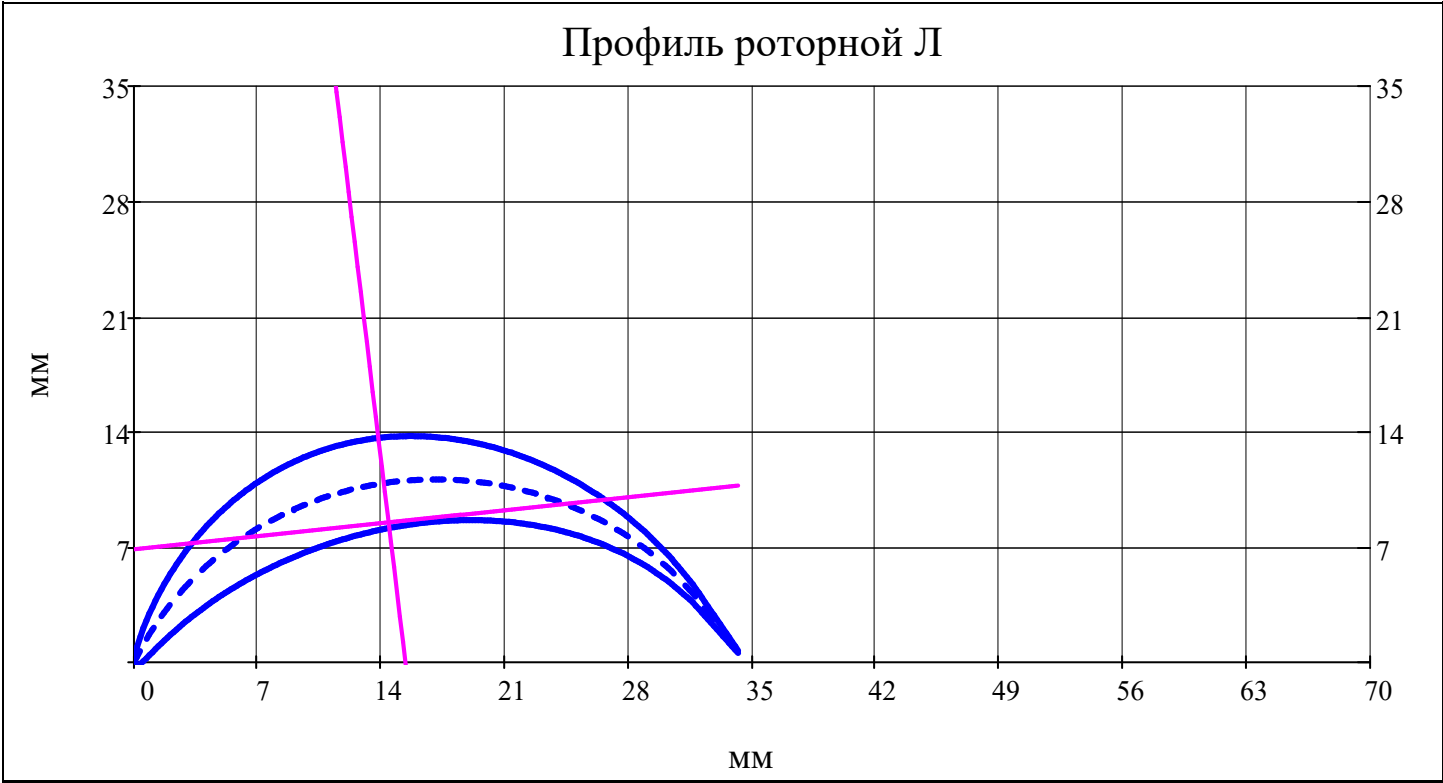
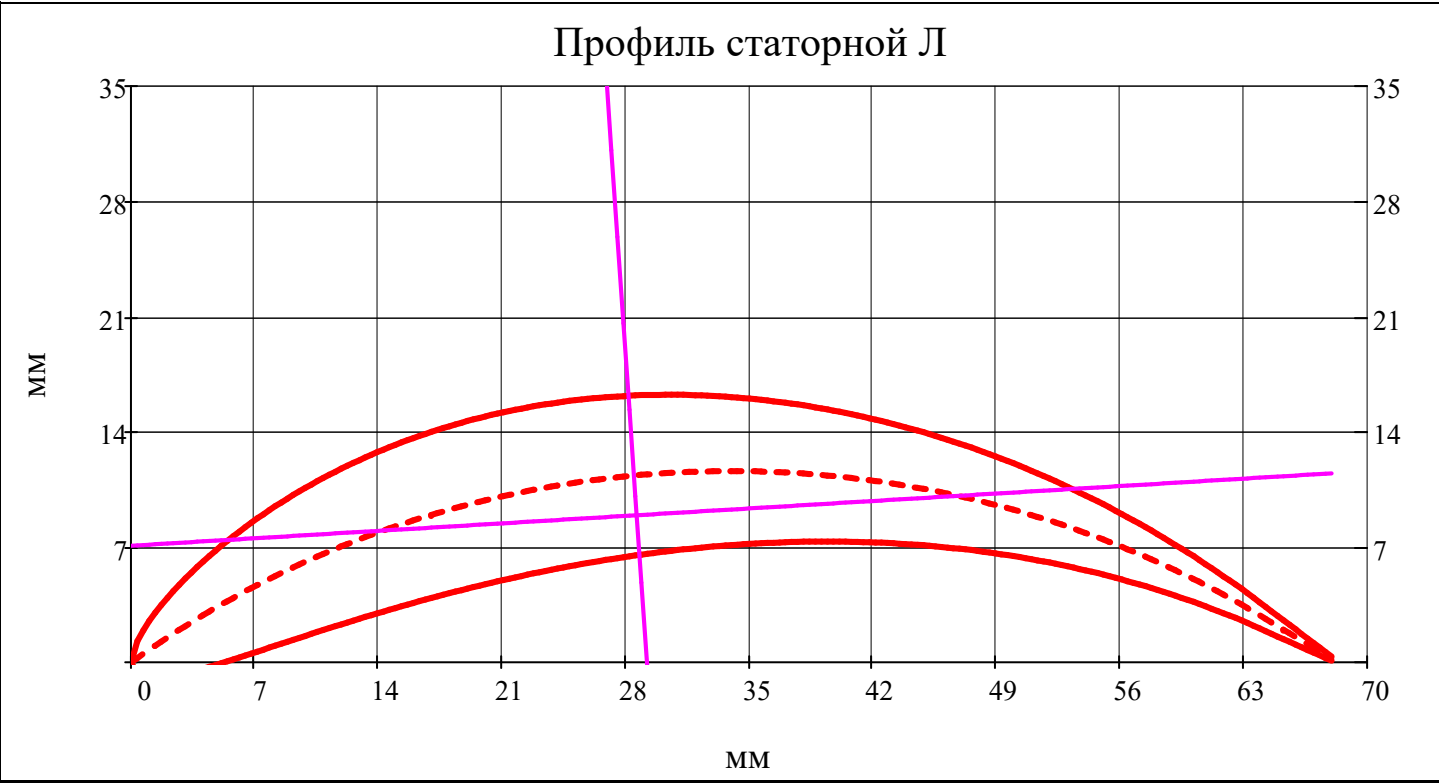
$$\text{AXLE90}(\text{type}, x, i, r) = \begin{cases} \frac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \tan\left(\alpha_{\text{major}_{\text{rotor}_{i,r}}} + \frac{\pi}{2}\right) \cdot \left(x - \frac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if (type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

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

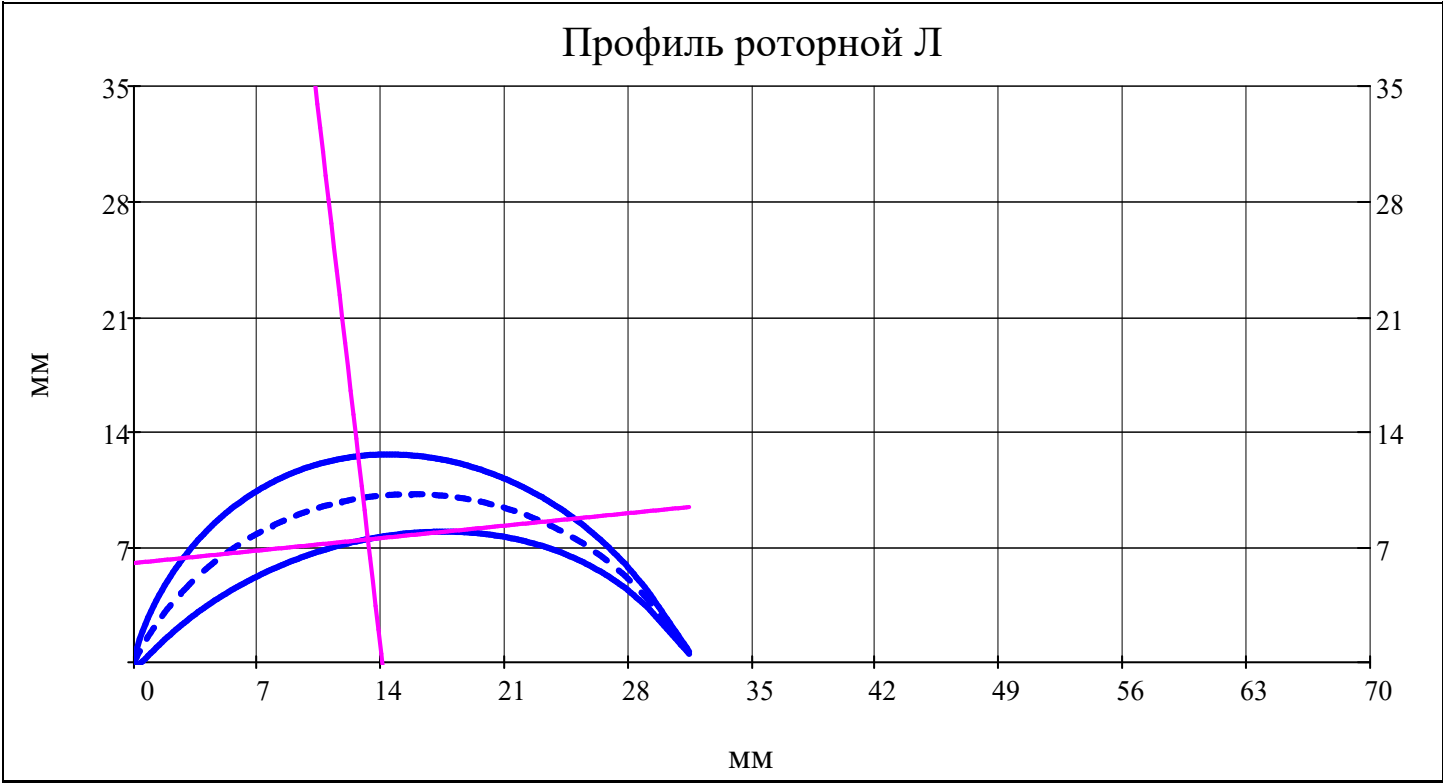
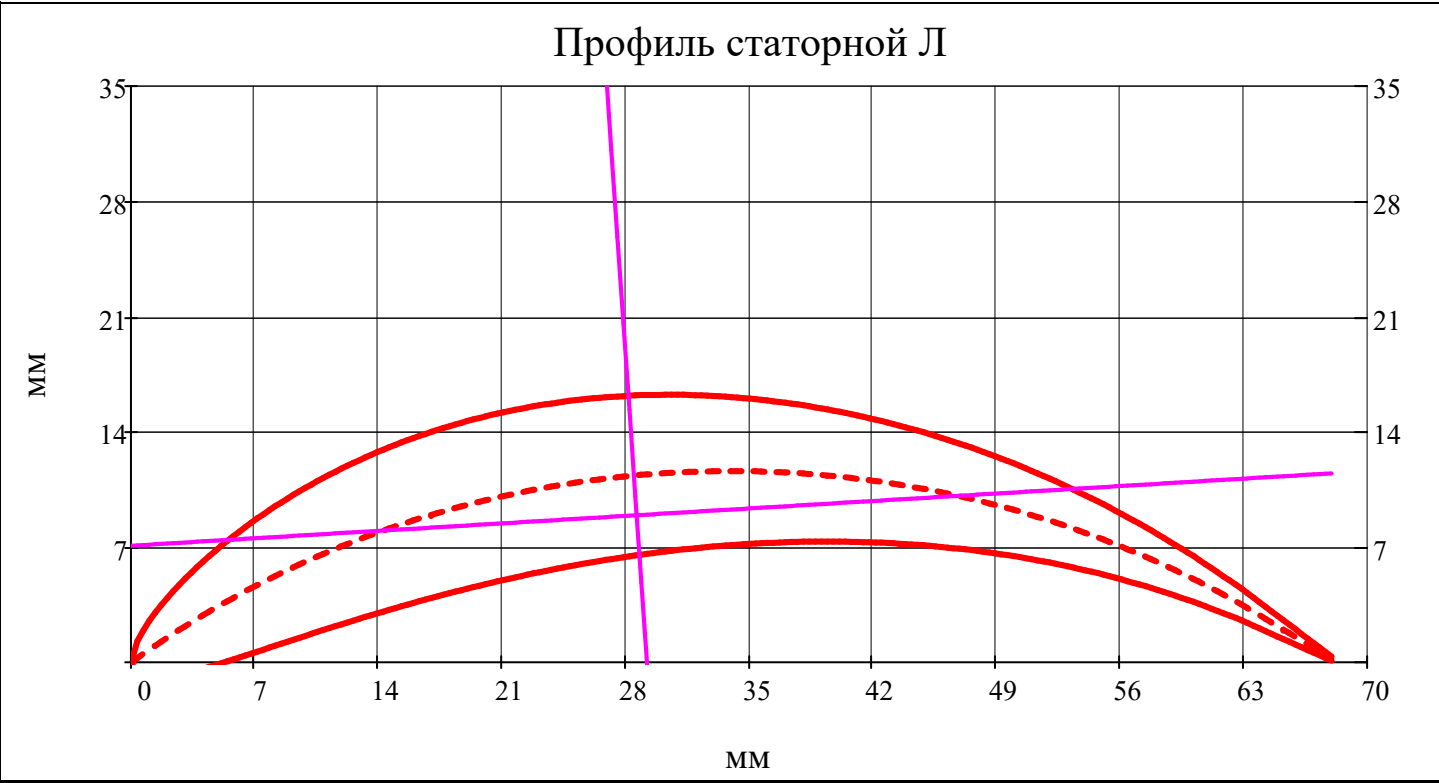
$r_w = 1$



$r_w = av(N_r)$



$r_w = N_r$







Вывод координат для построения профиля Л

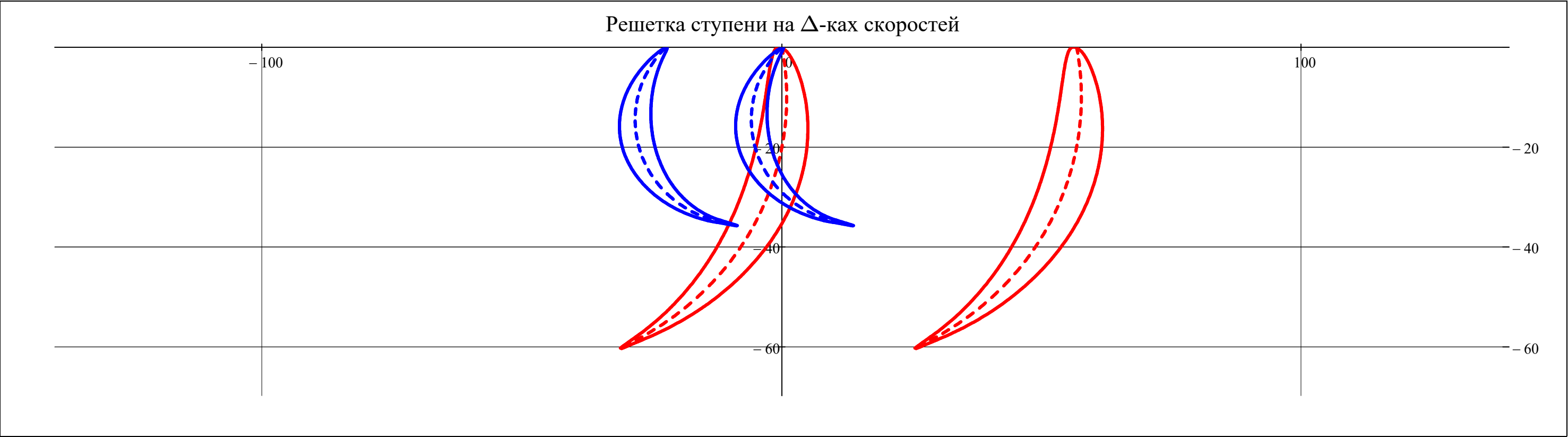
Рассматриваемая ступень:

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

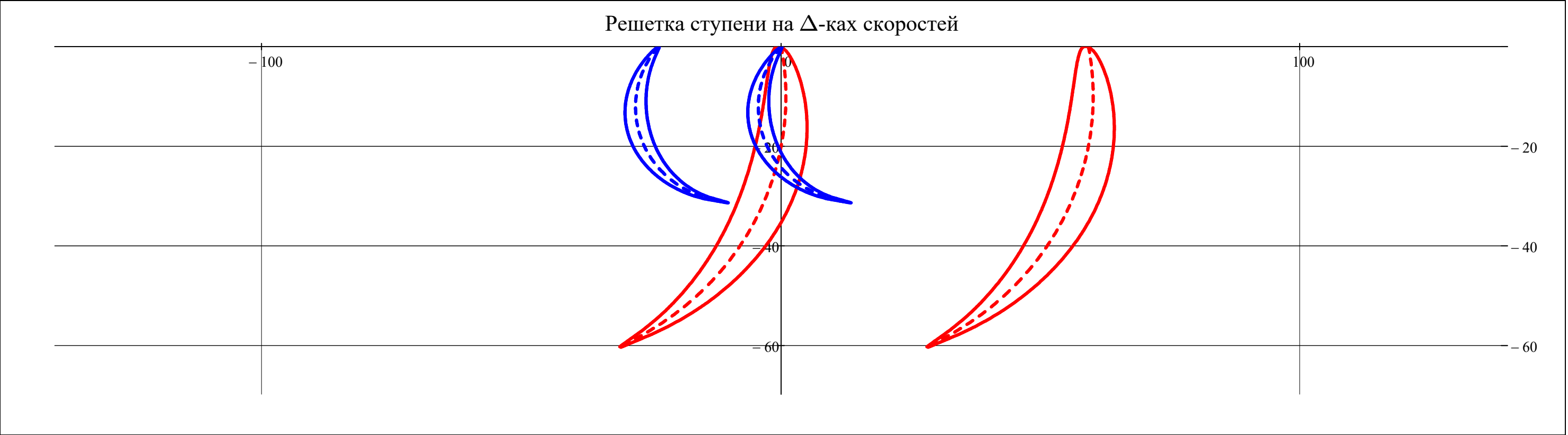
$$b_{lim} = \frac{\text{ceil}\left(\max\left(\text{chord}_{\text{rotor}_{j,N_r}}, \text{chord}_{\text{stator}_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 70.0 \cdot 10^{-3}$$

Построение плоских решеток профилей Л на треугольниках скоростей

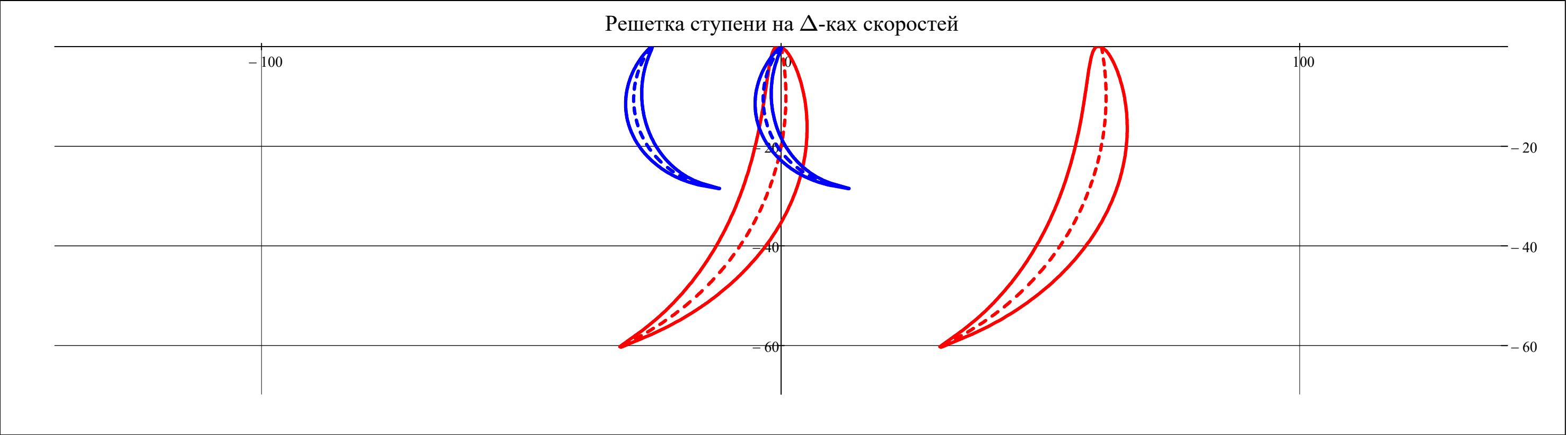
$$r_w = 1$$



$r_w = \text{av}(N_r)$



$r_w = N_r$





Рассматриваемая ступень:

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

▼ Поперечная часть ступени

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

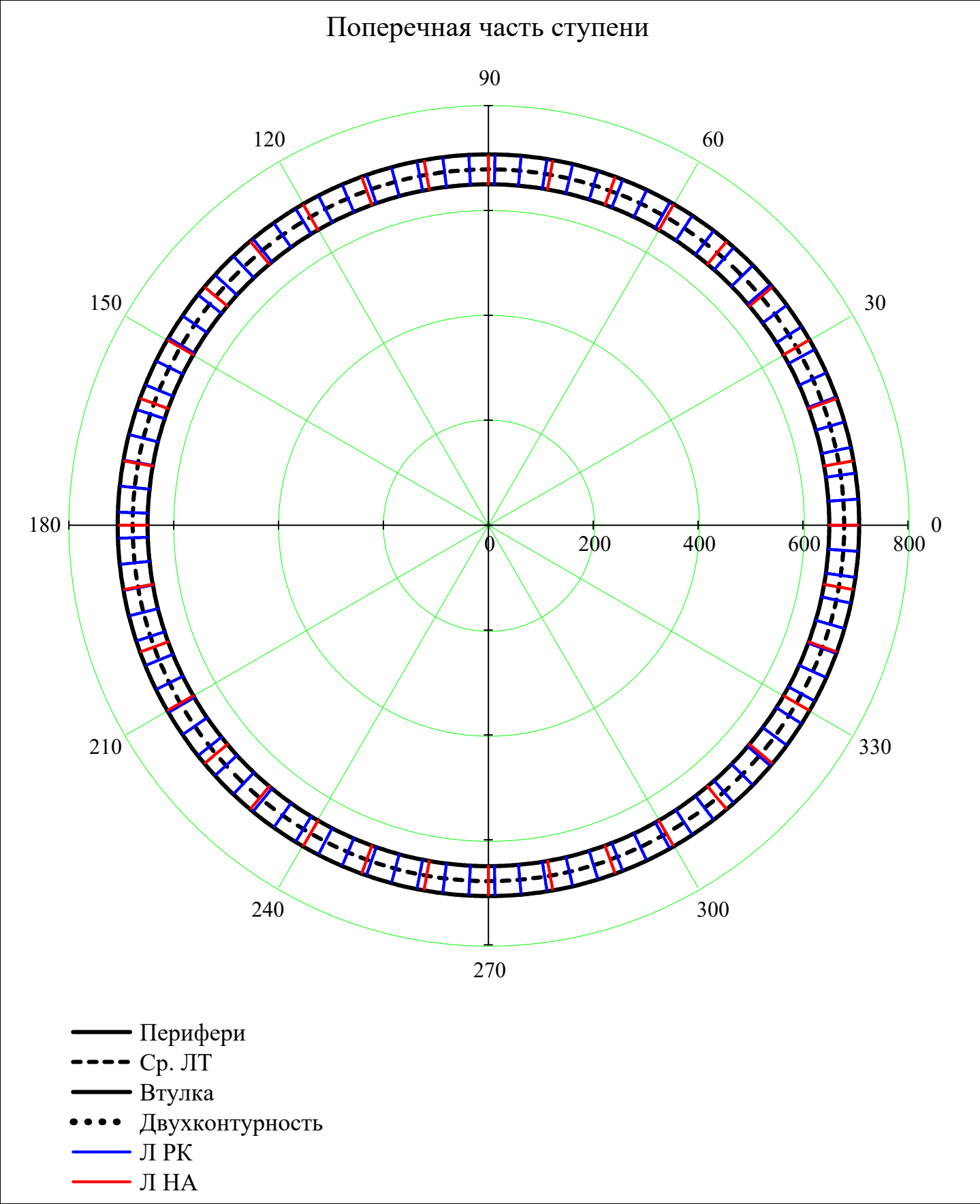
$$i_{\text{rotor}} = 1 \dots Z_{\text{rotor}_j}$$

$$i_{\text{stator}} = 1 \dots Z_{\text{stator}_j}$$

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

$$Л_{PK}(r,j) = \begin{cases} \frac{2 \cdot \pi}{Z_{\text{rotor}_j}} & \text{if } D_{\text{st}(j,1)}, 1 < r < D_{\text{st}(j,1)}, N_r \\ \text{NaN} & \text{otherwise} \end{cases}$$

$$Л_{HA}(r,j) = \begin{cases} \frac{2 \cdot \pi}{Z_{\text{stator}_j}} & \text{if } D_{\text{st}(j,2)}, 1 < r < D_{\text{st}(j,2)}, N_r \\ \text{NaN} & \text{otherwise} \end{cases}$$



$$\begin{pmatrix} \nu_{0\text{изГ.stator}} & \nu_{0\text{изГ.rotor}} \\ \nu_{0\text{угЛ.stator}} & \nu_{0\text{угЛ.rotor}} \\ \nu_{0\text{угЛ.stator\_bondage}} & \nu_{0\text{угЛ.rotor\_bondage}} \end{pmatrix}$$

=

for i ∈ 1..Z

for r ∈ av(N<sub>r</sub>)

for mode ∈ 1..6

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

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

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

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

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

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

$$\begin{pmatrix} \nu_{0\text{изГ.stator}} & \nu_{0\text{изГ.rotor}} \\ \nu_{0\text{угЛ.stator}} & \nu_{0\text{угЛ.rotor}} \\ \nu_{0\text{угЛ.stator\_bondage}} & \nu_{0\text{угЛ.rotor\_bondage}} \end{pmatrix}$$



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	12595	5145						
2	78937	32248						
3	221049	90305						
4	433492	177095						
5	716300	292630						
6	1069752	437026						

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
1	8364	5507
2	25091	16521
3	41819	27535
4	58546	38548
5	75274	49562
6	92001	60576

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

	1	2
1	16727	11014
2	33455	22028
3	50182	33041
4	66910	44055
5	83637	55069
6	100365	66083



Расчетный узел: type = "turbine"

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

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

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

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

► Определение координат точек профиля Л, наиболее удаленных от НЛ

Наиболее удаленные точки от НЛ (мм):

$$u_{u_{\text{rotor}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & -0.218 \\ \hline 2 & 0.395 \\ \hline 3 & -5.994 \\ \hline \end{array} \cdot 10^{-3}$$

$$u_{l_{\text{rotor}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 21.030 \\ \hline 2 & 18.832 \\ \hline 3 & -8.994 \\ \hline \end{array} \cdot 10^{-3}$$

$$u_{u_{\text{stator}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & -7.064 \\ \hline 2 & 8.165 \\ \hline 3 & 8.161 \\ \hline \end{array} \cdot 10^{-3}$$

$$u_{l_{\text{stator}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & -11.363 \\ \hline 2 & -25.857 \\ \hline 3 & -25.850 \\ \hline \end{array} \cdot 10^{-3}$$

$$v_{u_{\text{rotor}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 5.323 \\ \hline 2 & 4.047 \\ \hline 3 & 13.959 \\ \hline \end{array} \cdot 10^{-3}$$

$$v_{l_{\text{rotor}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & -11.789 \\ \hline 2 & -10.076 \\ \hline 3 & -17.325 \\ \hline \end{array} \cdot 10^{-3}$$

$$v_{u_{\text{stator}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 29.140 \\ \hline 2 & 8.190 \\ \hline 3 & 8.194 \\ \hline \end{array} \cdot 10^{-3}$$

$$v_{l_{\text{stator}}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & -38.695 \\ \hline 2 & -14.465 \\ \hline 3 & -14.477 \\ \hline \end{array} \cdot 10^{-3}$$

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

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

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

	1
1	-18.45
2	-8.87
3	0.00

 $\cdot 10^6$

$\sigma_{\text{p}_{\text{rotor}}}^{\text{T}} \leq 70 \cdot 10^6 =$ 

	1
1	1
2	1
3	1

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

	1
1	40.41
2	21.85
3	0.00

 $\cdot 10^6$

$\sigma_{\text{n}_{\text{rotor}}}^{\text{T}} \leq 70 \cdot 10^6 =$ 

	1
1	1
2	1
3	1

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

	1
1	0.00
2	3.47
3	13.87

 $\cdot 10^6$

$\sigma_{\text{p}_{\text{stator}}}^{\text{T}} \leq 70 \cdot 10^6 =$ 

	1
1	1
2	1
3	1

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

	1
1	0.00
2	-7.07
3	-28.26

 $\cdot 10^6$

$\sigma_{\text{n}_{\text{stator}}}^{\text{T}} \leq 70 \cdot 10^6 =$ 

	1
1	1
2	1
3	1



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

$$\begin{pmatrix} \sigma_{\text{rotor}} \\ \sigma_{\text{stator}} \end{pmatrix}$$

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

$$\begin{pmatrix} \sigma_{\text{rotor.}} \\ \sigma_{\text{stator.}} \end{pmatrix}$$

$$\sigma_{\text{rotor}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 161.59 \\ \hline 2 & 101.72 \\ \hline 3 & 0.00 \\ \hline \end{array} \cdot 10^6$$

$$\sigma_{\text{stator}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0.00 \\ \hline 2 & 5.61 \\ \hline 3 & 16.44 \\ \hline \end{array} \cdot 10^6$$

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

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

$$\text{safety}_{\text{rotor}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.27 \\ \hline 2 & 2.02 \\ \hline 3 & 000000000000000000000000000000 \\ \hline \end{array}$$

$$\text{safety}_{\text{stator}}^T = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 000000000000000000000000000000 \\ \hline 2 & 36.53 \\ \hline 3 & 12.47 \\ \hline \end{array}$$

$$\text{safety}_{\text{rotor}}^T \geq \text{safety} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 0 \\ \hline 2 & 1 \\ \hline 3 & 1 \\ \hline \end{array}$$

$$\text{safety}_{\text{stator}}^T \geq \text{safety} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1 \\ \hline 2 & 1 \\ \hline 3 & 1 \\ \hline \end{array}$$

Рассматриваемая ступень:

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

$$b_{lim} = \frac{ceil\left(\max\left(chord_{rotor_{j,N_r}},chord_{stator_{j,N_r}}\right)\cdot10^2\right)}{10^2} = 70.0\cdot10^{-3}$$

Расстояния от оси ЛМ до рассматриваемой ступени (м):

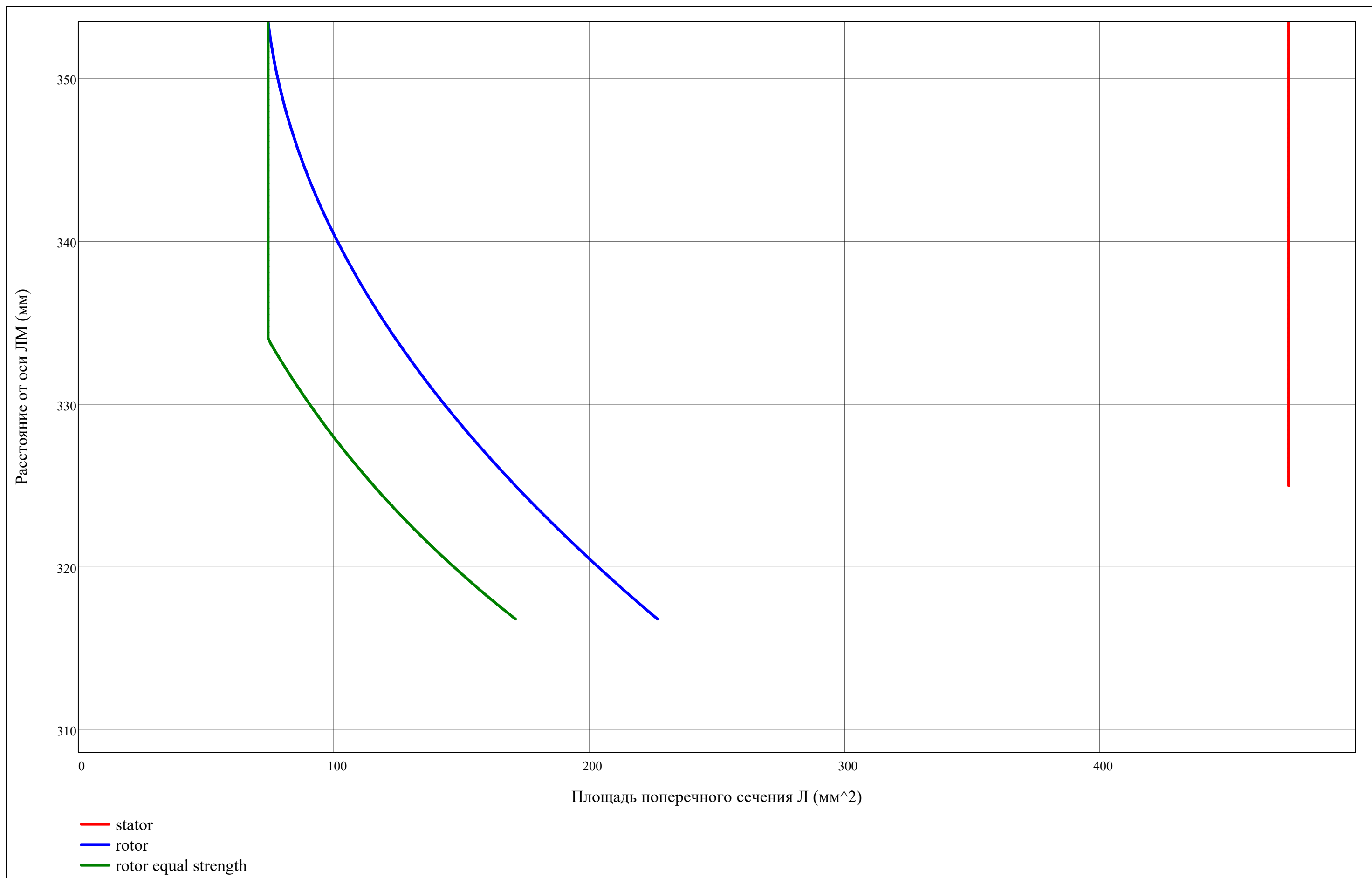
$$R_j = \text{submatrix}\Big(R,2\cdot j-1,2\cdot j+1,1,N_r\Big) = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 325.0 & 339.2 & 353.5 \\ \hline 2 & 325.0 & 339.2 & 353.5 \\ \hline 3 & 308.6 & 331.0 & 353.5 \\ \hline \end{array} \cdot 10^{-3}$$

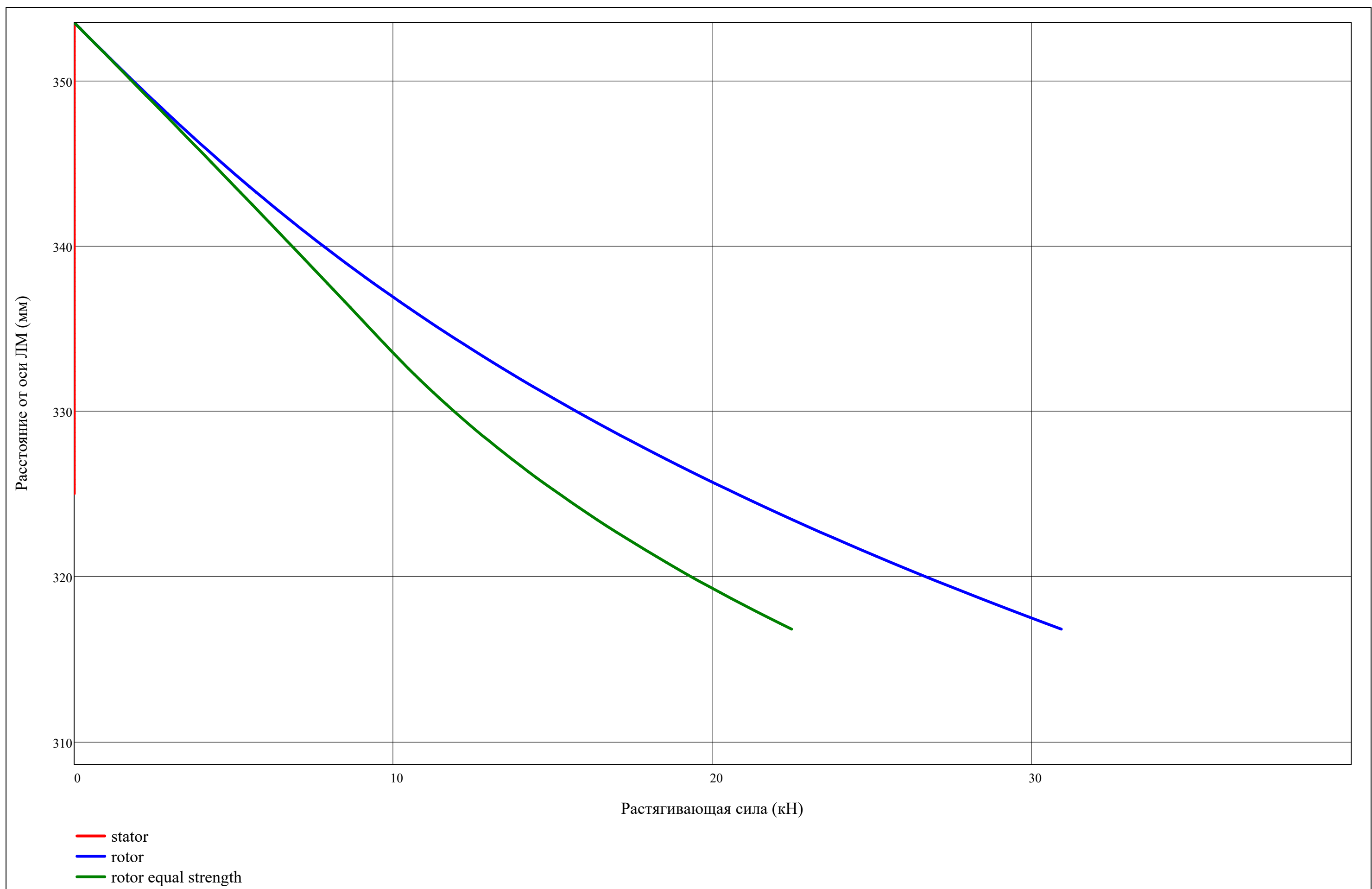
Дискретизация по высоте Л:

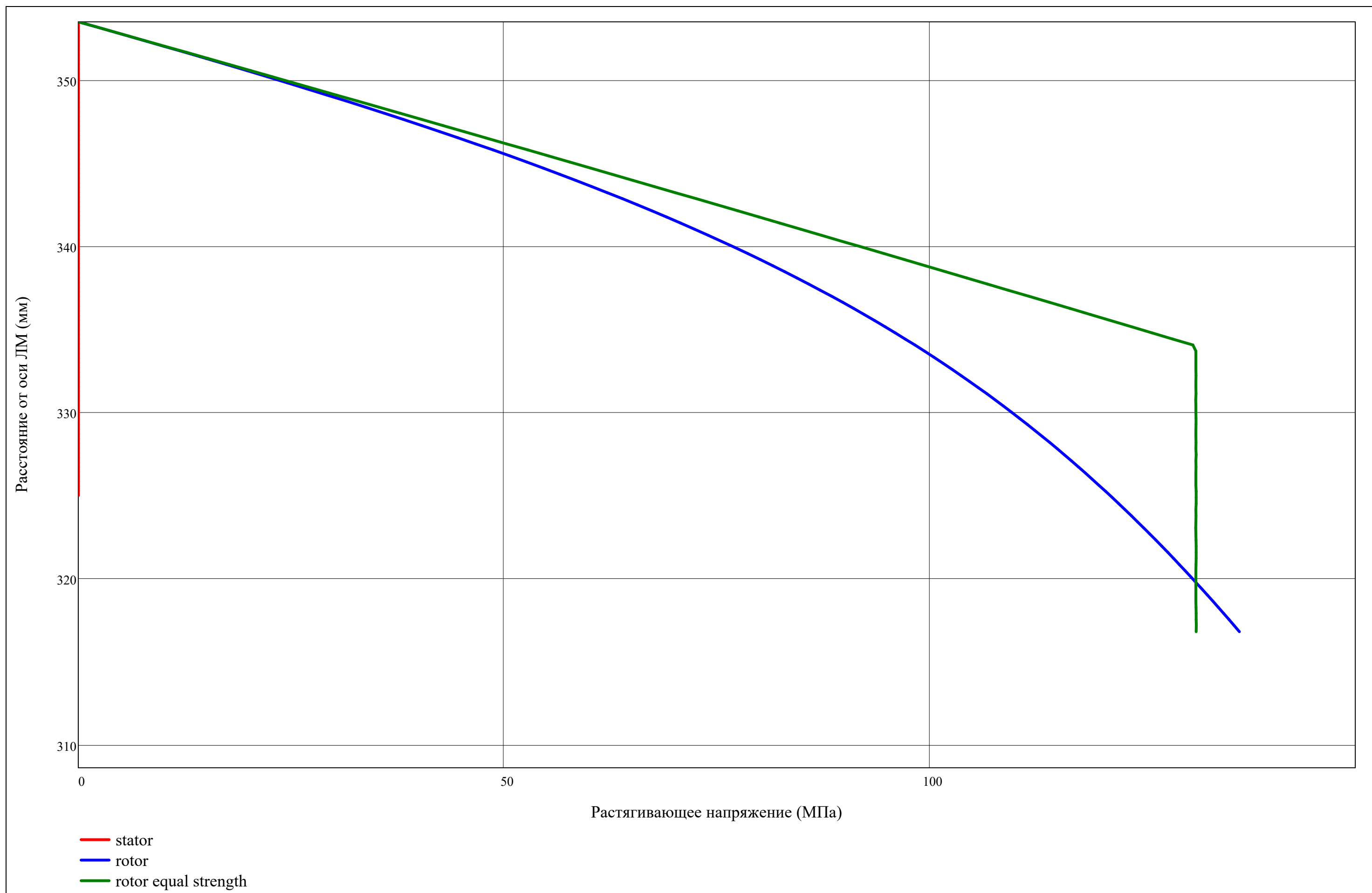
$$z = \min(R_j), \min(R_j) + \frac{\max(R_j) - \min(R_j)}{100} .. \max(R_j)$$

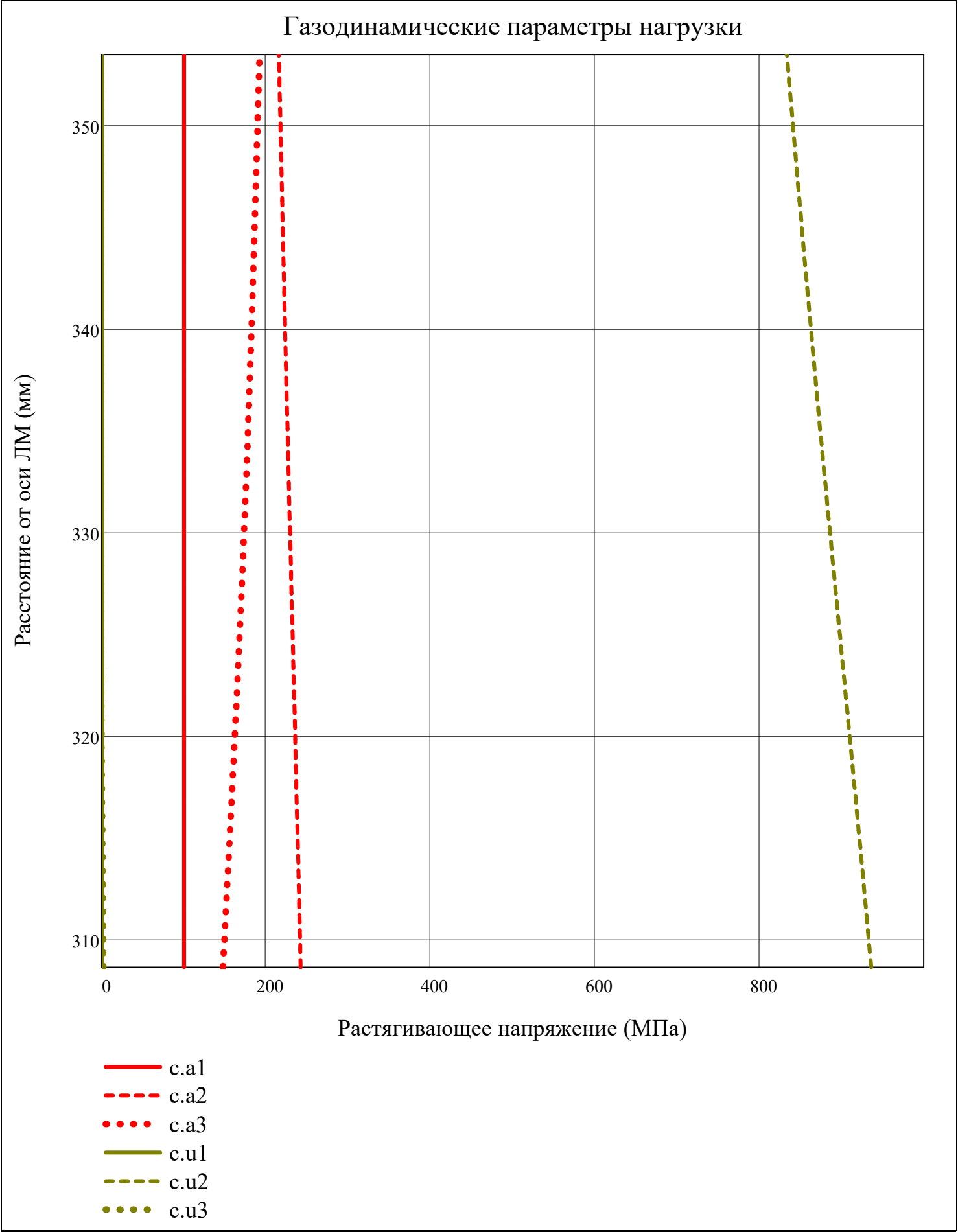
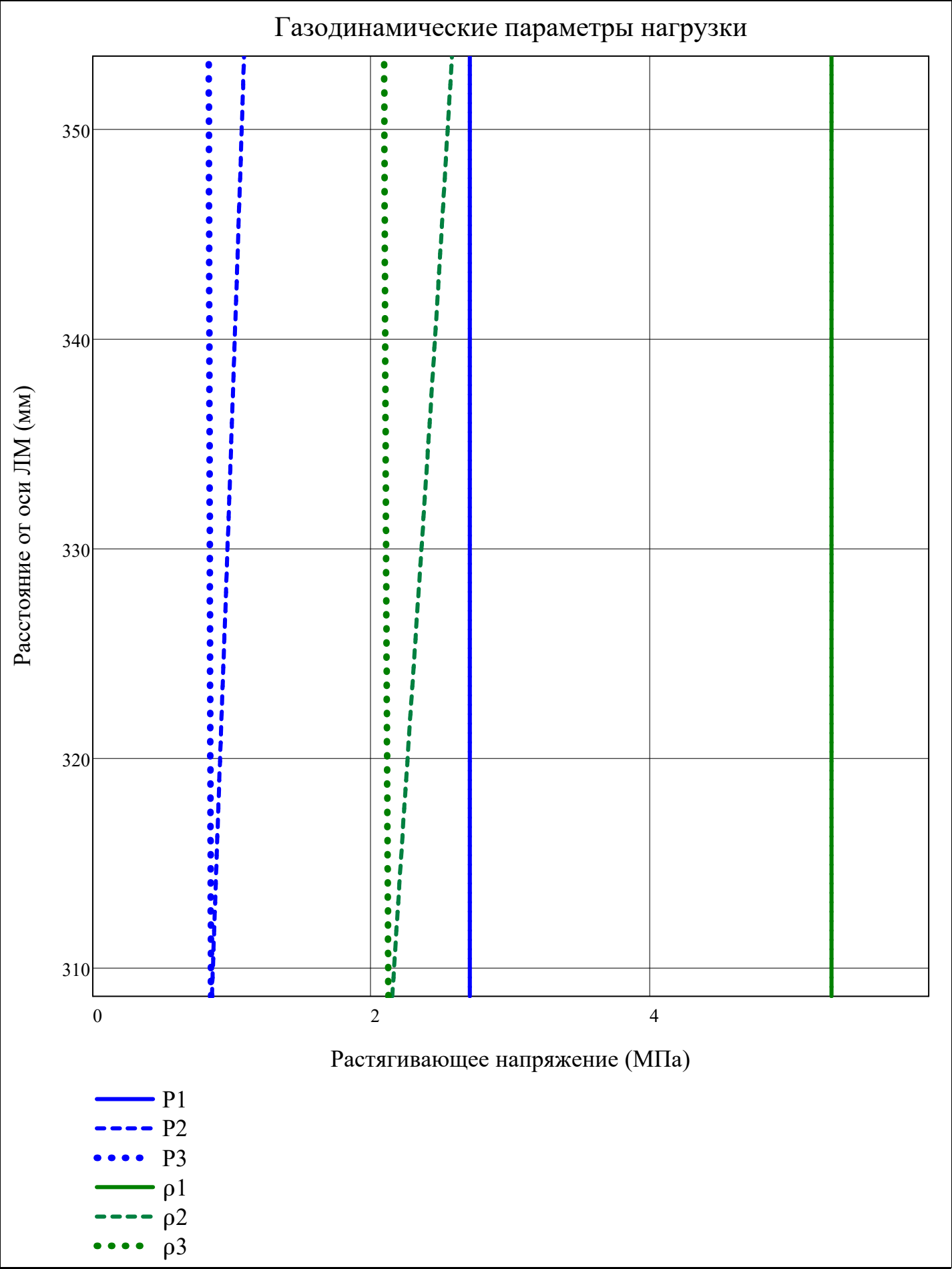
$$z_{rotor} = \begin{cases} \text{mean}\Big(R_{j1,1},R_{j2,1}\Big),\text{mean}\Big(R_{j1,1},R_{j2,1}\Big) + \frac{\text{mean}\Big(R_{j1,N_r},R_{j2,N_r}\Big) - \text{mean}\Big(R_{j1,1},R_{j2,1}\Big)}{100} .. \text{mean}\Big(R_{j1,N_r},R_{j2,N_r}\Big) & \text{if type = "compressor"} \\ \text{mean}\Big(R_{j2,1},R_{j3,1}\Big),\text{mean}\Big(R_{j2,1},R_{j3,1}\Big)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

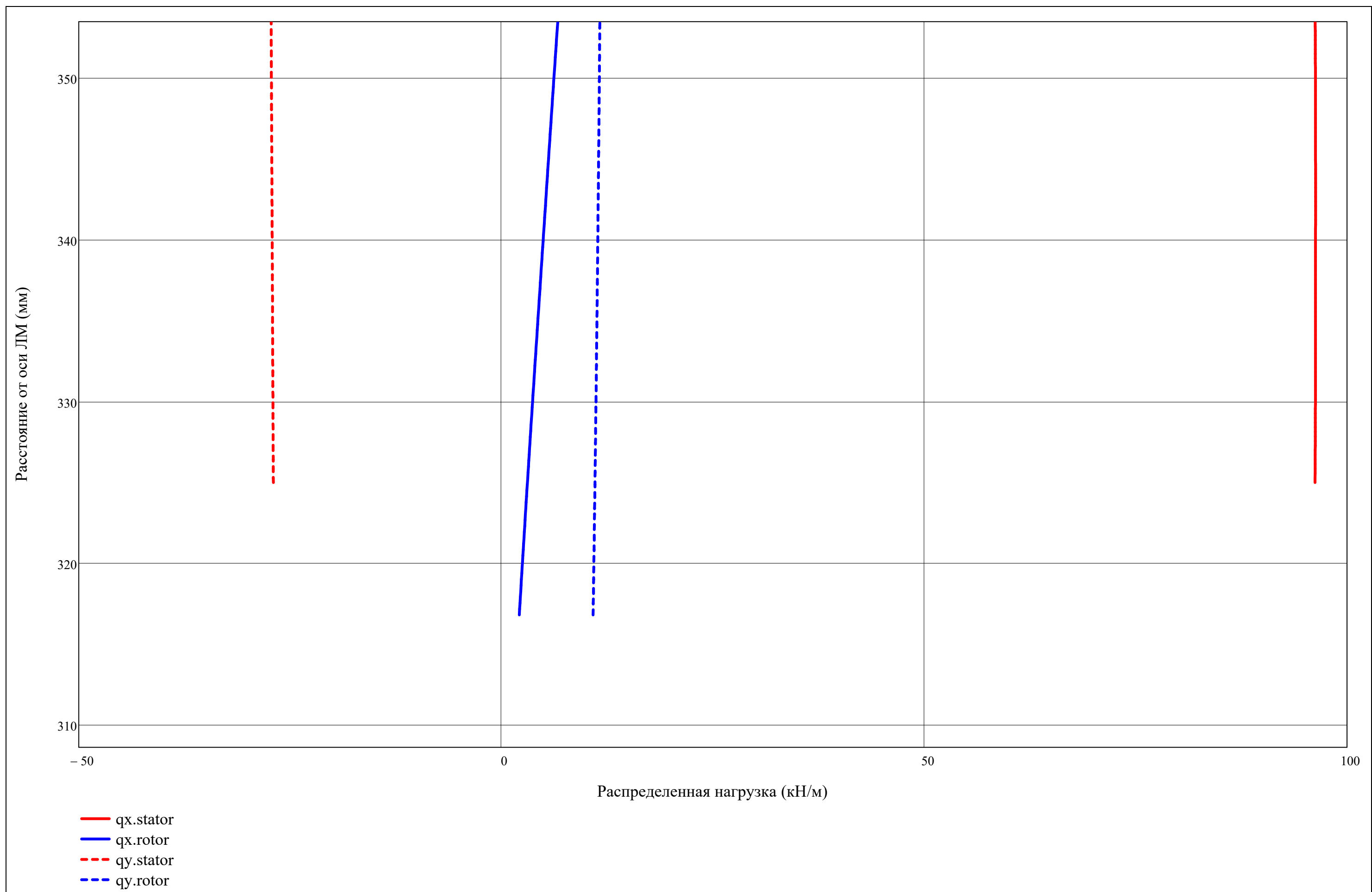
$$z_{stator} = \begin{cases} \text{mean}\Big(R_{j2,1},R_{j3,1}\Big),\text{mean}\Big(R_{j2,1},R_{j3,1}\Big) + \frac{\text{mean}\Big(R_{j2,N_r},R_{j3,N_r}\Big) - \text{mean}\Big(R_{j2,1},R_{j3,1}\Big)}{100} .. \text{mean}\Big(R_{j2,N_r},R_{j3,N_r}\Big) & \text{if type = "compressor"} \\ \text{mean}\Big(R_{j1,1},R_{j2,1}\Big),\text{mean}\Big(R_{j1,1},R_{j2,1}\Big)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

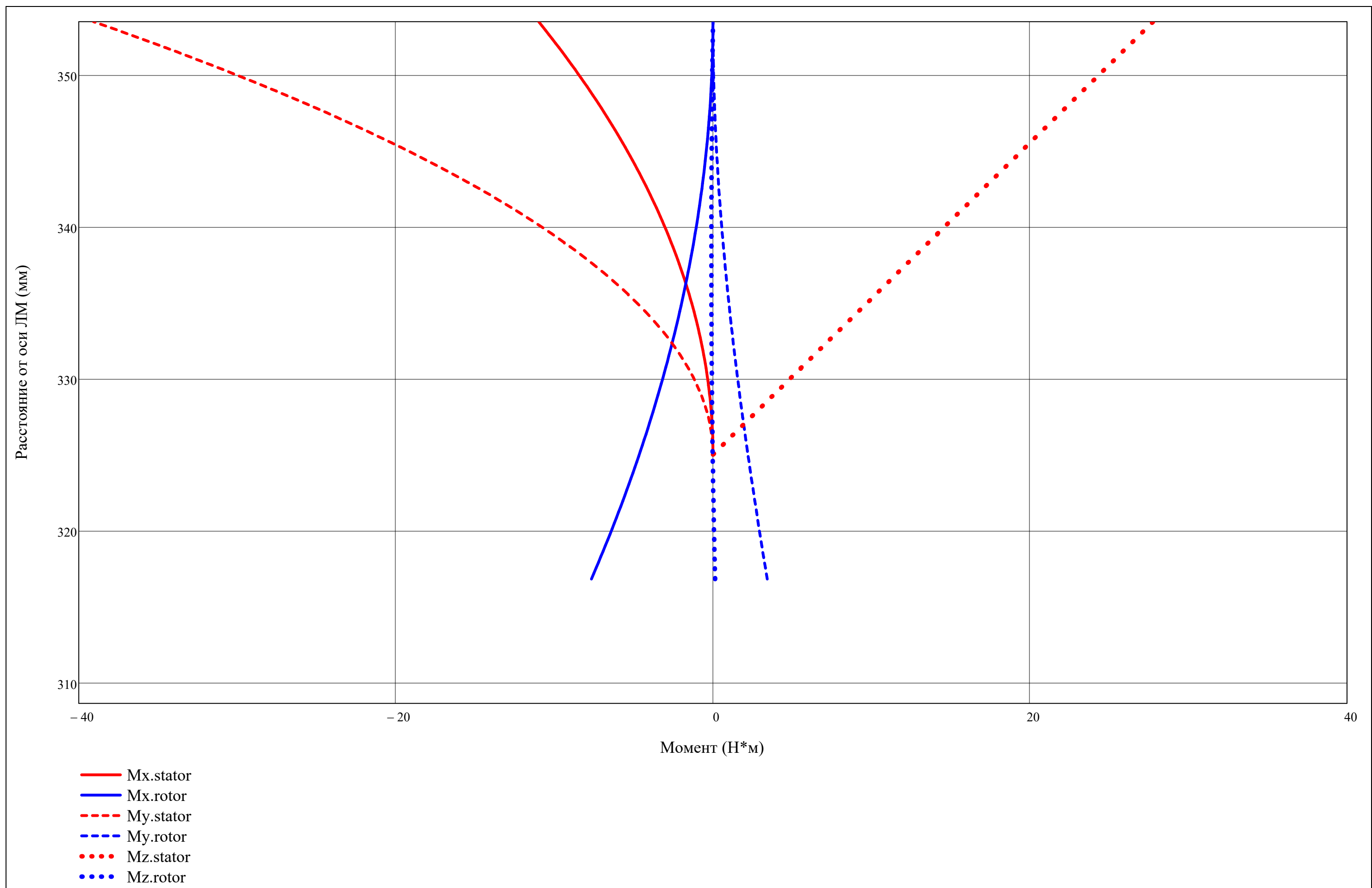




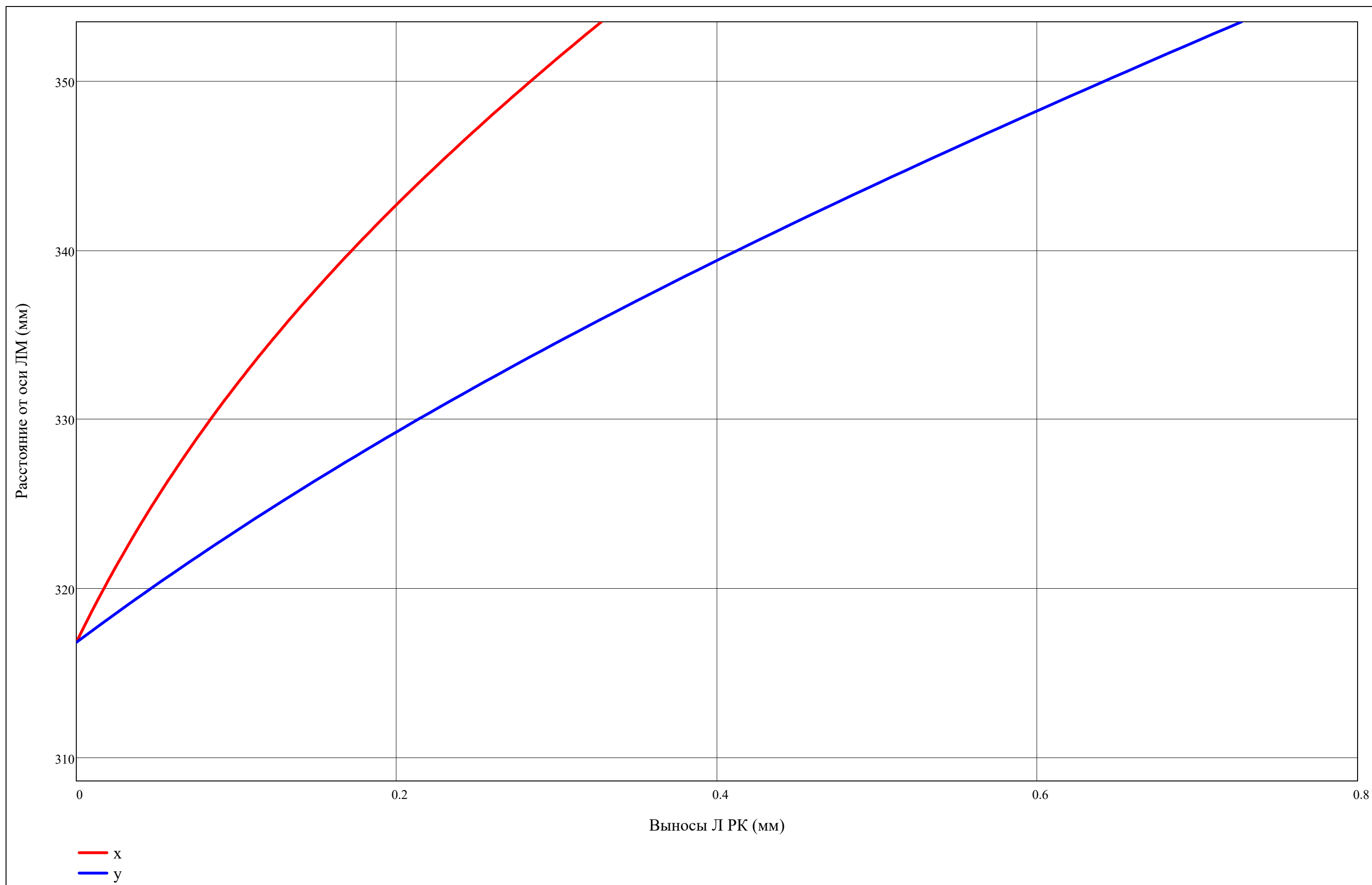


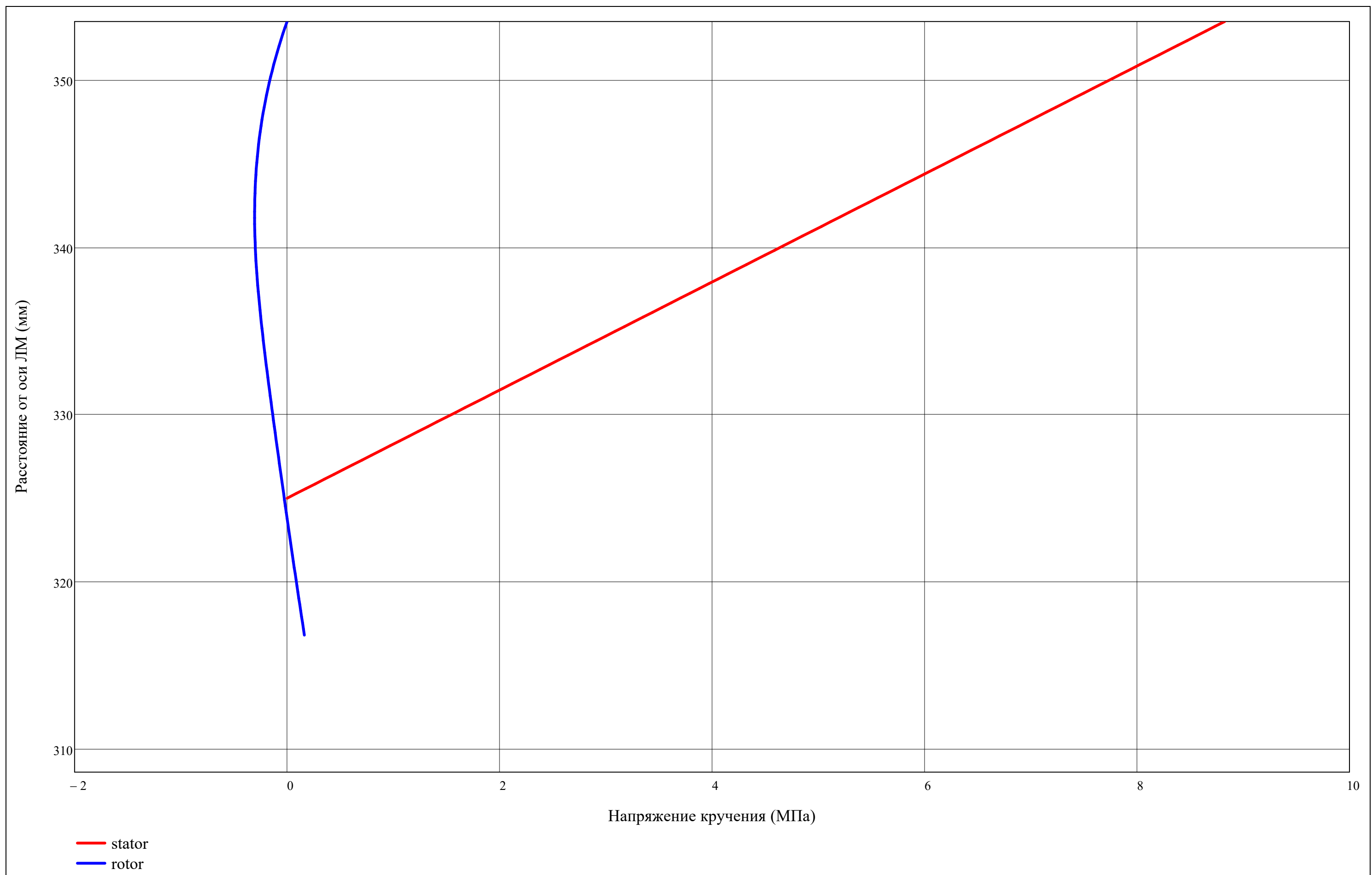


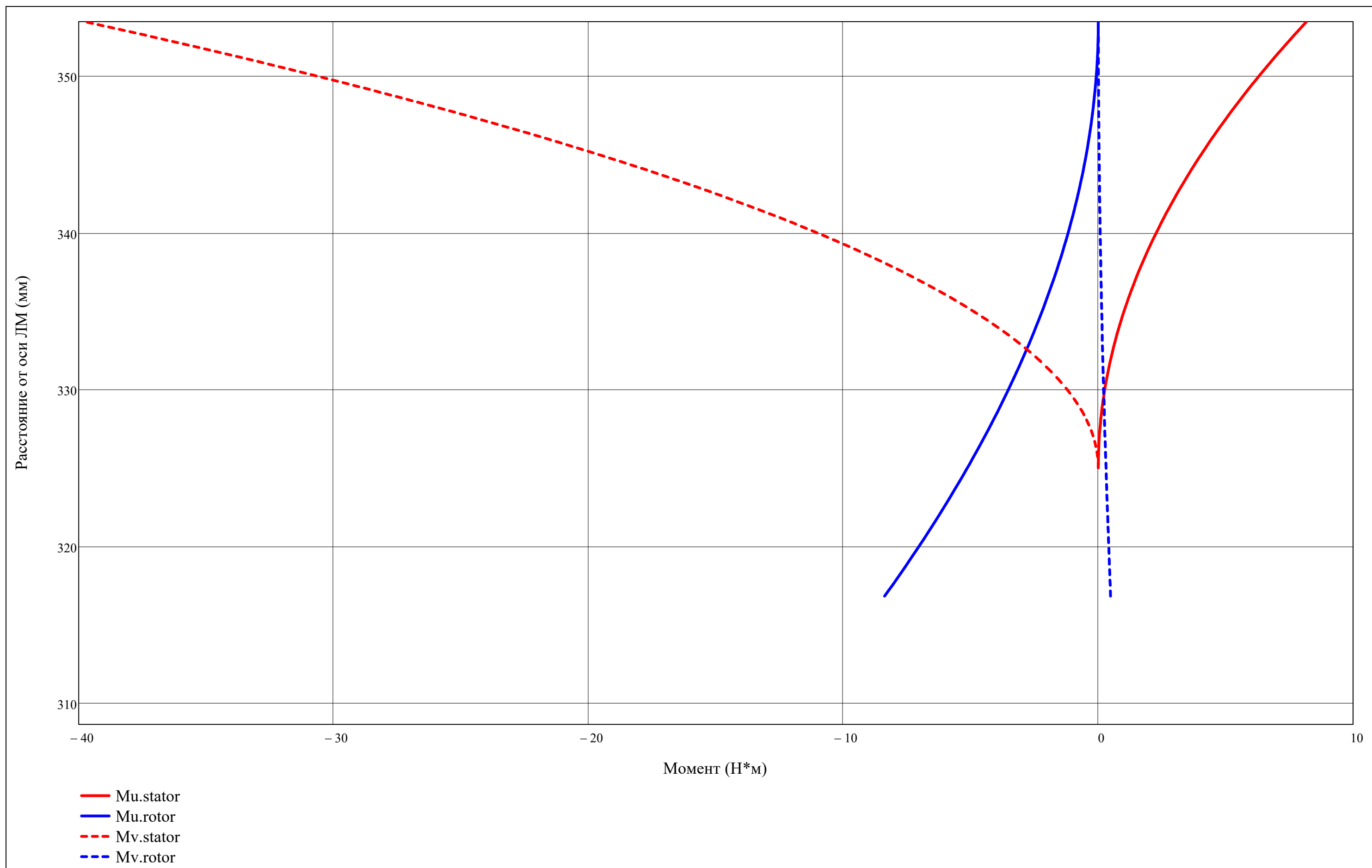


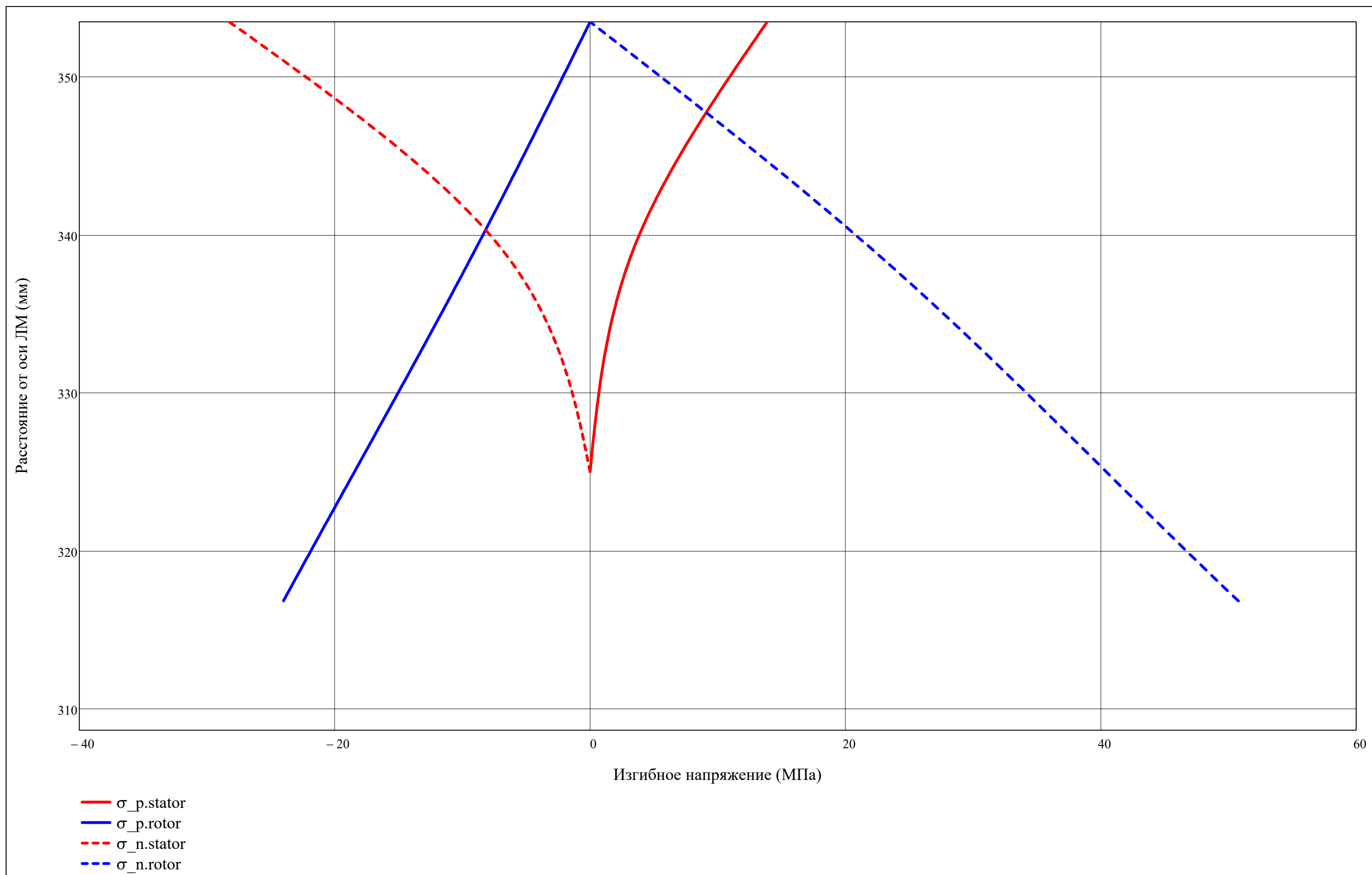


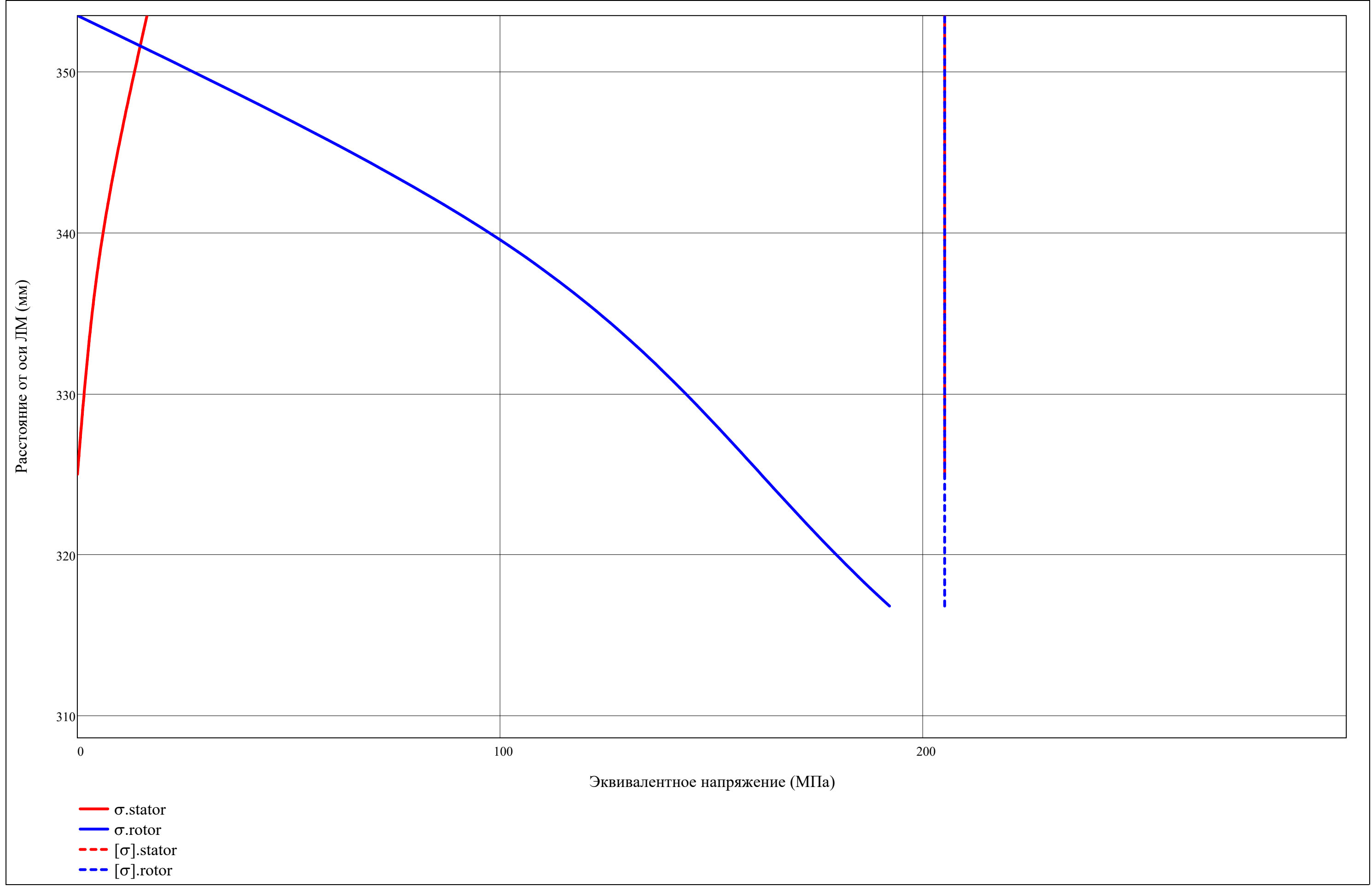












blade

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	0.40	4.05
2	18.83	-10.08
3	8.16	8.19
4	-25.86	-14.47

·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	-8.9	3.5
2	21.9	-7.1

·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	5.6
2	101.7

·10<sup>6</sup>

Коэф. запаса:

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

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

=

	1
1	36.526
2	2.015

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	8.190
2	-14.465

·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	28.623
2	8.931

·10<sup>-3</sup>

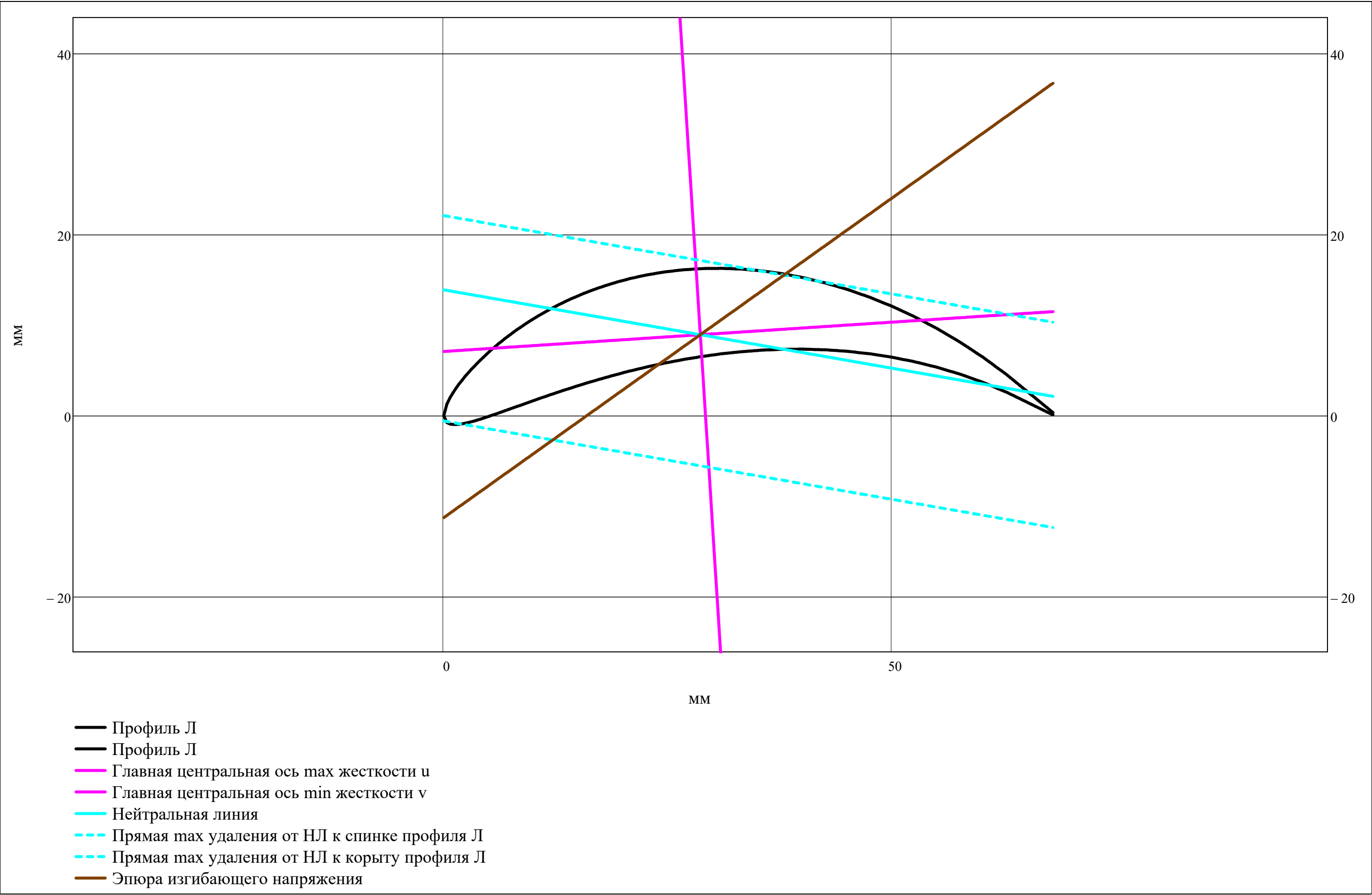
otherwise

chord = 

chord<sub>rotor<sub>j,r</sub></sub>if blade = "rotor"

chord<sub>stator<sub>j,r</sub></sub>if blade = "stator"

 = 68.0·10<sup>-3</sup>



blade

rw

=

"stator"

3

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	-5.99	13.96
2	-8.99	-17.32
3	8.16	8.19
4	-25.85	-14.48

·10<sup>-3</sup>

Изгибные напряжения (Па):

σ\_protorj,r

σ\_pstatorj,r

σ\_nrotorj,r

σ\_nstatorj,r

=

	1	2
1	0.0	13.9
2	0.0	-28.3

·10<sup>6</sup>

Эквивалентные напряжения (Па):

σ\_statorj,r

σ\_rotorj,r

=

	1
1	16.4
2	0.0

·10<sup>6</sup>

Коэф. запаса:

safety\_statorj,r

safety\_rotorj,r

=

	1
1	12.470
2	000000000000000000000000000000.0

v\_p

v\_n

=

v\_urotorj,r

v\_lrotorj,r

v\_ustatorj,r

v\_lstatorj,r

if blade = "rotor"

=

	1
1	8.194
2	-14.477

·10<sup>-3</sup>

otherwise

x0

y0

=

x0\_rotorj,r

y0\_rotorj,r

x0\_statorj,r

y0\_statorj,r

if blade = "rotor"

=

	1
1	28.623
2	8.931

·10<sup>-3</sup>

otherwise

chord

=

chord\_rotorj,r

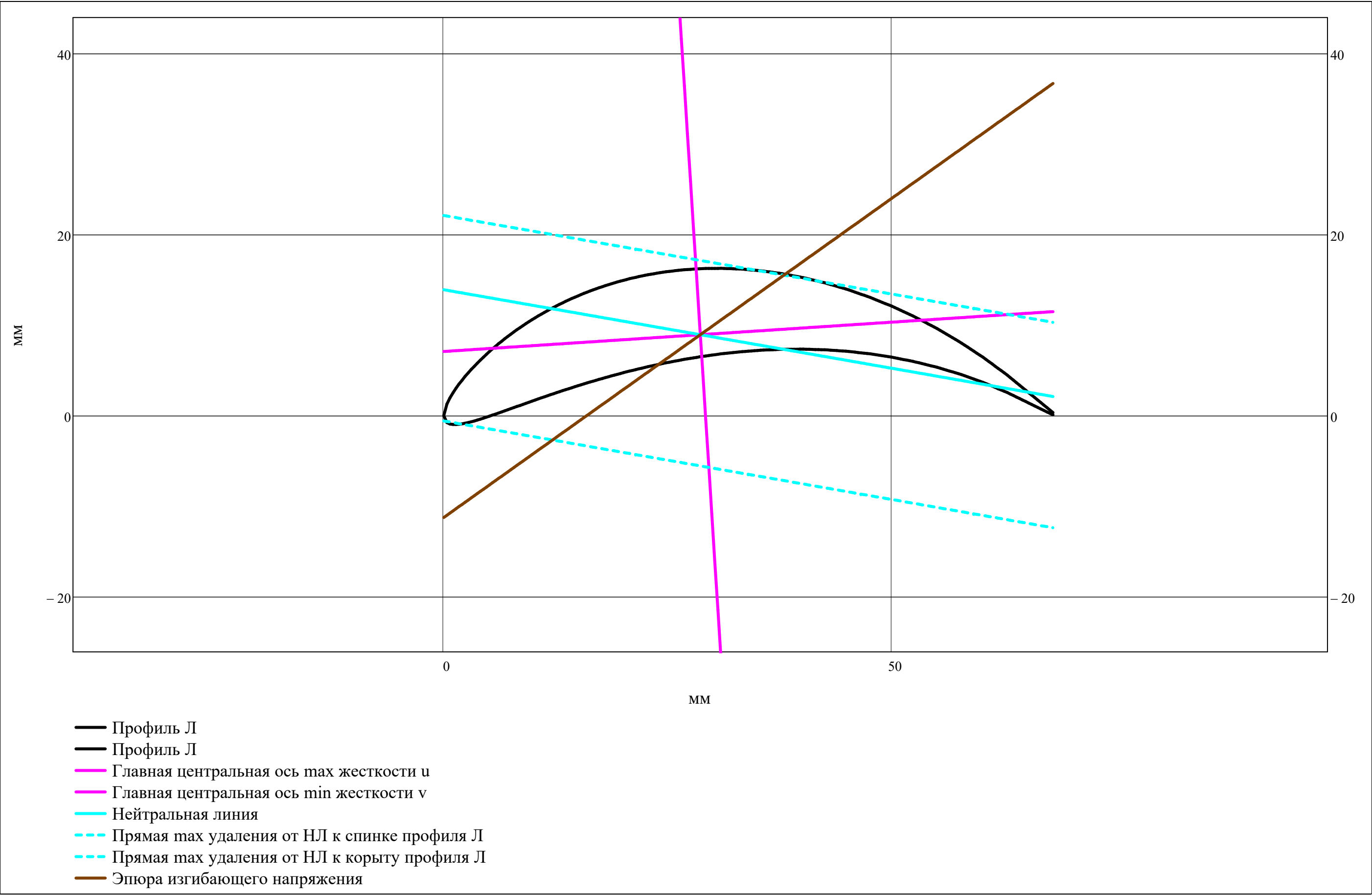
chord\_statorj,r

if blade = "rotor"

if blade = "stator"

= 68.0·10<sup>-3</sup>





blade

rw

=

"rotor"

1

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	-0.22	5.32
2	21.03	-11.79
3	-7.06	29.14
4	-11.36	-38.70

·10<sup>-3</sup>

Изгибные напряжения (Па):

σ\_protor<sub>j,r</sub>

σ\_nrotor<sub>j,r</sub>

σ\_pstator<sub>j,r</sub>

σ\_nstator<sub>j,r</sub>

=

	1	2
1	-18.4	0.0
2	40.4	0.0

·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	0.0
2	161.6

·10<sup>6</sup>

Коэф. запаса:

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

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

=

	1
1	000000000000000000000000000000.0
2	1.269

v\_p

v\_n

=

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	5.323
2	-11.789

·10<sup>-3</sup>

otherwise

x0

y0

=

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	16.158
2	10.001

·10<sup>-3</sup>

otherwise

chord

=

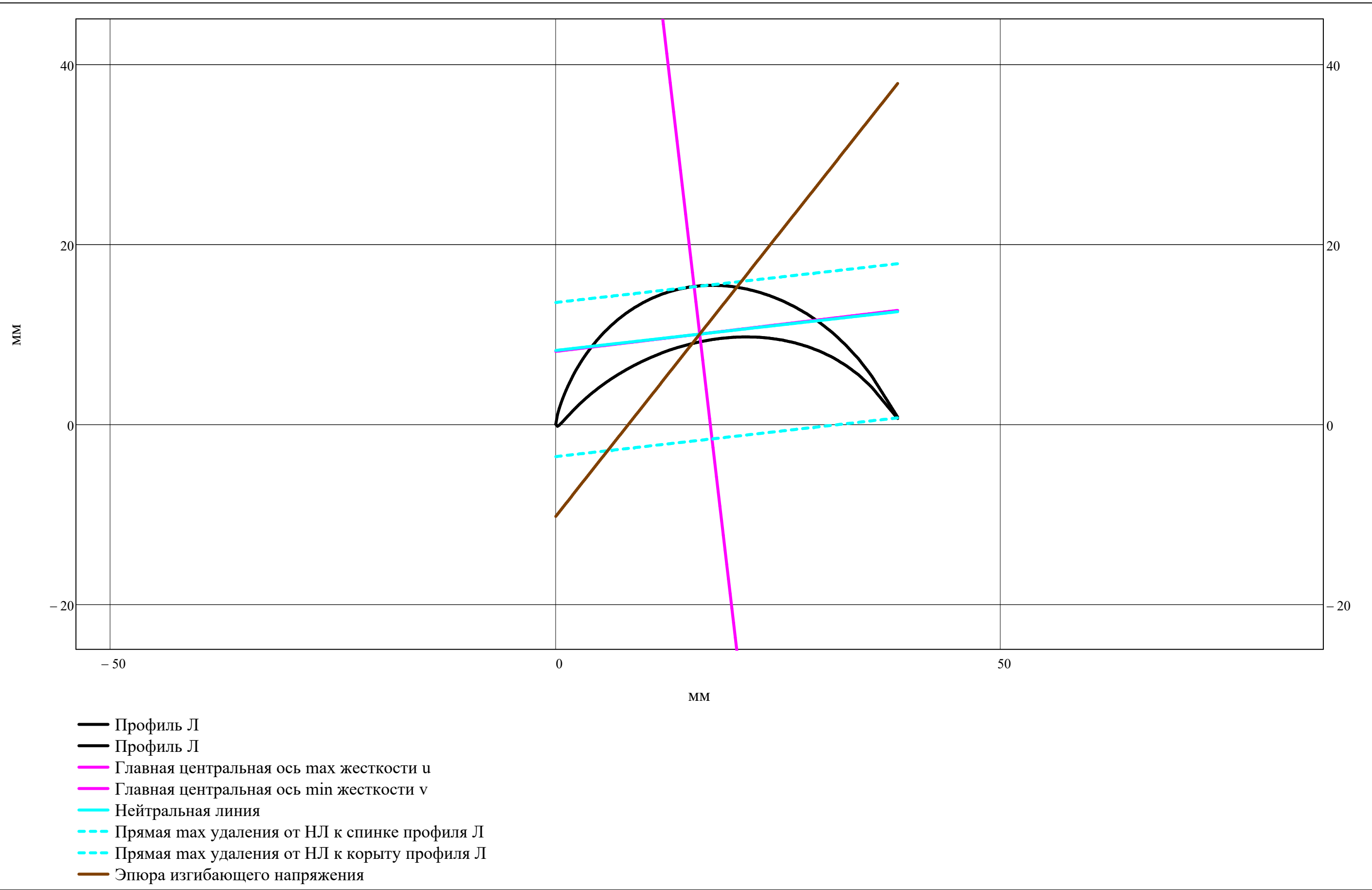
chord<sub>rotor<sub>j,r</sub></sub>

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

if blade = "rotor"

if blade = "stator"

= 38.4·10<sup>-3</sup>



$$\begin{pmatrix} \text{blade} \\ \text{r} \end{pmatrix} = \begin{pmatrix} \text{"rotor"} \\ 2 \end{pmatrix}$$

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	0.40	4.05
2	18.83	-10.08
3	8.16	8.19
4	-25.86	-14.47

$$\text{Коэф. запаса: } \begin{pmatrix} \text{safety}_{\text{stator}_{j,r}} \\ \text{safety}_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{table}
	1
1	36.526
2	2.015

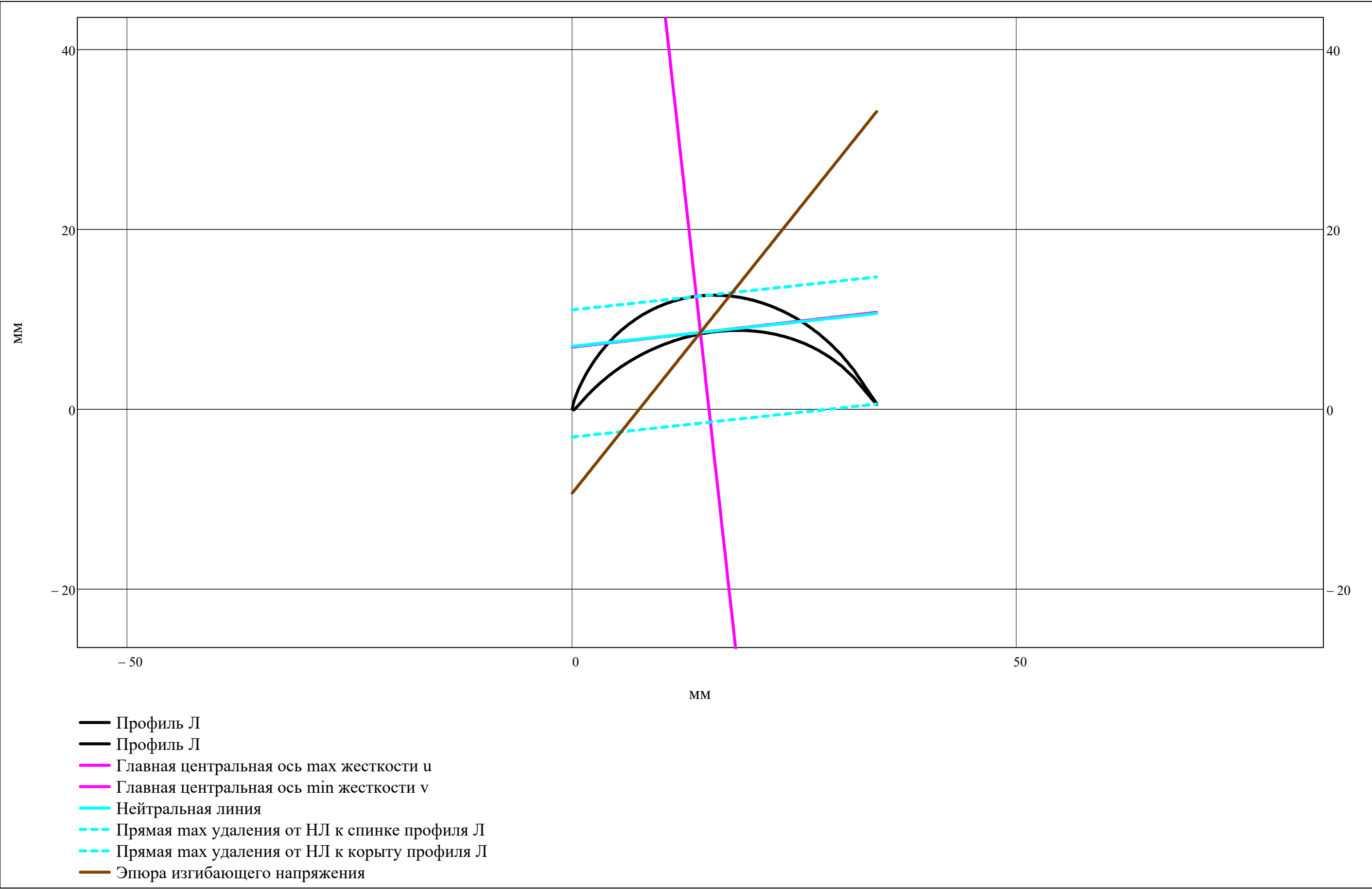
Изгибные напряжения (Па):

$$\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	-8.9	3.5
2	21.9	-7.1

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{\text{stator}_{j,r}} \\ \sigma_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{table}
	1
1	5.6
2	101.7

$$\begin{pmatrix} v_{p} \\ v_{n} \end{pmatrix} = \begin{cases} \begin{pmatrix} v_{u_{\text{rotor}_{j,r}}} \\ v_{l_{\text{rotor}_{j,r}}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v_{u_{\text{stator}_{j,r}}} \\ v_{l_{\text{stator}_{j,r}}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{table}
	1
1	4.047
2	-10.076
$$\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	14.401
2	8.496
$$\text{chord} = \begin{cases} \text{chord}_{\text{rotor}_{j,r}} & \text{if blade = "rotor"} \\ \text{chord}_{\text{stator}_{j,r}} & \text{if blade = "stator"} \end{cases} = 34.2 \cdot 10^{-3}$$$$$$





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):	Предел длительной прочности Д (Па):
$\rho_{\text{disk}}_i = \begin{cases} 8266 & \text{if material\_disk}_i = \text{"ВЖ175"} \\ 8320 & \text{if material\_disk}_i = \text{"ЭП742"} \\ 8393 & \text{if material\_disk}_i = \text{"ЖС-6К"} \\ 7900 & \text{if material\_disk}_i = \text{"BT41"} \\ 4500 & \text{if material\_disk}_i = \text{"BT25"} \\ 4570 & \text{if material\_disk}_i = \text{"BT23"} \\ 4510 & \text{if material\_disk}_i = \text{"BT9"} \\ 4430 & \text{if material\_disk}_i = \text{"BT6"} \\ \text{NaN} & \text{otherwise} \end{cases}$	$\sigma_{\text{disk\_long}}_i = 10^6 \cdot \begin{cases} 620 & \text{if material\_disk}_i = \text{"ВЖ175"} \\ 680 & \text{if material\_disk}_i = \text{"ЭП742"} \\ 125 & \text{if material\_disk}_i = \text{"ЖС-6К"} \\ 123 & \text{if material\_disk}_i = \text{"BT41"} \\ 150 & \text{if material\_disk}_i = \text{"BT25"} \\ 230 & \text{if material\_disk}_i = \text{"BT23"} \\ 200 & \text{if material\_disk}_i = \text{"BT9"} \\ 210 & \text{if material\_disk}_i = \text{"BT6"} \\ \text{NaN} & \text{otherwise} \end{cases}$

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

	1
1	"ВЖ175"

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

	1
1	8266

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

	1
1	620

$\cdot 10^6$

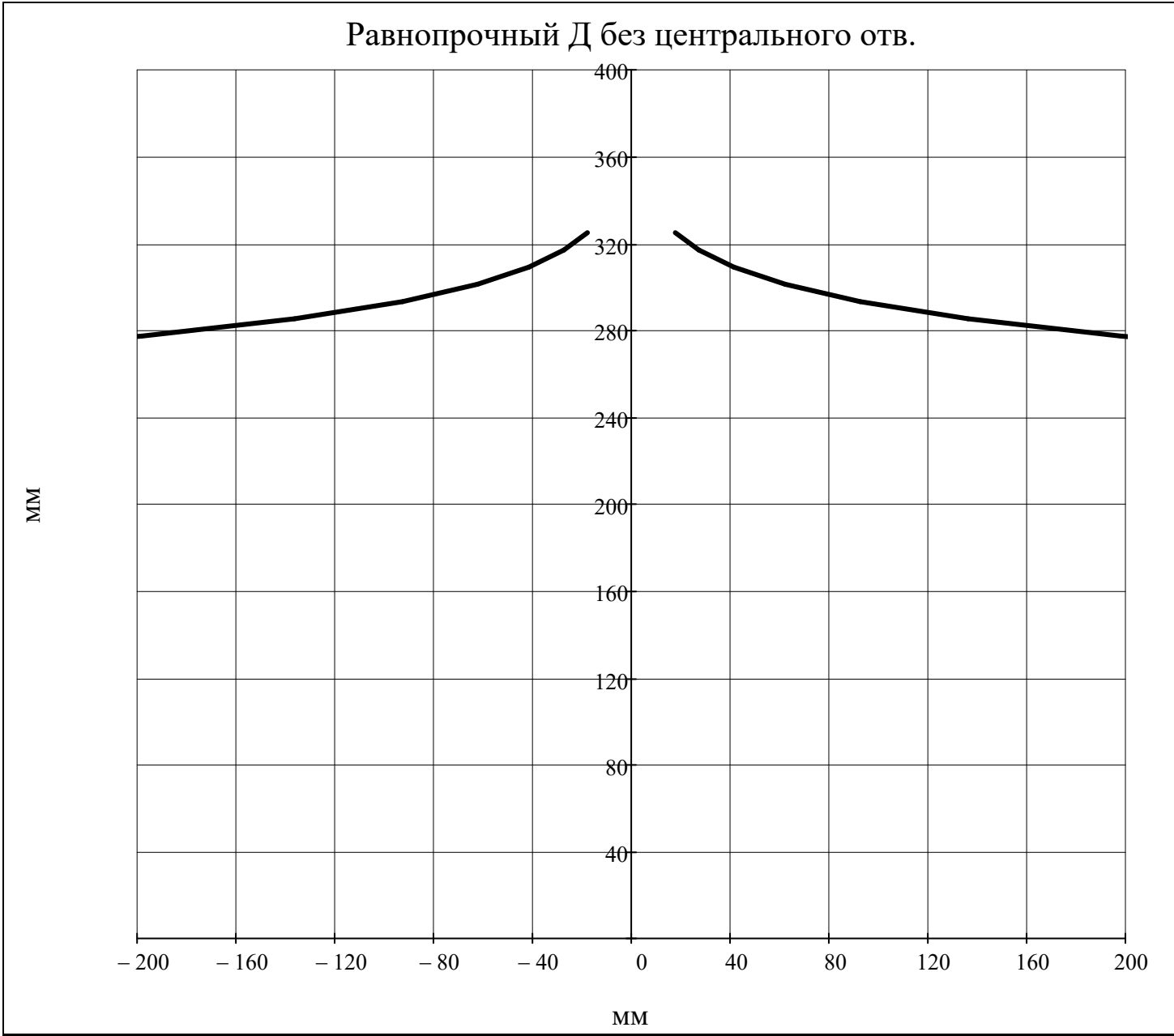
Рассматриваемая ступень:

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

Профилирование равнопрочного Д без центрального отв.

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

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



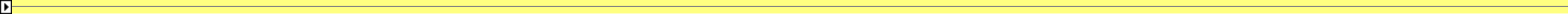
Профилирование равнопрочного Д без центрального отв.



$$type = \begin{cases} type = "stator" & \\ type = \begin{cases} "Нет\ такого\ типа!" & \text{if } type \neq "stator" \wedge type \neq "rotor" \\ type & \text{otherwise} \end{cases} & \end{cases} = "stator"$$

Рассматриваемая ступень:

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























$$\begin{pmatrix} c_{\text{st}(\text{j},1),\text{r}} \\ c_{\text{st}(\text{j},2),\text{r}} \\ c_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 100.00 \\ 927.16 \\ 147.28 \end{pmatrix}$$

$$\begin{pmatrix} c_{\text{a}_{\text{st}(\text{j},1),\text{r}} \\ c_{\text{a}_{\text{st}(\text{j},2),\text{r}} \\ c_{\text{a}_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 100.00 \\ 231.94 \\ 147.27 \end{pmatrix}$$

$$\begin{pmatrix} w_{\text{st}(\text{j},1),\text{r}} \\ w_{\text{st}(\text{j},2),\text{r}} \\ w_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 520.18 \\ 451.35 \\ 504.94 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{\text{st}(\text{j},1),\text{r}} \\ \alpha_{\text{st}(\text{j},2),\text{r}} \\ \alpha_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 90.00 \\ 14.49 \\ 89.31 \end{pmatrix} \cdot ^\circ$$

$$\begin{pmatrix} u_{\text{st}(\text{j},1),\text{r}} \\ u_{\text{st}(\text{j},2),\text{r}} \\ u_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 510.48 \\ 510.48 \\ 484.75 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{\text{st}(\text{j},1),\text{r}} \\ \beta_{\text{st}(\text{j},2),\text{r}} \\ \beta_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 11.08 \\ 149.08 \\ 16.96 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{\text{stator}_{\text{j},\text{r}}} = 75.51 \cdot ^\circ$$

$$\epsilon_{\text{rotor}_{\text{j},\text{r}}} = 132.12 \cdot ^\circ$$

$$\begin{pmatrix} c_{\text{st}(\text{j},1),\text{r}} \\ c_{\text{st}(\text{j},2),\text{r}} \\ c_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 100.00 \\ 892.55 \\ 174.05 \end{pmatrix}$$

$$\begin{pmatrix} c_{a_{\text{st}(\text{j},1),\text{r}}} \\ c_{a_{\text{st}(\text{j},2),\text{r}}} \\ c_{a_{\text{st}(\text{j},3),\text{r}}} \end{pmatrix} = \begin{pmatrix} 100.00 \\ 223.28 \\ 174.03 \end{pmatrix}$$

$$\begin{pmatrix} w_{\text{st}(\text{j},1),\text{r}} \\ w_{\text{st}(\text{j},2),\text{r}} \\ w_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 542.17 \\ 399.52 \\ 550.87 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{\text{st}(\text{j},1),\text{r}} \\ \alpha_{\text{st}(\text{j},2),\text{r}} \\ \alpha_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 90.00 \\ 14.49 \\ 90.87 \end{pmatrix} \cdot ^\circ$$

$$\begin{pmatrix} u_{\text{st}(\text{j},1),\text{r}} \\ u_{\text{st}(\text{j},2),\text{r}} \\ u_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 532.86 \\ 532.86 \\ 520.00 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{\text{st}(\text{j},1),\text{r}} \\ \beta_{\text{st}(\text{j},2),\text{r}} \\ \beta_{\text{st}(\text{j},3),\text{r}} \end{pmatrix} = \begin{pmatrix} 10.63 \\ 146.02 \\ 18.42 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{\text{stator}_{\text{j},\text{r}}} = 75.51 \cdot ^\circ$$

$$\epsilon_{\text{rotor}_{\text{j},\text{r}}} = 127.61 \cdot ^\circ$$

$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 100.00 \\ 860.58 \\ 191.81 \end{pmatrix}$$

$$\begin{pmatrix} c_{a_{st(j,1),r}} \\ c_{a_{st(j,2),r}} \\ c_{a_{st(j,3),r}} \end{pmatrix} = \begin{pmatrix} 100.00 \\ 215.28 \\ 191.70 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 564.18 \\ 351.59 \\ 593.43 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 90.00 \\ 14.49 \\ 91.90 \end{pmatrix} \cdot ^\circ$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 555.25 \\ 555.25 \\ 555.25 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 10.21 \\ 142.24 \\ 18.85 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{stator,j,r} = 75.51 \cdot ^\circ$$

$$\epsilon_{rotor,j,r} = 123.4 \cdot ^\circ$$

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