







Исходные данные

Коэф. запаса:	safety = 1.3
Степень двухконтурности:	m2 = 6
РТ: Воздух	compressor = "КНД"
Число Маха:	M = 0
Геометрическая высота работы (м):	H <sub>ww</sub> = 0
Массовый расход (кг/с):	<div>G<sub>ww</sub> = <div><div>35.65 + 213.93 if compressor = "Вл" = 35.65</div><div>35.65 if compressor = "КНД"</div><div>34.81 if compressor = "КВД"</div></div></div>
Полная температура на входе в К (К):	<div>T*<sub>K1</sub> = <div><div>418.2 if compressor = "КВД" = 288.2</div><div>288.2 otherwise</div></div></div>
Полное давление на входе в К (Па):	<div>P*<sub>K1</sub> = <div><div>316.2·10<sup>3</sup> if compressor = "КВД" = 101.3·10<sup>3</sup></div><div>101325 otherwise</div></div></div>
Степень повышения давления КВД:	<div>π*<sub>К</sub> = <div><div>1.6 if compressor = "Вл" = 2.000</div><div><div>3.2</div><div>1.6</div> if compressor = "КНД"</div><div>9 if compressor = "КВД"</div></div></div>

Ожидаемый адиабатический КПД ОК:

$\eta^*_K = \begin{cases} 0.86 & \text{if compressor = "Вл"} \\ 0.87 & \text{if compressor = "КНД"} \\ 0.88 & \text{if compressor = "КВД"} \end{cases} = 87.00\cdot\%$

Частота вращения ротора (с<sup>-1</sup>):

$\omega = \begin{cases} 1570.8 & \text{if compressor = "КВД"} \\ 555 & \text{otherwise} \end{cases} = 555.0$

Относ. диаметркорня 1ой ступени [14, с.7]:

$\overline{d}_1 = \begin{cases} 0.40 & \text{if compressor = "Вл"} \\ 0.75 & \text{if compressor = "КНД"} \\ 0.65 & \text{if compressor = "КВД"} \end{cases} = 0.75$

$0.3 \leq \overline{d}_1 \leq 0.6 = 0$

Частота вращения ротора (об/мин):

$n = \frac{60 \cdot \omega}{2 \cdot \pi} = 5300$

Закон профилирования проточной части (ЗППЧ):

$$\text{ЗППЧ} = \left( \begin{array}{c|c|c} \begin{array}{l} \text{"пер" if compressor = "Вл"} \\ \text{"пер" if compressor = "КНД"} \\ \text{"ср" if compressor = "КВД"} \end{array} & \begin{array}{l} \text{"пер" if compressor = "Вл"} \\ \text{"0.96" if compressor = "КНД"} \\ \text{"ср" if compressor = "КВД"} \end{array} & \begin{array}{l} \text{"пер" if compressor = "Вл"} \\ \text{"0.92" if compressor = "КНД"} \\ \text{"кор" if compressor = "КВД"} \end{array} \end{array} \begin{array}{cccccccccccccccc} \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} \end{array} \right)^T$$

Относ. параметры по относительным ступеням:

$$\begin{pmatrix} z_{\sim} \\ R_{L\sim \text{ср}} \\ K_{\sim \text{Н}} \\ \eta^*_{\sim} \\ \overline{c}_{\sim \text{a1}} \\ \overline{H}_{\sim \text{T}} \end{pmatrix} = \begin{bmatrix} (1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8)^T \\ (0.5 \ 0.5 \ 0.5 \ 0.5 \ 0.5 \ 0.5 \ 0.5 \ 0.5)^T \\ (0.99 \ 0.98 \ 0.97 \ 0.96 \ 0.95 \ 0.95 \ 0.95 \ 0.95)^T \\ (0.88 \ 0.89 \ 0.905 \ 0.91 \ 0.91 \ 0.905 \ 0.89 \ 0.88)^T \\ (0.435 \ 0.425 \ 0.415 \ 0.405 \ 0.395 \ 0.385 \ 0.375 \ 0.365)^T \\ (0.25 \ 0.29 \ 0.32 \ 0.33 \ 0.35 \ 0.32 \ 0.29 \ 0.27)^T \end{bmatrix}$$

Тип компрессора	Номер ступени и $\overline{L}_{СТ.i}$							
	I	II	III	IV	$z_{ср}$	$z - 2$	$z - 1$	$z$
Дозвуковой	0,18-0,20	0,24-0,25	0,24-0,25	0,29-0,30	0,30-0,32	0,28-0,29	0,27-0,28	0,26-0,27
Трансзвуковой	0,19-0,22	0,27-0,29	0,30-0,32	0,32-0,33	0,33-0,35	0,31-0,32	0,27-0,28	0,26-0,27
С одной св/зв ступенью	0,23-0,25	0,27-0,29	0,30-0,32	0,32-0,33	0,33-0,35	0,31-0,32	0,27-0,28	0,26-0,27
С 2-мя св/зв ступенями	0,23-0,25	0,27-0,29	0,30-0,32	0,32-0,33	0,33-0,35	0,31-0,32	0,27-0,28	0,26-0,27
С 3-мя св/зв ступенями	0,23-0,25	0,27-0,29	0,30-0,32	0,32-0,33	0,33-0,35	0,31-0,32	0,27-0,28	0,25-0,26

[16, с. 60]

[18, с. 24]

Уточнение параметров:

$$R_{L\sim cp} = R_{L\sim cp} + \begin{cases} 0.0 & \text{if compressor = "Вл"} \\ 0.1 & \text{if compressor = "КНД"} \\ 0.2 & \text{if compressor = "КВД"} \end{cases}$$

увеличение несущественно увеличивает  $\pi$

$$\eta^*_{\sim} = \eta^*_{\sim} + \begin{cases} -0.020 & \text{if compressor = "Вл"} \\ -0.028 & \text{if compressor = "КНД"} \\ -0.017 & \text{if compressor = "КВД"} \end{cases}$$

увеличение несущественно увеличивает  $\pi$

$$\overline{c}_{\sim a1} = \overline{c}_{\sim a1} - \begin{cases} 0.100 & \text{if compressor = "Вл"} \\ 0.141 & \text{if compressor = "КНД"} \\ 0.203 & \text{if compressor = "КВД"} \end{cases}$$

понижение существенно увеличивает  $\pi$

$$\overline{H}_{\sim T} = \overline{H}_{\sim T} + \begin{cases} 0.0145 & \text{if compressor = "Вл"} \\ 0.0164 & \text{if compressor = "КНД"} \\ 0.0173 & \text{if compressor = "КВД"} \end{cases}$$

увеличение существенно увеличивает  $\pi$

$$\text{stack}\left(R_{L\sim cp}^T, K_{\sim H}^T, \eta^{*}_{\sim}{}^T, \overline{c}_{\sim a1}^T, \overline{H}_{\sim T}^T\right) =$$

	1	2	3	4	5	6	7	8
1	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600
2	0.990	0.980	0.970	0.960	0.950	0.950	0.950	0.950
3	0.852	0.862	0.877	0.882	0.882	0.877	0.862	0.852
4	0.294	0.284	0.274	0.264	0.254	0.244	0.234	0.224
5	0.266	0.306	0.336	0.346	0.366	0.336	0.306	0.286

$$0.15 \leq \overline{c}_{\sim a1}^T = (1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1)$$

$$\overline{c}_{\sim a1}^T \leq 0.65 = (1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1)$$

$$0.18 \leq \overline{H}_{\sim T}^T = (1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1)$$

$$\overline{H}_{\sim T}^T \leq 0.35 = (1 \quad 1 \quad 1 \quad 1 \quad 0 \quad 1 \quad 1 \quad 1)$$

Коэф. теор. напора "средней" ступени [14, с.11]:

$$\overline{H}_{Tcp} = \frac{\sum_{i=1}^{rows(z_{\sim})} \overline{H}_{\sim T_i}}{rows(z_{\sim})} = 0.3189$$

$$0.25 \leq \overline{H}_{Tcp} \leq 0.32 = 1$$

Кинематическая степень реактивности:  $\widetilde{R_{L\sim cp}}(i) = \text{interp}\left(\text{lspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, R_{L\sim cp}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, R_{L\sim cp}, i\right)$

Коэф. уменьшения теор. напора:  $K_{\sim H}(i) = \text{interp}\left(\text{lspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, K_{\sim H}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, K_{\sim H}, i\right)$

Изоэнтропический КПД:  $\widetilde{\eta^*_{\sim}}(i) = \text{interp}\left(\text{lspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, \eta^*_{\sim}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, \eta^*_{\sim}, i\right)$

Коэф. расхода:  $\widetilde{\overline{c_{\sim a1}}}(i) = \text{interp}\left(\text{lspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, \overline{c_{\sim a1}}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, \overline{c_{\sim a1}}, i\right)$

Коэф. напора:  $\widetilde{\overline{H_{\sim T}}}(i) = \text{interp}\left(\text{lspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, \overline{H_{\sim T}}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, \overline{H_{\sim T}}, i\right)$

$$\begin{pmatrix} R_{L.cp} \\ K_{.H} \\ \eta^*_{.} \\ \overline{c}_{.a1} \\ \overline{H}_{.T} \end{pmatrix} =$$

$$R_{L.cp}(Z,i) = \begin{cases} R_{L\sim cp}\left(\frac{1}{rows(z_{\sim})}\right) & \text{if } i < 1 \\ R_{L\sim cp}(1) & \text{if } i > Z \\ R_{L\sim cp}\left(\frac{i}{Z}\right) & \text{otherwise} \end{cases}$$

$$K_{.H}(Z,i) = \begin{cases} K_{\sim H}\left(\frac{1}{rows(z_{\sim})}\right) & \text{if } i < 1 \\ K_{\sim H}(1) & \text{if } i > Z \\ K_{\sim H}\left(\frac{i}{Z}\right) & \text{otherwise} \end{cases}$$

$$\eta^*_{.}(Z,i) = \begin{cases} \eta^*_{\sim}\left(\frac{1}{rows(z_{\sim})}\right) & \text{if } i < 1 \\ \eta^*_{\sim}(1) & \text{if } i > Z \\ \eta^*_{\sim}\left(\frac{i}{Z}\right) & \text{otherwise} \end{cases}$$

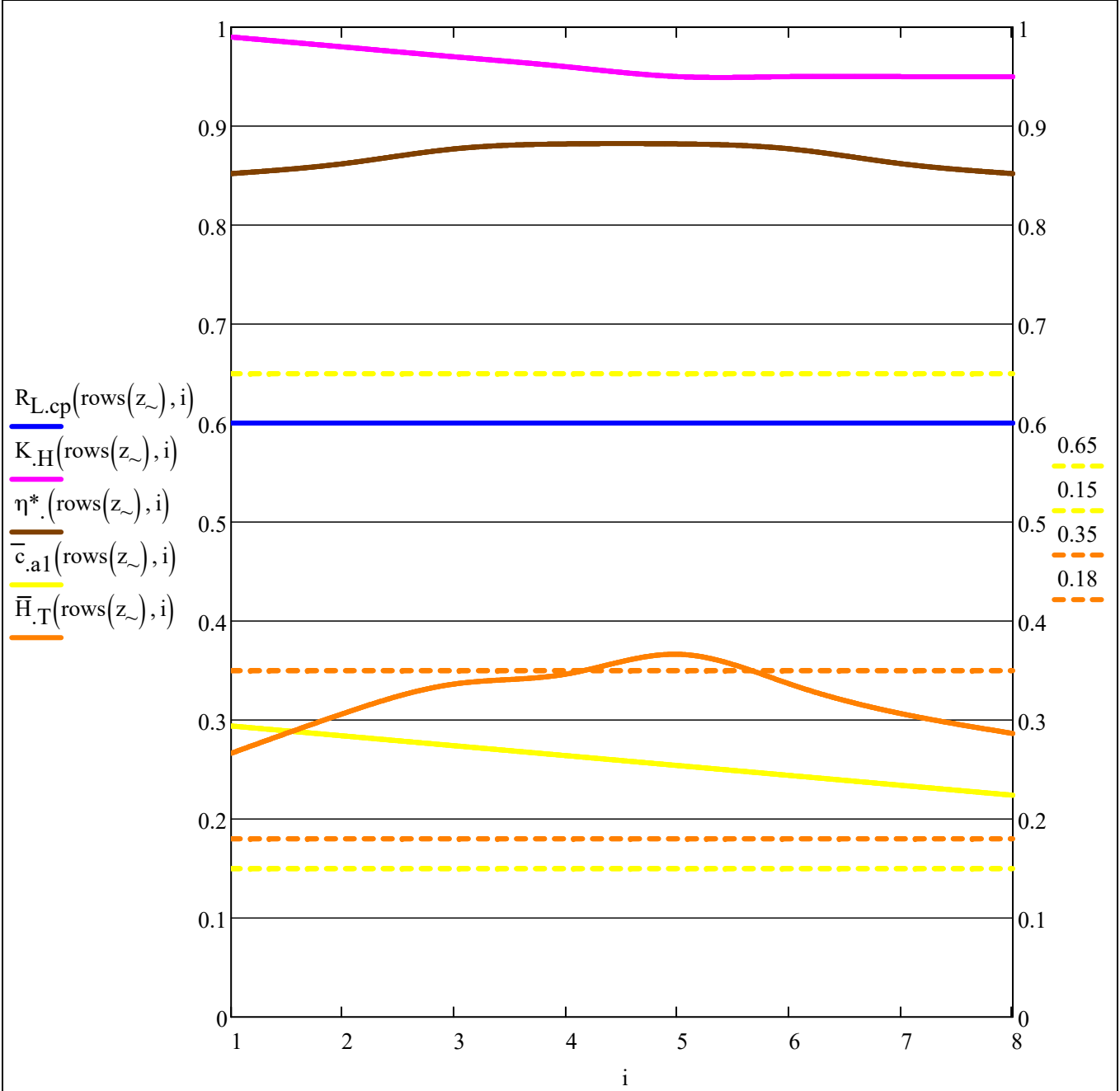
$$\overline{c}_{.a1}(Z,i) = \begin{cases} \overline{c}_{\sim a1}\left(\frac{1}{rows(z_{\sim})}\right) & \text{if } i < 1 \\ \overline{c}_{\sim a1}(1) & \text{if } i > Z \\ \overline{c}_{\sim a1}\left(\frac{i}{Z}\right) & \text{otherwise} \end{cases}$$

$$\overline{H}_{.T}(Z,i) = \begin{cases} \overline{H}_{\sim T}\left(\frac{1}{rows(z_{\sim})}\right) & \text{if } i < 1 \\ \overline{H}_{\sim T}(1) & \text{if } i > Z \\ \overline{H}_{\sim T}\left(\frac{i}{Z}\right) & \text{otherwise} \end{cases}$$

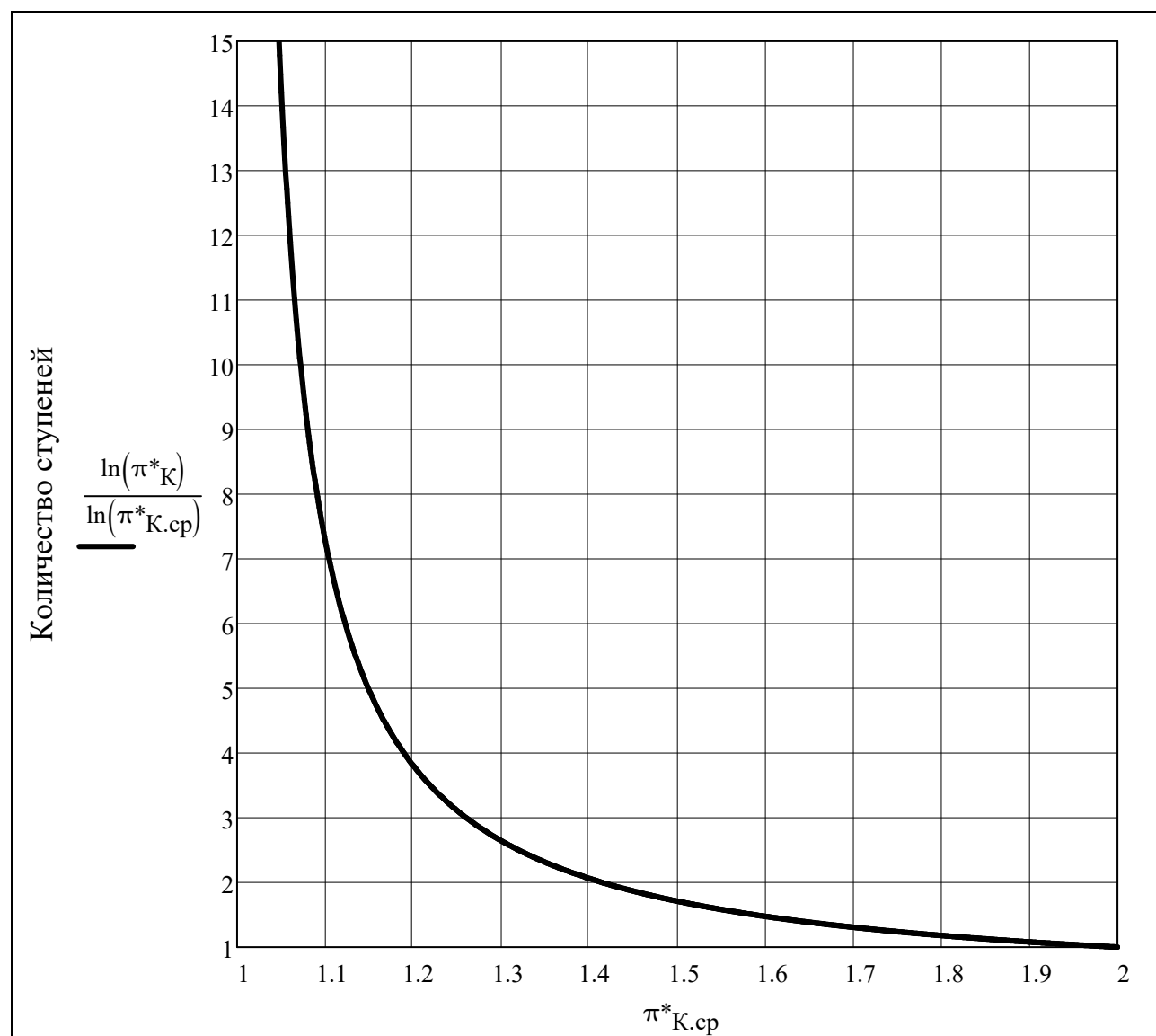
$$\left(R_{L.cp} \ K_{.H} \ \eta^*_{.} \ \overline{c}_{.a1} \ \overline{H}_{.T}\right)^T$$

$$\begin{pmatrix} Z_{temp} \\ i_{temp} \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} R_{L.cp}(Z_{temp},i_{temp}) \\ K_{.H}(Z_{temp},i_{temp}) \\ \eta^*_{.}(Z_{temp},i_{temp}) \\ \overline{c}_{.a1}(Z_{temp},i_{temp}) \\ \overline{H}_{.T}(Z_{temp},i_{temp}) \end{pmatrix} = \begin{pmatrix} 0.600 \\ 0.950 \\ 0.852 \\ 0.224 \\ 0.286 \end{pmatrix}$$







Показатель адиабаты перед K []:  $k_{K1} = k_{ад}(Cp_{воздух}(P^*_{K1}, T^*_{K1}), R_B) = 1.401$

Полное давление после K [Па]:  $P^*_{K3} = \pi^*_K \cdot P^*_{K1} = 203 \cdot 10^3$

iteration<sub>3</sub>

T<sup>\*</sup><sub>K3</sub>

k<sub>K3</sub>

=

iteration<sub>3</sub> = 0

k<sub>K3</sub> = k<sub>K1</sub>

while 0 < 1

iteration<sub>3</sub> = iteration<sub>3</sub> + 1

trace("iteration.3 = ", num2str(iteration<sub>3</sub>))

k<sub>ср</sub> = mean(k<sub>K1</sub>, k<sub>K3</sub>)

$T^*_{K3} = T^*_{K1} \cdot \left( 1 + \frac{\frac{k_{ср}-1}{k_{ср}} \pi^*_K}{\eta^*_K} - 1 \right)$

Cp<sub>K3</sub> = Cp<sub>воздух</sub>(P<sup>\*</sup><sub>K3</sub>, T<sup>\*</sup><sub>K3</sub>)

k'<sub>K3</sub> = k<sub>ад</sub>(Cp<sub>K3</sub>, R<sub>B</sub>)

if |eps("rel", k<sub>K3</sub>, k'<sub>K3</sub>)| ≤ epsilon

k<sub>K3</sub> = k'<sub>K3</sub>

break

k<sub>K3</sub> = k'<sub>K3</sub>

iteration<sub>3</sub>

T<sup>\*</sup><sub>K3</sub>

k<sub>K3</sub>

Количество итераций []: iteration<sub>3</sub> = 1

Полная температура после K [K]: T<sup>\*</sup><sub>K3</sub> = 360.9

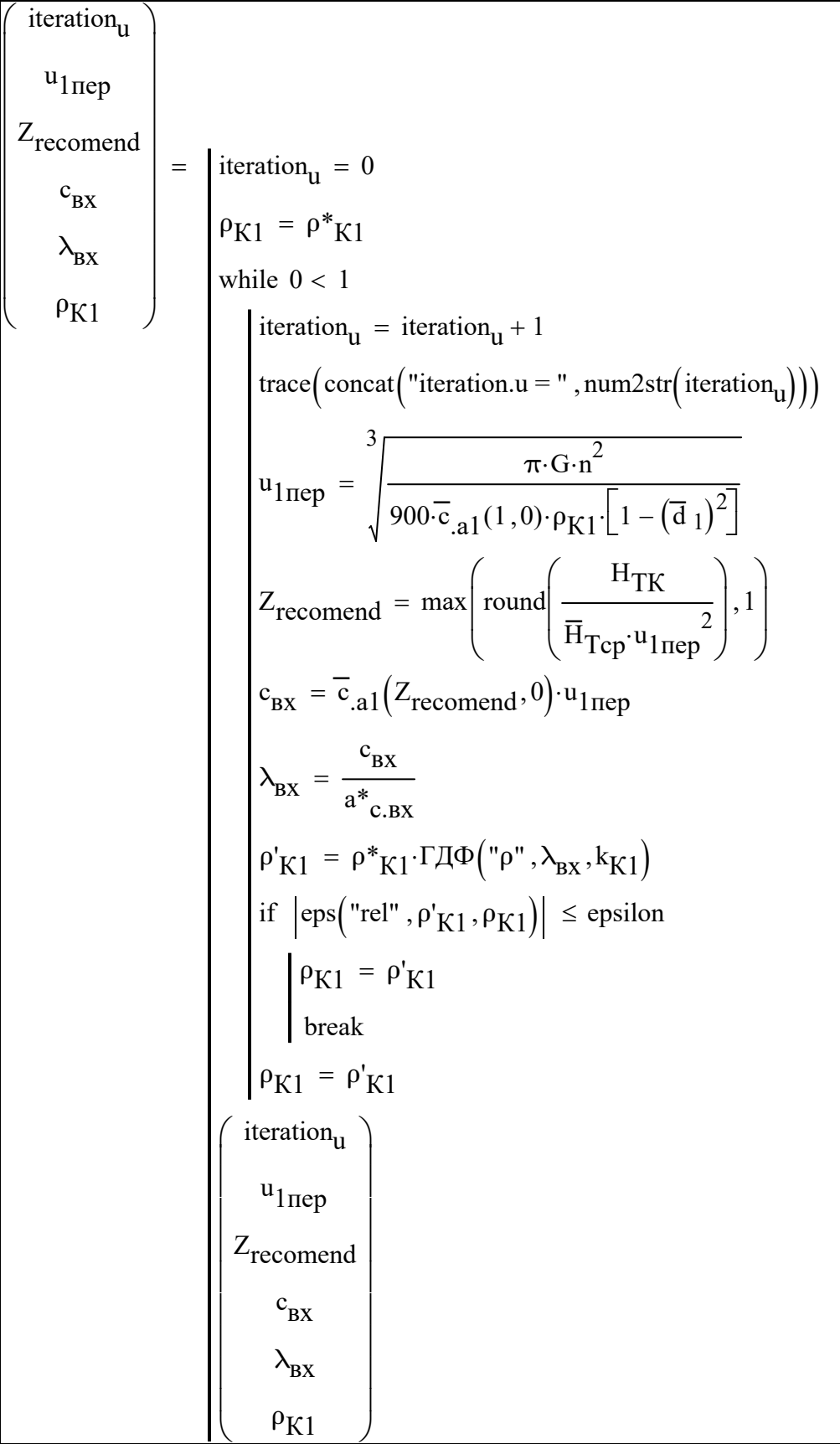
Показатель адиабаты после K []: k<sub>K3</sub> = 1.398

Полная плотность перед и после K [кг/м³]:  $\begin{pmatrix} \rho^*_{K1} \\ \rho^*_{K3} \end{pmatrix} = \frac{1}{R_B} \cdot \begin{pmatrix} \frac{P^*_{K1}}{T^*_{K1}} \\ \frac{P^*_{K3}}{T^*_{K3}} \end{pmatrix} = \begin{pmatrix} 1.224 \\ 1.955 \end{pmatrix}$

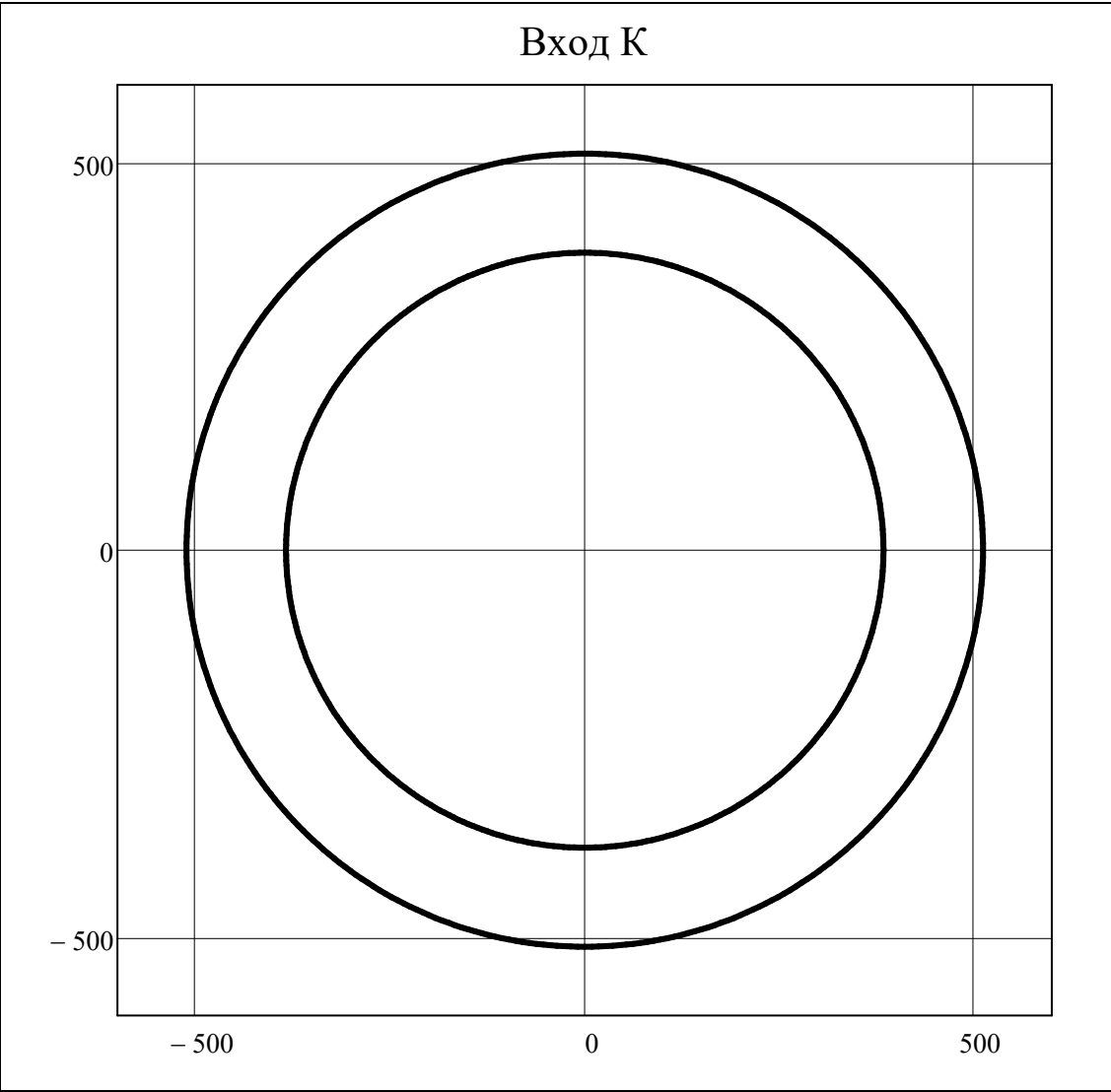
Критические скорости перед и после K [м/с]:  $\begin{pmatrix} a^*_{с.вх} \\ a^*_{с.вых} \end{pmatrix} = \begin{pmatrix} a_{кр}(k_{K1}, R_B, T^*_{K1}) \\ a_{кр}(k_{K3}, R_B, T^*_{K3}) \end{pmatrix} = \begin{pmatrix} 310.8 \\ 347.6 \end{pmatrix}$

Ср. показатель адиабаты K []: k<sub>ср</sub> = k<sub>ад</sub>(Cp<sub>воздух.ср</sub>(P<sup>\*</sup><sub>K1</sub>, P<sup>\*</sup><sub>K3</sub>, T<sup>\*</sup><sub>K1</sub>, T<sup>\*</sup><sub>K3</sub>), R<sub>B</sub>) = 1.4

Теоретический напор [Дж/кг]:  $H_{TK} = \frac{Cp_{воздух.ср}(P^*_{K1}, P^*_{K3}, T^*_{K1}, T^*_{K3}) \cdot T^*_{K1} \cdot \left( \pi^*_K \frac{k_{ср}-1}{k_{ср}} - 1 \right)}{\eta^*_K} = 72.9 \cdot 10^3$



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



Рекомендуемое количество ступеней []: Z<sub>recomend</sub> = 3

Количество ступеней []:

Z =	1	if compressor = "Вл"	= 3
	3	if compressor = "КНД"	
	9	if compressor = "КВД"	

BHA =

1 if compressor = "КВД"

= 0

0 otherwise

▼ Расчет BHA:

$\alpha_{1BHA}$

$\alpha_{3BHA}$

$\sigma_{BHA}$

$\sigma_{BHA}$

$\overline{d}_{1BHA}$

$\overline{d}_{3BHA}$

$T^*_{1BHA}$

$T^*_{3BHA}$

$P^*_{1BHA}$

$P^*_{3BHA}$

$\rho^*_{1BHA}$

$\rho^*_{3BHA}$

$k_{1BHA}$

$k_{3BHA}$

$a_{кр1BHA}$

$a_{кр3BHA}$

$\overline{c}_{a1BHA}$

$\overline{c}_{a3BHA}$

$\overline{c}_{u1BHA}$

$\overline{c}_{u3BHA}$

$c_{a1BHA}$

$c_{a3BHA}$

$c_{u1BHA}$

$c_{u3BHA}$

$c_{1BHA}$

$c_{3BHA}$

$\lambda_{c1BHA}$

$\lambda_{c3BHA}$

$F_{1BHA}$

$F_{3BHA}$

$\epsilon_{BHA}$

$\epsilon_{BHA}$

=

for r ∈ av(N<sub>r</sub>)

$\alpha_{1BHA_r} = 90^\circ$

$\overline{d}_{1BHA} = \overline{d}_1$

$\overline{d}_{3BHA} = \overline{d}_{1BHA}$

$T^*_{1BHA_r} = T^*_{K1}$

$T^*_{3BHA_r} = T^*_{1BHA_r}$

$P^*_{1BHA_r} = P^*_{K1}$

$\rho^*_{1BHA_r} = \frac{P^*_{1BHA_r}}{R_B \cdot T^*_{1BHA_r}}$

$k_{1BHA_r} = k_{ад}\Big(Cp_{\text{воздух}}\Big(P^*_{1BHA_r},T^*_{1BHA_r}\Big),R_B\Big)$

$a_{кр1BHA_r} = a_{кр}\Big(k_{1BHA_r},R_B,T^*_{1BHA_r}\Big)$

$\overline{c}_{a1BHA_r} = \overline{c}_{.a1}(Z,0)$

$\overline{c}_{u1BHA_r} = \left\{\begin{array}{l} \overline{r}_{cp}\big(\overline{d}_{1BHA}\big)\cdot\big(1-R_{L.cp}(Z,0)\big) - \frac{\overline{H}_{.T}(Z,0)}{2\cdot\overline{r}_{cp}\big(\overline{d}_{1BHA}\big)} \text{ if BHA} = 1 \\ 0 \text{ otherwise} \end{array}\right.$

$c_{a1BHA_r} = \overline{c}_{a1BHA_r} \cdot u_{1пер}$

$\sigma_{BHA} = 1.0000$

submatrix( $\epsilon_{BHA}$ ,av(N<sub>r</sub>),av(N<sub>r</sub>),1,1) = (0.00)·deg

submatrix( $\alpha_{1BHA}$ ,av(N<sub>r</sub>),av(N<sub>r</sub>),1,1) = (90.00)·deg

submatrix( $\alpha_{3BHA}$ ,av(N<sub>r</sub>),av(N<sub>r</sub>),1,1) = (90.00)·deg

$\overline{d}_{1BHA}$

$\overline{d}_{3BHA}$

=

$\begin{pmatrix} 0.7500 \\ 0.7500 \end{pmatrix}$

$\begin{pmatrix} F_{1BHA} \\ F_{3BHA} \end{pmatrix}$

=

$\begin{pmatrix} 0.3596 \\ 0.3596 \end{pmatrix}$

$$c_{u1BHA_r} = \frac{c_{a1BHA_r}}{\tan(\alpha_{1BHA_r})}$$

$$c_{1BHA_r} = \frac{c_{a1BHA_r}}{\sin(\alpha_{1BHA_r})}$$

$$\lambda_{c1BHA_r} = \frac{c_{1BHA_r}}{a_{kp1BHA_r}}$$

$$\sigma_{BHA} = \begin{cases} \left[ 1 + \text{mean}(0.03, 0.06) \cdot \Gamma\text{Д}\Phi\left("p", \lambda_{c1BHA_r}, k_{1BHA_r}\right) \cdot \frac{k_{1BHA_r}}{k_{1BHA_r} + 1} \cdot \left(\lambda_{c1BHA_r}\right)^2 \right]^{-1} & \text{if } BHA = 1 \\ 1 & \text{otherwise} \end{cases}$$

$$P^*_{3BHA_r} = P^*_{1BHA_r} \cdot \sigma_{BHA}$$

$$\rho^*_{3BHA_r} = \frac{P^*_{3BHA_r}}{R_B \cdot T^*_{3BHA_r}}$$

$$k_{3BHA_r} = k_{ад}\left(C_{p\text{воздух}}\left(P^*_{3BHA_r}, T^*_{3BHA_r}\right), R_B\right)$$

$$a_{kp3BHA_r} = a_{kp}\left(k_{3BHA_r}, R_B, T^*_{3BHA_r}\right)$$

$$\bar{c}_{a3BHA_r} = \begin{cases} \bar{c}_{a1}(Z, 1) & \text{if } BHA = 1 \\ \bar{c}_{a1BHA_r} & \text{otherwise} \end{cases}$$

$$\bar{c}_{u3BHA_r} = \begin{cases} \bar{r}_{cp}(\bar{d}_{3BHA}) \cdot (1 - R_{L,cp}(Z, 1)) - \frac{\bar{H}_T(Z, 1)}{2 \cdot \bar{r}_{cp}(\bar{d}_{3BHA})} & \text{if } BHA = 1 \\ 0 & \text{otherwise} \end{cases}$$

$$\alpha_{3BHA_r} = \begin{cases} \text{triangle}\left(\bar{c}_{a1BHA_r}, \bar{c}_{u1BHA_r}\right) & \text{if } BHA = 1 \\ \frac{\pi}{2} & \text{otherwise} \end{cases}$$

$$c_{a3BHA_r} = \bar{c}_{a1BHA_r} \cdot u_{1\text{пер}}$$

$$c_{u3BHA_r} = \frac{c_{a3BHA_r}}{\tan(\alpha_{3BHA_r})}$$

$$c_{3BHA_r} = \frac{c_{a3BHA_r}}{\sin(\alpha_{3BHA_r})}$$

$$\lambda_{c3BHA_r} = \frac{c_{3BHA_r}}{a_{kp3BHA_r}}$$

$$\text{submatrix}\left(T^*_{1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (288.2)$$

$$\text{submatrix}\left(T^*_{3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (288.2)$$

$$\text{submatrix}\left(P^*_{1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (101.3) \cdot 10^3$$

$$\text{submatrix}\left(P^*_{3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (101.3) \cdot 10^3$$

$$\text{submatrix}\left(\rho^*_{1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.224)$$

$$\text{submatrix}\left(\rho^*_{3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.224)$$

$$\text{submatrix}\left(k_{1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.401)$$

$$\text{submatrix}\left(k_{3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.401)$$

$$\text{submatrix}\left(a_{kp1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (310.8)$$

$$\text{submatrix}\left(a_{kp3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (310.8)$$

$$\text{submatrix}\left(\bar{c}_{a1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.294)$$

$$\text{submatrix}\left(\bar{c}_{a3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.294)$$

$$\text{submatrix}\left(\bar{c}_{u1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.000)$$

$$\text{submatrix}\left(\bar{c}_{u3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.000)$$

$$\text{submatrix}\left(c_{a1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (83.4)$$

$$\text{submatrix}\left(c_{a3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (83.4)$$

$$\text{submatrix}\left(c_{u1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.0)$$

$$\text{submatrix}\left(c_{u3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.0)$$

$$\text{submatrix}\left(c_{1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (83.4)$$

$$\text{submatrix}\left(c_{3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (83.4)$$

$$\text{submatrix}\left(\lambda_{c1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.268)$$

$$\text{submatrix}\left(\lambda_{c3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.268)$$

		$\left( \begin{matrix} F_{1BHA} \\ F_{3BHA} \end{matrix} \right) = G \cdot \sqrt{R_B} \cdot \left( \begin{matrix} \frac{\sqrt{T^*_{1BHA_r}}}{m_q(k_{1BHA_r}) \cdot P^*_{1BHA_r} \cdot \Gamma \Delta \Phi("G", \lambda_{c1BHA_r}, k_{1BHA_r}) \cdot \sin(\alpha_{1BHA_r})} \\ \frac{\sqrt{T^*_{3BHA_r}}}{m_q(k_{3BHA_r}) \cdot P^*_{3BHA_r} \cdot \Gamma \Delta \Phi("G", \lambda_{c3BHA_r}, k_{3BHA_r}) \cdot \sin(\alpha_{3BHA_r})} \end{matrix} \right)$
		$\epsilon_{BHA_r} = -1 \cdot (\alpha_{3BHA_r} - \alpha_{1BHA_r})$
	$\left( \begin{matrix} \alpha_{1BHA} & \alpha_{3BHA} \\ \sigma_{BHA} & \sigma_{BHA} \\ \overline{d}_{1BHA} & \overline{d}_{3BHA} \\ T^*_{1BHA} & T^*_{3BHA} \\ P^*_{1BHA} & P^*_{3BHA} \\ \rho^*_{1BHA} & \rho^*_{3BHA} \\ k_{1BHA} & k_{3BHA} \\ a_{kp1BHA} & a_{kp3BHA} \\ \overline{c}_{a1BHA} & \overline{c}_{a3BHA} \\ \overline{c}_{u1BHA} & \overline{c}_{u3BHA} \\ c_{a1BHA} & c_{a3BHA} \\ c_{u1BHA} & c_{u3BHA} \\ c_{1BHA} & c_{3BHA} \\ \lambda_{c1BHA} & \lambda_{c3BHA} \\ F_{1BHA} & F_{3BHA} \\ \epsilon_{BHA} & \epsilon_{BHA} \end{matrix} \right)$	

$R_L$	$\pi^*$	
$K_H$	$\eta^*$	
$C_p$	$k$	
$\bar{H}_T$	$H_T$	
$L^*$	$\underline{L}$	
$T^*$	$\underline{T}$	
$P^*$	$P$	
$\rho^*$	$\rho$	
$a^*_c$	$a_{3B}$	
$\lambda_c$	$\lambda_c$	
$\underline{F}$	$F$	$= r = av(N_r)$
$D$	$\underline{R}$	$T^*_{st(1,1),r} = T^*_{3BHA_r}$
$\bar{d}$	$h$	$P^*_{st(1,1),r} = P^*_{3BHA_r}$
$\bar{c}_a$	$\bar{c}_u$	$\rho^*_{st(1,1),r} = \rho^*_{3BHA_r}$
$c_a$	$c_u$	$C_{p_{st(1,1),r}} = C_{p_{\text{Борздух}}}(P^*_{st(1,1),r}, T^*_{st(1,1),r})$
$u$	$w_u$	$k_{st(1,1),r} = k_{a\Delta}(C_{p_{st(1,1),r}}, R_B)$
$\underline{c}$	$w$	$a^*_{c_{st(1,1),r}} = a_{kp}(k_{st(1,1),r}, R_B, T^*_{st(1,1),r})$
$M_c$	$M_w$	$\bar{c}_{a_{st(1,1),r}} = \bar{c}_{a3BHA_r}$
$\alpha$	$\beta$	$\bar{c}_{u_{st(1,1),r}} = \bar{c}_{u3BHA_r}$
$\epsilon_{rotor}$	$\epsilon_{stator}$	$c_{a_{st(1,1),r}} = c_{a3BHA_r}$
		$u_{st(1,1),N_r} = u_{1пер}$
		$\alpha_{st(1,1),r} = \alpha_{3BHA_r}$
		$c_{st(1,1),r} = \frac{c_{a_{st(1,1),r}}}{\sin(\alpha_{st(1,1),r})}$
		$\lambda_{c_{st(1,1),r}} = \frac{c_{st(1,1),r}}{a^*_{c_{st(1,1),r}}}$
		$F_{st(1,1)} = \frac{G \cdot \sqrt{R_B \cdot T^*_{st(1,1),r}}}{m_q(k_{st(1,1),r}) \cdot \Gamma \Delta \Phi(G, \lambda_{c_{st(1,1),r}}, k_{st(1,1),r}) \cdot \sin(\alpha_{st(1,1),r}) \cdot P^*_{st(1,1),r}}$



$$D_{st(1,1),N_r} = \frac{2 \cdot u_{st(1,1),N_r}}{\omega}$$

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

$$D_{st(1,1),r} = \overline{r}_{cp}\left(\frac{D_{st(1,1),1}}{D_{st(1,1),N_r}}\right) \cdot D_{st(1,1),N_r}$$

$$\overline{d}_{st(1,1)} = \frac{D_{st(1,1),1}}{D_{st(1,1),N_r}}$$

for i ∈ 1..Z

```
trace(concat("ступень i = ", num2str(i)))
```

$$\begin{pmatrix} \overline{H}_{T_i} \\ K_{H_i} \\ \eta^*_{i} \\ R_{L_{i,r}} \end{pmatrix} = \begin{pmatrix} \overline{H}_{.T}(Z,i) \\ K_{.H}(Z,i) \\ \eta^*_{.}(Z,i) \\ R_{L.cp}(Z,i) \end{pmatrix}$$

$$H_{T_{i,r}} = \overline{H}_{T_i} \cdot \left(u_{st(i,1),N_r}\right)^2$$

$$L_i = K_{H_i} \cdot H_{T_{i,r}}$$

$$L^*_{i} = L_i \cdot \eta^*_{i}$$

$$iteration_{12} = 0$$

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

while 0 < 1

```
iteration12 = iteration12 + 1
```

```
trace\big(concat\big(" iteration.12 = ", num2str\big(iteration12\big)\big)\big)
```

$$k_{12} = \text{mean}\big(k_{st(i,1),r}, k_{st(i,2),r}\big)$$

$$Cp_{12} = \frac{k_{12}}{k_{12}-1} \cdot R_B$$

$$T^*_{st(i,2),r} = T^*_{st(i,1),r} + \frac{L_i}{Cp_{12}}$$

$$\pi^*_{i} = \left(1 + \frac{L^*_{i}}{Cp_{12} \cdot T^*_{st(i,1),r}}\right)^{\frac{k_{12}}{k_{12}-1}}$$

$$P^*_{st(i,2),r} = P^*_{st(i,1),r} \cdot \pi^*_{i}$$

$$Cp_{st(i,2),r} = Cp_{mean}\big(P^*_{st(i,2),r}, T^*_{st(i,2),r}\big)$$

1 st(i, 2), r = k'2  
1 BO3ДУХ\ st(i, 2), r = k'2  
st(i, 2), r = k'2

$$k'_2 = k_{a\text{Д}}\left(C_{\text{Pst}(i, 2), r}, R_{\text{Б}}\right)$$

$$\text{if } \left| \text{eps}\left(\text{"rel"}, k_{\text{st}(i, 2), r}, k'_2\right) \right| < \text{epsilon}$$

$$k_{\text{st}(i, 2), r} = k'_2$$

break

$$k_{\text{st}(i, 2), r} = k'_2$$

$$a^*_{c_{\text{st}(i, 2), r}} = a_{\text{КР}}\left(k_{\text{st}(i, 2), r}, R_{\text{Б}}, T^*_{\text{st}(i, 2), r}\right)$$

$$T^*_{\text{st}(i, 3), r} = T^*_{\text{st}(i, 2), r}$$

$$P^*_{\text{st}(i, 3), r} = P^*_{\text{st}(i, 2), r}$$

$$C_{\text{Pst}(i, 3), r} = C_{\text{BO3ДУХ}}\left(P^*_{\text{st}(i, 3), r}, T^*_{\text{st}(i, 3), r}\right)$$

$$k_{\text{st}(i, 3), r} = k_{a\text{Д}}\left(C_{\text{Pst}(i, 3), r}, R_{\text{Б}}\right)$$

$$a^*_{c_{\text{st}(i, 3), r}} = a_{\text{КР}}\left(k_{\text{st}(i, 3), r}, R_{\text{Б}}, T^*_{\text{st}(i, 3), r}\right)$$

$$\overline{c}_{a_{\text{st}(i, 3), r}} = \overline{c}_{.a1}(Z, i + 1)$$

$$\text{iteration}_3 = 0$$

$$\begin{pmatrix} \alpha_{\text{st}(i, 3), r} \\ u_{\text{st}(i, 3), N_{\text{r}}} \end{pmatrix} = \begin{pmatrix} \alpha_{\text{st}(i, 1), r} \\ u_{\text{st}(i, 1), N_{\text{r}}} \end{pmatrix}$$

$$c_{a_{\text{st}(i, 3), r}} = \overline{c}_{a_{\text{st}(i, 3), r}} \cdot u_{\text{st}(i, 3), N_{\text{r}}}$$

$$c_{\text{st}(i, 3), r} = \frac{c_{a_{\text{st}(i, 3), r}}}{\sin\left(\alpha_{\text{st}(i, 3), r}\right)}$$

$$\lambda_{\text{c}_{\text{st}(i, 3), r}} = \frac{c_{\text{st}(i, 3), r}}{a^*_{c_{\text{st}(i, 3), r}}}$$

$$F_{\text{st}(i, 3)} = \frac{F_{\text{st}(i, 1)} \cdot m_{\text{q}}\left(k_{\text{st}(i, 1), r}\right) \cdot \Gamma \text{Д} \Phi\left(\text{"G"}, \lambda_{\text{c}_{\text{st}(i, 1), r}}, k_{\text{st}(i, 1), r}\right) \cdot \sin\left(\alpha_{\text{st}(i, 1), r}\right) \cdot P^*_{\text{st}(i, 1), r} \sqrt{T^*_{\text{st}(i, 3), r}}}{m_{\text{q}}\left(k_{\text{st}(i, 3), r}\right) \cdot \Gamma \text{Д} \Phi\left(\text{"G"}, \lambda_{\text{c}_{\text{st}(i, 3), r}}, k_{\text{st}(i, 3), r}\right) \cdot \sin\left(\alpha_{\text{st}(i, 3), r}\right) \cdot P^*_{\text{st}(i, 3), r} \sqrt{T^*_{\text{st}(i, 1), r}}}$$

while 0 < 1

$$\text{iteration}_3 = \text{iteration}_3 + 1$$

$$\text{trace}\left(\text{concat}\left(\text{" iteration.3 = "}, \text{num2str}\left(\text{iteration}_3\right)\right)\right)$$

$$\text{if } \left(3\Pi\Pi\Pi_i \neq \text{"nep"}\right) \wedge \left(3\Pi\Pi\Pi_i \neq \text{"kop"}\right) \wedge \left(3\Pi\Pi\Pi_i \neq \text{"cp"}\right)$$

$$D_{\text{st}(i, 3), N_{\text{r}}} = D_{\text{st}(i, 1), N_{\text{r}}} \cdot \text{str2num}\left(3\Pi\Pi\Pi_i\right)$$

$$D_{\text{st}(i, 3), 1} = \sqrt{\left(D_{\text{st}(i, 3), N_{\text{r}}}\right)^2 - \frac{4F_{\text{st}(i, 3)}}{\pi}}$$

if 3ΠΠΠ<sub>i</sub> = "nep"

$$\left| \begin{array}{l} D_{\text{st}(i,3),N_r} = D_{\text{st}(i,1),N_r} \\ D_{\text{st}(i,3),1} = \sqrt{\left(D_{\text{st}(i,3),N_r}\right)^2 - \frac{4F_{\text{st}(i,3)}}{\pi}} \end{array} \right.$$

if  $3\Pi\Pi\Pi_i = \text{"kop"}$

$$\left| \begin{array}{l} D_{\text{st}(i,3),1} = D_{\text{st}(i,1),1} \\ D_{\text{st}(i,3),N_r} = \sqrt{\left(D_{\text{st}(i,3),1}\right)^2 + \frac{4F_{\text{st}(i,3)}}{\pi}} \end{array} \right.$$

if  $3\Pi\Pi\Pi_i = \text{"cp"}$

$$\left| \begin{array}{l} D_{\text{st}(i,3),N_r} = \sqrt{\left(D_{\text{st}(i,1),r}\right)^2 + \frac{2F_{\text{st}(i,3)}}{\pi}} \\ D_{\text{st}(i,3),1} = \sqrt{\left(D_{\text{st}(i,1),r}\right)^2 - \frac{2F_{\text{st}(i,3)}}{\pi}} \end{array} \right.$$

$$\overline{d}_{\text{st}(i,3)} = \frac{D_{\text{st}(i,3),1}}{D_{\text{st}(i,3),N_r}}$$

$$D_{\text{st}(i,3),r} = \overline{r}_{\text{cp}}(\overline{d}_{\text{st}(i,3)}) \cdot D_{\text{st}(i,3),N_r}$$

$$\overline{c}_{u_{\text{st}(i,3),r}} = \overline{r}_{\text{cp}}(\overline{d}_{\text{st}(i,3)}) \cdot \left(1 - R_{\text{L.cp}}(Z,i+1)\right) - \frac{\overline{H}.T(Z,i+1)}{2 \cdot \overline{r}_{\text{cp}}(\overline{d}_{\text{st}(i,3)})}$$

$$\alpha_{\text{st}(i,3),r} = \left| \begin{array}{l} \text{atan}\left(\frac{\overline{c}_{a_{\text{st}(i,3),r}}}{\overline{c}_{u_{\text{st}(i,3),r}}}\right) \quad \text{if } \text{atan}\left(\frac{\overline{c}_{a_{\text{st}(i,3),r}}}{\overline{c}_{u_{\text{st}(i,3),r}}}\right) \geq 0 \\ \text{atan}\left(\frac{\overline{c}_{a_{\text{st}(i,3),r}}}{\overline{c}_{u_{\text{st}(i,3),r}}}\right) + 2\pi \quad \text{otherwise} \end{array} \right.$$

$$u_{\text{st}(i,3),N_r} = u_{\text{st}(i,1),N_r} \cdot \frac{D_{\text{st}(i,3),N_r}}{D_{\text{st}(i,1),N_r}}$$

$$c_{a_{\text{st}(i,3),r}} = \overline{c}_{a_{\text{st}(i,3),r}} \cdot u_{\text{st}(i,3),N_r}$$

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

$$\lambda_{c_{\text{st}(i,3),r}} = \frac{c_{\text{st}(i,3),r}}{a^* c_{\text{st}(i,3),r}}$$

$$F'_3 = \frac{G \cdot \sqrt{R_B \cdot T^*_{\text{st}(i,3),r}}}{m_q(k_{\text{st}(i,3),r}) \cdot \Gamma \mathcal{D} \Phi\left("G", \lambda_{c_{\text{st}(i,3),r}}, k_{\text{st}(i,3),r}\right) \cdot \sin(\alpha_{\text{st}(i,3),r}) \cdot P^*_{\text{st}(i,3),r}}$$

break if  $\left(\left|\text{eps}(\text{"rel"}, F'_3, F_{\text{st}(i,3)})\right| < \text{epsilon}\right) \wedge \left(\text{iteration}_3 = 0\right)$

$\text{iteration}_3 = -1$  if  $\left(\left|\text{eps}(\text{"rel"}, F'_3, F_{\text{st}(i,3)})\right| < \text{epsilon}\right)$

```

Fst(i,3) = F'3
 $\overline{c}_{a_{st(i,2)},r} = \text{mean}(\overline{c}_{a_{st(i,1)},r}, \overline{c}_{a_{st(i,3)},r})$ 
iteration2 = 0
Fst(i,2) = mean(Fst(i,1), Fst(i,3))
while 0 < 1
    iteration2 = iteration2 + 1
    trace(concat(" iteration.2 = ", num2str(iteration2)))
    if (3ΠΠΨi ≠ "nep") ∧ (3ΠΠΨi ≠ "kop") ∧ (3ΠΠΨi ≠ "cp")
         $D_{st(i,2),N_r} = \text{mean}(D_{st(i,1),N_r}, D_{st(i,3),N_r})$ 
         $\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$ 
         $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}(\overline{d}_{st(i,2)})$ 
         $D_{st(i,2),l} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$ 
    if 3ΠΠΨi = "nep"
         $D_{st(i,2),N_r} = D_{st(i,1),N_r}$ 
         $\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$ 
         $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}(\overline{d}_{st(i,2)})$ 
         $D_{st(i,2),l} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$ 
    if 3ΠΠΨi = "kop"
         $D_{st(i,2),l} = D_{st(i,1),l}$ 
         $\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$ 
         $D_{st(i,2),N_r} = \frac{D_{st(i,2),l}}{\overline{d}_{st(i,2)}}$ 
         $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}(\overline{d}_{st(i,2)})$ 
    if 3ΠΠΨi = "cp"
         $D_{st(i,2),r} = D_{st(i,1),r}$ 
         $\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$ 
         $D_{st(i,2),N_r} = \frac{D_{st(i,2),r}}{\overline{r}_{cp}(\overline{d}_{st(i,2)})}$ 
         $D_{st(i,2),l} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$ 

```

$$\overline{c}_{u_{st(i,2),r}} = \frac{1}{\overline{r}_{cp}(\overline{d}_{st(i,2)})} \left( \frac{\nu_{st(i,1),N_r}}{D_{st(i,2),N_r}} \right) \cdot \left( \overline{H}_{T_i} + \overline{c}_{u_{st(i,1),r}} \cdot \frac{D_{st(i,1),r}}{D_{st(i,1),N_r}} \right)$$

$$\alpha_{st(i,2),r} = \text{triangle}\Big(\overline{c}_{a_{st(i,2),r}}, \overline{c}_{u_{st(i,2),r}}\Big)$$

$$u_{st(i,2),N_r} = u_{st(i,1),N_r} \cdot \frac{D_{st(i,2),N_r}}{D_{st(i,1),N_r}}$$

$$c_{a_{st(i,2),r}} = \overline{c}_{a_{st(i,2),r}} \cdot u_{st(i,2),N_r}$$

$$c_{st(i,2),r} = \frac{c_{a_{st(i,2),r}}}{\sin(\alpha_{st(i,2),r})}$$

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

$$F'_2 = \frac{G \cdot \sqrt{R_B \cdot T^*_{st(i,2),r}}}{m_q(k_{st(i,2),r}) \cdot \Gamma \mathcal{D} \Phi\Big( "G", \lambda_{c_{st(i,2),r}}, k_{st(i,2),r} \Big) \cdot \sin(\alpha_{st(i,2),r}) \cdot P^*_{st(i,2),r}}$$

$$\text{break if } \Big(\left|\text{eps}\Big( "rel", F'_2, F_{st(i,2)} \Big)\right| < \text{epsilon}\Big) \wedge \Big(\text{iteration}_2 = 0\Big)$$

$$\text{iteration}_2 = -1 \quad \text{if } \Big(\left|\text{eps}\Big( "rel", F'_2, F_{st(i,2)} \Big)\right| < \text{epsilon}\Big)$$

$$F_{st(i,2)} = F'_2$$

for a ∈ 1 .. 3

$$\rho^*_{st(i,a),r} = \frac{P^*_{st(i,a),r}}{R_B \cdot T^*_{st(i,a),r}}$$

$$T_{st(i,a),r} = T^*_{st(i,a),r} \cdot \Gamma \mathcal{D} \Phi\Big( "T", \lambda_{c_{st(i,a),r}}, k_{st(i,a),r} \Big)$$

$$P_{st(i,a),r} = P^*_{st(i,a),r} \cdot \Gamma \mathcal{D} \Phi\Big( "P", \lambda_{c_{st(i,a),r}}, k_{st(i,a),r} \Big)$$

$$\rho_{st(i,a),r} = \rho^*_{st(i,a),r} \cdot \Gamma \mathcal{D} \Phi\Big( " \rho", \lambda_{c_{st(i,a),r}}, k_{st(i,a),r} \Big)$$

$$a_{3B_{st(i,a),r}} = \sqrt{k_{st(i,a),r} \cdot R_B \cdot T_{st(i,a),r}}$$

$$\beta_{st(i,a),r} = \text{triangle}\Big(\overline{c}_{a_{st(i,a),r}}, \overline{r}_{cp}(\overline{d}_{st(i,a)}) - \overline{c}_{u_{st(i,a),r}}\Big)$$

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

$$w_{u_{st(i,a),r}} = w_{st(i,a),r} \cdot \cos(\beta_{st(i,a),r})$$

$$c_{u_{st(i,a),r}} = c_{st(i,a),r} \cdot \cos(\alpha_{st(i,a),r})$$

$$M_{w_{st(i,a),r}} = \frac{w_{st(i,a),r}}{a_{3B_{st(i,a),r}}}$$

$$u_{st(i,a),r} = c_{st(i,a),r}$$

$$M_{c_{st(i,a),r}} = \overline{a_{3B_{st(i,a),r}}}$$

$$h_{st(i,a)} = 0.5 \cdot \left( D_{st(i,a),N_r} - D_{st(i,a),1} \right)$$

for radius  $\in 1..N_r$

$$u_{st(i,a),radius} = \omega \cdot \frac{D_{st(i,a),radius}}{2}$$

$$\begin{pmatrix} \epsilon_{rotor_{i,av(N_r)}} \\ \epsilon_{stator_{i,av(N_r)}} \end{pmatrix} = \begin{pmatrix} \beta_{st(i,2),av(N_r)} - \beta_{st(i,1),av(N_r)} \\ \alpha_{st(i,3),av(N_r)} - \alpha_{st(i,2),av(N_r)} \end{pmatrix}$$

for i  $\in 1..Z$

for a  $\in 1..3$

for r  $\in 1..N_r$

$$R_{st(i,a),r} = 0.5 \cdot D_{st(i,a),r}$$

$$\begin{pmatrix} R_L & K_H & C_p & \bar{H}_T & L^* & T^* & P^* & \rho^* & a^*_c & \lambda_c & F & D & \bar{d} & \bar{c}_a & c_a & u & c & M_c & \alpha & \epsilon_{rotor} \\ \pi^* & \eta^* & k & H_T & L & T & P & \rho & a_{3B} & \lambda_c & F & R & h & \bar{c}_u & c_u & w_u & w & M_w & \beta & \epsilon_{stator} \end{pmatrix}^T$$



$$CA = \begin{cases} 1 & \text{if compressor = "КВД"} \\ 0 & \text{otherwise} \end{cases} = 0$$

Расчет CA:

$$\begin{pmatrix} \alpha_{1CA} & \alpha_{3CA} \\ \sigma_{CA} & \sigma_{CA} \\ \overline{d}_{1CA} & \overline{d}_{3CA} \\ T^*_{1CA} & T^*_{3CA} \\ P^*_{1CA} & P^*_{3CA} \\ \rho^*_{1CA} & \rho^*_{3CA} \\ k_{1CA} & k_{3CA} \\ a_{kp1CA} & a_{kp3CA} \\ \overline{c}_{a1CA} & \overline{c}_{a3CA} \\ \overline{c}_{u1CA} & \overline{c}_{u3CA} \\ c_{a1CA} & c_{a3CA} \\ c_{u1CA} & c_{u3CA} \\ c_{1CA} & c_{3CA} \\ \lambda_{1CA} & \lambda_{3CA} \\ F_{1CA} & F_{3CA} \\ \varepsilon_{CA} & \varepsilon_{CA} \end{pmatrix} = \begin{cases} \text{for } r \in \text{av}\left(N_r\right) \\ \left| \begin{array}{l} \alpha_{1CA_r} = \alpha_{st(Z,3),r} \\ \alpha_{3CA_r} = \begin{cases} 90^\circ & \text{if } CA = 1 \\ \alpha_{1CA_r} & \text{otherwise} \end{cases} \\ \overline{d}_{1CA} = \overline{d}_{st(Z,3)} \\ \overline{d}_{3CA} = \overline{d}_{1CA} \\ T^*_{1CA_r} = T^*_{st(Z,3),r} \\ T^*_{3CA_r} = T^*_{1CA_r} \\ P^*_{1CA_r} = P^*_{st(Z,3),r} \\ \text{iterarion}_{CA} = 0 \\ \sigma_{CA} = 1 \\ \text{while } 0 < 1 \\ \left| \begin{array}{l} \text{iterarion}_{CA} = \text{iterarion}_{CA} + 1 \\ \text{trace}\left(\text{concat}\left(\text{"iterarion.CA = "}, \text{num2str}\left(\text{iterarion}_{CA}\right)\right)\right) \\ P^*_{3CA_r} = P^*_{1CA_r} \cdot \sigma_{CA} \\ \left(\rho^*_{1CA_r}\right)_1 = \frac{\left(P^*_{1CA_r}\right)}{T^*_{1CA_r}} \end{array} \right. \end{array} \right. \end{cases}$$

$$\sigma_{CA} = 1.0000$$

$$\text{submatrix}\left(\varepsilon_{CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.00) \cdot \text{deg}$$

$$\text{submatrix}\left(\alpha_{1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (51.49) \cdot \text{deg}$$

$$\text{submatrix}\left(\alpha_{3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (51.49) \cdot \text{deg}$$

$$\begin{pmatrix} \overline{d}_{1CA} \\ \overline{d}_{3CA} \end{pmatrix} = \begin{pmatrix} 0.6953 \\ 0.6953 \end{pmatrix} \qquad \begin{pmatrix} F_{1CA} \\ F_{3CA} \end{pmatrix} = \begin{pmatrix} 0.3310 \\ 0.3310 \end{pmatrix}$$



$$\left(\rho^*_{3CA_r}\right) = \frac{1}{R_B} \cdot \left(\frac{P^*_{3CA_r}}{T^*_{3CA_r}}\right)$$

$$\begin{pmatrix} k_{1CA_r} \\ k_{3CA_r} \end{pmatrix} = \begin{pmatrix} k_{aд}\left(Cp_{\text{воздух}}\left(P^*_{1CA_r}, T^*_{1CA_r}\right), R_B\right) \\ k_{aд}\left(Cp_{\text{воздух}}\left(P^*_{3CA_r}, T^*_{3CA_r}\right), R_B\right) \end{pmatrix}$$

$$\begin{pmatrix} a_{kp1CA_r} \\ a_{kp3CA_r} \end{pmatrix} = \begin{pmatrix} a_{kp}\left(k_{1CA_r}, R_B, T^*_{1CA_r}\right) \\ a_{kp}\left(k_{3CA_r}, R_B, T^*_{3CA_r}\right) \end{pmatrix}$$

$$\overline{c}_{a1CA_r} = \overline{c}_{a_{st}(Z, 3), r}$$

$$\overline{c}_{a3CA_r} = \overline{c}_{.a1}(Z, Z + 1)$$

$$\overline{c}_{u1CA_r} = \overline{c}_{u_{st}(Z, 3), r}$$

$$\overline{c}_{u3CA_r} = \begin{cases} 0 & \text{if } CA = 1 \\ \overline{c}_{u1CA_r} & \text{otherwise} \end{cases}$$

$$c_{a1CA_r} = \overline{c}_{a3CA_r} \cdot u_{st(Z, 3), N_r}$$

$$c_{a3CA_r} = c_{a1CA_r} - \begin{cases} 10 & \text{if } CA = 1 \\ 0 & \text{otherwise} \end{cases}$$

$$\begin{pmatrix} c_{u1CA_r} \\ c_{u3CA_r} \end{pmatrix} = \begin{pmatrix} \frac{c_{a1CA_r}}{\tan(\alpha_{1CA_r})} \\ \frac{c_{a3CA_r}}{\tan(\alpha_{3CA_r})} \end{pmatrix}$$

$$\begin{pmatrix} c_{1CA_r} \\ c_{3CA_r} \end{pmatrix} = \begin{pmatrix} \frac{c_{a1CA_r}}{\sin(\alpha_{1CA_r})} \\ \frac{c_{a3CA_r}}{\sin(\alpha_{3CA_r})} \end{pmatrix}$$

$$\begin{pmatrix} \lambda_{1CA_r} \\ \lambda_{3CA_r} \end{pmatrix} = \begin{pmatrix} \frac{c_{1CA_r}}{a_{kp1CA_r}} \\ \frac{c_{3CA_r}}{a_{kp3CA_r}} \end{pmatrix}$$

$$\sigma'_{CA} = \begin{cases} 1 - \text{mean}(0.25, 0.5) \cdot \Gamma\text{Д}\Phi\left("p", \lambda_{3CA_r}, k_{3CA_r}\right) \cdot \frac{k_{3CA_r}}{k_{3CA_r} + 1} \cdot \left(\lambda_{3CA_r}\right)^2 & \text{if } CA = 1 \end{cases}$$

$$\text{submatrix}\left(T^*_{1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (361.5)$$

$$\text{submatrix}\left(T^*_{3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (361.5)$$

$$\text{submatrix}\left(P^*_{1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (202.7) \cdot 10^3$$

$$\text{submatrix}\left(P^*_{3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (202.7) \cdot 10^3$$

$$\text{submatrix}\left(\rho^*_{1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.952)$$

$$\text{submatrix}\left(\rho^*_{3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.952)$$

$$\text{submatrix}\left(k_{1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.398)$$

$$\text{submatrix}\left(k_{3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.398)$$

$$\text{submatrix}\left(a_{kp1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (347.9)$$

$$\text{submatrix}\left(a_{kp3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (347.9)$$

$$\text{submatrix}\left(\overline{c}_{a1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.224)$$

$$\text{submatrix}\left(\overline{c}_{a3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.224)$$

$$\text{submatrix}\left(\overline{c}_{u1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.178)$$

$$\text{submatrix}\left(\overline{c}_{u3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.178)$$

$$\text{submatrix}\left(c_{a1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (56.1)$$

$$\text{submatrix}\left(c_{a3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (56.1)$$

$$\text{submatrix}\left(c_{u1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (44.7)$$

$$\text{submatrix}\left(c_{u3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (44.7)$$

$$\text{submatrix}\left(c_{1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (71.8)$$

$$\text{submatrix}\left(c_{3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (71.8)$$

$$\text{submatrix}\left(\lambda_{1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.206)$$

$$\text{submatrix}\left(\lambda_{3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.206)$$

$$\begin{array}{l} \quad \quad \quad | \quad 1 \quad \text{otherwise} \\ \text{break if } \left( \left| \text{eps}(\text{"rel"}, \sigma'_{CA}, \sigma_{CA}) \right| < \text{epsilon} \right) \wedge \left( \text{iterarion}_{CA} = 0 \right) \\ \text{iterarion}_{CA} = -1 \quad \text{if } \left( \left| \text{eps}(\text{"rel"}, \sigma'_{CA}, \sigma_{CA}) \right| < \text{epsilon} \right) \\ \sigma_{CA} = \sigma'_{CA} \end{array}$$

$$\begin{pmatrix} F_{1CA} \\ F_{3CA} \end{pmatrix} = \begin{pmatrix} F_{st}(Z, 3) \\ G \cdot \sqrt{R_B \cdot T^*_{3CA_r}} \\ \frac{m_q(k_{3CA_r}) \cdot P^*_{3CA_r} \cdot \Gamma_D \Phi("G", \lambda_{3CA_r}, k_{3CA_r}) \cdot \sin(\alpha_{3CA_r})}{m_q(k_{3CA_r}) \cdot P^*_{3CA_r} \cdot \Gamma_D \Phi("G", \lambda_{3CA_r}, k_{3CA_r}) \cdot \sin(\alpha_{3CA_r})} \end{pmatrix}$$

$$\left| \varepsilon_{CA_r} = \alpha_3 CA_r - \alpha_1 CA_r \right|$$

$$\left( \begin{array}{cc} \alpha_{1CA} & \alpha_{3CA} \\ \sigma_{CA} & \sigma_{CA} \\ \bar{d}_{1CA} & \bar{d}_{3CA} \\ T^*_{1CA} & T^*_{3CA} \\ P^*_{1CA} & P^*_{3CA} \\ \rho^*_{1CA} & \rho^*_{3CA} \\ k_{1CA} & k_{3CA} \\ a_{kp1CA} & a_{kp3CA} \\ \bar{c}_{a1CA} & \bar{c}_{a3CA} \\ \bar{c}_{u1CA} & \bar{c}_{u3CA} \\ c_{a1CA} & c_{a3CA} \\ c_{u1CA} & c_{u3CA} \\ c_{1CA} & c_{3CA} \\ \lambda_{1CA} & \lambda_{3CA} \\ F_{1CA} & F_{3CA} \\ \varepsilon_{CA} & \varepsilon_{CA} \end{array} \right)$$

Относ. погрешность расчета по массовому расходу (кг/с):

$\overline{\Delta G} =$

for i ∈ 1..Z

for a ∈ 1..3

$\overline{\Delta G}_{st(i,a)} = \left| \text{eps}\left( \text{"rel"}, G, \rho_{st(i,a),av(N_r)} \cdot c_{a_{st(i,a),av(N_r)}} \cdot F_{st(i,a)} \right) \right|$

$\overline{\Delta G}$

$\overline{\Delta G}^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.00	0.00	0.01	0.00	0.00	0.00	0.00												

.%

$\overline{\Delta G}^T < 1\% =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	1	1	1	1	1	1												

Количество ступеней ОК: 

Z = 3

Дискретизация сечений:      ii = 1..2Z + 1

Дискретизация ступеней:      i = 1..Z

$\pi^{*T} =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.300	1.297	1.187												

[16, с 114]  $\pi^{*T} \leq 1.9 =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1												

Полученная степень повышения полного давления []:  $\prod_{i = 1}^Z \pi^{*}_i = 2.000$

Степень повышения давления в ЛА:

$\pi^{*}_{\text{ЛА}} = \frac{P^{*}_{3CA_{av(N_r)}}}{P^{*}_{1BHA_{av(N_r)}} = 2.000$

$\pi^{*}_{\text{ЛА}} \geq \pi^{*}_{\text{К}} = 1$

$H_T^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	26.51	29.08	21.26												
2	26.51	29.08	21.26												
3	26.51	29.08	21.26												

$\cdot 10^3$

Действительная работа К (Дж/кг):
$$L_K = \sum_{i=1}^Z L_i = 73.6 \cdot 10^3$$

Адиабатная работа К [Дж/кг]:
$$L_K^* = \sum_{i=1}^Z L_{i}^* = 64.1 \cdot 10^3$$

Адиабатная КПД К [%]:

$$\eta_K^* = \frac{L_K^*}{L_K} = 87.02\%$$

Мощность К (Вт):
$$N_K = G \cdot L_K = 2.62 \cdot 10^6$$

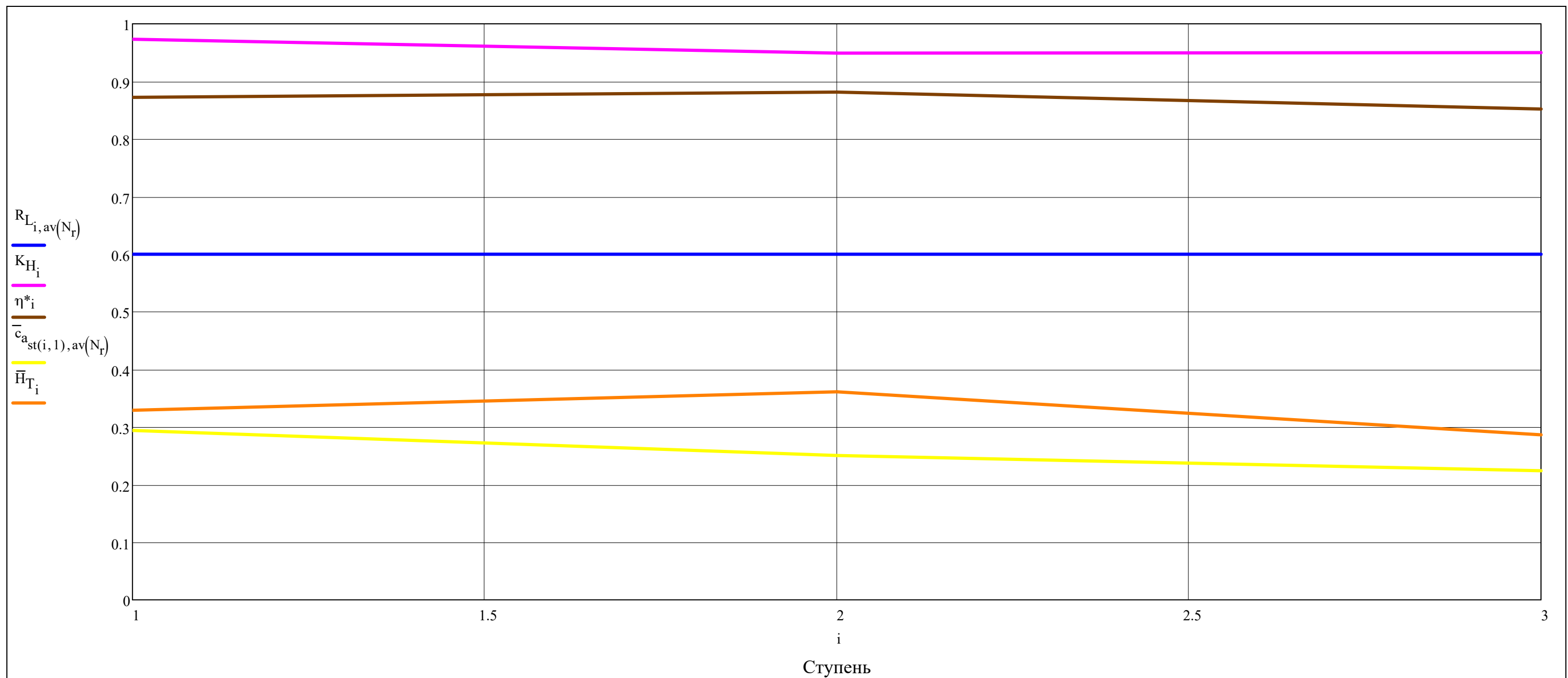
[illegible]

[illegible]

[illegible]

[illegible]

$$\bar{H}_T^T = \begin{array}{c|cccccccccccccccc} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 0.33 & 0.36 & 0.29 & & & & & & & & & & & & \end{array}$$



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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1002.6	1004.1	1004.1	1006.4	1006.4	1008.5	1008.5												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.401	1.401	1.401	1.399	1.399	1.398	1.398														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	288.2	313.9	313.9	341.4	341.4	361.5	361.5														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	284.7	305.4	310.5	326.2	338.3	349	359														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	101.3	131.7	131.7	170.8	170.8	202.7	202.7											

·10<sup>3</sup>

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	97.1	119.6	126.7	145.5	165.3	179.1	197.7											

·10<sup>3</sup>

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

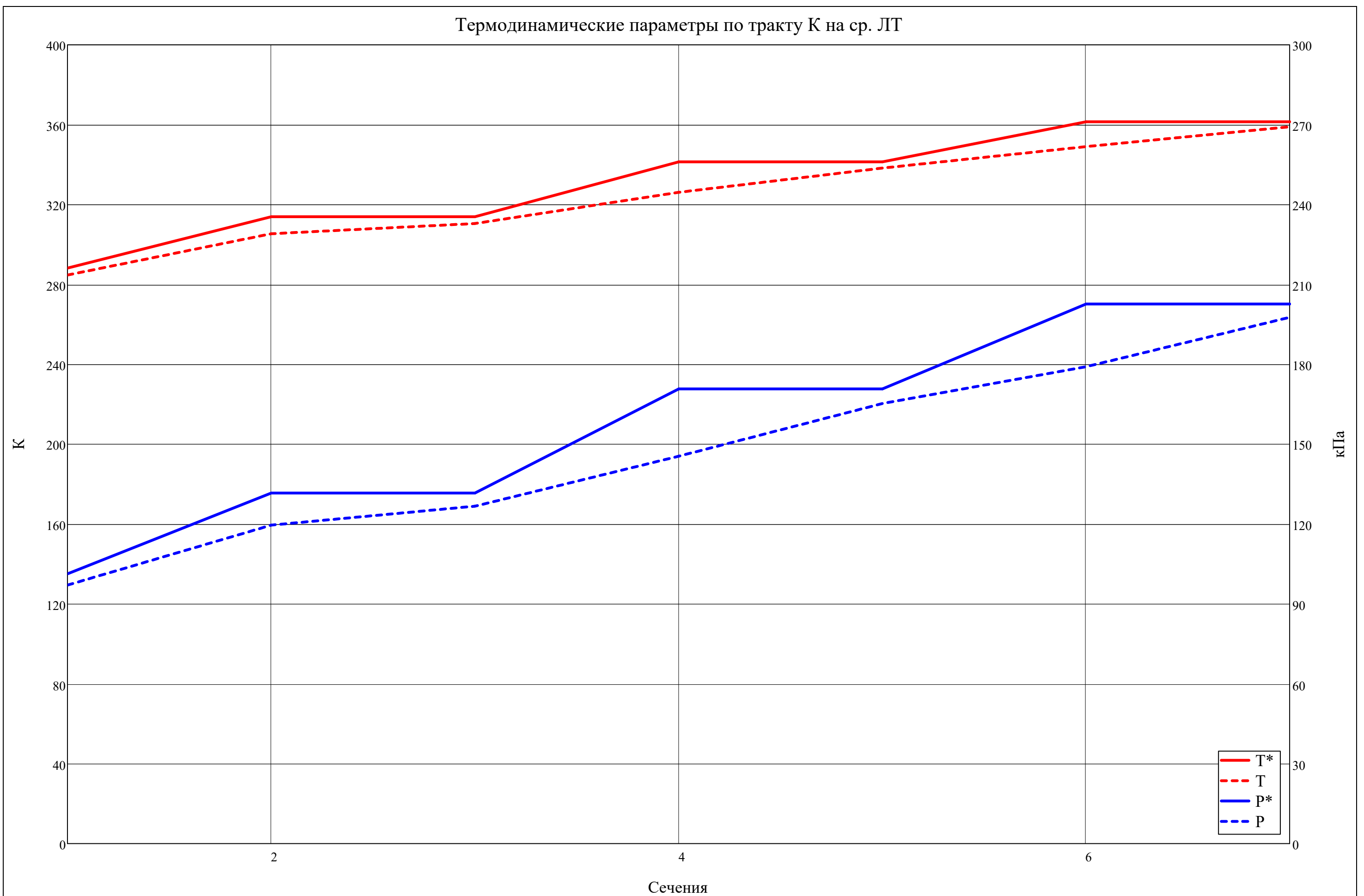
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1.224	1.461	1.461	1.742	1.742	1.952	1.952												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1.188	1.364	1.421	1.553	1.702	1.787	1.918												

$$\textcolor{green}{k_{\text{cp}}} = k_{\text{ад}}\Big(\text{Cp}_{\text{воздух.ср}}\Big(\text{P}^*_{\text{st}(1,1),\text{av}\Big(\text{N}_{\text{r}}\Big)},\text{P}^*_{\text{st}(Z,3),\text{av}\Big(\text{N}_{\text{r}}\Big)},\text{T}^*_{\text{st}(1,1),\text{av}\Big(\text{N}_{\text{r}}\Big)},\text{T}^*_{\text{st}(Z,3),\text{av}\Big(\text{N}_{\text{r}}\Big)}\Big),\text{R}_{\text{B}}\Big) = 1.400$$

Термодинамические параметры по тракту К на ср. ЛТ



$F^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0.3596	0.3382	0.3526	0.3476	0.3433	0.3404	0.331														

$\overline{d}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.7498	0.7527	0.7555	0.7474	0.7393	0.7175	0.6953																

$\overline{d}_{st(Z,3)} = 0.6953$

$\overline{d}_{st(Z,3)} \leq 0.9 = 1$

$D^T =$

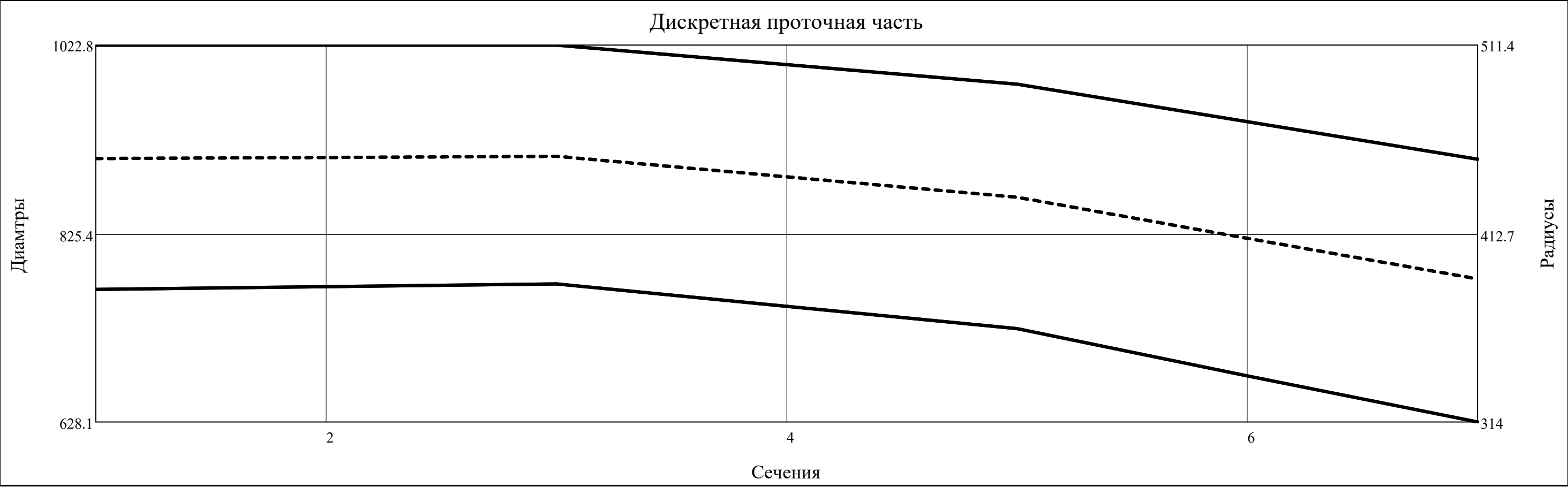
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	766.9	769.8	772.7	749.2	725.9	676.3	628.1														
2	903.9	905.2	906.4	884.8	863.4	820.3	777.9														
3	1022.8	1022.8	1022.8	1002.3	981.8	942.6	903.3														

$\cdot 10^{-3}$

$R^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	383.4	384.9	386.3	374.6	363.0	338.2	314.0																		
2	452.0	452.6	453.2	442.4	431.7	410.2	389.0																		
3	511.4	511.4	511.4	501.1	490.9	471.3	451.6																		

$\cdot 10^{-3}$



$h^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	127.9	126.5	125.0	126.6	128.0	133.1	137.6																		

$\cdot 10^{-3}$



[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

$$c_{a_{st(Z,3),av}(N_r)} = 56.15 \quad c_{a_{st(Z,3),av}(N_r)} \leq 130 = 1 \quad \text{Для КС}$$

[illegible]

[illegible]

[illegible]

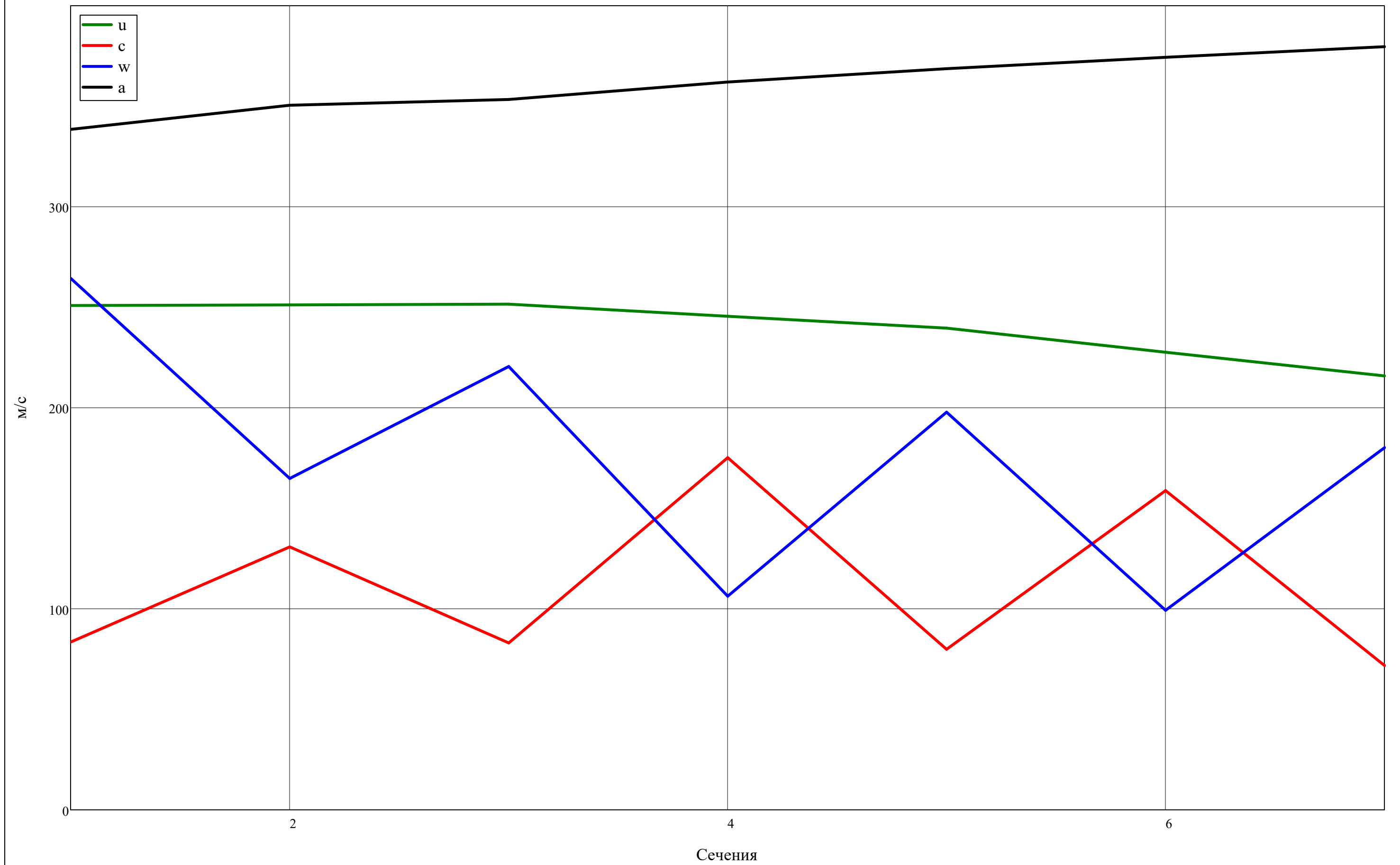
$$\Delta c_{a,i,av(N_r)} = \left( c_{a,st(i,2),av(N_r)} - c_{a,st(i,1),av(N_r)} \right)$$

$$\text{submatrix}(\Delta c_a, l, Z, \text{av}(N_r), \text{av}(N_r))^T =$$

	1	2	3	4	5	6	7	8	9	10	11	12
1	-6.15	-5.13	-2.44									

[illegible]

Скорости по тракту К на ср. ЛТ



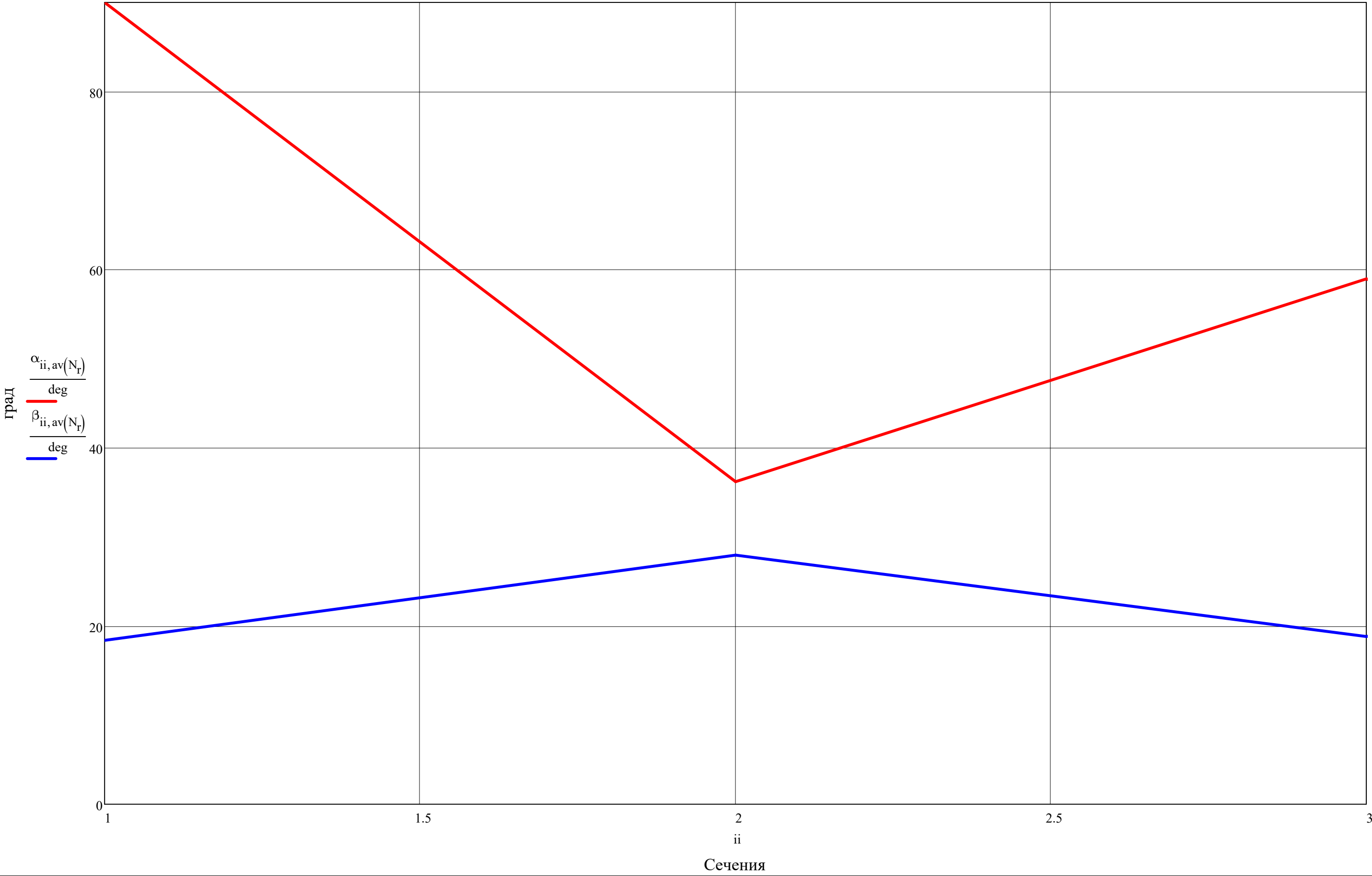
[illegible]

[illegible]

[illegible]

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Углы по тракту К на ср. ЛТ



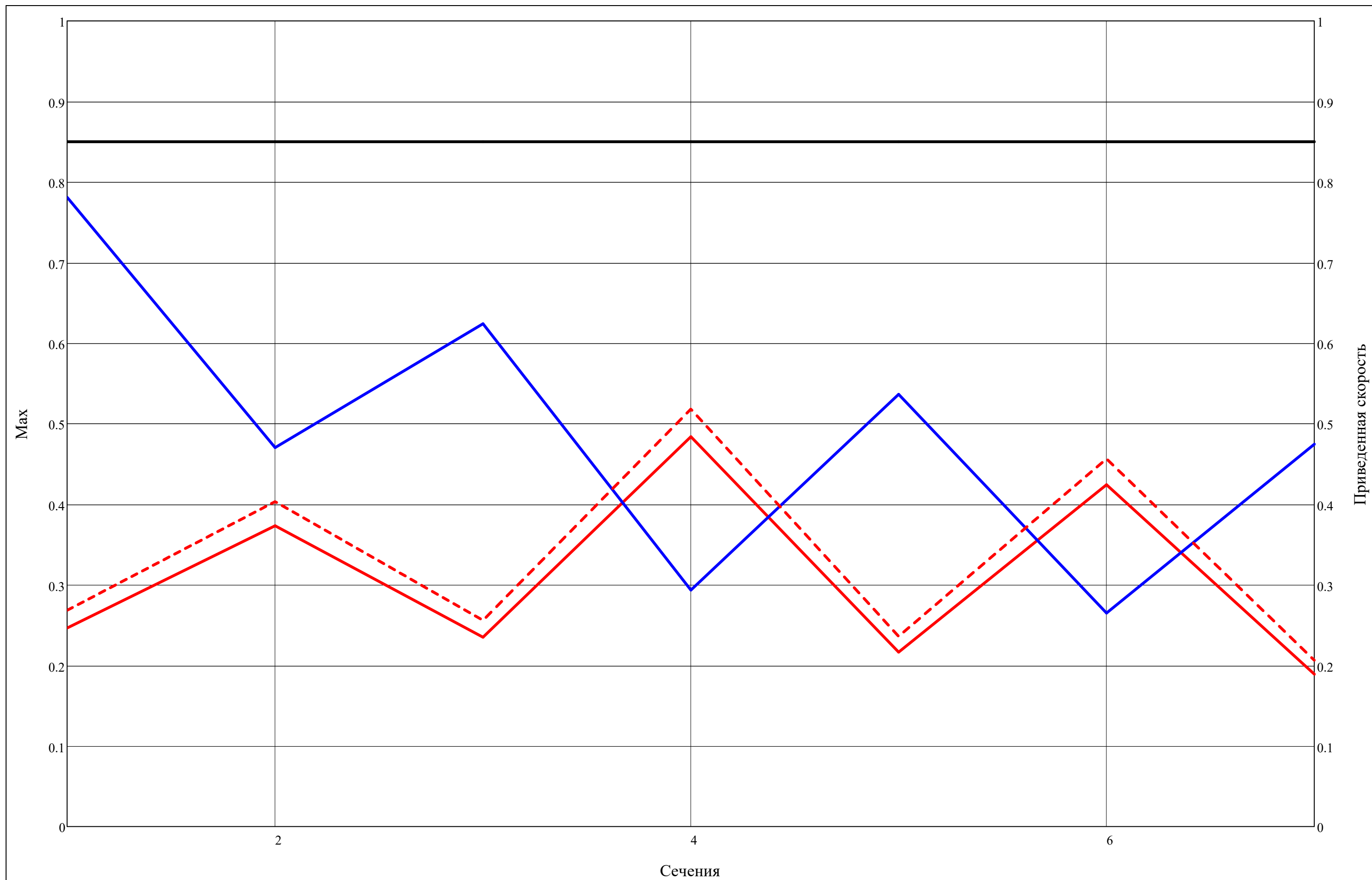
[illegible]

[16, c. 87]  $\text{submatrix}(\lambda_{\mathbf{c}}, 1, 2Z + 1, \text{av}(\mathbf{N}_{\mathbf{r}}), \text{av}(\mathbf{N}_{\mathbf{r}}))^{\mathbf{T}} \leq 0.85 =$

	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1

[illegible]

[illegible]











$$\begin{pmatrix} T^*_{1BHA} & T^*_{3BHA} \\ P^*_{1BHA} & P^*_{3BHA} \\ \rho^*_{1BHA} & \rho^*_{3BHA} \\ C_{p1BHA} & C_{p3BHA} \\ k_{1BHA} & k_{3BHA} \\ a^*_{c1BHA} & a^*_{c3BHA} \\ c_{u1BHA} & c_{u3BHA} \\ c_{a1BHA} & c_{a3BHA} \\ \alpha_{1BHA} & \alpha_{3BHA} \\ c_{1BHA} & c_{3BHA} \\ \lambda_{c1BHA} & \lambda_{c3BHA} \\ \epsilon_{BHA} & \epsilon_{BHA} \end{pmatrix} = \begin{cases} \text{for } i \in 1 \\ \text{for } r \in 1..N_r \\ \begin{pmatrix} T^*_{1BHA_r} \\ T^*_{3BHA_r} \end{pmatrix} = \begin{pmatrix} T^*_{1BHA_{av}(N_r)} \\ T^*_{3BHA_{av}(N_r)} \end{pmatrix} \\ \begin{pmatrix} P^*_{1BHA_r} \\ P^*_{3BHA_r} \end{pmatrix} = \begin{pmatrix} P^*_{1BHA_{av}(N_r)} \\ P^*_{3BHA_{av}(N_r)} \end{pmatrix} \\ \begin{pmatrix} \rho^*_{1BHA_r} \\ \rho^*_{3BHA_r} \end{pmatrix} = \begin{pmatrix} \rho^*_{1BHA_{av}(N_r)} \\ \rho^*_{3BHA_{av}(N_r)} \end{pmatrix} \\ \begin{pmatrix} C_{p1BHA_r} \\ C_{p3BHA_r} \end{pmatrix} = \begin{pmatrix} C_{p_{\text{воздух}}}(P^*_{1BHA_r}, T^*_{1BHA_r}) \\ C_{p_{\text{воздух}}}(P^*_{3BHA_r}, T^*_{3BHA_r}) \end{pmatrix} \\ \begin{pmatrix} k_{1BHA_r} \\ k_{3BHA_r} \end{pmatrix} = \begin{pmatrix} k_{ад}(C_{p1BHA_r}, R_B) \\ k_{ад}(C_{p3BHA_r}, R_B) \end{pmatrix} \\ \begin{pmatrix} a^*_{c1BHA_r} \\ a^*_{c3BHA_r} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{2 \cdot k_{1BHA_r}}{k_{1BHA_r} + 1} \cdot R_B \cdot T^*_{1BHA_r}} \\ \sqrt{\frac{2 \cdot k_{3BHA_r}}{k_{3BHA_r} + 1} \cdot R_B \cdot T^*_{3BHA_r}} \end{pmatrix} \\ A = \left(1 - R_{L_{1, av}(N_r)}\right) \cdot \omega \cdot \left(R_{st(i, 1), av}(N_r)\right)^{m_i+1} \\ B = \frac{H_{T_{i, av}(N_r)}}{2 \cdot \omega} \\ \begin{pmatrix} c_{u1BHA_r} \\ c_{u3BHA_r} \end{pmatrix} = \begin{pmatrix} c_{u1BHA_{av}(N_r)} \\ c_{u3BHA_{av}(N_r)} \end{pmatrix} \end{cases}
\end{cases}$$

$$\begin{aligned}
\begin{pmatrix} c_{1BHA_r} \\ c_{u3BHA_r} \end{pmatrix} &= \begin{bmatrix} \frac{A}{\left(R_{st(i,1),r}\right)^{m_i}} - \frac{B}{\left(R_{st(i,1),r}\right)} \text{ if } BHA = 1 \\ c_{u1BHA_{av}(N_r)} \text{ otherwise} \end{bmatrix} \\
\begin{pmatrix} c_{a1BHA_r} \\ c_{a3BHA_r} \end{pmatrix} &= \begin{bmatrix} c_{a1BHA_{av}(N_r)} \\ \begin{bmatrix} \text{if } BHA = 1 \\ \sqrt{\left(c_{a3BHA_{av}(N_r)}\right)^2 - 2 \cdot A^2 \cdot \left[\left(R_{st(i,1),r}\right)^2 - \left(R_{st(i,1),av(N_r)}\right)^2\right] + 4 \cdot A \cdot B \cdot \ln\left(\frac{R_{st(i,1),r}}{R_{st(i,1),av(N_r)}}\right)} \text{ if } m_i = -1 \\ \sqrt{\left(c_{a3BHA_{av}(N_r)}\right)^2 - 2 \cdot A^2 \cdot \ln\left(\frac{R_{st(i,1),r}}{R_{st(i,1),av(N_r)}}\right) - 2 \cdot A \cdot B \cdot \left(\frac{1}{R_{st(i,1),r}} - \frac{1}{R_{st(i,1),av(N_r)}}\right)} \text{ if } m_i = 0 \\ \sqrt{\left(c_{a3BHA_{av}(N_r)}\right)^2 + \frac{A \cdot (m_i - 1) \cdot \left[-A \cdot (m_i + 1) \cdot \left[\frac{1}{\left(R_{st(i,1),r}\right)^{2 \cdot m_i}} - \frac{1}{\left(R_{st(i,1),av(N_r)}\right)^{2 \cdot m_i}}\right] \dots}{+ 2 \cdot B \cdot m_i \cdot \left[\frac{1}{\left(R_{st(i,1),r}\right)^{m_i+1}} - \frac{1}{\left(R_{st(i,1),av(N_r)}\right)^{m_i+1}}\right]} } \text{ otherwise} \end{bmatrix} \\ c_{a1BHA_{av}(N_r)} \text{ otherwise} \end{bmatrix} \\
\begin{pmatrix} \alpha_{1BHA_r} \\ \alpha_{3BHA_r} \end{pmatrix} &= \begin{pmatrix} \text{triangle}(c_{a1BHA_r}, c_{u1BHA_r}) \\ \text{triangle}(c_{a3BHA_r}, c_{u3BHA_r}) \end{pmatrix} \\
\begin{pmatrix} c_{1BHA_r} \\ c_{3BHA_r} \end{pmatrix} &= \begin{pmatrix} \frac{c_{a1BHA_r}}{\sin(\alpha_{1BHA_r})} \\ \frac{c_{a3BHA_r}}{\sin(\alpha_{3BHA_r})} \end{pmatrix} \\
\begin{pmatrix} \lambda_{c1BHA_r} \\ \lambda_{c3BHA_r} \end{pmatrix} &= \begin{pmatrix} \frac{c_{1BHA_r}}{a^*_{c1BHA_r}} \\ \frac{c_{3BHA_r}}{a^*_{c3BHA_r}} \end{pmatrix} \\
\epsilon_{BHA_r} &= -1 \cdot (\alpha_{3BHA_r} - \alpha_{1BHA_r}) \\
\begin{pmatrix} T^*_{1BHA} & P^*_{1BHA} & \rho^*_{1BHA} & C_{P1BHA} & k_{1BHA} & a^*_{c1BHA} & c_{u1BHA} & c_{a1BHA} & \alpha_{1BHA} & c_{1BHA} & \lambda_{c1BHA} & \epsilon_{BHA} \\ T^*_{3BHA} & P^*_{3BHA} & \rho^*_{3BHA} & C_{P3BHA} & k_{3BHA} & a^*_{c3BHA} & c_{u3BHA} & c_{a3BHA} & \alpha_{3BHA} & c_{3BHA} & \lambda_{c3BHA} & \epsilon_{BHA} \end{pmatrix}^T
\end{aligned}$$

$T^*$	$T$
$P^*$	$P$
$\rho^*$	$\rho$
$C_p$	$k$
$a_c^*$	$a_{3B}$
$c_u$	$c_a$
$\alpha$	$\beta$
$c$	$w$
$\lambda_c$	$w_u$
$M_w$	$M_c$
$R_L$	$R_L$
$\epsilon_{rotor}$	$\epsilon_{stator}$

$$= \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } a \in 1..3 \\ \quad \quad \text{for } r \in 1..N_r \\ \quad \quad \quad T_{st(i,a),r}^* = T_{st(i,a),av(N_r)}^* \\ \quad \quad \quad P_{st(i,a),r}^* = P_{st(i,a),av(N_r)}^* \\ \quad \quad \quad \rho_{st(i,a),r}^* = \rho_{st(i,a),av(N_r)}^* \\ \quad \quad \quad C_{p_{st(i,a),r}} = C_{p_{BO3DYX}}(P_{st(i,a),r}^*, T_{st(i,a),r}^*) \\ \quad \quad \quad k_{st(i,a),r} = k_{a\mathcal{D}}(C_{p_{st(i,a),r}}, R_B) \\ \quad \quad \quad a_{c_{st(i,a),r}}^* = \sqrt{\frac{2 \cdot k_{st(i,a),r}}{k_{st(i,a),r} + 1}} \cdot R_B \cdot T_{st(i,a),r}^* \\ \quad \quad \text{if } \Delta H_{Tmax} = 0 \\ \quad \quad \quad A_{st(i,a)} = \left(1 - R_{L_{i,av(N_r)}}\right) \cdot \omega \cdot \left(R_{st(i,a),av(N_r)}\right)^{m_i+1} \\ \quad \quad \quad B_{st(i,a)} = \frac{H_{T_{i,av(N_r)}}}{2 \cdot \omega} \\ \quad \quad \quad c_{u_{st(i,a),r}} = \begin{array}{l} c_{u_{st(i,a-1),r}} \cdot \frac{R_{st(i,a),r}}{R_{st(i,a-1),r}} + \frac{H_{T_{i,av(N_r)}}}{\omega \cdot R_{st(i,a),r}} \text{ if } a = 2 \\ \text{otherwise} \\ \left| \begin{array}{l} 0 \text{ if } (a = 1) \wedge (i = 1) \wedge (BHA = 0) \\ \frac{A_{st(i,a)}}{\left(R_{st(i,a),r}\right)^{m_i}} - \frac{B_{st(i,a)}}{\left(R_{st(i,a),r}\right)} \text{ otherwise} \end{array} \right| \\ c_{a_{st(i,a),r}} = \begin{array}{l} c_{a3BHA_r} \text{ if } (a = 1) \wedge (i = 1) \wedge (BHA = 1) \\ \sqrt{\left(c_{a_{st(i,a),av(N_r)}}\right)^2 - 2 \cdot \left(A_{st(i,a)}\right)^2 \cdot \left[\left(R_{st(i,a),r}\right)^2 - \left(R_{st(i,a),av(N_r)}\right)^2\right] + 4 \cdot A_{st(i,a)} \cdot B_{st(i,a)} \cdot \ln\left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)} \cdot \left| \begin{array}{l} -1 \text{ if } a = 2 \\ 1 \text{ otherwise} \end{array} \right| \text{ if } m_i = -1 \\ \sqrt{\left(c_{a_{st(i,a),av(N_r)}}\right)^2 - 2 \cdot \left(A_{st(i,a)}\right)^2 \cdot \ln\left[\frac{R_{st(i,a),r}}{\mathfrak{p}_{st(i,a),av(N_r)}}\right] - 2 \cdot A_{st(i,a)} \cdot B_{st(i,a)} \cdot \left(\frac{1}{\mathfrak{p}_{st(i,a),r}} - \frac{1}{\mathfrak{p}_{st(i,a),av(N_r)}}\right)} \cdot \left| \begin{array}{l} -1 \text{ if } a = 2 \\ \end{array} \right| \text{ if } m_i = 0 \end{array} \end{array} \end{array}$$

$$\sqrt{\left(\frac{c_{st(i,a),av(N_r)}}{A_{st(i,a)} \cdot (m_i - 1) \cdot \left[ -A_{st(i,a)} \cdot (m_i + 1) \cdot \left[ \frac{1}{(R_{st(i,a),r})^{2 \cdot m_i}} - \frac{1}{(R_{st(i,a),av(N_r)})^{2 \cdot m_i}} \right] \dots \right.} \right.} \left. \left. + 2 \cdot B_{st(i,a)} \cdot m_i \cdot \left[ \frac{1}{(R_{st(i,a),r})^{m_i+1}} - \frac{1}{(R_{st(i,a),av(N_r)})^{m_i+1}} \right] \cdot \begin{cases} -1 & \text{if } a = 2 \\ 1 & \text{otherwise} \end{cases} \right] \right)^2 + \frac{\dots}{m_i \cdot (m_i + 1)}}{m_i \cdot (m_i + 1)} \quad \text{otherwise}$$

if  $\Delta H_{Tmax} \neq 0$

$$A_{st(i,a)} = \frac{1}{(R_{st(i,a),av(N_r)})^2 - (R_{st(i,a),l})^2} \cdot \left[ \omega \cdot (R_{st(i,a),av(N_r)})^2 \cdot (1 - R_{L_{i,av(N_r)}}) - \omega \cdot (R_{st(i,a),l})^2 \cdot (1 - R_{L_{i,l}}) + \frac{H_{T_{i,l}} - H_{T_{i,av(N_r)}}}{2 \cdot \omega} \right]$$

$$B_{st(i,a)} = \frac{(R_{st(i,a),l}) \cdot (R_{st(i,a),av(N_r)})}{(R_{st(i,a),av(N_r)})^2 - (R_{st(i,a),l})^2} \cdot \left[ \omega \cdot R_{st(i,a),l} \cdot R_{st(i,a),av(N_r)} \cdot (1 - R_{L_{i,l}}) - \omega \cdot R_{st(i,a),av(N_r)} \cdot R_{st(i,a),l} \cdot (1 - R_{L_{i,av(N_r)}}) \dots \right]$$

$$\left[ + - \frac{1}{2 \cdot \omega} \cdot \left( \frac{H_{T_{i,l}} \cdot R_{st(i,a),av(N_r)}}{R_{st(i,a),l}} - \frac{H_{T_{i,av(N_r)}} \cdot R_{st(i,a),l}}{R_{st(i,a),av(N_r)}} \right) \right]$$

$$c_{u_{st(i,a),r}} = \begin{cases} A_{st(i,a)} \cdot R_{st(i,a),r} + \frac{B_{st(i,a)}}{R_{st(i,a),r}} + \frac{H_{T_{i,r}}}{\omega \cdot R_{st(i,a),r}} & \text{if } a = 2 \\ \text{otherwise} \\ \begin{cases} 0 & \text{if } (a = 1) \wedge (i = 1) \wedge (BHA = 0) \\ A_{st(i,a)} \cdot R_{st(i,a),r} + \frac{B_{st(i,a)}}{R_{st(i,a),r}} & \text{otherwise} \end{cases} \end{cases}$$

$$k_{HT} = \frac{H_{T_{i,av(N_r)}} - H_{T_{i,l}}}{R_{st(i,a),av(N_r)} - R_{st(i,a),l}}$$

$$b_{HT} = H_{T_{i,av(N_r)}} - k_{HT} \cdot R_{st(i,a),av(N_r)}$$

$$c_{a_{st(i,a),r}} = \begin{cases} c_{a3BHA_r} & \text{if } (a = 1) \wedge (i = 1) \wedge (BHA = 1) \\ \sqrt{\left( c_{a_{st(i,a),av(N_r)}}^2 - 2 \cdot (A_{st(i,a)})^2 \cdot \left[ (R_{st(i,a),r})^2 - (R_{st(i,a),av(N_r)})^2 \right] \dots \right.} & \text{if } a = 2 \\ \left. + - \left( 6 \cdot \frac{A_{st(i,a)}}{\omega} - 2 \right) \cdot k_{HT} \cdot (R_{st(i,a),r} - R_{st(i,a),av(N_r)}) \dots \right. \\ \left. + - 2 \cdot \frac{k_{HT}}{\omega} \cdot \left( B_{st(i,a)} + \frac{b_{HT}}{\omega} \right) \cdot \frac{R_{st(i,a),r} - R_{st(i,a),av(N_r)}}{R_{st(i,a),r} \cdot R_{st(i,a),av(N_r)}} - 2 \cdot \left[ 2 \cdot A_{st(i,a)} \cdot \left( B_{st(i,a)} + \frac{b_{HT}}{\omega} \right) + \frac{k_{HT}^2}{\omega^2} \right] \cdot \ln \left( \frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}} \right) \right. \\ \left. \sqrt{\left( c_{a_{st(i,a),av(N_r)}}^2 - 2 \cdot (A_{st(i,a)})^2 \cdot \left[ (R_{st(i,a),r})^2 - (R_{st(i,a),av(N_r)})^2 \right] - 4 \cdot A_{st(i,a)} \cdot B_{st(i,a)} \cdot \ln \left( \frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}} \right) \right)} & \text{otherwise} \end{cases}$$

$$\alpha_{\text{st}(i,a),r} = \text{triangle}\left(c_{\text{a}_{\text{st}(i,a),r}}, c_{\text{u}_{\text{st}(i,a),r}}\right)$$

$$c_{\text{st}(i,a),r} = \frac{c_{\text{a}_{\text{st}(i,a),r}}}{\sin\left(\alpha_{\text{st}(i,a),r}\right)}$$

$$\lambda_{\text{c}_{\text{st}(i,a),r}} = \frac{c_{\text{st}(i,a),r}}{a^*_{\text{c}_{\text{st}(i,a),r}}}$$

$$\begin{pmatrix} T_{\text{st}(i,a),r} \\ P_{\text{st}(i,a),r} \\ \rho_{\text{st}(i,a),r} \end{pmatrix} = \begin{pmatrix} T^*_{\text{st}(i,a),r} \cdot \Gamma \mathcal{D} \Phi\left("T", \lambda_{\text{c}_{\text{st}(i,a),r}}, k_{\text{st}(i,a),r}\right) \\ P^*_{\text{st}(i,a),r} \cdot \Gamma \mathcal{D} \Phi\left("P", \lambda_{\text{c}_{\text{st}(i,a),r}}, k_{\text{st}(i,a),r}\right) \\ \rho^*_{\text{st}(i,a),r} \cdot \Gamma \mathcal{D} \Phi\left(" \rho", \lambda_{\text{c}_{\text{st}(i,a),r}}, k_{\text{st}(i,a),r}\right) \end{pmatrix}$$

$$a_{3B_{\text{st}(i,a),r}} = \sqrt{k_{\text{st}(i,a),r} \cdot R_B \cdot T_{\text{st}(i,a),r}}$$

$$\beta_{\text{st}(i,a),r} = \text{triangle}\left(c_{\text{a}_{\text{st}(i,a),r}}, u_{\text{st}(i,a),r} - c_{\text{u}_{\text{st}(i,a),r}}\right)$$

$$w_{\text{st}(i,a),r} = \frac{c_{\text{a}_{\text{st}(i,a),r}}}{\sin\left(\beta_{\text{st}(i,a),r}\right)}$$

$$w_{\text{u}_{\text{st}(i,a),r}} = w_{\text{st}(i,a),r} \cdot \cos\left(\beta_{\text{st}(i,a),r}\right)$$

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

for  $r \in 1..N_r$

$$\left| \begin{aligned} R_{L_{i,r}} &= 1 - \frac{c_{\text{u}_{\text{st}(i,1),r}} + c_{\text{u}_{\text{st}(i,2),r}}}{u_{\text{st}(i,1),r} + u_{\text{st}(i,2),r}} \\ \begin{pmatrix} \varepsilon_{\text{rotor}_{i,r}} \\ \varepsilon_{\text{stator}_{i,r}} \end{pmatrix} &= \begin{pmatrix} \beta_{\text{st}(i,2),r} - \beta_{\text{st}(i,1),r} \\ \alpha_{\text{st}(i,3),r} - \alpha_{\text{st}(i,2),r} \end{pmatrix} \end{aligned} \right|$$

$$\begin{pmatrix} T^* & P^* & \rho^* & C_p & a^*_c & c_u & \alpha & c & \lambda_c & M_w & R_L & \varepsilon_{\text{rotor}} \\ T & P & \rho & k & a_{3B} & c_a & \beta & w & w_u & M_c & R_L & \varepsilon_{\text{stator}} \end{pmatrix}^T$$

$$\begin{pmatrix} T^*_{1CA} & T^*_{3CA} \\ P^*_{1CA} & P^*_{3CA} \\ \rho^*_{1CA} & \rho^*_{3CA} \\ C_{p1CA} & C_{p3CA} \\ k_{1CA} & k_{3CA} \\ a^*_{c1CA} & a^*_{c3CA} \\ c_{u1CA} & c_{u3CA} \\ c_{a1CA} & c_{a3CA} \\ \alpha_{1CA} & \alpha_{3CA} \\ c_{1CA} & c_{3CA} \\ \lambda_{c1CA} & \lambda_{c3CA} \\ \varepsilon_{CA} & \varepsilon_{CA} \end{pmatrix} =$$

$$\begin{array}{l} \text{for } i \in Z \\ \text{for } r \in 1..N_r \end{array}$$

$$\begin{pmatrix} T^*_{1CA_r} \\ T^*_{3CA_r} \end{pmatrix} = \begin{pmatrix} T^*_{st(i,3),r} \\ T^*_{3CA_{av}(N_r)} \end{pmatrix}$$

$$\begin{pmatrix} P^*_{1CA_r} \\ P^*_{3CA_r} \end{pmatrix} = \begin{pmatrix} P^*_{st(i,3),r} \\ P^*_{3CA_{av}(N_r)} \end{pmatrix}$$

$$\begin{pmatrix} \rho^*_{1CA_r} \\ \rho^*_{3CA_r} \end{pmatrix} = \begin{pmatrix} \rho^*_{st(i,3),r} \\ \rho^*_{3CA_{av}(N_r)} \end{pmatrix}$$

$$\begin{pmatrix} C_{p1CA_r} \\ C_{p3CA_r} \end{pmatrix} = \begin{pmatrix} C_{p_{\text{БозДух}}}\left(P^*_{1CA_r},T^*_{1CA_r}\right) \\ C_{p_{\text{БозДух}}}\left(P^*_{3CA_r},T^*_{3CA_r}\right) \end{pmatrix}$$

$$\begin{pmatrix} k_{1CA_r} \\ k_{3CA_r} \end{pmatrix} = \begin{pmatrix} k_{a\text{д}}\left(C_{p1CA_r},R_B\right) \\ k_{a\text{д}}\left(C_{p3CA_r},R_B\right) \end{pmatrix}$$

$$\begin{pmatrix} a^*_{c1CA_r} \\ a^*_{c3CA_r} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{2 \cdot k_{1CA_r}}{k_{1CA_r} + 1} \cdot R_B \cdot T^*_{1CA_r}} \\ \sqrt{\frac{2 \cdot k_{3CA_r}}{k_{3CA_r} + 1} \cdot R_B \cdot T^*_{3CA_r}} \end{pmatrix}$$

$$A = \left(1 - R_{L_i,av(N_r)}\right) \cdot \omega \cdot \left(R_{st(i,3),av(N_r)}\right)^{m_i+1}$$

$$B = \frac{H_{T_{i,av(N_r)}}}{2 \cdot \omega}$$

$$\begin{pmatrix} c_{u1CA_r} \\ c_{u3CA_r} \end{pmatrix} = \begin{pmatrix} c_{u_{st(i,3),r}} \\ c_{u3CA_{av}(N_r)} \text{ if } CA = 1 \end{pmatrix}$$





$T^*_{1BHA} = \begin{pmatrix} 288.2 \\ 288.2 \\ 288.2 \end{pmatrix}$	$T^*_{3BHA} = \begin{pmatrix} 288.2 \\ 288.2 \\ 288.2 \end{pmatrix}$	$a^*_{c1BHA} = \begin{pmatrix} 310.78 \\ 310.78 \\ 310.78 \end{pmatrix}$	$a^*_{c3BHA} = \begin{pmatrix} 310.78 \\ 310.78 \\ 310.78 \end{pmatrix}$	$\alpha_{1BHA} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ^\circ$	$\alpha_{3BHA} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ^\circ$
$P^*_{1BHA} = \begin{pmatrix} 101.3 \\ 101.3 \\ 101.3 \end{pmatrix} \cdot 10^3$	$P^*_{3BHA} = \begin{pmatrix} 101.3 \\ 101.3 \\ 101.3 \end{pmatrix} \cdot 10^3$	$c_{1BHA} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix}$	$c_{3BHA} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix}$	$\epsilon_{BHA} = \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot ^\circ$	
$\rho^*_{1BHA} = \begin{pmatrix} 1.224 \\ 1.224 \\ 1.224 \end{pmatrix}$	$\rho^*_{3BHA} = \begin{pmatrix} 1.224 \\ 1.224 \\ 1.224 \end{pmatrix}$	$c_{u1BHA} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix}$	$c_{u3BHA} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix}$		
$Cp_{1BHA} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix}$	$Cp_{3BHA} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix}$	$c_{a1BHA} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix}$	$c_{a3BHA} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix}$	$\lambda_{c1BHA} = \begin{pmatrix} 0.268 \\ 0.268 \\ 0.268 \end{pmatrix}$	$\lambda_{c3BHA} = \begin{pmatrix} 0.268 \\ 0.268 \\ 0.268 \end{pmatrix}$
$k_{1BHA} = \begin{pmatrix} 1.401 \\ 1.401 \\ 1.401 \end{pmatrix}$	$k_{3BHA} = \begin{pmatrix} 1.401 \\ 1.401 \\ 1.401 \end{pmatrix}$				

[illegible]

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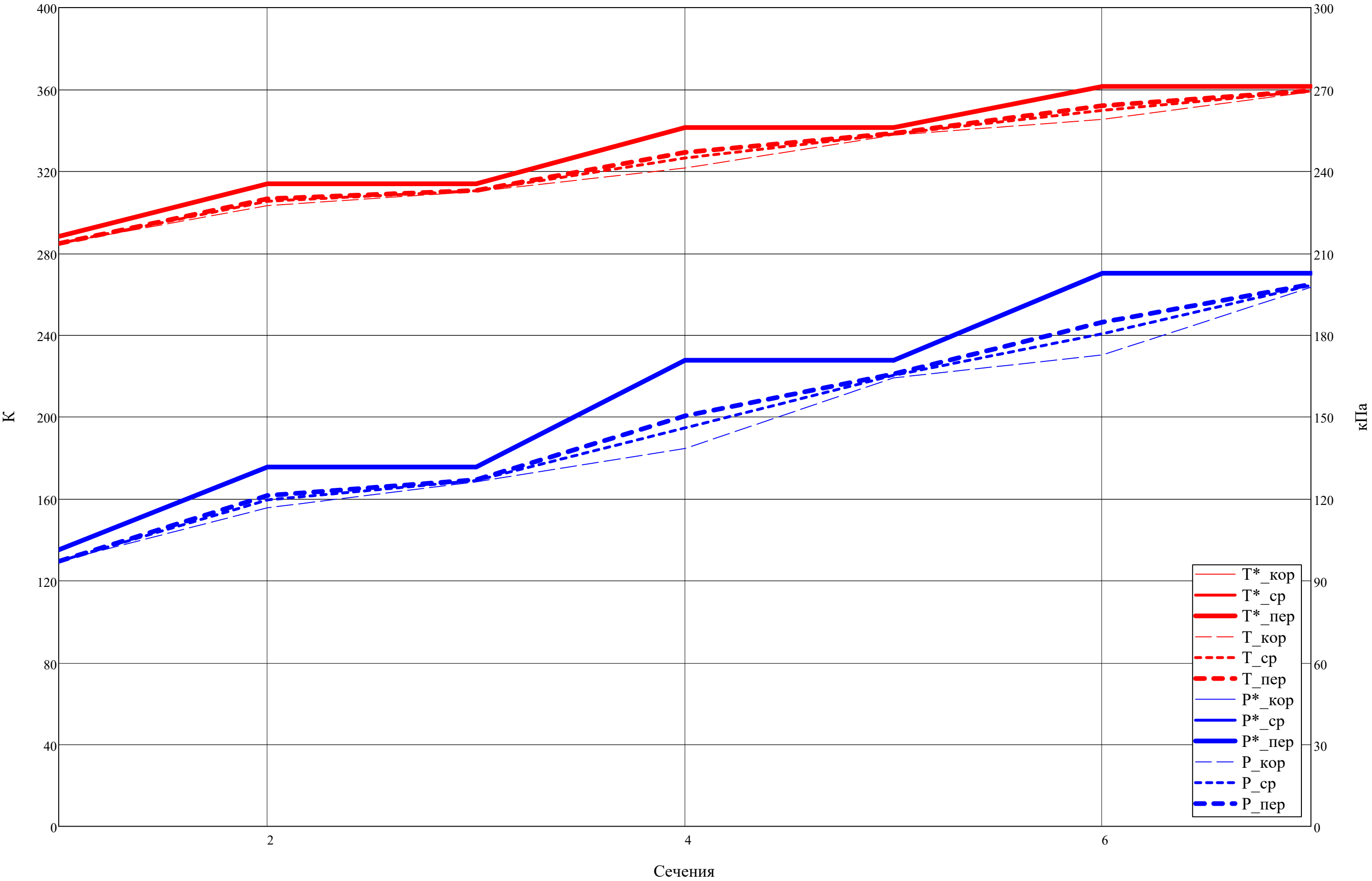
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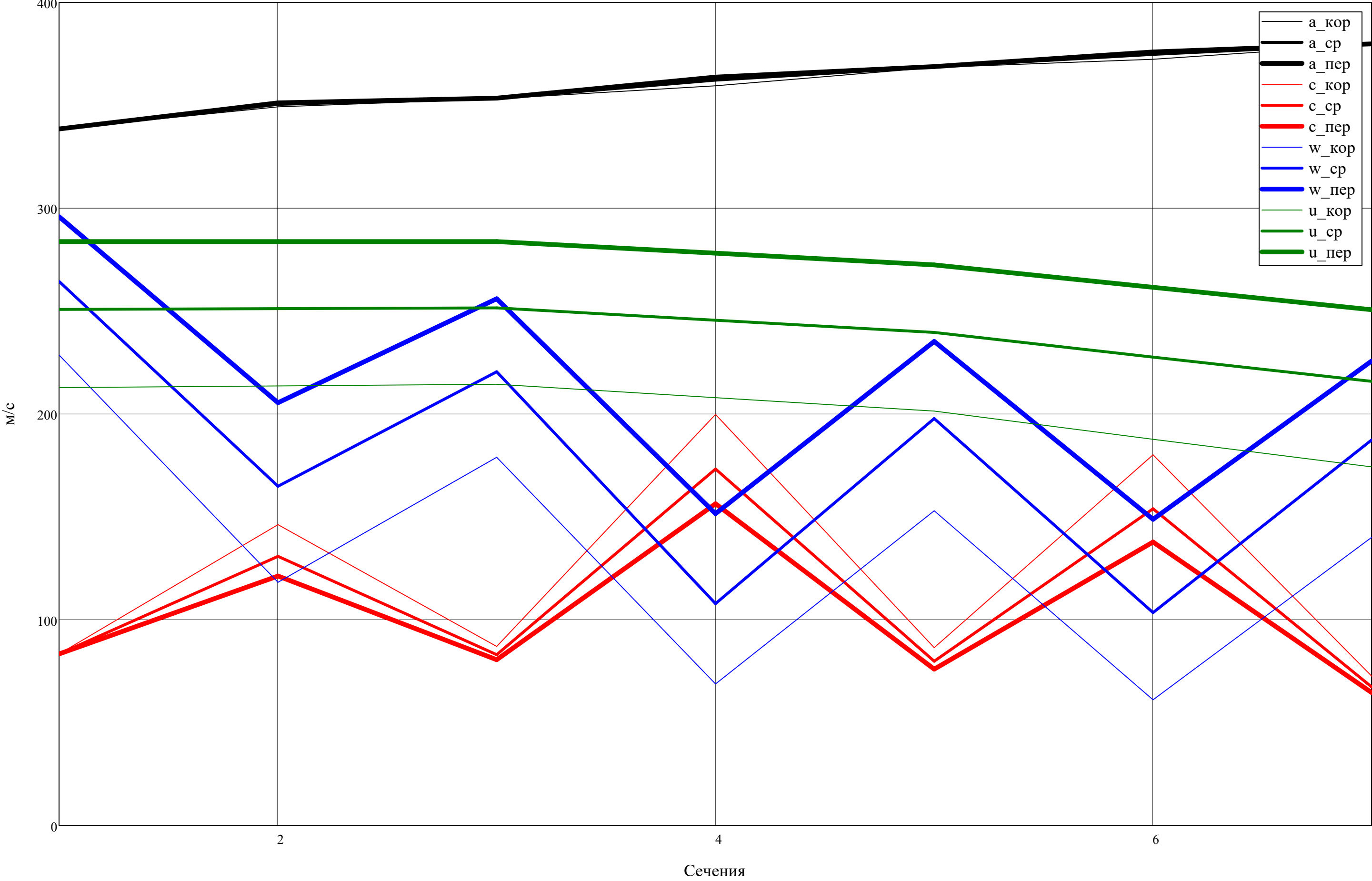
Термодинамические параметры по тракту К







Скорости по тракту К



$\alpha^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	90.00	31.91	54.79	19.29	44.91	18.98	50.69																		
2	90.00	36.21	58.97	22.39	49.86	22.38	56.54																		
3	90.00	39.60	61.94	24.97	53.44	25.16	60.35																		

 $\text{.}^\circ$

$\beta^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	21.41	40.81	23.42	73.68	23.52	73.49	23.63														
2	18.40	27.96	18.82	37.73	17.97	34.47	17.44														
3	16.38	22.10	16.14	25.82	15.04	23.18	14.40														

 $\text{.}^\circ$

$\beta^T \leq 91.^\circ =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1	1	1	1	1	1	1														
2	1	1	1	1	1	1	1														
3	1	1	1	1	1	1	1														

$\beta.2 > 91 \Rightarrow$  поменять 3-н профилирования

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	19.40	50.26	49.97												
2	9.56	18.91	16.50												
3	5.71	9.69	8.14												

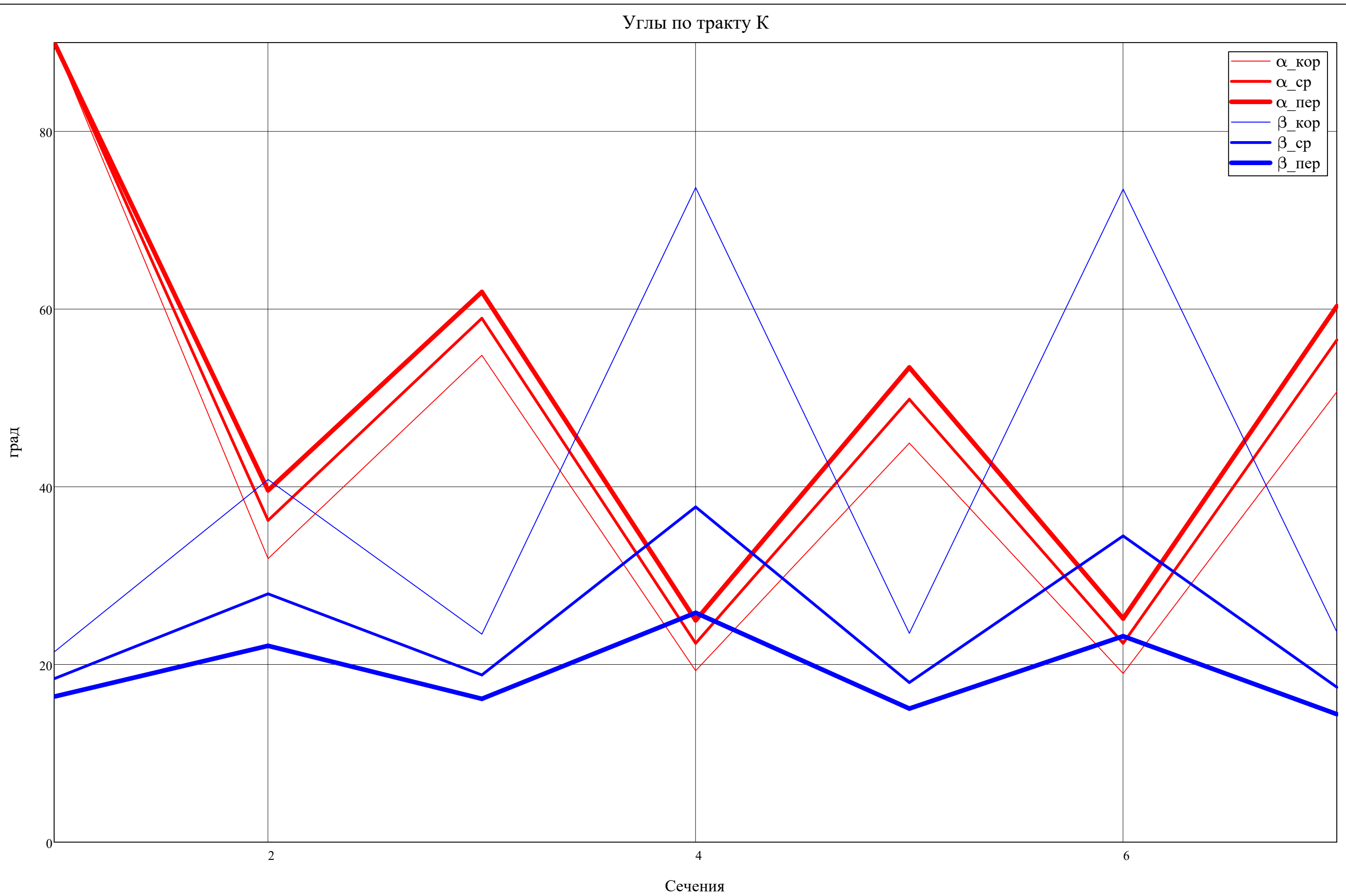
 $\text{.}^\circ$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	19.79	36.30	31.71												
2	19.83	37.67	34.16												
3	19.57	38.17	35.19												

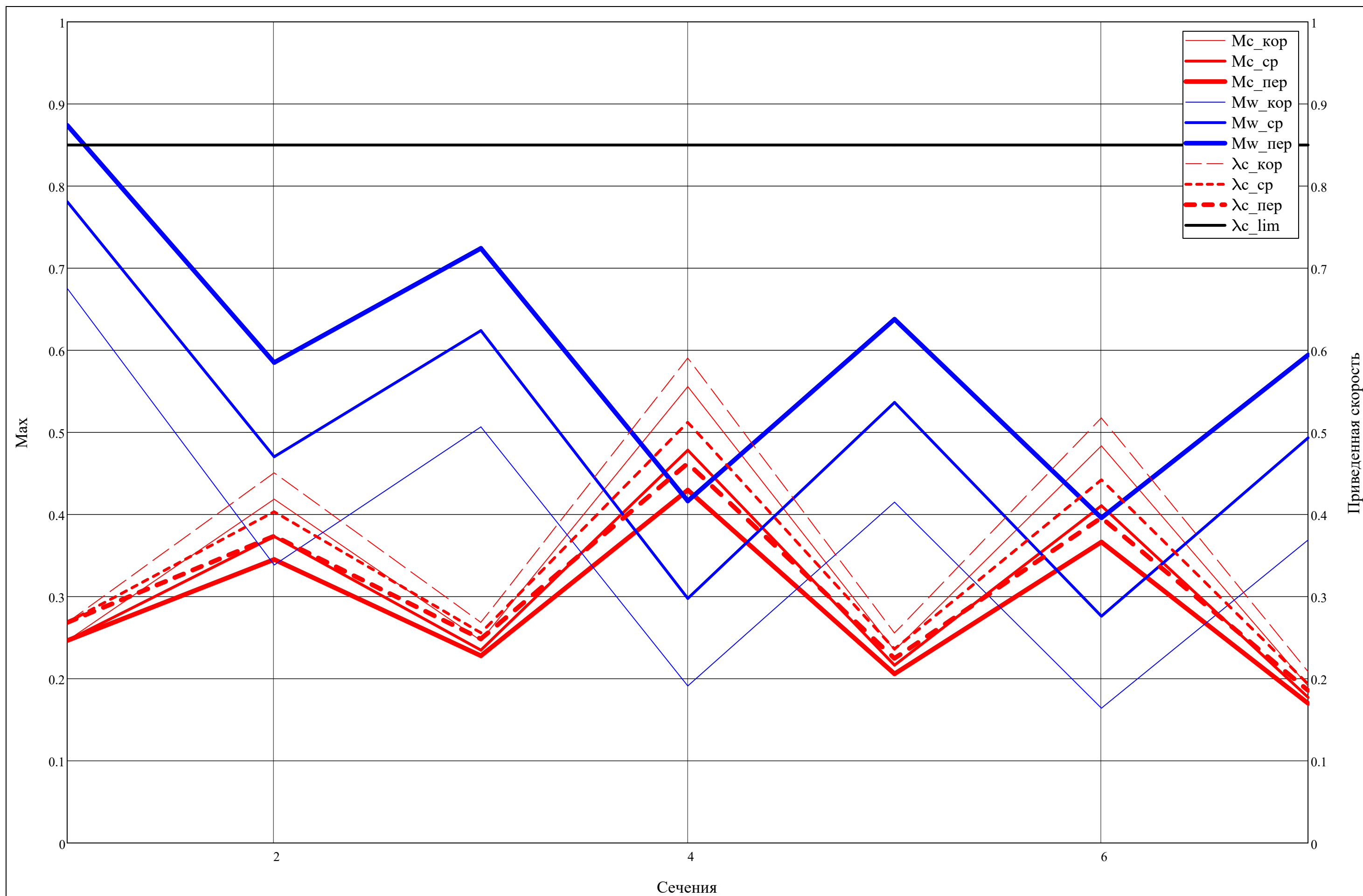
 $\text{.}^\circ$

Углы по тракту К





[illegible][illegible][illegible][illegible]



$T^*_{1CA} = \begin{pmatrix} 361.5 \\ 361.5 \\ 361.5 \end{pmatrix}$	$T^*_{3CA} = \begin{pmatrix} 361.5 \\ 361.5 \\ 361.5 \end{pmatrix}$	$a^*_{c1CA} = \begin{pmatrix} 347.9 \\ 347.9 \\ 347.9 \end{pmatrix}$	$a^*_{c3CA} = \begin{pmatrix} 347.9 \\ 347.9 \\ 347.9 \end{pmatrix}$	$\alpha_{1CA} = \begin{pmatrix} 50.69 \\ 56.54 \\ 60.35 \end{pmatrix} \cdot ^\circ$	$\alpha_{3CA} = \begin{pmatrix} 50.69 \\ 56.54 \\ 60.35 \end{pmatrix} \cdot ^\circ$
$P^*_{1CA} = \begin{pmatrix} 202.7 \\ 202.7 \\ 202.7 \end{pmatrix} \cdot 10^3$	$P^*_{3CA} = \begin{pmatrix} 202.7 \\ 202.7 \\ 202.7 \end{pmatrix} \cdot 10^3$	$c_{1CA} = \begin{pmatrix} 72.6 \\ 67.3 \\ 64.6 \end{pmatrix}$	$c_{3CA} = \begin{pmatrix} 72.6 \\ 67.3 \\ 64.6 \end{pmatrix}$	$\varepsilon_{CA} = \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot ^\circ$	
$\rho^*_{1CA} = \begin{pmatrix} 1.952 \\ 1.952 \\ 1.952 \end{pmatrix}$	$\rho^*_{3CA} = \begin{pmatrix} 1.952 \\ 1.952 \\ 1.952 \end{pmatrix}$	$c_{u1CA} = \begin{pmatrix} 46.0 \\ 37.1 \\ 32.0 \end{pmatrix}$	$c_{u3CA} = \begin{pmatrix} 46.0 \\ 37.1 \\ 32.0 \end{pmatrix}$		
$Cp_{1CA} = \begin{pmatrix} 1008.5 \\ 1008.5 \\ 1008.5 \end{pmatrix}$	$Cp_{3CA} = \begin{pmatrix} 1008.5 \\ 1008.5 \\ 1008.5 \end{pmatrix}$	$c_{a1CA} = \begin{pmatrix} 56.1 \\ 56.1 \\ 56.1 \end{pmatrix}$	$c_{a3CA} = \begin{pmatrix} 56.1 \\ 56.1 \\ 56.1 \end{pmatrix}$	$\lambda_{c1CA} = \begin{pmatrix} 0.209 \\ 0.193 \\ 0.186 \end{pmatrix}$	$\lambda_{c3CA} = \begin{pmatrix} 0.209 \\ 0.193 \\ 0.186 \end{pmatrix}$
$k_{1CA} = \begin{pmatrix} 1.398 \\ 1.398 \\ 1.398 \end{pmatrix}$	$k_{3CA} = \begin{pmatrix} 1.398 \\ 1.398 \\ 1.398 \end{pmatrix}$				



Рассматриваемая ступень:

j =

j = 1

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 ≠ 3)

−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 ≠ 3)

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 ≠ 3)

NaN otherwise

v<sub>lim</sub> =

ceil

(

max(c,w,u)

)

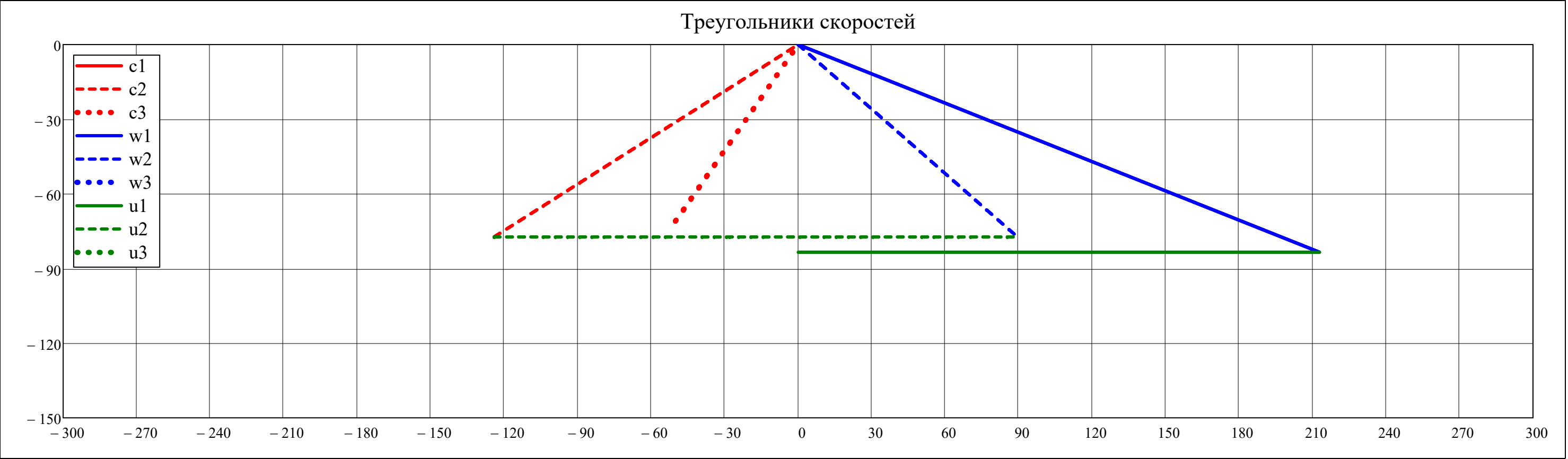
·10<sup>2</sup> = 300

Дискретизация скорости:

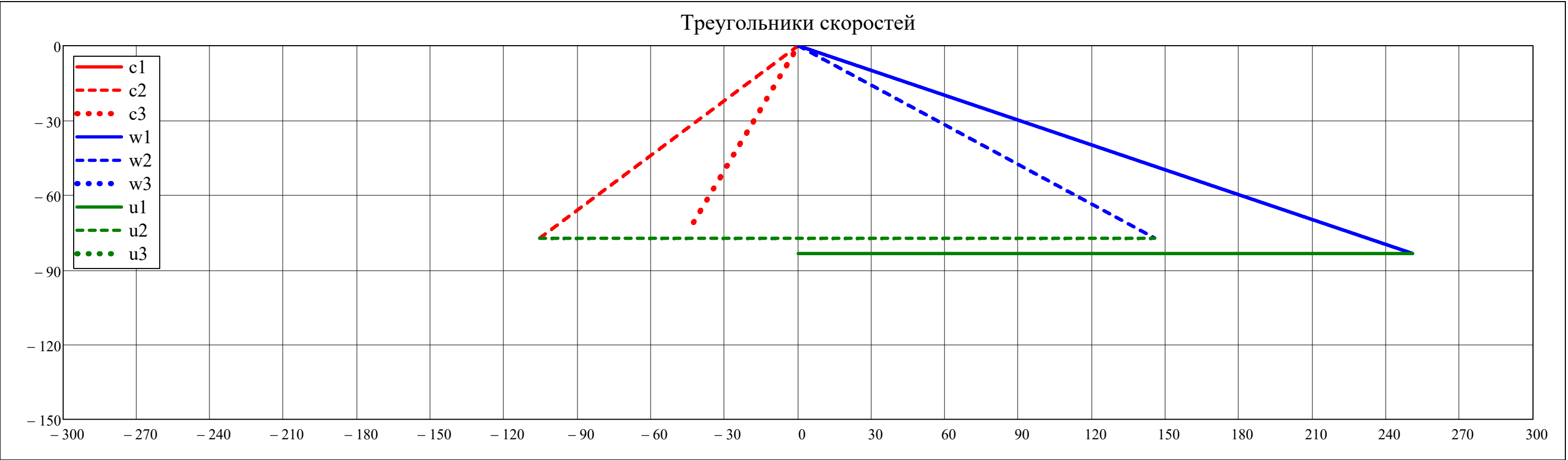
v =

−v<sub>lim</sub>, −v<sub>lim</sub> +  $\frac{v_{lim}}{3000}$  .. v<sub>lim</sub>

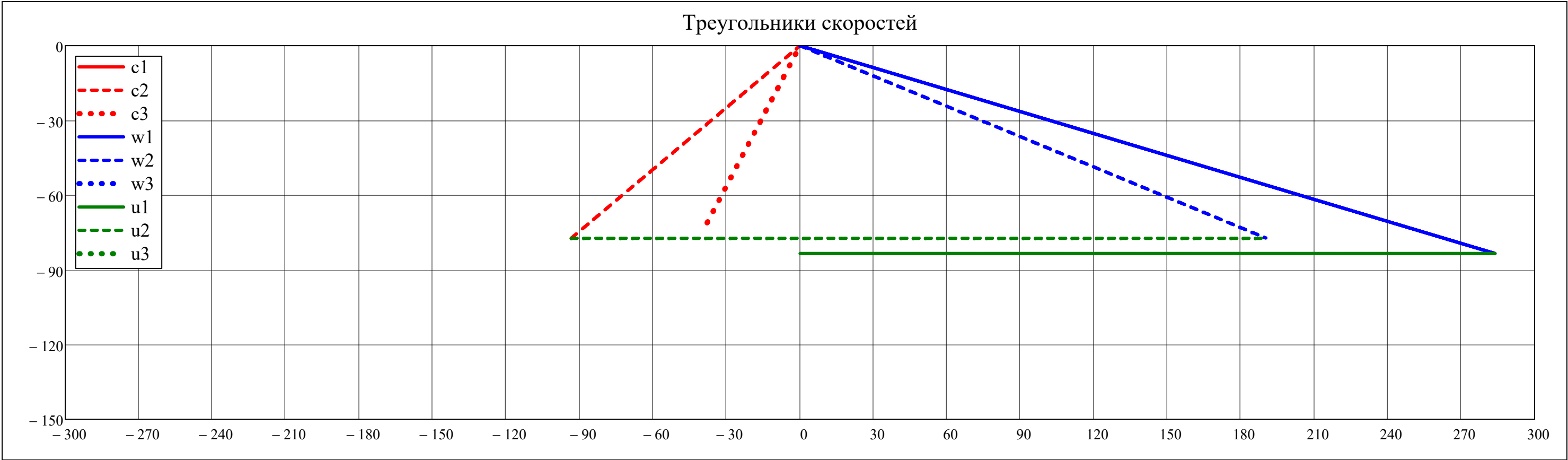
r = 1



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



$r_w = N_r$



Построение треугольников скоростей в 3х сечениях



```

    ( F_I  F_II
      D2  R2 ) =
      for i ∈ 1..Z
        for a ∈ 1..3
          ρ.(z) = interp( lspline( submatrix( R, st(i,a), st(i,a), 1, N_r )^T, submatrix( ρ, st(i,a), st(i,a), 1, N_r )^T ), submatrix( R, st(i,a), st(i,a), 1, N_r )^T, submatrix( ρ, st(i,a), st(i,a), 1, N_r )^T, z )
          c_a.(z) = interp( lspline( submatrix( R, st(i,a), st(i,a), 1, N_r )^T, submatrix( c_a, st(i,a), st(i,a), 1, N_r )^T ), submatrix( R, st(i,a), st(i,a), 1, N_r )^T, submatrix( c_a, st(i,a), st(i,a), 1, N_r )^T, z )
          R2 = sqrt( (R_st(i,a), N_r)^2 + m2.(R_st(i,a), 1)^2 / (1 + m2)
          R2_st(i,a) = root( [ ρ.(R2).c_a.(R2).π.[ (R_st(i,a), N_r)^2 - (R2)^2 ] / [ ρ.(R2).c_a.(R2).π.[ (R2)^2 - (R_st(i,a), 1)^2 ] - m2, R2 ]
          D2_st(i,a) = 2.R2_st(i,a)
          ( F_II_st(i,a)
            F_I_st(i,a) ) = π.[ (R_st(i,a), N_r)^2 - (R2_st(i,a))^2 ] / [ (R2_st(i,a))^2 - (R_st(i,a), 1)^2 ]
        ( F_I  F_II
          D2  R2 )

```

Кольцевые площади (м<sup>2</sup>):

[illegible]

Радиус и диаметр двухконтурности (м):

[illegible]

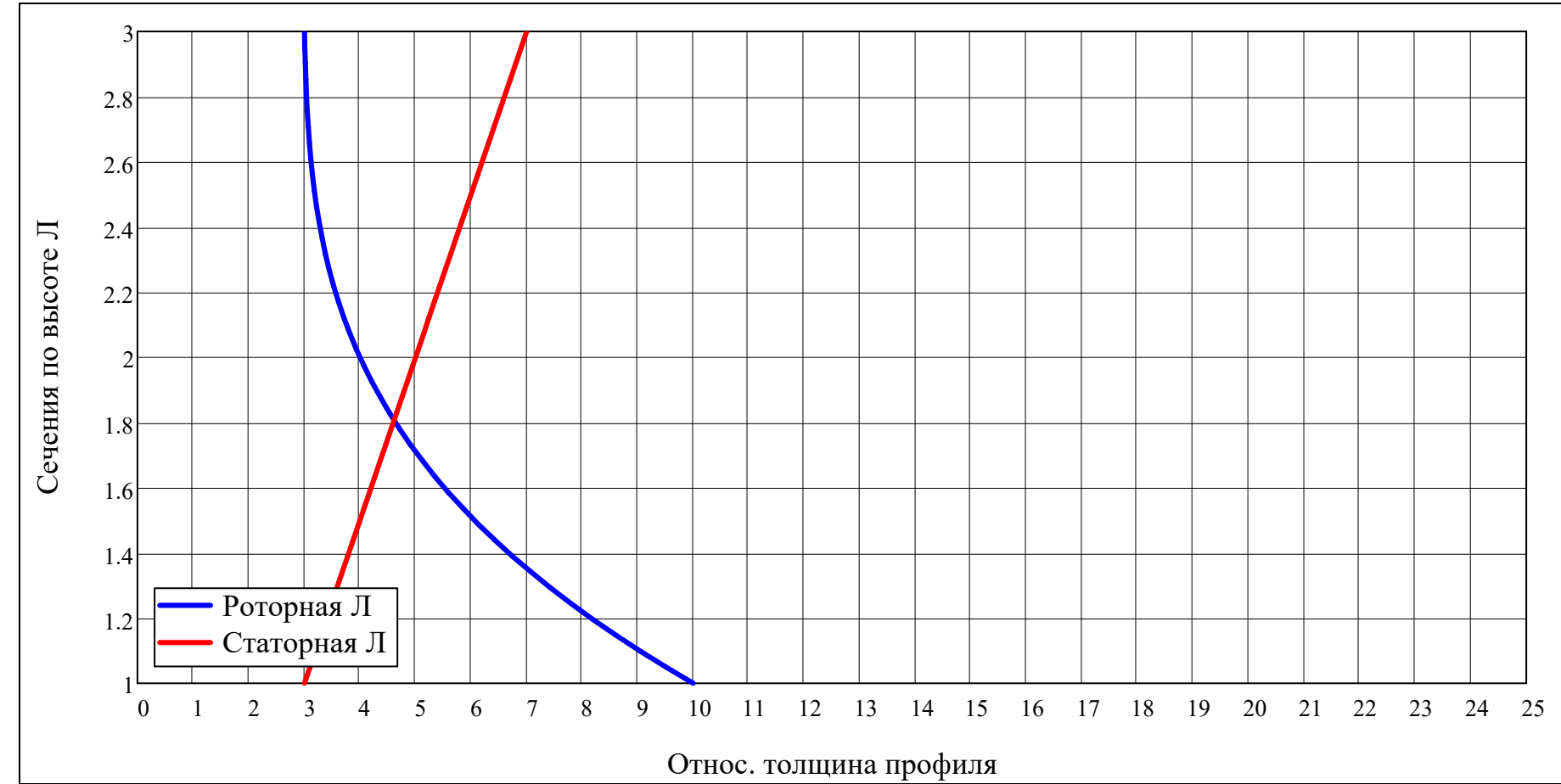


Относ. толщины ЛРК и СА:

$$\overline{c}_{\text{rotor.}}(r) = \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 13 + \begin{cases} 3 & \text{if compressor} = \text{"Вл"} \\ -3 & \text{if compressor} = \text{"КНД"} \\ -1 & \text{otherwise} \end{cases} \\ 5 + \begin{cases} 1 & \text{if compressor} = \text{"Вл"} \\ -1 & \text{if compressor} = \text{"КНД"} \\ 0 & \text{otherwise} \end{cases} \\ 3 \end{pmatrix} \% , \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 13 + \begin{cases} 3 & \text{if compressor} = \text{"Вл"} \\ -3 & \text{if compressor} = \text{"КНД"} \\ -1 & \text{otherwise} \end{cases} \\ 5 + \begin{cases} 1 & \text{if compressor} = \text{"Вл"} \\ -1 & \text{if compressor} = \text{"КНД"} \\ 0 & \text{otherwise} \end{cases} \\ 3 \end{pmatrix} \% , r \right]$$

$$\overline{c}_{\text{stator.}}(r) = \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 3 \\ 5 \\ 7 \end{pmatrix} \% , \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} 3 \\ 5 \\ 7 \end{pmatrix} \% , r \right]$$

$$\textcolor{green}{r} = \text{ORIGIN}, \text{ORIGIN} + \frac{N_r - \text{ORIGIN}}{N_{\text{dis}}} .. N_r$$



$$\overline{c}_{\text{BHA}} = \left| \begin{array}{l} \text{for } r \in 1..N_r \\ \overline{c}_{\text{BHA}_r} = \overline{c}_{\text{stator.}(r)} \\ \overline{c}_{\text{BHA}} \end{array} \right.$$

$$\left( \begin{array}{c} \overline{c}_{\text{stator}} \\ \overline{c}_{\text{rotor}} \end{array} \right) =$$

for i ∈ 1..Z

for r ∈ 1..N<sub>r</sub>

$$\left( \begin{array}{c} \overline{c}_{\text{stator}_{i,r}} \\ \overline{c}_{\text{rotor}_{i,r}} \end{array} \right) = \left( \begin{array}{c} \overline{c}_{\text{stator.}(r)} \\ \overline{c}_{\text{rotor.}(r)} \end{array} \right)$$

$$\left( \begin{array}{c} \overline{c}_{\text{stator}} \\ \overline{c}_{\text{rotor}} \end{array} \right)$$

$$\overline{c}_{\text{CA}} = \left| \begin{array}{l} \text{for } r \in 1..N_r \\ \overline{c}_{\text{CA}_r} = \overline{c}_{\text{stator.}(r)} \\ \overline{c}_{\text{CA}} \end{array} \right.$$

$$\overline{c}_{\text{BHA}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 3.00 \\ \hline 2 & 5.00 \\ \hline 3 & 7.00 \\ \hline \end{array} \cdot\%$$

$$\overline{c}_{\text{stator}}^{\text{T}} = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 3.00 & 3.00 & 3.00 \\ \hline 2 & 5.00 & 5.00 & 5.00 \\ \hline 3 & 7.00 & 7.00 & 7.00 \\ \hline \end{array} \cdot\%$$

$$\overline{c}_{\text{rotor}}^{\text{T}} = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 10.00 & 10.00 & 10.00 \\ \hline 2 & 4.00 & 4.00 & 4.00 \\ \hline 3 & 3.00 & 3.00 & 3.00 \\ \hline \end{array} \cdot\%$$

$$\overline{c}_{\text{CA}} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 3.00 \\ \hline 2 & 5.00 \\ \hline 3 & 7.00 \\ \hline \end{array} \cdot\%$$

$$\begin{pmatrix} \overline{r\_inlet_{BHA}} \\ \overline{r\_outlet_{BHA}} \end{pmatrix} = \begin{cases} \text{for } r \in 1..N_r & \text{if } BHA = 1 \\ \begin{pmatrix} \overline{r\_inlet_{BHA_r}} \\ \overline{r\_outlet_{BHA_r}} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c_{stator.}(r)} \\ \begin{pmatrix} \overline{r\_inlet_{BHA}} \\ \overline{r\_outlet_{BHA}} \end{pmatrix} \end{cases}$$

$$\begin{pmatrix} \overline{r\_inlet_{CA}} \\ \overline{r\_outlet_{CA}} \end{pmatrix} = \begin{cases} \text{for } r \in 1..N_r & \text{if } CA = 1 \\ \begin{pmatrix} \overline{r\_inlet_{CA_r}} \\ \overline{r\_outlet_{CA_r}} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c_{stator.}(r)} \\ \begin{pmatrix} \overline{r\_inlet_{CA}} \\ \overline{r\_outlet_{CA}} \end{pmatrix} \end{cases}$$

$$\overline{r\_inlet_{BHA}} = 0.000 \cdot \%$$

$$\overline{r\_inlet_{stator}}^T = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 0.600 & 0.600 & 0.600 \\ \hline 2 & 1.000 & 1.000 & 1.000 \\ \hline 3 & 1.400 & 1.400 & 1.400 \\ \hline \end{array} \cdot \%$$

$$\overline{r\_outlet_{stator}}^T = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 0.300 & 0.300 & 0.300 \\ \hline 2 & 0.500 & 0.500 & 0.500 \\ \hline 3 & 0.700 & 0.700 & 0.700 \\ \hline \end{array} \cdot \%$$

$$\overline{r\_outlet_{BHA}} = 0.000 \cdot \%$$

$$\begin{pmatrix} \overline{r\_inlet_{rotor}} & \overline{r\_inlet_{stator}} \\ \overline{r\_outlet_{rotor}} & \overline{r\_outlet_{stator}} \end{pmatrix} = \begin{cases} \text{for } i \in 1..Z \\ \text{for } r \in 1..N_r \\ \begin{pmatrix} \overline{r\_inlet_{stator_{i,r}}} \\ \overline{r\_outlet_{stator_{i,r}}} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c_{stator.}(r)} \\ \begin{pmatrix} \overline{r\_inlet_{rotor_{i,r}}} \\ \overline{r\_outlet_{rotor_{i,r}}} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c_{rotor.}(r)} \\ \begin{pmatrix} \overline{r\_inlet_{rotor}} & \overline{r\_inlet_{stator}} \\ \overline{r\_outlet_{rotor}} & \overline{r\_outlet_{stator}} \end{pmatrix} \end{cases}$$

$$\overline{r\_inlet_{CA}} = 0.000 \cdot \%$$

$$\overline{r\_inlet_{rotor}}^T = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 2.000 & 2.000 & 2.000 \\ \hline 2 & 0.800 & 0.800 & 0.800 \\ \hline 3 & 0.600 & 0.600 & 0.600 \\ \hline \end{array} \cdot \%$$

$$\overline{r\_outlet_{rotor}}^T = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 1.000 & 1.000 & 1.000 \\ \hline 2 & 0.400 & 0.400 & 0.400 \\ \hline 3 & 0.300 & 0.300 & 0.300 \\ \hline \end{array} \cdot \%$$

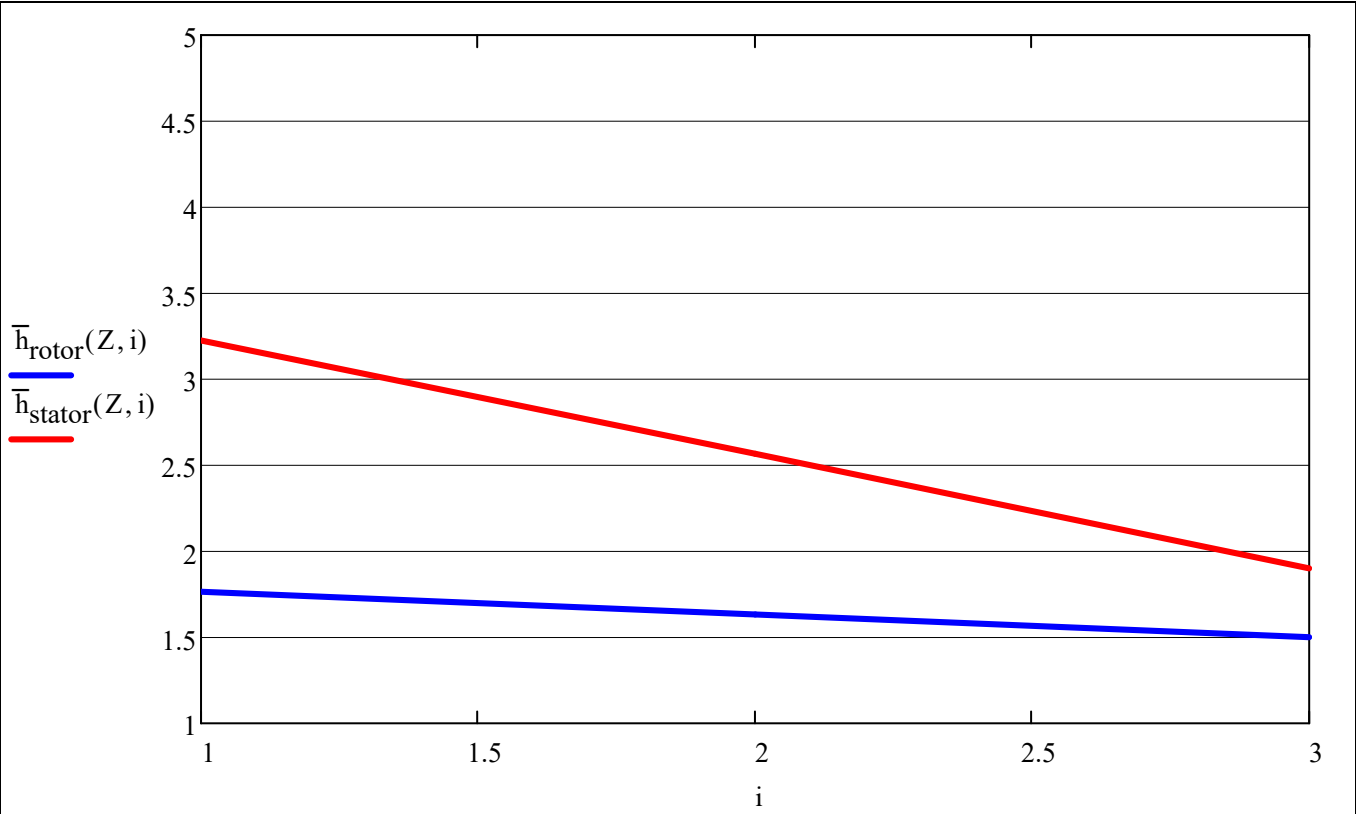
$$\overline{r\_outlet_{CA}} = 0.000 \cdot \%$$

Относ. удлинение ЛРК и НА: [16, с. 244]

$$\bar{h}_{\sim\text{rotor}} = (2 \ 1.9 \ 1.85 \ 1.8 \ 1.75 \ 1.7 \ 1.65 \ 1.6)^T + \begin{cases} 1.1 & \text{if compressor = "Вл"} \\ -0.1 & \text{if compressor = "КНД"} \\ -0.55 & \text{if compressor = "КВД"} \end{cases}$$

$$\bar{h}_{\sim\text{stator}} = (4 \ 3.5 \ 3.25 \ 3 \ 2.75 \ 2.5 \ 2.25 \ 2)^T + \begin{cases} 1.1 & \text{if compressor = "Вл"} \\ -0.1 & \text{if compressor = "КНД"} \\ -0.7 & \text{if compressor = "КВД"} \end{cases}$$

$$\bar{h}_{\text{rotor}}(Z,i) = \begin{cases} \bar{h}_{\sim\text{rotor}}\left(\frac{1}{\text{rows}(z_{\sim})}\right) & \text{if } i < 1 \\ \bar{h}_{\sim\text{rotor}}(1) & \text{if } i > Z \\ \bar{h}_{\sim\text{rotor}}\left(\frac{i}{Z}\right) & \text{otherwise} \end{cases} \quad \bar{h}_{\text{stator}}(Z,i) = \begin{cases} \bar{h}_{\sim\text{stator}}\left(\frac{1}{\text{rows}(z_{\sim})}\right) & \text{if } i < 1 \\ \bar{h}_{\sim\text{stator}}(1) & \text{if } i > Z \\ \bar{h}_{\sim\text{stator}}\left(\frac{i}{Z}\right) & \text{otherwise} \end{cases}$$



$$\bar{h}_{\sim\text{rotor}}(i) = \text{interp}\left(\text{cspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, \bar{h}_{\sim\text{rotor}}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, \bar{h}_{\sim\text{rotor}}, i\right)$$

$$\bar{h}_{\sim\text{stator}}(i) = \text{interp}\left(\text{cspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, \bar{h}_{\sim\text{stator}}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, \bar{h}_{\sim\text{stator}}, i\right)$$

Для компрессора газогенератора

$\frac{h_{PK}}{S_{PK}} = 2,5 \dots 4,5$  – для первой дозвуковой ступени;

$\frac{h_{PK}}{S_{PK}} = 2,0 \dots 3,5$  – для первой околосвуковой ступени;

$\frac{h_{PK}}{S_{PK}} = 1,7 \dots 3,0$  – для первой сверхзвуковой ступени;

$\frac{h_{PK}}{S_{PK}} = 1,0 \dots 2,5$  – для последней ступени.

Парусность:

$$\begin{pmatrix} \text{sail}_{\text{rotor}} \\ \text{sail}_{\text{stator}} \end{pmatrix} = \begin{pmatrix} 1.3 \\ 1.2 \end{pmatrix}$$

Расчет длин хорд по высоте Л

```
chordBHA = for i ∈ 1 if BHA = 1
| chordBHAav(Nr) =  $\frac{h_{\text{st}(i, 1)}}{\bar{h}_{\text{stator}}(Z, 0)}$ 
| sail =  $\frac{R_{\text{st}(1, 1), N_r} - R_{\text{st}(1, 1), 1}}{R_{\text{st}(1, 1), \text{av}(N_r)} - R_{\text{st}(1, 1), 1}}$ 
| for r ∈ 1 .. Nr
| |  $b_{\text{BHAkop}} = \frac{\text{chord}_{\text{BHA}_{\text{av}(N_r)}} \cdot \text{sail}}{\text{sail}_{\text{stator}} - 1 + \text{sail}}$ 
| | bBHAпер = bBHAkop · sailstator
| |  $b_{\text{BHA.}}(z) = \text{interp} \left[ \text{cspline} \left[ \begin{pmatrix} R_{\text{st}(i, 1), 1} \\ R_{\text{st}(i, 1), \text{av}(N_r)} \\ R_{\text{st}(i, 1), N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{BHAkop}} \\ \text{chord}_{\text{BHA}_{\text{av}(N_r)}} \\ b_{\text{BHAпер}} \end{pmatrix} \right], \begin{pmatrix} R_{\text{st}(i, 1), 1} \\ R_{\text{st}(i, 1), \text{av}(N_r)} \\ R_{\text{st}(i, 1), N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{BHAkop}} \\ \text{chord}_{\text{BHA}_{\text{av}(N_r)}} \\ b_{\text{BHAпер}} \end{pmatrix}, z \right]$ 
| | chordBHAr = bBHA.(Rst(i, 1), r)
chordBHA
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$\left( \text{chord}_{\text{rotor}} \quad \text{chord}_{\text{stator}} \right) =$	<div>for <math>i \in 1 \dots Z</math></div> <div style="border-left: 1px solid black; padding-left: 10px; margin-left: 10px;"> <math display="block">\left( \begin{array}{c} \text{chord}_{\text{rotor}_{i, \text{av}}(N_r)} \\ \text{chord}_{\text{stator}_{i, \text{av}}(N_r)} \end{array} \right) = \left( \begin{array}{c} \frac{\text{mean}(h_{\text{st}}(i, 1), h_{\text{st}}(i, 2))}{\bar{h}_{\text{rotor}}(Z, i)} \\ \frac{\text{mean}(h_{\text{st}}(i, 2), h_{\text{st}}(i, 3))}{\bar{h}_{\text{stator}}(Z, i)} \end{array} \right)</math> <math display="block">\text{sail} = \frac{R_{\text{st}(i, 2), N_r} - R_{\text{st}(i, 2), 1}}{R_{\text{st}(i, 2), \text{av}}(N_r) - R_{\text{st}(i, 2), 1}}</math> <div>for <math>r \in 1 \dots N_r</math></div> <div style="border-left: 1px solid black; padding-left: 10px; margin-left: 10px;"> <math display="block">b_{\text{PKkop}} = \frac{\text{chord}_{\text{rotor}_{i, \text{av}}(N_r)} \cdot \text{sail}}{\text{sail}_{\text{rotor}} - 1 + \text{sail}}</math> <math display="block">b_{\text{HAKop}} = \frac{\text{chord}_{\text{stator}_{i, \text{av}}(N_r)} \cdot \text{sail}}{\text{sail}_{\text{stator}} - 1 + \text{sail}}</math> <math display="block">\left( \begin{array}{c} b_{\text{PKпер}} \\ b_{\text{HAпер}} \end{array} \right) = \left( \begin{array}{c} b_{\text{PKkop}} \cdot \text{sail}_{\text{rotor}} \\ b_{\text{HAKop}} \cdot \text{sail}_{\text{stator}} \end{array} \right)</math> <math display="block">\text{chord}_{\text{rotor.}}(z) = \text{interp} \left[ \text{cspline} \left[ \left( \begin{array}{c} R_{\text{st}(i, 2), 1} \\ R_{\text{st}(i, 2), \text{av}}(N_r) \\ R_{\text{st}(i, 2), N_r} \end{array} \right), \left( \begin{array}{c} b_{\text{PKkop}} \\ \text{chord}_{\text{rotor}_{i, \text{av}}(N_r)} \\ b_{\text{PKпер}} \end{array} \right) \right], \left( \begin{array}{c} R_{\text{st}(i, 2), 1} \\ R_{\text{st}(i, 2), \text{av}}(N_r) \\ R_{\text{st}(i, 2), N_r} \end{array} \right), \left( \begin{array}{c} b_{\text{PKkop}} \\ \text{chord}_{\text{rotor}_{i, \text{av}}(N_r)} \\ b_{\text{PKпер}} \end{array} \right), z \right]</math> <math display="block">\text{chord}_{\text{stator.}}(z) = \text{interp} \left[ \text{cspline} \left[ \left( \begin{array}{c} R_{\text{st}(i, 2), 1} \\ R_{\text{st}(i, 2), \text{av}}(N_r) \\ R_{\text{st}(i, 2), N_r} \end{array} \right), \left( \begin{array}{c} b_{\text{HAKop}} \\ \text{chord}_{\text{stator}_{i, \text{av}}(N_r)} \\ b_{\text{HAпер}} \end{array} \right) \right], \left( \begin{array}{c} R_{\text{st}(i, 2), 1} \\ R_{\text{st}(i, 2), \text{av}}(N_r) \\ R_{\text{st}(i, 2), N_r} \end{array} \right), \left( \begin{array}{c} b_{\text{HAKop}} \\ \text{chord}_{\text{stator}_{i, \text{av}}(N_r)} \\ b_{\text{HAпер}} \end{array} \right), z \right]</math> <math display="block">\text{chord}_{\text{rotor}_{i, r}} = \text{chord}_{\text{rotor.}}(R_{\text{st}(i, 2), r})</math> <math display="block">\text{chord}_{\text{stator}_{i, r}} = \text{chord}_{\text{stator.}}(R_{\text{st}(i, 2), r})</math> </div> </div> <div><math>\left( \text{chord}_{\text{rotor}} \quad \text{chord}_{\text{stator}} \right)</math></div>
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chord<sub>CA</sub> =

for i ∈ Z

chord<sub>CA<sub>av</sub>(N<sub>r</sub>)</sub> =  $\frac{h_{st(i,3)}}{\overline{h}_{stator}(Z,Z+1)}$

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

for r ∈ 1 .. N<sub>r</sub>

b<sub>CA<sub>коп</sub></sub> =  $\frac{chord_{CA_{av}(N_r)} \cdot sail}{sail_{stator} - 1 + sail}$

b<sub>CA<sub>пер</sub></sub> = b<sub>CA<sub>коп</sub></sub> · sail<sub>stator</sub>

b<sub>CA.</sub>(z) = interp  $\left[cspline \left[ \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CA_{коп}} \\ chord_{CA_{av}(N_r)} \\ b_{CA_{пер}} \end{pmatrix} \right], \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CA_{коп}} \\ chord_{CA_{av}(N_r)} \\ b_{CA_{пер}} \end{pmatrix}, z \right]$

chord<sub>CA<sub>r</sub></sub> = b<sub>CA.</sub>(R<sub>st(i,1),r</sub>)

chord<sub>CA</sub>

if CA = 1

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

$\overline{x_f} = 0.5$

Определение количества Л РК и НА

$$\left( \begin{array}{l} \varepsilon_{BHA(b/t)=1} \\ Z_{BHA} \\ r_{inlet_{BHA}} \\ r_{outlet_{BHA}} \\ t_{BHA} \\ i_{BHA} \\ m_{BHA} \\ \theta_{BHA} \\ \delta_{BHA} \\ \chi_{BHA} \\ v_{BHA} \\ R_{CЛ.BHA} \\ K_{BHA} \\ D_{BHA} \end{array} \right)$$

= if BHA = 1

for  $r \in av(N_r)$

$$\varepsilon_{BHA(b/t)=1_r} = \varepsilon_{(b/t)=1}(\alpha_{3BHA_r})$$

$$b/t_{BHA_r} = b/t=1 \left( \frac{\varepsilon_{BHA_r}}{\varepsilon_{BHA(b/t)=1_r}} \right)$$

$$t_{BHA_r} = \frac{chord_{BHA_r}}{b/t_{BHA_r}}$$

$$Z_{BHA} = \left| \begin{array}{l} \text{round}\left(\frac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right) \text{ if } \text{mod}\left(\text{round}\left(\frac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right), 2\right) = 0 \\ \text{round}\left(\frac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right) + 1 \text{ otherwise} \end{array} \right|$$

for  $r \in 1..N_r$

$$\left( r_{inlet_{BHA_r}} \ r_{outlet_{BHA_r}} \right) = chord_{BHA_r} \cdot \left( \overline{r}_{inlet_{BHA_r}} \ \overline{r}_{outlet_{BHA_r}} \right)$$

$$t_{BHA_r} = \frac{D_{st(1,1),r}}{Z_{BHA}}$$

$$i_{BHA_r} = 2.5 \cdot \left( \frac{chord_{BHA_r}}{t_{BHA_r}} - 2 \right) \cdot ^\circ$$

$$m_{BHA} = 0.23 \cdot (2 \cdot \overline{x_f})^2 + 0.18 - \frac{0.002}{1 + \overline{x_f}} \cdot (\alpha_{3BHA_r})$$

$$\theta_{\text{BHA}_r} = \frac{\epsilon_{\text{BHA}_r} - i_{\text{BHA}_r}}{1 - m_{\text{BHA}_r} \cdot \sqrt{\frac{t_{\text{BHA}_r}}{\text{chord}_{\text{BHA}_r}}}}$$

$$\delta_{\text{BHA}_r} = m_{\text{BHA}_r} \cdot \theta_{\text{BHA}_r} \cdot \sqrt{\frac{t_{\text{BHA}_r}}{\text{chord}_{\text{BHA}_r}}}$$

$$\chi_{\text{BHA}_r} = \theta_{\text{BHA}_r} \cdot \frac{1 + 2 \cdot (1 - 2 \cdot \bar{x}_f)}{2}$$

$$v_{\text{BHA}_r} = \chi_{\text{BHA}_r} + \alpha_{1\text{BHA}_r} + i_{\text{BHA}_r}$$

$$R_{CJL.BHA_r} = \frac{\text{chord}_{BHA_r}}{2 \cdot \sin\left(0.5 \cdot \theta_{BHA_r}\right)}$$

$$K_{\text{BHA}_r} = \frac{c_{a3\text{BHA}_r}}{c_{a1\text{BHA}_r}}$$

$$D_{BHA_r} = \left( 1 - K_{BHA_r} \cdot \frac{\sin(\alpha_{1BHA_r})}{\sin(\alpha_{3BHA_r})} \right) + \left( \frac{1}{\tan(\alpha_{1BHA_r})} - K_{BHA_r} \cdot \frac{1}{\tan(\alpha_{3BHA_r})} \right) \cdot \frac{\sin(\alpha_{1BHA_r})}{2 \cdot \frac{\text{chord}_{BHA_r}}{t_{BHA_r}}}$$

$$\left( \varepsilon_{\text{BHA(b/t)=1}} \quad Z_{\text{BHA}} \quad r_{\text{inlet}}_{\text{BHA}} \quad r_{\text{outlet}}_{\text{BHA}} \quad t_{\text{BHA}} \quad i_{\text{BHA}} \quad m_{\text{BHA}} \quad \theta_{\text{BHA}} \quad \delta_{\text{BHA}} \quad \chi_{\text{BHA}} \quad v_{\text{BHA}} \quad R_{\text{CJL.BHA}} \quad K_{\text{BHA}} \quad D_{\text{BHA}} \right)^T$$

$\epsilon_{\text{PK}(b/t)=1}$	$\epsilon_{\text{HA}(b/t)=1}$	=	for $i \in 1..Z$	for $r \in \text{av}(N_r)$	$\begin{pmatrix} \epsilon_{\text{PK}(b/t)=1_{i,r}} \\ \epsilon_{\text{HA}(b/t)=1_{i,r}} \end{pmatrix} = \begin{pmatrix} \epsilon_{(b/t)=1}(\beta_{\text{st}(i,2)}, r) \\ \epsilon_{(b/t)=1}(\alpha_{\text{st}(i,3)}, r) \end{pmatrix}$ $\begin{pmatrix} b/t_{\text{PK}_{i,r}} \\ b/t_{\text{HA}_{i,r}} \end{pmatrix} = \begin{pmatrix} b/t=1 \left( \frac{\epsilon_{\text{rotor}_{i,r}}}{\epsilon_{\text{PK}(b/t)=1_{i,r}}} \right) \\ b/t=1 \left( \frac{\epsilon_{\text{stator}_{i,r}}}{\epsilon_{\text{HA}(b/t)=1_{i,r}}} \right) \end{pmatrix}$ $\begin{pmatrix} t_{\text{rotor}_{i,r}} \\ t_{\text{stator}_{i,r}} \end{pmatrix} = \begin{pmatrix} \frac{\text{chord}_{\text{rotor}_{i,r}}}{b/t_{\text{PK}_{i,r}}} \\ \frac{\text{chord}_{\text{stator}_{i,r}}}{b/t_{\text{HA}_{i,r}}} \end{pmatrix}$ $\begin{pmatrix} t_{\text{rotor}_{i,r}} \\ t_{\text{stator}_{i,r}} \end{pmatrix} = \frac{2}{3} \begin{pmatrix} \text{chord}_{\text{rotor}_{i,r}} \cdot \cos(\beta_{\text{st}(i,1)}, r) \\ \text{chord}_{\text{stator}_{i,r}} \cdot \cos(\alpha_{\text{st}(i,2)}, r) \end{pmatrix}$ $Z_{\text{stator}_i} = \begin{cases} \text{round}\left(\frac{\pi \cdot \text{mean}(D_{\text{st}(i,2)}, r, D_{\text{st}(i,3)}, r)}{t_{\text{stator}_{i,r}}}\right) & \text{if } \text{mod}\left(\text{round}\left(\frac{\pi \cdot \text{mean}(D_{\text{st}(i,2)}, r, D_{\text{st}(i,3)}, r)}{t_{\text{stator}_{i,r}}}\right), 2\right) = 0 \\ \text{round}\left(\frac{\pi \cdot \text{mean}(D_{\text{st}(i,2)}, r, D_{\text{st}(i,3)}, r)}{t_{\text{stator}_{i,r}}}\right) + 1 & \text{otherwise} \end{cases}$ $Z_{\text{rotor}_i} = \begin{cases} Z_{\text{rotor}_i} = \text{round}\left(\frac{\pi \cdot \text{mean}(D_{\text{st}(i,1)}, r, D_{\text{st}(i,2)}, r)}{t_{\text{rotor}_{i,r}}}\right) \end{cases}$
$Z_{\text{rotor}}$	$Z_{\text{stator}}$				
$r_{\text{inlet}_{\text{rotor}}}$	$r_{\text{inlet}_{\text{stator}}}$				
$r_{\text{outlet}_{\text{rotor}}}$	$r_{\text{outlet}_{\text{stator}}}$				
$t_{\text{rotor}}$	$t_{\text{stator}}$				
$i_{\text{rotor}}$	$i_{\text{stator}}$				
$m_{\text{rotor}}$	$m_{\text{stator}}$				
$\theta_{\text{rotor}}$	$\theta_{\text{stator}}$				
$\delta_{\text{rotor}}$	$\delta_{\text{stator}}$				
$\chi_{\text{rotor}}$	$\chi_{\text{stator}}$				
$v_{\text{rotor}}$	$v_{\text{stator}}$				
$R_{\text{CJL.rotor}}$	$R_{\text{CJL.stator}}$				
$K_{\text{rotor}}$	$K_{\text{stator}}$				
$D_{\text{rotor}}$	$D_{\text{stator}}$				
$\zeta_{\text{rotor}}$	$\zeta_{\text{stator}}$				
$\text{quality}_{\text{rotor}}$	$\text{quality}_{\text{stator}}$				
$\eta_{\text{stage}}$	$\eta_{\text{stage}}$				

while  $\gcd(Z_{\text{rotor}_i}, Z_{\text{stator}_i}) \neq 1$

$$Z_{\text{rotor}_i} = Z_{\text{rotor}_i} + 1$$

for  $r \in 1 \dots N_r$

$$\begin{pmatrix} r_{\text{inlet}_{\text{stator}_i, r}} & r_{\text{outlet}_{\text{stator}_i, r}} \\ r_{\text{inlet}_{\text{rotor}_i, r}} & r_{\text{outlet}_{\text{rotor}_i, r}} \end{pmatrix} = \begin{pmatrix} \bar{r}_{\text{inlet}_{\text{stator}_i, r}} \cdot \text{chord}_{\text{stator}_i, r} & \bar{r}_{\text{outlet}_{\text{stator}_i, r}} \cdot \text{chord}_{\text{stator}_i, r} \\ \bar{r}_{\text{inlet}_{\text{rotor}_i, r}} \cdot \text{chord}_{\text{rotor}_i, r} & \bar{r}_{\text{outlet}_{\text{rotor}_i, r}} \cdot \text{chord}_{\text{rotor}_i, r} \end{pmatrix}$$

$$\begin{pmatrix} t_{\text{rotor}_i, r} \\ t_{\text{stator}_i, r} \end{pmatrix} = \pi \cdot \begin{pmatrix} \frac{\text{mean}(D_{\text{st}(i, 1), r}, D_{\text{st}(i, 2), r})}{Z_{\text{rotor}_i}} \\ \frac{\text{mean}(D_{\text{st}(i, 2), r}, D_{\text{st}(i, 3), r})}{Z_{\text{stator}_i}} \end{pmatrix}$$

$$\begin{pmatrix} i_{\text{rotor}_i, r} \\ i_{\text{stator}_i, r} \end{pmatrix} = 2.5 \cdot \begin{pmatrix} \frac{\text{chord}_{\text{rotor}_i, r} - 1}{t_{\text{rotor}_i, r}} \\ \frac{\text{chord}_{\text{stator}_i, r} - 2}{t_{\text{stator}_i, r}} \end{pmatrix} \cdot \circ$$

$$\begin{pmatrix} m_{\text{rotor}_i, r} \\ m_{\text{stator}_i, r} \end{pmatrix} = 0.23 \cdot (2 \cdot \bar{x}_f)^2 + 0.18 - \frac{0.002}{\text{deg}} \cdot \begin{pmatrix} \beta_{\text{st}(i, 2), r} \\ \alpha_{\text{st}(i, 3), r} \end{pmatrix}$$

$$\begin{pmatrix} \theta_{\text{rotor}_i, r} \\ \theta_{\text{stator}_i, r} \end{pmatrix} = \begin{pmatrix} \frac{\varepsilon_{\text{rotor}_i, r} - i_{\text{rotor}_i, r}}{1 - m_{\text{rotor}_i, r} \cdot \sqrt{\frac{t_{\text{rotor}_i, r}}{\text{chord}_{\text{rotor}_i, r}}}} \\ \frac{\varepsilon_{\text{stator}_i, r} - i_{\text{stator}_i, r}}{1 - m_{\text{stator}_i, r} \cdot \sqrt{\frac{t_{\text{stator}_i, r}}{\text{chord}_{\text{stator}_i, r}}}} \end{pmatrix}$$

$$\begin{pmatrix} \delta_{\text{rotor}_i, r} \\ \delta_{\text{stator}_i, r} \end{pmatrix} = \begin{pmatrix} m_{\text{rotor}_i, r} \cdot \theta_{\text{rotor}_i, r} \cdot \sqrt{\frac{t_{\text{rotor}_i, r}}{\text{chord}_{\text{rotor}_i, r}}} \\ m_{\text{stator}_i, r} \cdot \theta_{\text{stator}_i, r} \cdot \sqrt{\frac{t_{\text{stator}_i, r}}{\text{chord}_{\text{stator}_i, r}}} \end{pmatrix}$$

$$\begin{pmatrix} \chi_{\text{rotor}_i, r} \\ \chi_{\text{stator}_i, r} \end{pmatrix} = \begin{pmatrix} \theta_{\text{rotor}_i, r} \\ \theta_{\text{stator}_i, r} \end{pmatrix} \cdot \frac{1 + 2 \cdot (1 - 2 \cdot \bar{x}_f)}{2}$$

$$\begin{pmatrix} v_{\text{rotor}_i, r} \\ v_{\text{stator}_i, r} \end{pmatrix} = \begin{pmatrix} \chi_{\text{rotor}_i, r} + \beta_{\text{st}(i, 1), r} + i_{\text{rotor}_i, r} \\ \chi_{\text{stator}_i, r} + \beta_{\text{st}(i, 2), r} + i_{\text{stator}_i, r} \end{pmatrix}$$

$$\begin{aligned}
\begin{pmatrix} v_{\text{stator}_{i,r}}^{1,r} \end{pmatrix} &= \begin{pmatrix} x_{\text{stator}_{i,r}}^{1,r} + \alpha_{\text{st}(i,2),r} + i_{\text{stator}_{i,r}}^{1,r} \end{pmatrix} \\
\begin{pmatrix} R_{\text{CJL.rotor}_{i,r}} \\ R_{\text{CJL.stator}_{i,r}} \end{pmatrix} &= \frac{1}{2} \cdot \begin{pmatrix} \frac{\text{chord}_{\text{rotor}_{i,r}}}{\sin(0.5 \cdot \theta_{\text{rotor}_{i,r}})} \\ \frac{\text{chord}_{\text{stator}_{i,r}}}{\sin(0.5 \cdot \theta_{\text{stator}_{i,r}})} \end{pmatrix} \\
\begin{pmatrix} K_{\text{rotor}_{i,r}} \\ K_{\text{stator}_{i,r}} \end{pmatrix} &= \begin{pmatrix} \frac{c_{a_{\text{st}(i,2),r}}}{c_{a_{\text{st}(i,1),r}}} \\ \frac{c_{a_{\text{st}(i,3),r}}}{c_{a_{\text{st}(i,2),r}}} \end{pmatrix} \\
\begin{pmatrix} D_{\text{rotor}_{i,r}} \\ D_{\text{stator}_{i,r}} \end{pmatrix} &= \begin{bmatrix} \left( 1 - K_{\text{rotor}_{i,r}} \cdot \frac{\sin(\beta_{\text{st}(i,1),r})}{\sin(|\beta_{\text{st}(i,2),r}|)} \right) + \left( \frac{1}{\tan(\beta_{\text{st}(i,1),r})} - K_{\text{rotor}_{i,r}} \cdot \frac{1}{\tan(\beta_{\text{st}(i,2),r})} \right) \cdot \frac{\sin(\beta_{\text{st}(i,1),r})}{2 \cdot \frac{\text{chord}_{\text{rotor}_{i,r}}}{t_{\text{rotor}_{i,r}}}} \\ \left( 1 - K_{\text{stator}_{i,r}} \cdot \frac{\sin(\alpha_{\text{st}(i,2),r})}{\sin(\alpha_{\text{st}(i,3),r})} \right) + \left( \frac{1}{\tan(\alpha_{\text{st}(i,2),r})} - K_{\text{stator}_{i,r}} \cdot \frac{1}{\tan(\alpha_{\text{st}(i,3),r})} \right) \cdot \frac{\sin(\alpha_{\text{st}(i,2),r})}{2 \cdot \frac{\text{chord}_{\text{stator}_{i,r}}}{t_{\text{stator}_{i,r}}}} \end{bmatrix} \\
\begin{pmatrix} \zeta_{\text{rotor}_{i,r}} \\ \zeta_{\text{stator}_{i,r}} \end{pmatrix} &= \begin{pmatrix} \frac{\zeta \cdot \sin(\beta_3) / (2b/t) \left( D_{\text{rotor}_{i,r}} \right) \cdot 2 \cdot \frac{\text{chord}_{\text{rotor}_{i,r}}}{t_{\text{rotor}_{i,r}}}}{\sin(\beta_{\text{st}(i,2),r})} \\ \frac{\zeta \cdot \sin(\beta_3) / (2b/t) \left( D_{\text{stator}_{i,r}} \right) \cdot 2 \cdot \frac{\text{chord}_{\text{stator}_{i,r}}}{t_{\text{stator}_{i,r}}}}{\sin(\alpha_{\text{st}(i,3),r})} \end{pmatrix} \\
\begin{pmatrix} \beta_{\text{cp}_{i,r}} \\ \alpha_{\text{cp}_{i,r}} \end{pmatrix} &= \begin{pmatrix} \text{atan} \left( \frac{c_{a_{\text{st}(i,1),r}}}{\text{mean}(w_{u_{\text{st}(i,1),r}}, w_{u_{\text{st}(i,2),r}})} \right) \\ \text{atan} \left( \frac{c_{a_{\text{st}(i,2),r}}}{\text{mean}(c_{u_{\text{st}(i,2),r}}, c_{u_{\text{st}(i,3),r}})} \right) \end{pmatrix} \\
\begin{pmatrix} \text{quality}_{\text{rotor}_{i,r}} \\ \text{quality}_{\text{stator}_{i,r}} \end{pmatrix} &= \begin{bmatrix} \frac{2}{\zeta_{\text{rotor}_{i,r}}} \cdot \left( \frac{1}{\tan(\beta_{\text{st}(i,1),r})} - \frac{1}{\tan(\beta_{\text{st}(i,2),r})} \right) \cdot \left( \frac{\sin(\beta_{\text{st}(i,1),r})}{\sin(\beta_{\text{cp}_{i,r}})} \right)^2 - \frac{1}{\tan(\beta_{\text{cp}_{i,r}})} \\ \frac{2}{\zeta_{\text{stator}_{i,r}}} \cdot \left( \frac{1}{\tan(\alpha_{\text{st}(i,2),r})} - \frac{1}{\tan(\alpha_{\text{st}(i,3),r})} \right) \cdot \left( \frac{\sin(\alpha_{\text{st}(i,2),r})}{\sin(\alpha_{\text{cn}})} \right)^2 - \frac{1}{\tan(\alpha_{\text{cn}})} \end{bmatrix}
\end{aligned}$$

$$\eta_{\text{stage}_{i,r}} = 1 - \frac{\left( \frac{c_{a_{\text{st}(i,1),r}}}{u_{\text{st}(i,1),r}} \right)^2 + (R_{L_{i,r}})^2}{\text{quality}_{\text{rotor}_{i,r}} \cdot \frac{c_{a_{\text{st}(i,1),r}}}{u_{\text{st}(i,1),r}} + R_{L_{i,r}}} + \frac{\left( \frac{c_{a_{\text{st}(i,2),r}}}{u_{\text{st}(i,2),r}} \right)^2 + (1 - R_{L_{i,r}})^2}{\text{quality}_{\text{stator}_{i,r}} \cdot \frac{c_{a_{\text{st}(i,2),r}}}{u_{\text{st}(i,2),r}} + (1 - R_{L_{i,r}})}$$

$$\left( \begin{matrix} \varepsilon_{\text{PK(b/t)=1}} & Z_{\text{rotor}} & r_{\text{inlet}_{\text{rotor}}} & r_{\text{outlet}_{\text{rotor}}} & t_{\text{rotor}} & i_{\text{rotor}} & m_{\text{rotor}} & \theta_{\text{rotor}} & \delta_{\text{rotor}} & \chi_{\text{rotor}} & v_{\text{rotor}} & R_{\text{CJL.rotor}} & K_{\text{rotor}} & D_{\text{rotor}} & \zeta_{\text{rotor}} & \text{quality}_{\text{rotor}} & \eta_{\text{stage}} \end{matrix} \right)^T$$

$$\left( \begin{matrix} \varepsilon_{\text{HA(b/t)=1}} & Z_{\text{stator}} & r_{\text{inlet}_{\text{stator}}} & r_{\text{outlet}_{\text{stator}}} & t_{\text{stator}} & i_{\text{stator}} & m_{\text{stator}} & \theta_{\text{stator}} & \delta_{\text{stator}} & \chi_{\text{stator}} & v_{\text{stator}} & R_{\text{CJL.stator}} & K_{\text{stator}} & D_{\text{stator}} & \zeta_{\text{stator}} & \text{quality}_{\text{stator}} & \eta_{\text{stage}} \end{matrix} \right)^T$$

$$\begin{pmatrix} \varepsilon_{CA(b/t)=1} \\ Z_{CA} \\ r_{inlet_{CA}} \\ r_{outlet_{CA}} \\ t_{CA} \\ i_{CA} \\ m_{CA} \\ \theta_{CA} \\ \delta_{CA} \\ \chi_{CA} \\ v_{CA} \\ R_{CJL,CA} \\ K_{CA} \\ D_{CA} \end{pmatrix} = \begin{cases} \text{if } CA = 1 \\ \quad \text{for } r \in av(N_r) \\ \quad \left| \begin{array}{l} \varepsilon_{CA(b/t)=1_r} = \varepsilon_{(b/t)=1}(\alpha_{3CA_r}) \\ b/t_{CA_r} = b/t=1 \left( \frac{\varepsilon_{CA_r}}{\varepsilon_{CA(b/t)=1_r}} \right) \\ t_{CA_r} = \frac{chord_{CA_r}}{b/t_{CA_r}} \\ Z_{CA} = \begin{cases} \text{round}\left(\frac{\pi \cdot D_{st}(Z, 3)_r}{t_{CA_r}}\right) & \text{if } \text{mod}\left(\text{round}\left(\frac{\pi \cdot D_{st}(Z, 3)_r}{t_{CA_r}}\right), 2\right) = 0 \\ \text{round}\left(\frac{\pi \cdot D_{st}(Z, 3)_r}{t_{CA_r}}\right) + 1 & \text{otherwise} \end{cases} \end{array} \right. \\ \quad \text{for } r \in 1..N_r \\ \quad \left| \begin{array}{l} (r_{inlet_{CA_r}} \ r_{outlet_{CA_r}}) = chord_{CA_r} \cdot (\bar{r}_{inlet_{CA_r}} \ \bar{r}_{outlet_{CA_r}}) \\ t_{CA_r} = \frac{D_{st}(Z, 3)_r}{Z_{CA}} \\ i_{CA_r} = 2.5 \cdot \left( \frac{chord_{CA_r}}{t_{CA_r}} - 2 \right) \cdot ^\circ \\ m_{CA_r} = 0.23 \cdot (2 \cdot \bar{x}_f)^2 + 0.18 - \frac{0.002}{deg} \cdot (\alpha_{3CA_r}) \\ \theta_{CA_r} = \frac{\varepsilon_{CA_r} - i_{CA_r}}{1 - m_{CA_r} \cdot \sqrt{\frac{t_{CA_r}}{chord_{CA_r}}}} \end{array} \right. \end{cases}
\end{pmatrix}$$



$$\delta_{CA_r} = m_{CA_r} \cdot \theta_{CA_r} \cdot \sqrt{\frac{r_{CA_r}}{\text{chord}_{CA_r}}}$$

$$\chi_{CA_r} = \theta_{CA_r} \cdot \frac{1 + 2 \cdot (1 - 2 \cdot \bar{x}_f)}{2}$$

$$v_{\text{CA}_r} = \chi_{\text{CA}_r} + \alpha_{1\text{CA}_r} + i_{\text{CA}_r}$$

$$R_{CJL.CA_r} = \frac{\text{chord}_{CA_r}}{2 \cdot \sin\left(0.5 \cdot \theta_{CA_r}\right)}$$

$$K_{CA_r} = \frac{c_{a3CA_r}}{c_{a1CA_r}}$$

$$D_{CA_r} = \left( 1 - K_{CA_r} \cdot \frac{\sin(\alpha_{1CA_r})}{\sin(\alpha_{3CA_r})} \right) + \left( \frac{1}{\tan(\alpha_{1CA_r})} - K_{CA_r} \cdot \frac{1}{\tan(\alpha_{3CA_r})} \right) \cdot \frac{\sin(\alpha_{1CA_r})}{2 \cdot \frac{\text{chord}_{CA_r}}{t_{CA_r}}}$$

$$\left( \varepsilon_{CA(b/t)=1} \quad Z_{CA} \quad r_{inlet\_CA} \quad r_{outlet\_CA} \quad t_{CA} \quad i_{CA} \quad m_{CA} \quad \theta_{CA} \quad \delta_{CA} \quad \chi_{CA} \quad v_{CA} \quad R_{CJ,CA} \quad K_{CA} \quad D_{CA} \right)^T$$

$\text{chord}_{\text{BHA}} = 0.00 \cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	62.10	66.35	74.88												
2	72.07	77.02	87.03												
3	80.73	86.26	97.34												

$\cdot 10^{-3}$

Длина хорды Л (м):

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	35.22	44.78	64.29												
2	38.99	49.58	71.24												
3	42.27	53.74	77.15												

$\cdot 10^{-3}$

$\text{chord}_{\text{CA}} = 0.00 \cdot 10^{-3}$

Радисы входных и выходных кромок профилей Л (мм):

$\text{r\_inlet}_{\text{BHA}} = 0.00 \cdot 10^{-3}$

$\text{r\_outlet}_{\text{BHA}} = 0.00 \cdot 10^{-3}$

$\text{r\_inlet}_{\text{rotor}}^{\text{T}} =$

	1	2	3
1	1.24	1.33	1.50
2	0.58	0.62	0.70
3	0.48	0.52	0.58

$\cdot 10^{-3}$

$\text{r\_inlet}_{\text{stator}}^{\text{T}} =$

	1	2	3
1	0.21	0.27	0.39
2	0.39	0.50	0.71
3	0.59	0.75	1.08

$\cdot 10^{-3}$

$\text{r\_outlet}_{\text{rotor}}^{\text{T}} =$

	1	2	3
1	0.62	0.66	0.75
2	0.29	0.31	0.35
3	0.24	0.26	0.29

$\cdot 10^{-3}$

$\text{r\_outlet}_{\text{stator}}^{\text{T}} =$

	1	2	3
1	0.11	0.13	0.19
2	0.19	0.25	0.36
3	0.30	0.38	0.54

$\cdot 10^{-3}$

$\text{r\_inlet}_{\text{CA}} = 0.00 \cdot 10^{-3}$

$\text{r\_outlet}_{\text{CA}} = 0.00 \cdot 10^{-3}$



$t_{BHA} = 0.00 \cdot 10^{-3}$

Шаг решетки (м):

$t_{rotor}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	38.31	40.52	44.95												
2	45.11	47.69	53.98												
3	51.00	53.91	61.69												

$\cdot 10^{-3}$

$t_{stator}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	17.82	25.74	35.33												
2	20.92	30.51	43.29												
3	23.63	34.63	49.99												

$\cdot 10^{-3}$

$t_{CA} = 0.00 \cdot 10^{-3}$

$i_{BHA} = 0.000 \cdot ^\circ$

Угол атаки:

$i_{rotor}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.552	1.594	1.664												
2	1.495	1.538	1.531												
3	1.457	1.500	1.445												

$\cdot ^\circ$

$i_{stator}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-0.057	-0.652	-0.450												
2	-0.341	-0.938	-0.885												
3	-0.527	-1.121	-1.142												

$\cdot ^\circ$

$i_{CA} = 0.000 \cdot ^\circ$

$m_{BHA} = 0.0000$

$m_{rotor}^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.3284	0.2626	0.2630												
2	0.3541	0.3345	0.3411												
3	0.3658	0.3584	0.3636												

Коэф. формы ср. линии профиля по Ховеллу:

$m_{stator}^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.3004	0.3202	0.3086												
2	0.2921	0.3103	0.2969												
3	0.2861	0.3031	0.2893												

$m_{CA} = 0.0000$

$\theta_{BHA} = 0.00^{\circ}$

$\theta_{rotor}^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	24.06	61.24	60.67												
2	11.20	23.58	20.46												
3	6.00	11.42	9.43												

 $.^{\circ}$

Угол изгиба ср. линии профиля:

$\theta_{stator}^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	25.23	48.80	41.70												
2	25.67	51.03	45.60												
3	25.57	51.93	47.36												

 $.^{\circ}$

$\theta_{CA} = 0.00^{\circ}$

$\delta_{\text{BHA}} = 0.000 \cdot ^\circ$

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

	1	2	3
1	6.205	12.567	12.364
2	3.138	6.207	5.496
3	1.744	3.237	2.730

 $\cdot ^\circ$

Угол отставания:

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

	1	2	3
1	5.391	11.847	9.540
2	5.491	12.423	10.553
3	5.469	12.636	11.030

 $\cdot ^\circ$

$\delta_{\text{CA}} = 0.000 \cdot ^\circ$

$v_{\text{BHA}} = 0.00 \cdot ^\circ$

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

	1	2	3
1	34.99	55.63	55.52
2	25.50	32.15	29.74
3	20.84	23.35	21.20

 $\cdot ^\circ$

Угол установки Л:

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

	1	2	3
1	44.47	43.04	39.38
2	48.70	46.97	44.29
3	51.86	49.82	47.70

 $\cdot ^\circ$

$v_{\text{CA}} = 0.00 \cdot ^\circ$

$R_{\text{СЛ.ВНА}} = 0.00 \cdot 10^{-3}$

Радиус дуги ср. линии (м):

$R_{\text{СЛ.rotor}}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	148.99	65.14	74.13												
2	369.23	188.48	244.98												
3	771.49	433.29	592.10												

$\cdot 10^{-3}$

$R_{\text{СЛ.stator}}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	80.63	54.20	90.31												
2	87.78	57.55	91.93												
3	95.51	61.37	96.04												

$\cdot 10^{-3}$

$R_{\text{СЛ.СА}} = 0.00 \cdot 10^{-3}$

$K_{\text{ВНА}} = 0.0000$

Фактор диффузорности решетки:

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.9263	0.9279	0.9600												
2	0.9263	0.9279	0.9600												
3	0.9263	0.9279	0.9600												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.9204	0.9246	0.9583												
2	0.9204	0.9246	0.9583												
3	0.9204	0.9246	0.9583												

$K_{\text{СА}} = 0.0000$

$D_{BHA} = 0.0000$

$D_{rotor}^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.6491	0.8629	0.8416												
2	0.5009	0.6841	0.6378												
3	0.4051	0.5417	0.4890												

Диффузорность решетки:

$D_{stator}^T =$ 

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.5324	0.7506	0.7868												
2	0.4941	0.7324	0.7703												
3	0.4630	0.7128	0.7493												

$D_{CA} = 0.0000$

$D_{BHA} \leq 0.6 = 1$

$D_{rotor}^T \leq 0.6 =$ 

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

[18, с. 71]

$D_{stator}^T \leq 0.6 =$ 

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

$D_{CA} \leq 0.6 = 1$



Коэф. потерь полного давления:

$\zeta_{\text{rotor}}^T =$		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	0.1642	0.2239	0.2139												
	2	0.1334	0.1968	0.1814												
	3	0.1167	0.1666	0.1503												

$\zeta_{\text{stator}}^T =$		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	0.1062	0.2285	0.2447												
	2	0.0831	0.1859	0.1949												
	3	0.0692	0.1585	0.1640												

Качество профилей решеток РК и НА:

$\text{quality}_{\text{rotor}}^T =$		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	7.867	6.291	6.658												
	2	8.757	7.086	8.035												
	3	8.768	7.906	9.308												

$\text{quality}_{\text{stator}}^T =$		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	9.639	6.219	6.112												
	2	11.373	7.226	7.263												
	3	12.814	8.088	8.247												

КПД элементарной ступени:

$\eta_{\text{stage}}^T =$		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	.%
	1	76.99	71.59	71.40													
	2	76.42	73.27	74.09													
	3	74.25	73.18	74.39													



EXCEL<sub>AIRFOIL.subsonic</sub> =  
...\\A40.xlsx

X/B<sub>subsonic</sub> = submatrix( EXCEL<sub>AIRFOIL.subsonic</sub>, 2, rows( EXCEL<sub>AIRFOIL.subsonic</sub>), ORIGIN + 0, ORIGIN + 0)

Y/B<sub>subsonic</sub> = submatrix( EXCEL<sub>AIRFOIL.subsonic</sub>, 2, rows( EXCEL<sub>AIRFOIL.subsonic</sub>), ORIGIN + 1, ORIGIN + 1)

EXCEL<sub>AIRFOIL.supersonic</sub> =  
...\\Емин сверхзвуковой профиль.xlsx

X/B<sub>supersonic</sub> = submatrix( EXCEL<sub>AIRFOIL.supersonic</sub>, 2, rows( EXCEL<sub>AIRFOIL.supersonic</sub>), ORIGIN + 0, ORIGIN + 0)

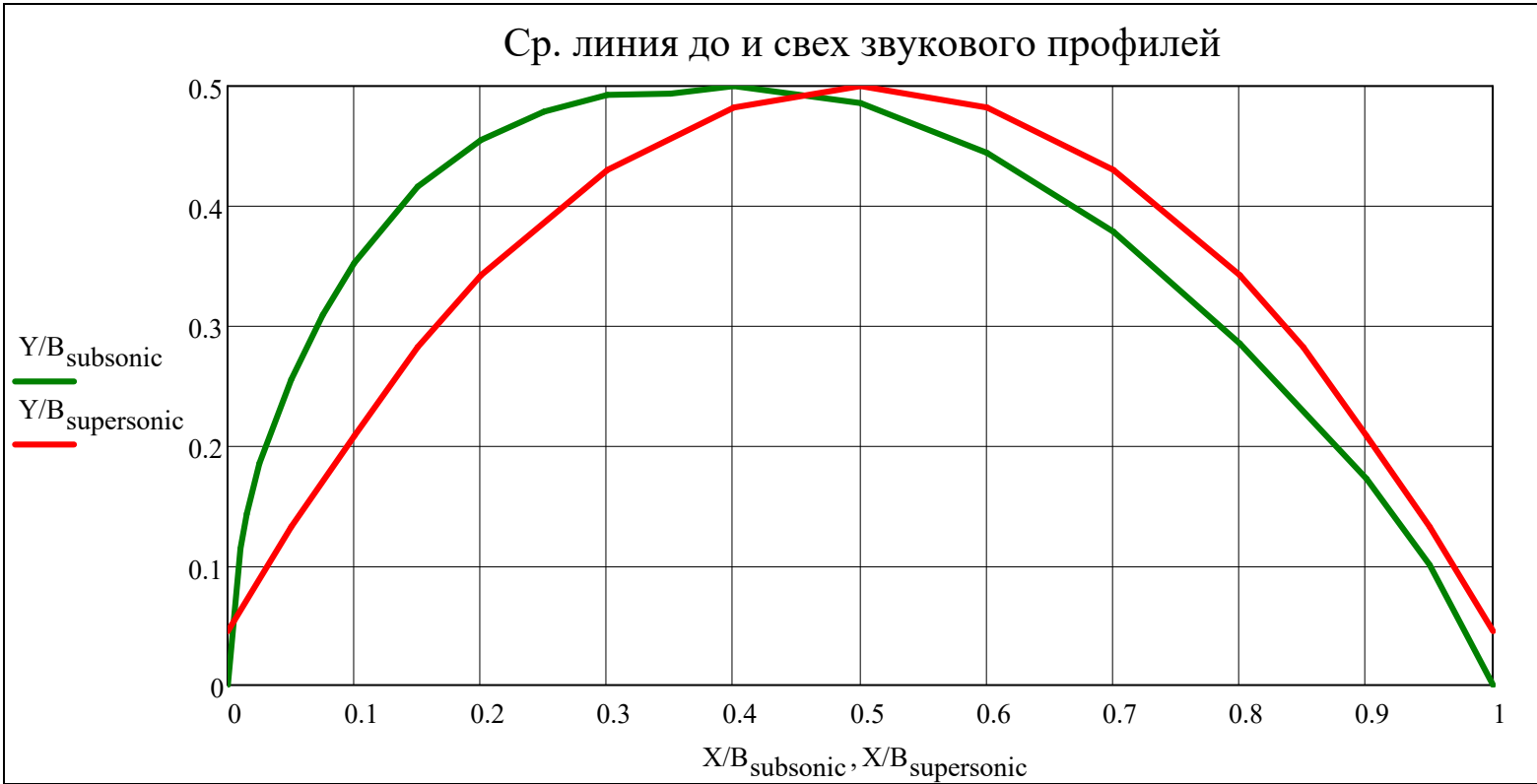
Y/B<sub>supersonic</sub> = submatrix( EXCEL<sub>AIRFOIL.supersonic</sub>, 2, rows( EXCEL<sub>AIRFOIL.supersonic</sub>), ORIGIN + 1, ORIGIN + 1)

augment( X/B<sub>subsonic</sub>, Y/B<sub>subsonic</sub> )<sup>T</sup> =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.000	0.010	0.015	0.025	0.050	0.075	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.500	0.600	0.700	0.800	0.900	0.950	1.000
2	0.000	0.114	0.143	0.185	0.255	0.309	0.352	0.416	0.455	0.479	0.493	0.494	0.500	0.486	0.444	0.378	0.285	0.172	0.100	0.000

augment( X/B<sub>supersonic</sub>, Y/B<sub>supersonic</sub> )<sup>T</sup> =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.000	0.050	0.100	0.150	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.850	0.900	0.950	1.000
2	0.045	0.132	0.208	0.282	0.342	0.430	0.482	0.500	0.482	0.430	0.342	0.282	0.208	0.132	0.045



AIRFOIL<sub>subsonic</sub>(x,line, $\overline{c}$ , $\theta$ ) =

if 0 ≤ x ≤ 1

$\text{interp}\left(\text{cspline}\left(X/B_{\text{subsonic}},y/b_{\text{cp.л}}\left(X/B_{\text{subsonic}},\theta\right)+Y/B_{\text{subsonic}}\cdot\overline{c}\right),X/B_{\text{subsonic}},y/b_{\text{cp.л}}\left(X/B_{\text{subsonic}},\theta\right)+Y/B_{\text{subsonic}}\cdot\overline{c},x\right)$

if line = "+"

$\text{interp}\left(\text{cspline}\left(X/B_{\text{subsonic}},y/b_{\text{cp.л}}\left(X/B_{\text{subsonic}},\theta\right)\right),X/B_{\text{subsonic}},y/b_{\text{cp.л}}\left(X/B_{\text{subsonic}},\theta\right),x\right)$

if line = "0"

$\text{interp}\left(\text{cspline}\left(X/B_{\text{subsonic}},y/b_{\text{cp.л}}\left(X/B_{\text{subsonic}},\theta\right)-Y/B_{\text{subsonic}}\cdot\overline{c}\right),X/B_{\text{subsonic}},y/b_{\text{cp.л}}\left(X/B_{\text{subsonic}},\theta\right)-Y/B_{\text{subsonic}}\cdot\overline{c},x\right)$

if line = "-"

NaN otherwise

AIRFOIL<sub>supersonic</sub>(x,line, $\overline{c}$ , $\theta$ ) =

if 0 ≤ x ≤ 1

$\text{interp}\left(\text{cspline}\left(X/B_{\text{supersonic}},y/b_{\text{cp.л}}\left(X/B_{\text{supersonic}},\theta\right)+Y/B_{\text{supersonic}}\cdot\overline{c}\right),X/B_{\text{supersonic}},y/b_{\text{cp.л}}\left(X/B_{\text{supersonic}},\theta\right)+Y/B_{\text{supersonic}}\cdot\overline{c},x\right)$

if line = "+"

$\text{interp}\left(\text{cspline}\left(X/B_{\text{supersonic}},y/b_{\text{cp.л}}\left(X/B_{\text{supersonic}},\theta\right)\right),X/B_{\text{supersonic}},y/b_{\text{cp.л}}\left(X/B_{\text{supersonic}},\theta\right),x\right)$

if line = "0"

$\text{interp}\left(\text{cspline}\left(X/B_{\text{supersonic}},y/b_{\text{cp.л}}\left(X/B_{\text{supersonic}},\theta\right)-Y/B_{\text{supersonic}}\cdot\overline{c}\right),X/B_{\text{supersonic}},y/b_{\text{cp.л}}\left(X/B_{\text{supersonic}},\theta\right)-Y/B_{\text{supersonic}}\cdot\overline{c},x\right)$

if line = "-"

NaN otherwise

x = 0,0.005.. 1

$\dot{w} = 1$









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

	1	2	3
1	35.57	45.89	65.57
2	39.55	51.20	73.27
3	43.08	55.90	79.95

$\cdot 10^{-3}$

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

	1	2	3
1	35.31	45.28	64.80
2	39.07	50.05	71.76
3	42.37	54.16	77.65

$\cdot 10^{-3}$

$$area_{stator}^T =$$

	1	2	3
1	27.22	44.00	90.69
2	55.60	89.89	185.62
3	91.47	147.83	304.72

$\cdot 10^{-6}$

$$Sx_{stator}^T =$$

	1	2	3
1	31.7	120.5	310.6
2	71.8	283.1	760.0
3	126.4	511.5	1392.7

$\cdot 10^{-9}$

$$Sy_{stator}^T =$$

	1	2	3
1	433.1	889.8	2633.2
2	979.2	2012.8	5972.5
3	1746.1	3587.6	10617.2

$\cdot 10^{-9}$

$$x0_{stator}^T =$$

	1	2	3
1	15.91	20.22	29.04
2	17.61	22.39	32.18
3	19.09	24.27	34.84

$\cdot 10^{-3}$

$$y0_{stator}^T =$$

	1	2	3
1	1.16	2.74	3.42
2	1.29	3.15	4.09
3	1.38	3.46	4.57

$\cdot 10^{-3}$

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

	1	2	3
1	63.84	71.14	80.24
2	72.47	77.89	87.86
3	80.95	86.62	97.69

$\cdot 10^{-3}$

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

	1	2	3
1	62.41	67.23	75.86
2	72.13	77.16	87.14
3	80.77	86.30	97.38

$\cdot 10^{-3}$

$$area_{rotor}^T =$$

	1	2	3
1	282.07	321.98	410.06
2	151.96	173.54	221.57
3	143.01	163.24	207.90

$\cdot 10^{-6}$

$$Sx_{rotor}^T =$$

	1	2	3
1	567.5	1830.2	2614.5
2	174.3	421.9	530.6
3	109.8	227.2	274.4

$\cdot 10^{-9}$

$$Sy_{rotor}^T =$$

	1	2	3
1	7911.0	9648.4	13867.0
2	4946.1	6036.3	8708.5
3	5214.2	6359.3	9139.7

$\cdot 10^{-9}$

$$x0_{rotor}^T =$$

	1	2	3
1	28.05	29.97	33.82
2	32.55	34.78	39.30
3	36.46	38.96	43.96

$\cdot 10^{-3}$

$$y0_{rotor}^T =$$

	1	2	3
1	2.01	5.68	6.38
2	1.15	2.43	2.39
3	0.77	1.39	1.32

$\cdot 10^{-3}$



$$J_{x_{\text{stator}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 42 & 367 & 1188 \\ 2 & 115 & 1012 & 3559 \\ 3 & 241 & 2069 & 7528 \end{array} \cdot 10^{-12}$$

$$J_{y_{\text{stator}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 8814 & 23022 & 97817 \\ 2 & 22061 & 57660 & 245859 \\ 3 & 42645 & 111393 & 473297 \end{array} \cdot 10^{-12}$$

$$J_{xy_{\text{stator}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 524 & 2533 & 9375 \\ 2 & 1315 & 6590 & 25420 \\ 3 & 2508 & 12903 & 50444 \end{array} \cdot 10^{-12}$$

$$J_{x0_{\text{stator}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 5.51 & 37.05 & 124.93 \\ 2 & 22.05 & 120.53 & 447.85 \\ 3 & 66.00 & 299.59 & 1162.81 \end{array} \cdot 10^{-12}$$

$$J_{y0_{\text{stator}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1925 & 5027 & 21360 \\ 2 & 4817 & 12591 & 53687 \\ 3 & 9313 & 24327 & 103364 \end{array} \cdot 10^{-12}$$

$$J_{xy0_{\text{stator}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 20.05 & 96.26 & 357.11 \\ 2 & 50.32 & 250.26 & 967.13 \\ 3 & 95.98 & 489.85 & 1918.18 \end{array} \cdot 10^{-12}$$

$$\alpha_{\text{major}_{\text{stator}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0.60 & 1.10 & 0.96 \\ 2 & 0.60 & 1.15 & 1.04 \\ 3 & 0.59 & 1.17 & 1.07 \end{array} \cdot ^\circ$$

$$J_{x_{\text{rotor}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1917 & 12258 & 19660 \\ 2 & 297 & 1228 & 1560 \\ 3 & 144 & 414 & 506 \end{array} \cdot 10^{-12}$$

$$J_{y_{\text{rotor}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 283876 & 369905 & 599965 \\ 2 & 205969 & 268621 & 437896 \\ 3 & 243225 & 316934 & 514049 \end{array} \cdot 10^{-12}$$

$$J_{xy_{\text{rotor}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 16551 & 56985 & 91868 \\ 2 & 5900 & 15260 & 21686 \\ 3 & 4161 & 9202 & 12545 \end{array} \cdot 10^{-12}$$

$$J_{x0_{\text{rotor}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 774.96 & 1855.03 & 2990.13 \\ 2 & 96.72 & 201.97 & 289.56 \\ 3 & 59.43 & 97.97 & 143.92 \end{array} \cdot 10^{-12}$$

$$J_{y0_{\text{rotor}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 61996 & 80784 & 131027 \\ 2 & 44976 & 58657 & 95620 \\ 3 & 53111 & 69207 & 112249 \end{array} \cdot 10^{-12}$$

$$J_{xy0_{\text{rotor}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 633.43 & 2141.99 & 3453.98 \\ 2 & 226.27 & 584.10 & 830.57 \\ 3 & 159.65 & 352.89 & 481.18 \end{array} \cdot 10^{-12}$$

$$\alpha_{\text{major}_{\text{rotor}}}^T = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0.59 & 1.55 & 1.54 \\ 2 & 0.29 & 0.57 & 0.50 \\ 3 & 0.17 & 0.29 & 0.25 \end{array} \cdot ^\circ$$

$J_{u_{stator}}$ <sup>T</sup> =

	1	2	3
1	5.30	35.19	118.93
2	21.52	115.51	430.29
3	65.01	289.61	1126.82

·10<sup>-12</sup>

$J_{v_{stator}}$ <sup>T</sup> =

	1	2	3
1	1925	5029	21366
2	4818	12596	53704
3	9314	24337	103400

·10<sup>-12</sup>

$J_{uv_{stator}}$ <sup>T</sup> =

	1	2	3
1	-0.00	-0.00	0.00
2	-0.00	0.00	0.00
3	0.00	0.00	-0.00

·10<sup>-12</sup>

$J_{p_{stator}}$ <sup>T</sup> =

	1	2	3
1	1930	5064	21485
2	4839	12711	54135
3	9379	24627	104527

·10<sup>-12</sup>

$W_{p_{stator}}$ <sup>T</sup> =

	1	2	3
1	99.7	205.0	606.5
2	225.9	464.4	1378.1
3	403.9	830.0	2456.4

·10<sup>-9</sup>

$stiffness_{stator}$ <sup>T</sup> =

	1	2	3
1	7.39	19.31	82.06
2	51.41	134.37	572.95
3	194.78	508.78	2161.75

·10<sup>-12</sup>

$J_{u_{rotor}}$ <sup>T</sup> =

	1	2	3
1	768.40	1796.94	2897.02
2	95.58	196.13	282.33
3	58.95	96.17	141.86

·10<sup>-12</sup>

$J_{v_{rotor}}$ <sup>T</sup> =

	1	2	3
1	62003	80842	131120
2	44977	58663	95628
3	53112	69209	112252

·10<sup>-12</sup>

$J_{uv_{rotor}}$ <sup>T</sup> =

	1	2	3
1	-0.00	0.00	0.00
2	0.00	0.00	0.00
3	0.00	0.00	0.00

·10<sup>-12</sup>

$J_{p_{rotor}}$ <sup>T</sup> =

	1	2	3
1	62771	82639	134017
2	45073	58859	95910
3	53171	69305	112393

·10<sup>-12</sup>

$W_{p_{rotor}}$ <sup>T</sup> =

	1	2	3
1	1840.0	2244.0	3225.2
2	1140.0	1391.3	2007.2
3	1200.8	1464.6	2104.9

·10<sup>-9</sup>

$stiffness_{rotor}$ <sup>T</sup> =

	1	2	3
1	2646.10	3448.00	5592.45
2	307.19	400.64	653.10
3	204.05	265.89	431.26

·10<sup>-12</sup>

$$CP_{x_{stator}}^T =$$

	1	2	3
1	12.328	15.673	22.502
2	13.648	17.353	24.936
3	14.794	18.807	27.002

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

$$CP_{y_{stator}}^T =$$

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

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

$$CP_{x_{rotor}}^T =$$

	1	2	3
1	21.736	23.223	26.207
2	25.225	26.956	30.459
3	28.256	30.189	34.069

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

$$CP_{y_{rotor}}^T =$$

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

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



Абс. координаты профиля:

Airfoil(type,x,line,i,r) =	<div><div>if type = "BHA"<div><div>AIRFOIL<sub>subsonic</sub><math>\left(x,\text{line},\overline{c}_{\text{BHA}_r},\varepsilon_{\text{BHA}_r}\right)</math> if <math>M_{c_{\text{st}(1,1),r}} &lt; 1</math></div><div>AIRFOIL<sub>supersonic</sub><math>\left(x,\text{line},\overline{c}_{\text{BHA}_r},\varepsilon_{\text{BHA}_r}\right)</math> otherwise</div></div></div><div><div>if type = "rotor"<div><div>AIRFOIL<sub>subsonic</sub><math>\left(x,\text{line},\overline{c}_{\text{rotor}_{i,r}},\varepsilon_{\text{rotor}_{i,r}}\right)</math> if <math>M_{w_{\text{st}(i,1),r}} &lt; 1</math></div><div>AIRFOIL<sub>supersonic</sub><math>\left(x,\text{line},\overline{c}_{\text{rotor}_{i,r}},\varepsilon_{\text{rotor}_{i,r}}\right)</math> otherwise</div></div></div><div><div>if type = "stator"<div><div>AIRFOIL<sub>subsonic</sub><math>\left(x,\text{line},\overline{c}_{\text{stator}_{i,r}},\varepsilon_{\text{stator}_{i,r}}\right)</math> if <math>M_{c_{\text{st}(i,2),r}} &lt; 1</math></div><div>AIRFOIL<sub>supersonic</sub><math>\left(x,\text{line},\overline{c}_{\text{stator}_{i,r}},\varepsilon_{\text{stator}_{i,r}}\right)</math> otherwise</div></div></div><div><div>if type = "CA"<div><div>AIRFOIL<sub>subsonic</sub><math>\left(x,\text{line},\overline{c}_{\text{CA}_r},\varepsilon_{\text{CA}_r}\right)</math> if <math>M_{c_{\text{st}(Z,3),r}} &lt; 1</math></div><div>AIRFOIL<sub>supersonic</sub><math>\left(x,\text{line},\overline{c}_{\text{CA}_r},\varepsilon_{\text{CA}_r}\right)</math> otherwise</div></div></div></div></div></div></div>
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Рассматриваемая ступень:

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

Построение профилей Л РК и НА

AXLE0(type,x,i,r) =

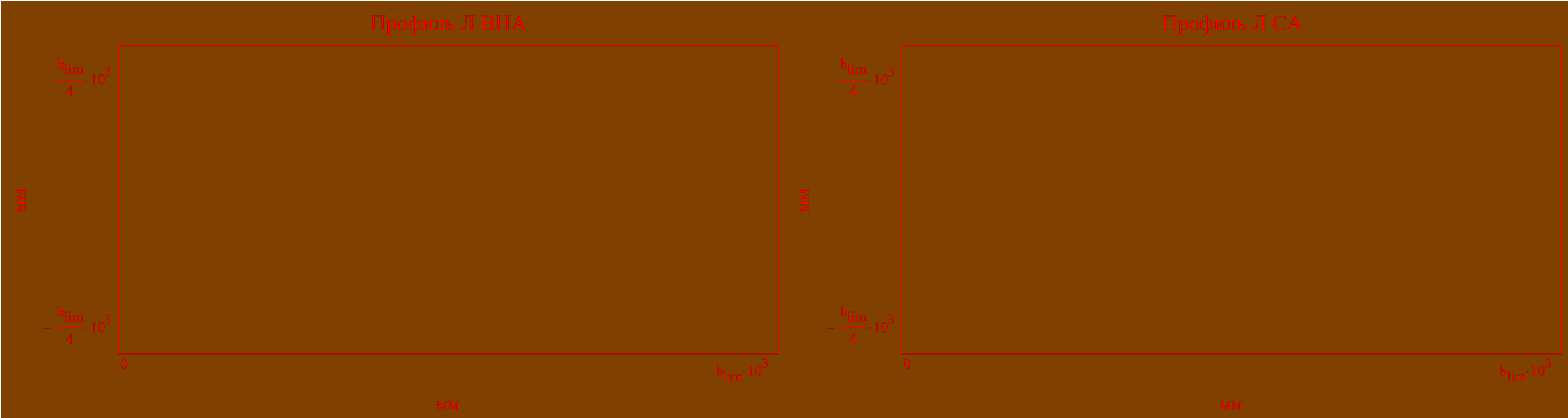
$$\begin{cases} \frac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \tan\left(\alpha_{\text{major}_{\text{rotor}_{i,r}}}\right) \cdot \left(x - \frac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if type = "rotor"} \\ \frac{y0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}}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

AXLE90(type,x,i,r) =

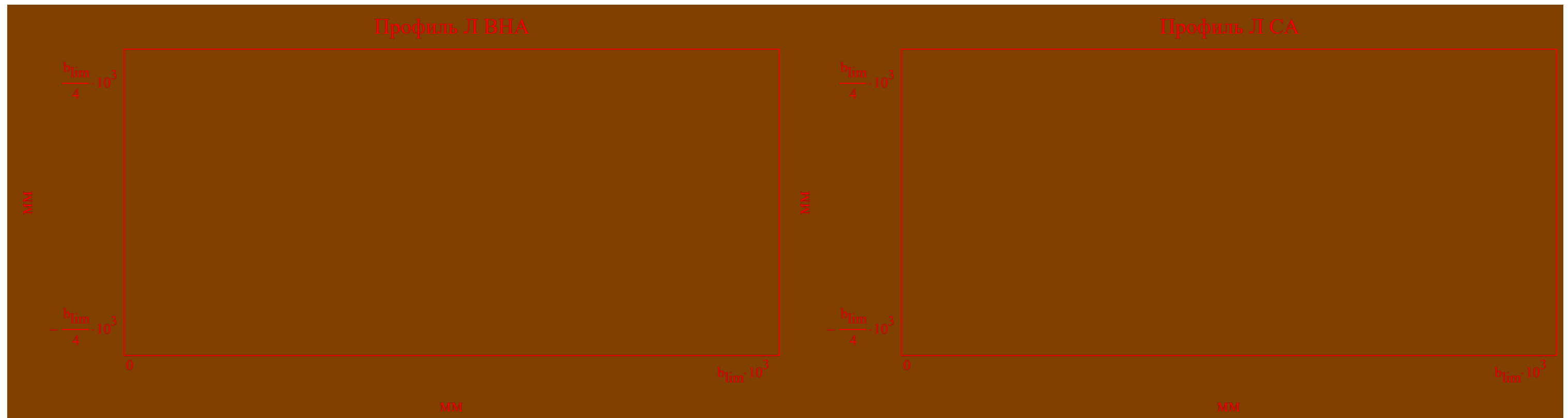
$$\begin{cases} \frac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \tan\left(\alpha_{\text{major}_{\text{rotor}_{i,r}}} + \frac{\pi}{2}\right) \cdot \left(x - \frac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if (type = "rotor") } \wedge \left|\alpha_{\text{major}_{\text{rotor}_{i,r}}}\right|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

$$b_{\text{lim}} = \frac{\text{ceil}\left(\max\left(\text{chord}_{\text{rotor}_{j,N_r}}, \text{chord}_{\text{stator}_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 90 \cdot 10^{-3}$$

$r = 1$

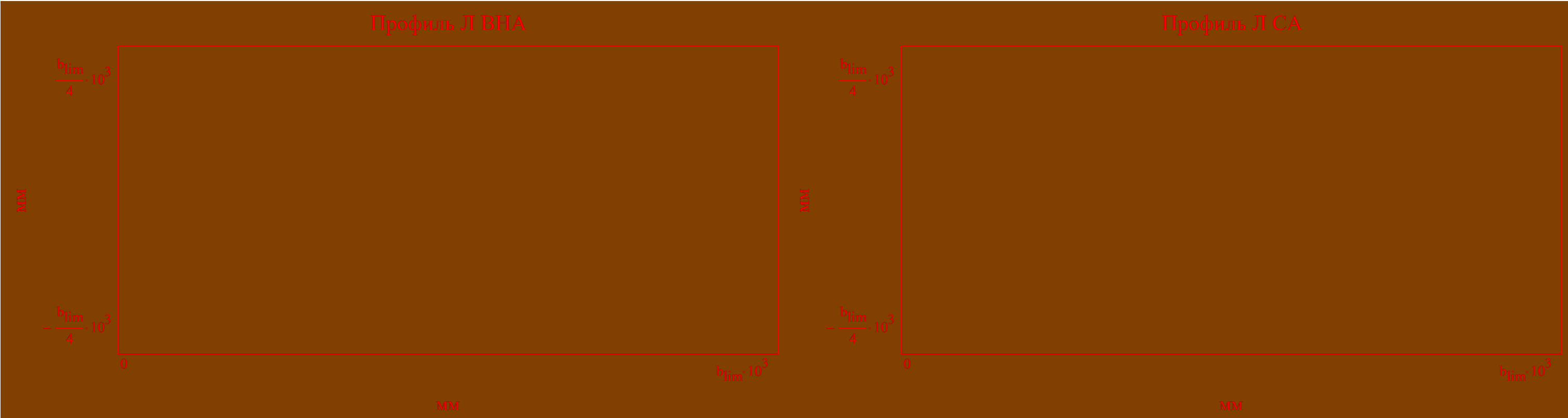


$$\underline{r} = \text{av}(\mathbf{N}_r)$$

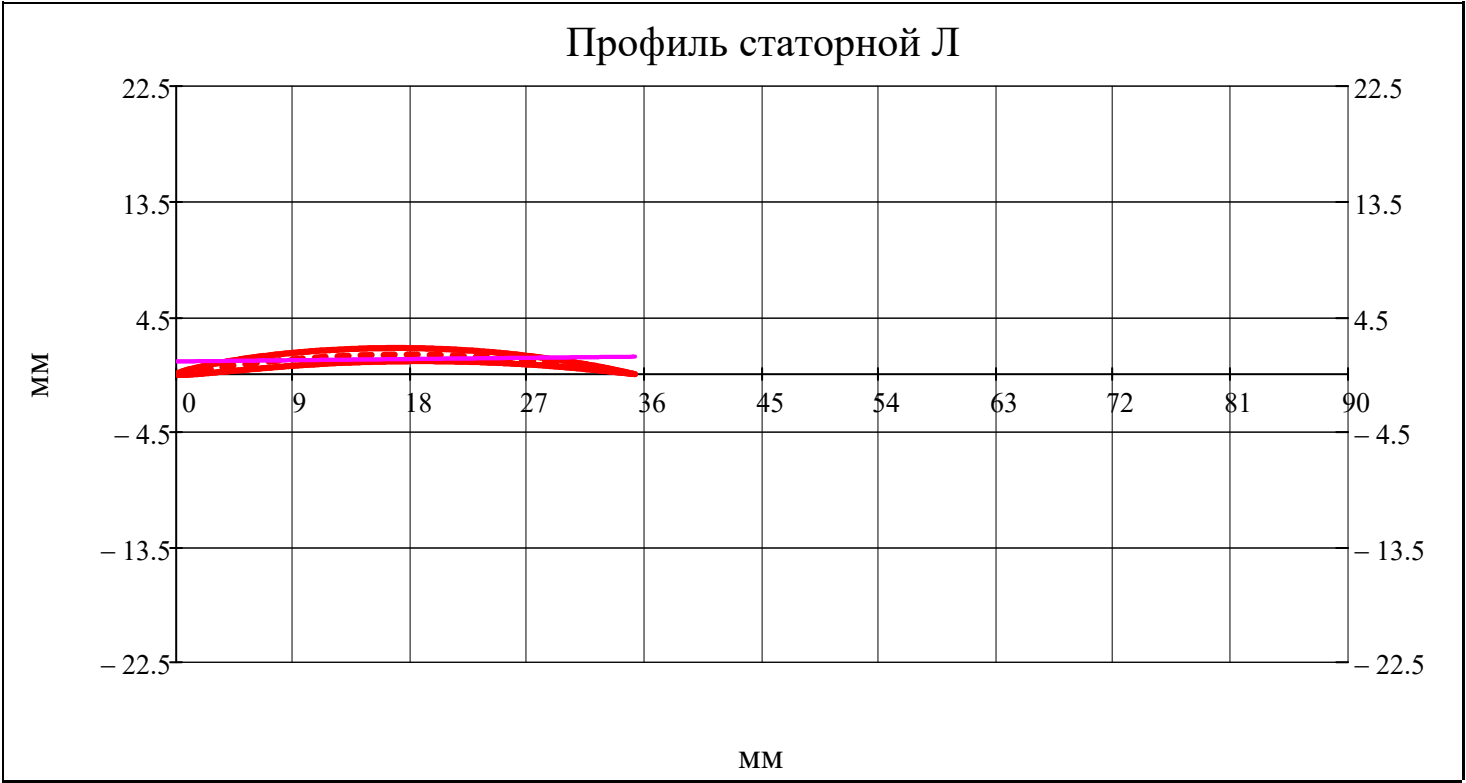
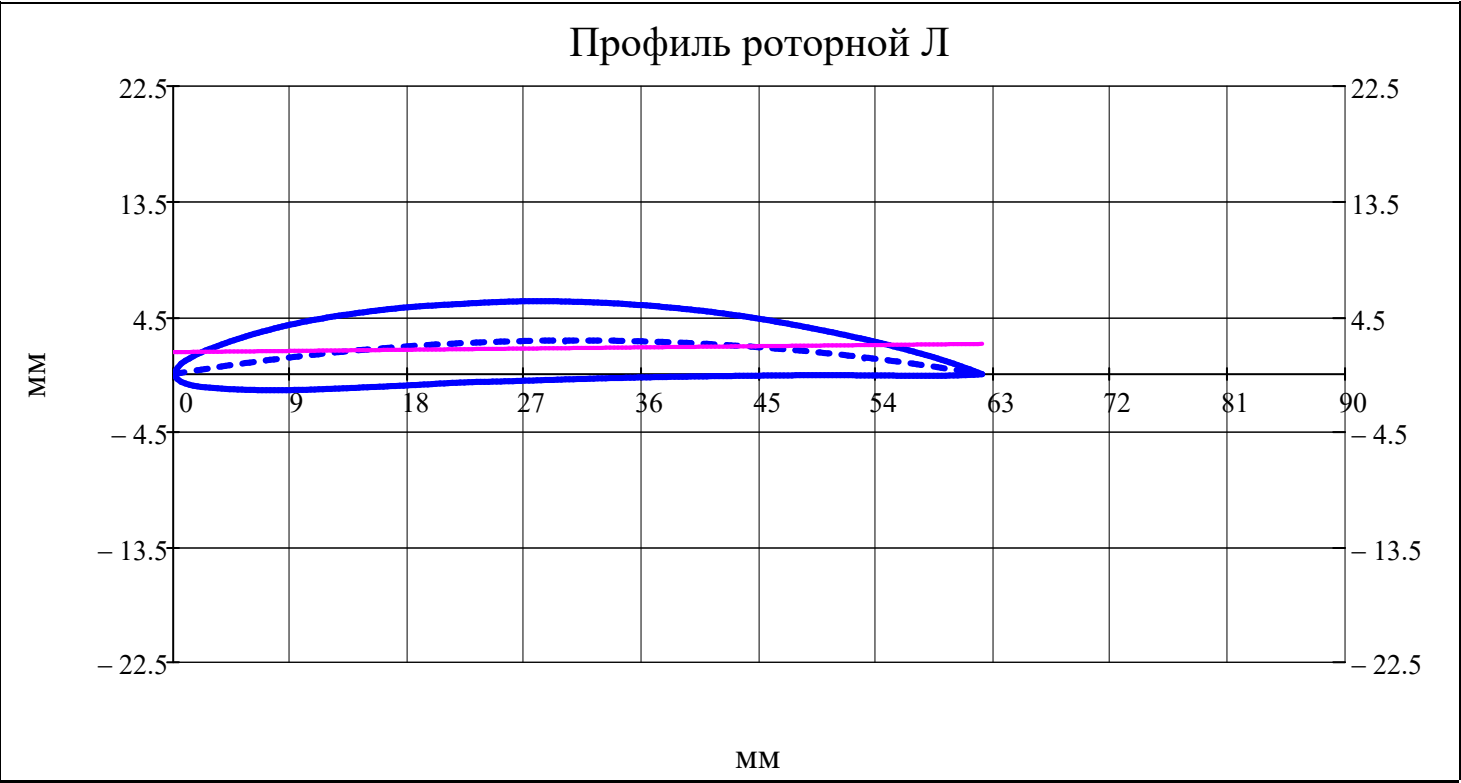




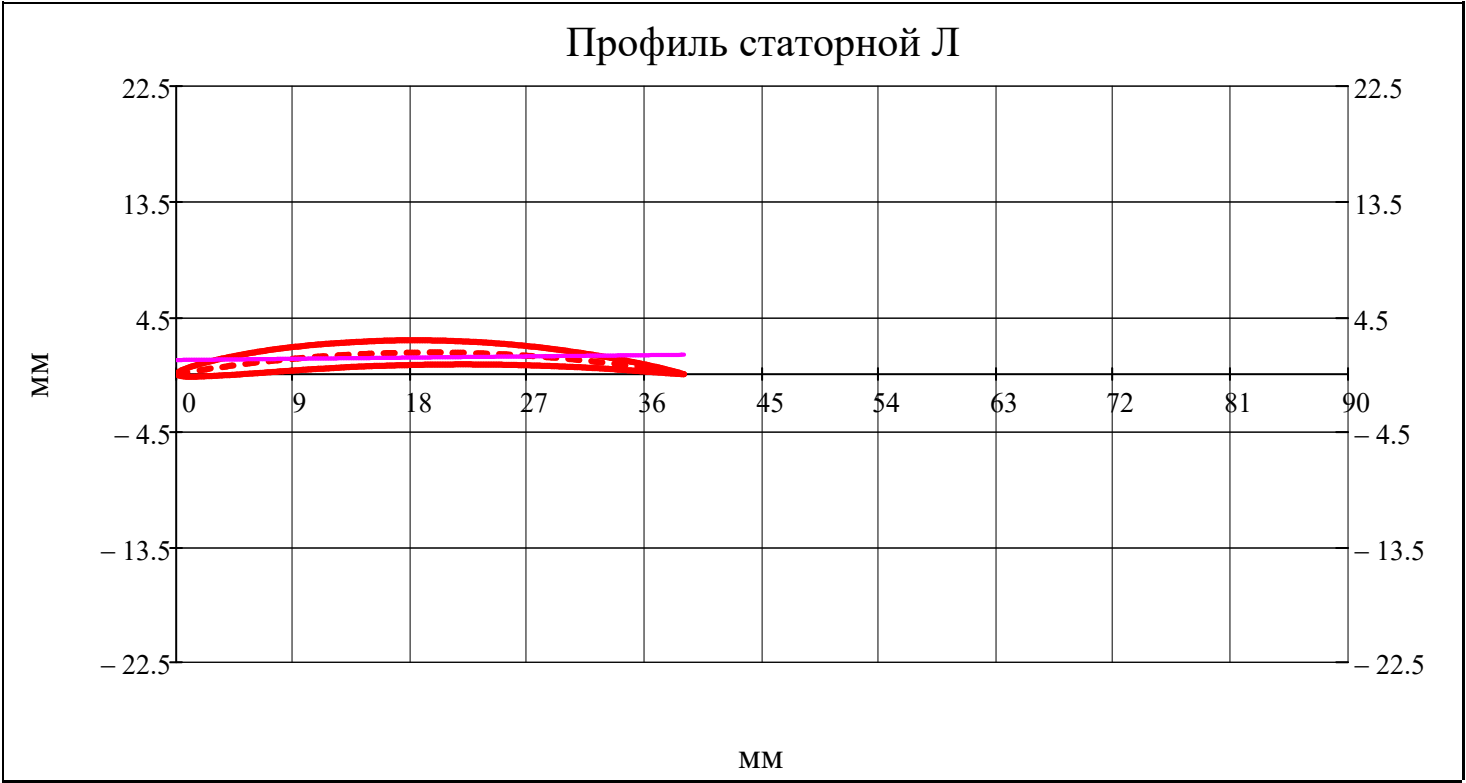
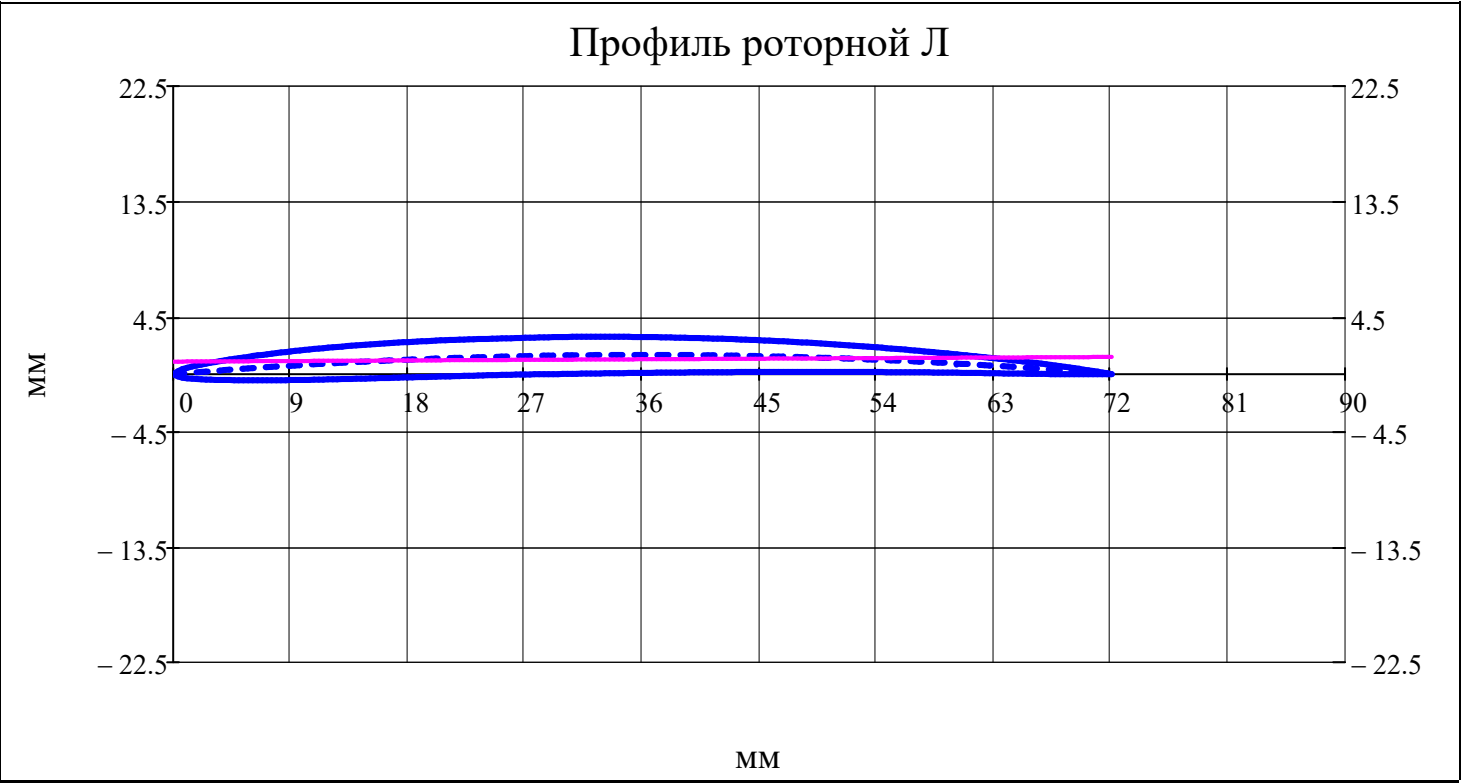
$r_w = N_r$



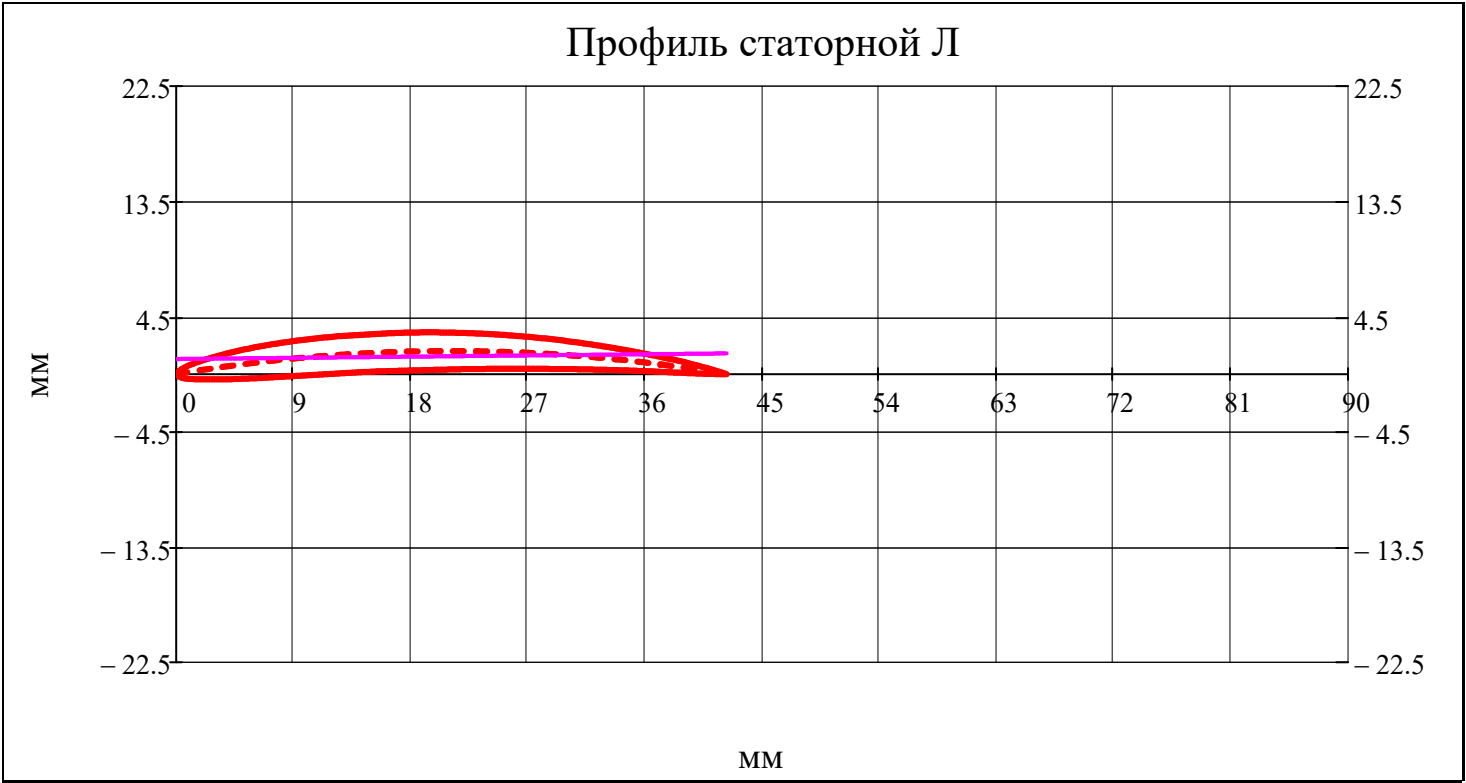
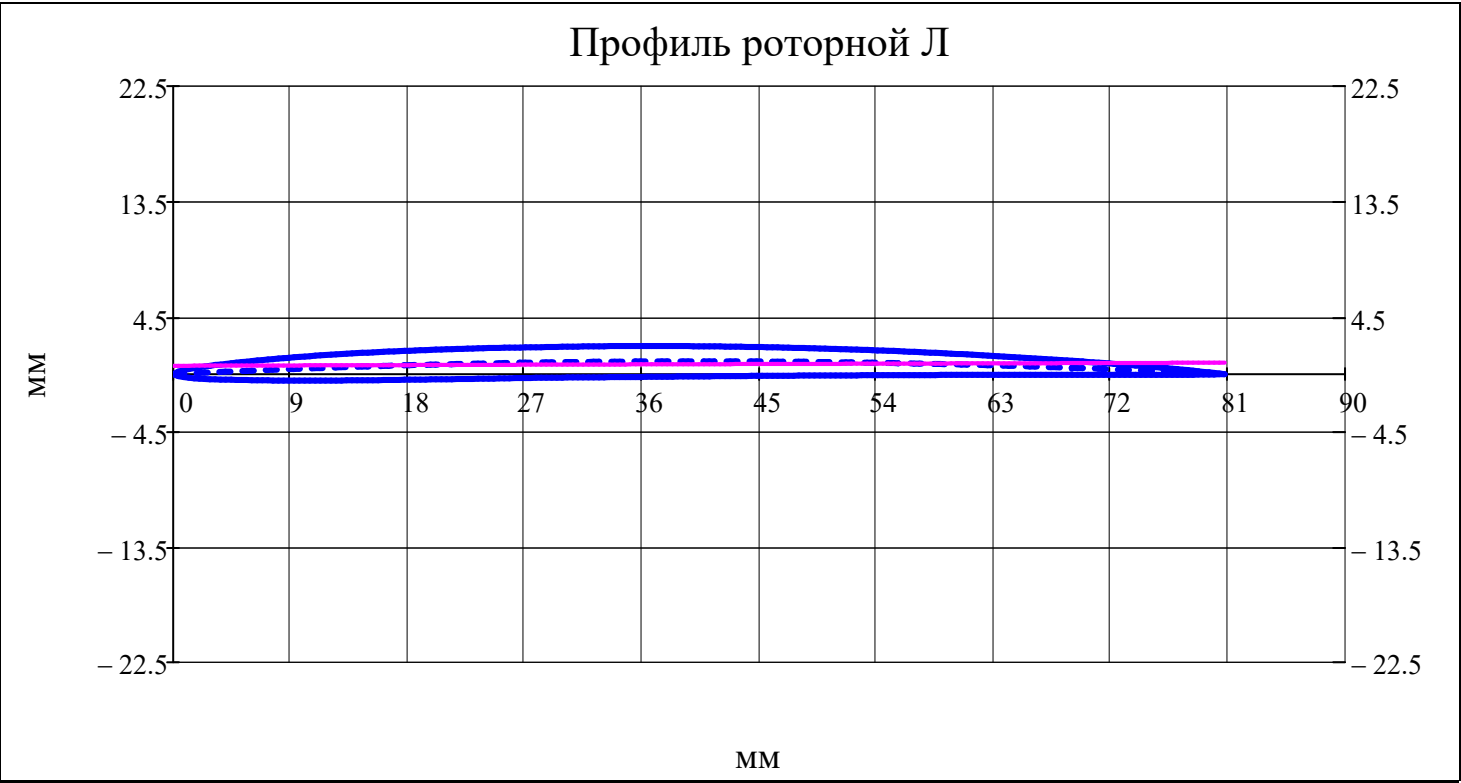
$r_w = 1$



$r_w = av(N_r)$



$r_w = N_r$





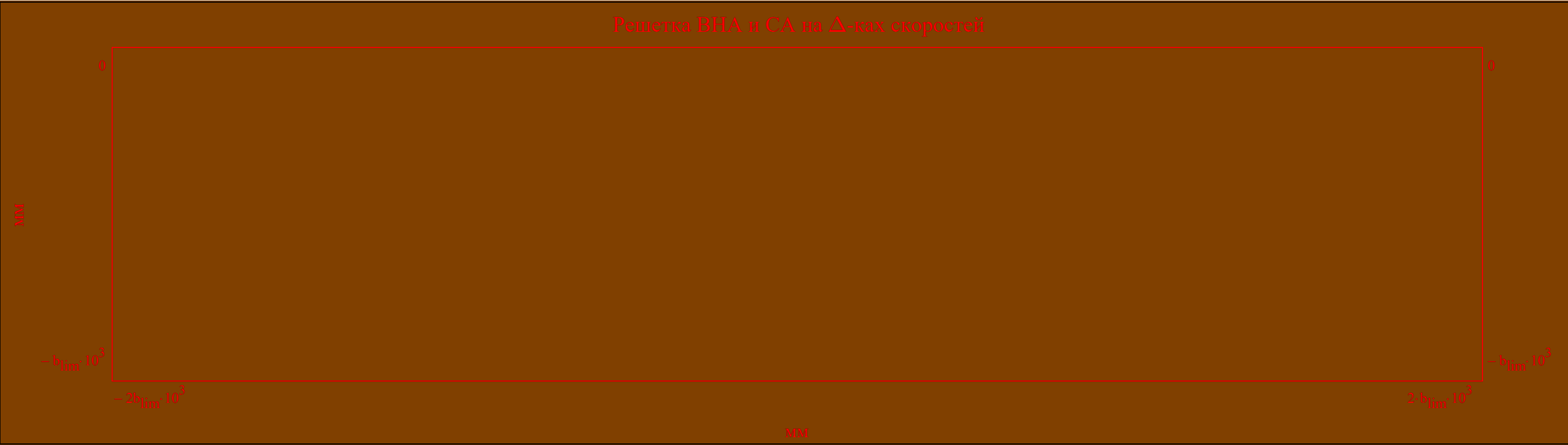
Рассматриваемая ступень:

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

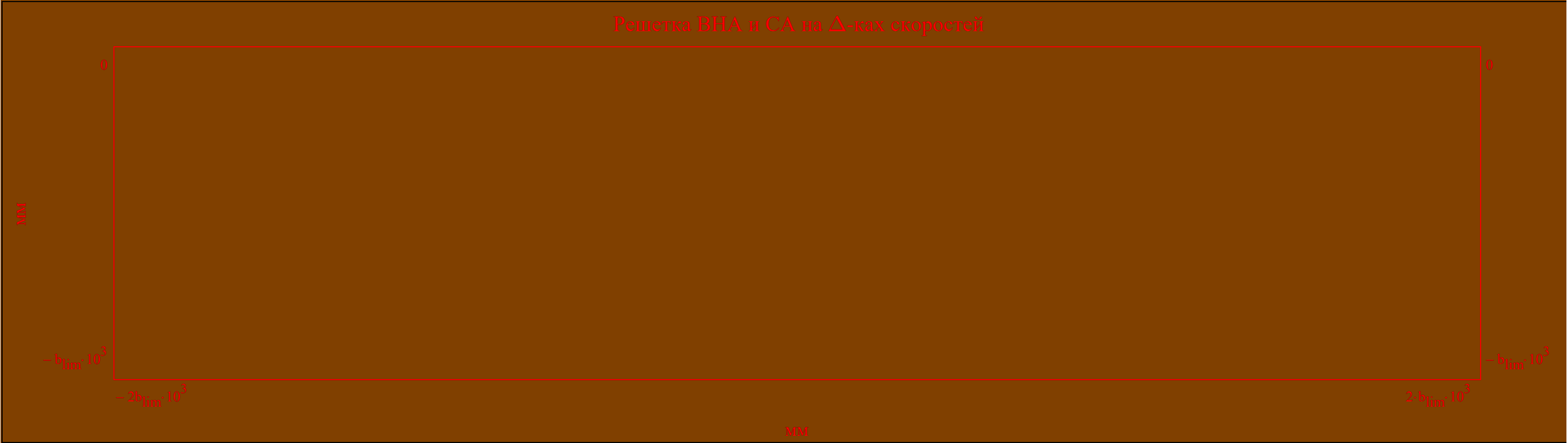
$$b_{lim} = \frac{ceil\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 90 \cdot 10^{-3}$$

Построение плоских решеток профилей Л РК и НА (+ ВНА и СА) на треугольниках скоростей

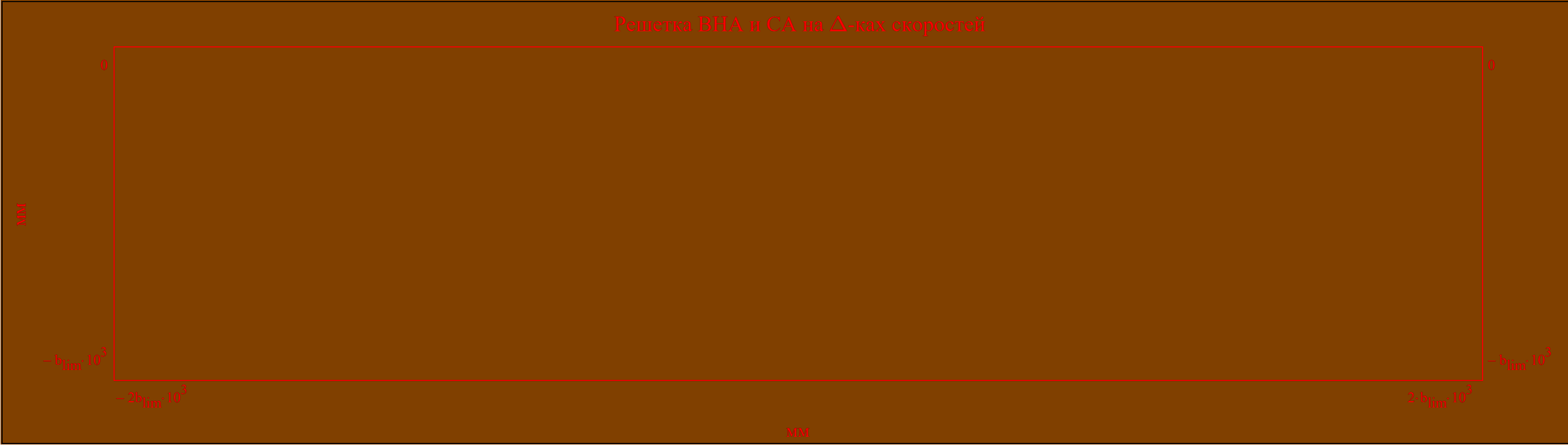
$$r_w = 1$$



$\tilde{r}_w = \text{av}\left(N_r\right)$

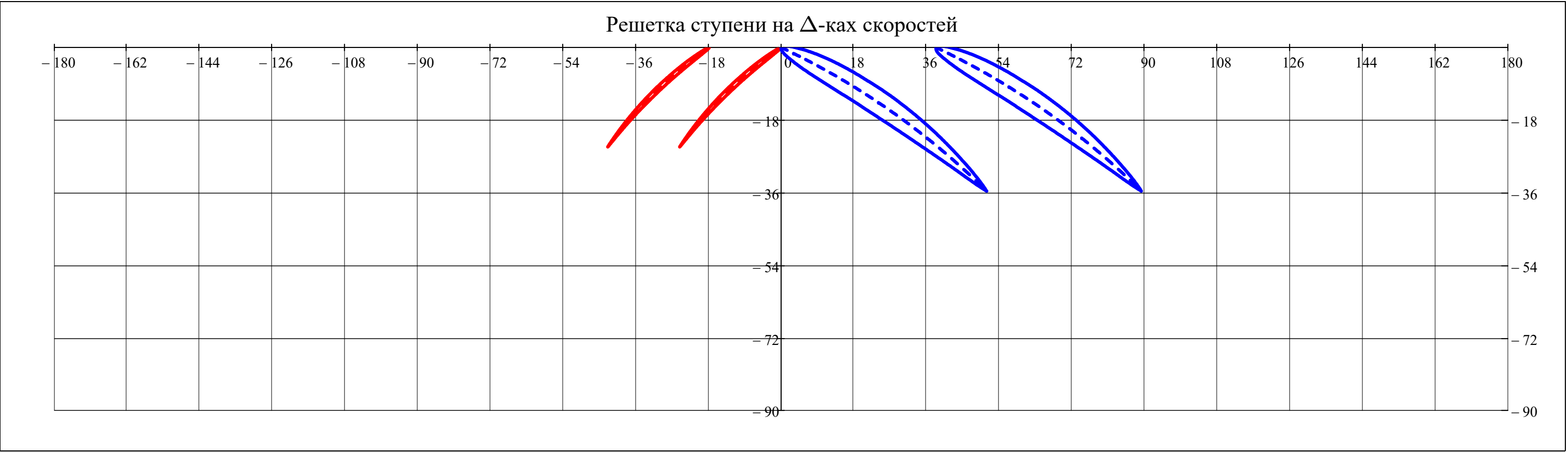


$\tilde{r}_w = N_r$

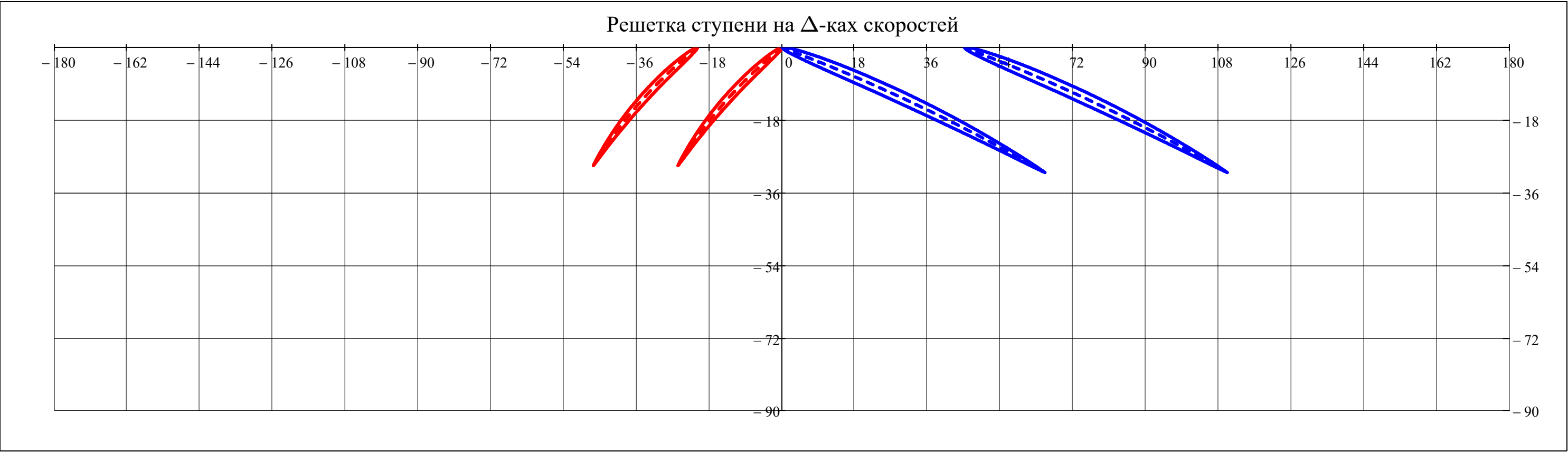




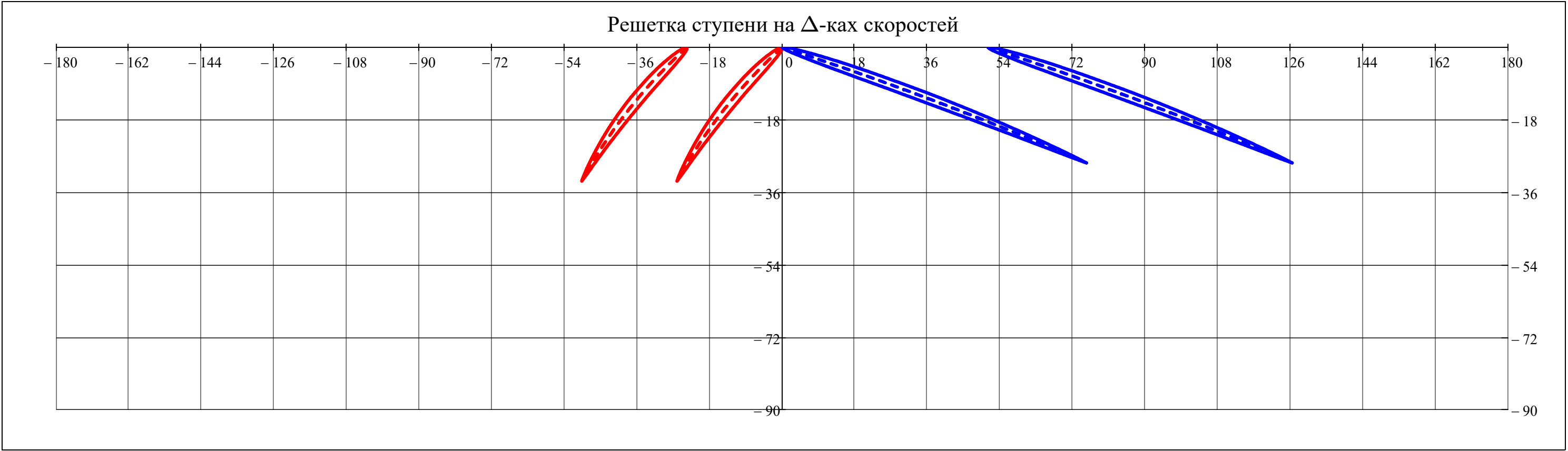
$r_w = 1$



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



$r_w = N_r$



Построение плоских решеток профилей Л РК и НА (+ ВНА и СА) на треугольниках скоростей



Радиальный зазор (м)  
[с.64 казаджан]:  

$\overline{\Delta}_r = 0.0025$

$0.0015 \leq \overline{\Delta}_r \leq 0.0035 = 1$

$$\Delta_{r_i} = \overline{\Delta}_r \cdot D_{st(i, 2), N_r}$$

$$\Delta_r^T = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 2.56 & 2.51 & 2.36 \\ \hline \end{array} \cdot 10^{-3}$$

Относительный осевой зазор () [16,с. 245]:  

$\overline{\Delta}_a = 0.17$

$0.1 \leq \overline{\Delta}_a \leq 0.2 = 1$

Осевой зазор (м):  
$$\Delta a_i = \overline{\Delta}_a \cdot \text{chord}_{\text{rotor}_{i, av}(N_r)}$$

$$\Delta a^T = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 12.25 & 13.09 & 14.79 \\ \hline \end{array} \cdot 10^{-3}$$

Односторонний осевой зазор (м):

$$\frac{\Delta a^T}{2} = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 6.13 & 6.55 & 7.40 \\ \hline \end{array} \cdot 10^{-3}$$

Длина ОК (м):

$$\text{Length} = \left[ \begin{array}{l} \Delta a_1 + \left\{ \begin{array}{l} \text{chord}_{\text{BHA}_{av}(N_r)} \cdot \sin\left(v_{\text{BHA}_{av}(N_r)}\right) \text{ if BHA} = 1 \quad \dots \\ 0 \text{ otherwise} \end{array} \right. \\ + \sum_{i=1}^Z \left( \text{chord}_{\text{rotor}_{i, av}(N_r)} \cdot \sin\left(v_{\text{rotor}_{i, av}(N_r)}\right) \right) + 2 \cdot \sum_{i=1}^Z \Delta a_i + \sum_{i=1}^Z \left( \text{chord}_{\text{stator}_{i, av}(N_r)} \cdot \sin\left(v_{\text{stator}_{i, av}(N_r)}\right) \right) \dots \\ + \left\{ \begin{array}{l} \text{chord}_{\text{CA}_{av}(N_r)} \cdot \sin\left(v_{\text{CA}_{av}(N_r)}\right) \text{ if CA} = 1 \quad + \Delta a_Z \\ 0 \text{ otherwise} \end{array} \right. \end{array} \right] = 337.8 \cdot 10^{-3}$$

$x_{\text{ПЧ}}$  $y_{\text{ПЧпер}}$  $y_{\text{ПЧср}}$  $y_{\text{ПЧкор}}$  $y_{\text{Лпер}}$

=

$c = 1$

$x_{\text{ПЧ}}_c = \begin{cases} \text{chord}_{\text{BHA}_{\text{av}}(N_r)} \cdot \sin\left(v_{\text{BHA}_{\text{av}}(N_r)}\right) & \text{if } \text{BHA} = 1 \\ 0 & \text{otherwise} \end{cases}$

$y_{\text{ПЧпер}}_c = R_{\text{st}(c, 1), N_r}$

$y_{\text{Лпер}}_c = y_{\text{ПЧпер}}_c - \Delta_{r_c}$

$y_{\text{ПЧср}}_c = R_{\text{st}(c, 1), \text{av}(N_r)}$

$y_{\text{ПЧкор}}_c = R_{\text{st}(c, 1), \text{ORIGIN}}$

for  $i \in 1..Z$

$c = c + 1$

$x_{\text{ПЧ}}_c = x_{\text{ПЧ}}_{c-1} + 0.5 \cdot \Delta a_i + \text{chord}_{\text{rotor}_{i, \text{av}}(N_r)} \cdot \sin\left(v_{\text{rotor}_{i, \text{av}}(N_r)}\right) + 0.5 \cdot \Delta a_i$

$\begin{pmatrix} y_{\text{ПЧпер}}_c \\ y_{\text{ПЧср}}_c \\ y_{\text{ПЧкор}}_c \end{pmatrix} = \begin{pmatrix} R_{\text{st}(i, 2), N_r} \\ R_{\text{st}(i, 2), \text{av}(N_r)} \\ R_{\text{st}(i, 2), \text{ORIGIN}} \end{pmatrix}$

$y_{\text{Лпер}}_c = y_{\text{ПЧпер}}_c - \Delta_{r_i}$

$c = c + 1$

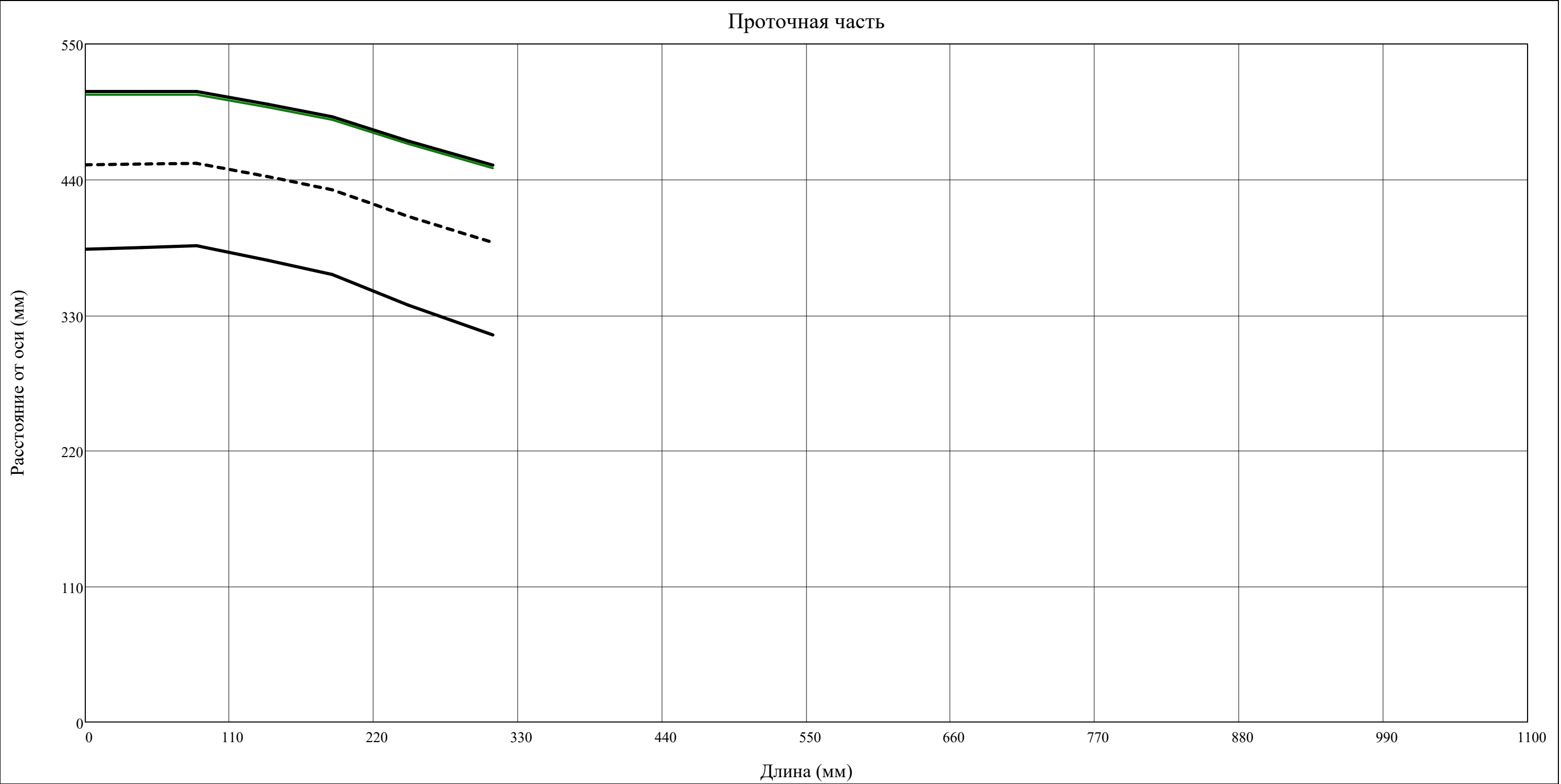
$x_{\text{ПЧ}}_c = x_{\text{ПЧ}}_{c-1} + 0.5 \cdot \Delta a_i + \text{chord}_{\text{stator}_{i, \text{av}}(N_r)} \cdot \sin\left(v_{\text{stator}_{i, \text{av}}(N_r)}\right) + 0.5 \cdot \Delta a_i$

$\begin{pmatrix} y_{\text{ПЧпер}}_c \\ y_{\text{ПЧср}}_c \\ y_{\text{ПЧкор}}_c \end{pmatrix} = \begin{pmatrix} R_{\text{st}(i, 3), N_r} \\ R_{\text{st}(i, 3), \text{av}(N_r)} \\ R_{\text{st}(i, 3), \text{ORIGIN}} \end{pmatrix}$

$y_{\text{Лпер}}_c = y_{\text{ПЧпер}}_c - \Delta_{r_i}$

$\begin{pmatrix} x_{\text{ПЧ}} & y_{\text{ПЧпер}} & y_{\text{ПЧср}} & y_{\text{ПЧкор}} & y_{\text{Лпер}} \end{pmatrix}^T$

$y_{\text{ПЧпер}}(l) = \text{interp}\left(\text{cspline}\left(x_{\text{ПЧ}}, y_{\text{ПЧпер}}\right), x_{\text{ПЧ}}, y_{\text{ПЧпер}}, l\right)$  $y_{\text{ПЧср}}(l) = \text{interp}\left(\text{cspline}\left(x_{\text{ПЧ}}, y_{\text{ПЧср}}\right), x_{\text{ПЧ}}, y_{\text{ПЧср}}, l\right)$  $y_{\text{ПЧкор}}(l) = \text{interp}\left(\text{cspline}\left(x_{\text{ПЧ}}, y_{\text{ПЧкор}}\right), x_{\text{ПЧ}}, y_{\text{ПЧкор}}, l\right)$  $y_{\text{Лпер}}(l) = \text{interp}\left(\text{cspline}\left(x_{\text{ПЧ}}, y_{\text{Лпер}}\right), x_{\text{ПЧ}}, y_{\text{Лпер}}, l\right)$



Рассматриваемая ступень:

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

▼ Поперечная часть ступени

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

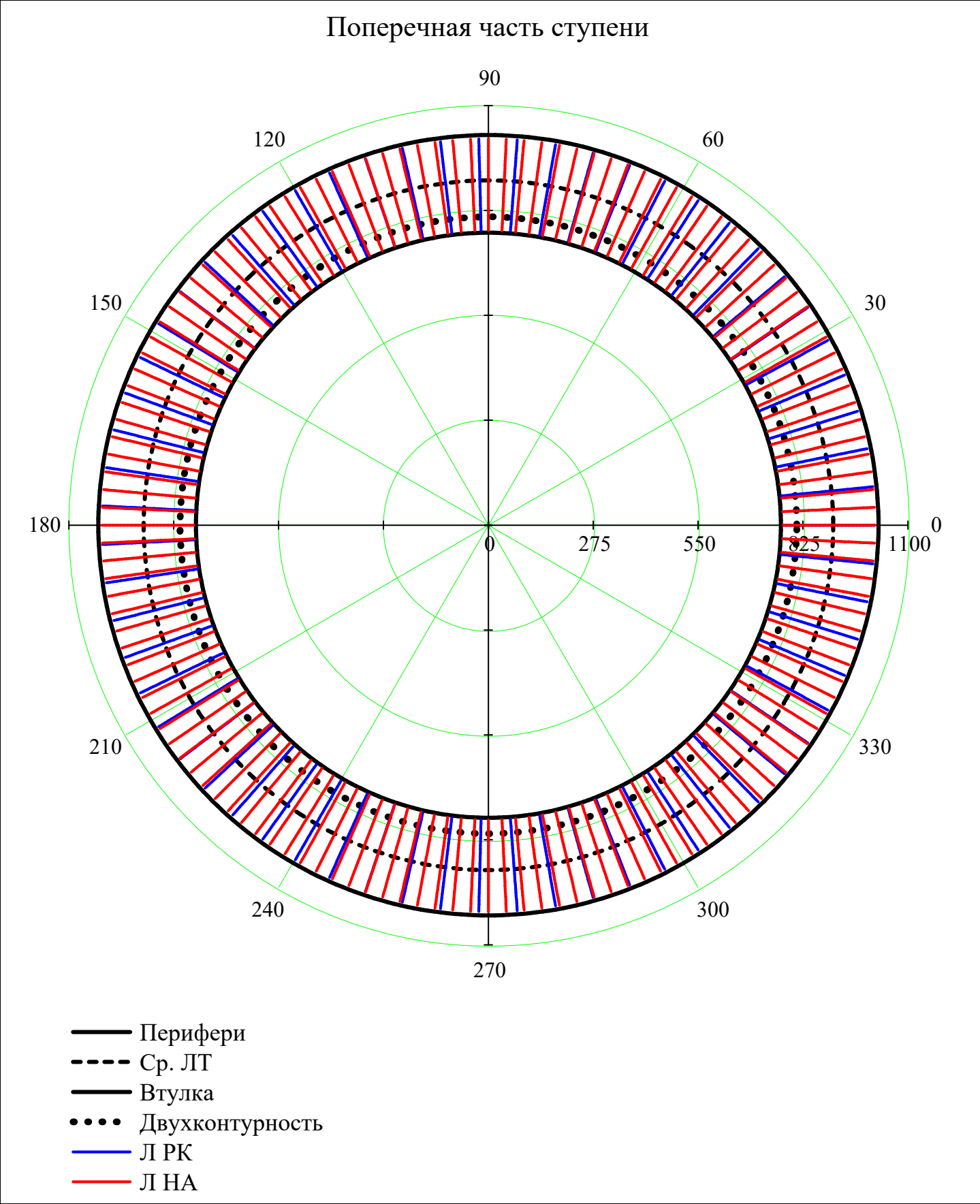
$$i_{\text{rotor}} = 1 \dots Z_{\text{rotor}_j}$$

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

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

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





Запас по температуре (K):

$\Delta T_{\text{safety}} = 50$

Выбранный материал Л:

$\text{material\_blade}_i = \begin{cases} \text{"ЖС-6K"} & \text{if } 1123 \leq T_{\text{st}(i, 2), \text{av}(N_r)}^* + \Delta T_{\text{safety}} \\ \text{"BT41"} & \text{if } 873 \leq T_{\text{st}(i, 2), \text{av}(N_r)}^* + \Delta T_{\text{safety}} < 1123 \\ \text{"BT25"} & \text{if } 753 \leq T_{\text{st}(i, 2), \text{av}(N_r)}^* + \Delta T_{\text{safety}} < 873 \\ \text{"BT9"} & \text{otherwise} \end{cases}$

$\text{material\_blade}_i = \begin{cases} \text{"BT23"} & \text{if compressor = "Бл"} \\ \text{"BT6"} & \text{if compressor = "КНД"} \\ \text{material\_blade}_i & \text{otherwise} \end{cases}$

Плотность материала Л (кг/м^3):

$\rho_{\text{blade}_i} = \begin{cases} 8393 & \text{if material\_blade}_i = \text{"ЖС-6K"} \\ 7900 & \text{if material\_blade}_i = \text{"BT41"} \\ 4500 & \text{if material\_blade}_i = \text{"BT25"} \\ 4570 & \text{if material\_blade}_i = \text{"BT23"} \\ 4510 & \text{if material\_blade}_i = \text{"BT9"} \\ 4430 & \text{if material\_blade}_i = \text{"BT6"} \\ \text{NaN} & \text{otherwise} \end{cases}$

Предел длительной прочности Л РК (Па):

$\sigma_{\text{blade\_long}_i} = 10^6 \cdot \begin{cases} 125 & \text{if material\_blade}_i = \text{"ЖС-6K"} \\ 123 & \text{if material\_blade}_i = \text{"BT41"} \\ 150 & \text{if material\_blade}_i = \text{"BT25"} \\ 230 & \text{if material\_blade}_i = \text{"BT23"} \\ 200 & \text{if material\_blade}_i = \text{"BT9"} \\ 210 & \text{if material\_blade}_i = \text{"BT6"} \\ \text{NaN} & \text{otherwise} \end{cases}$

Коэф. формы:

$k_n = 6.8$

Модуль Юнга I рода материала Л (Па):

$E_{\text{blade}} = 210 \cdot 10^9$

Коэф. Пуассона материала Л():

$\mu_{\text{steel}} = 0.3$

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

	1	2	3	4	5	6	7	8	9
1	"BT6"	"BT6"	"BT6"						

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

	1	2	3
1	4430	4430	4430

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

	1	2	3
1	210.0	210.0	210.0

$\cdot 10^6$

$$\begin{pmatrix} \nu0_{\text{изг.stator}} & \nu0_{\text{изг.rotor}} \\ \nu0_{\text{угл.stator}} & \nu0_{\text{угл.rotor}} \\ \nu0_{\text{угл.stator\_bondage}} & \nu0_{\text{угл.rotor\_bondage}} \end{pmatrix}$$

=

for i ∈ 1..Z

for r ∈ av(N<sub>r</sub>)

for mode ∈ 1..6

$$\nu0_{\text{изг.stator}_{i,\text{mode}}} = \nu0_{\text{изгиб}}\left(\text{mode}, \text{mean}\left(h_{\text{st}}(i, 2), h_{\text{st}}(i, 3)\right), E_{\text{blade}}, \rho_{\text{blade}_i}, \text{area}_{\text{stator}_{i,r}}, J_{\text{u}_{\text{stator}_{i,r}}}\right)$$

$$\nu0_{\text{изг.rotor}_{i,\text{mode}}} = \nu0_{\text{изгиб}}\left(\text{mode}, \text{mean}\left(h_{\text{st}}(i, 1), h_{\text{st}}(i, 2)\right), E_{\text{blade}}, \rho_{\text{blade}_i}, \text{area}_{\text{rotor}_{i,r}}, J_{\text{u}_{\text{rotor}_{i,r}}}\right)$$

$$\nu0_{\text{угл.stator}_{i,\text{mode}}} = \nu0_{\text{угл}}\left(\text{mode}, 0, \text{mean}\left(h_{\text{st}}(i, 2), h_{\text{st}}(i, 3)\right), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{stator}_{i,r}}, J_{\text{p}_{\text{stator}_{i,r}}}\right)$$

$$\nu0_{\text{угл.rotor}_{i,\text{mode}}} = \nu0_{\text{угл}}\left(\text{mode}, 0, \text{mean}\left(h_{\text{st}}(i, 1), h_{\text{st}}(i, 2)\right), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{rotor}_{i,r}}, J_{\text{p}_{\text{rotor}_{i,r}}}\right)$$

$$\nu0_{\text{угл.stator\_bondage}_{i,\text{mode}}} = \nu0_{\text{угл}}\left(\text{mode}, 1, \text{mean}\left(h_{\text{st}}(i, 2), h_{\text{st}}(i, 3)\right), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{stator}_{i,r}}, J_{\text{p}_{\text{stator}_{i,r}}}\right)$$

$$\nu0_{\text{угл.rotor\_bondage}_{i,\text{mode}}} = \nu0_{\text{угл}}\left(\text{mode}, 1, \text{mean}\left(h_{\text{st}}(i, 1), h_{\text{st}}(i, 2)\right), \text{Jung}(2, \mu_{\text{steel}}, E_{\text{blade}}), \rho_{\text{blade}_i}, \text{stiffness}_{\text{rotor}_{i,r}}, J_{\text{p}_{\text{rotor}_{i,r}}}\right)$$

$$\begin{pmatrix} \nu0_{\text{изг.stator}} & \nu0_{\text{изг.rotor}} \\ \nu0_{\text{угл.stator}} & \nu0_{\text{угл.rotor}} \\ \nu0_{\text{угл.stator\_bondage}} & \nu0_{\text{угл.rotor\_bondage}} \end{pmatrix}$$

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

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	875	862	811	693	700	675												
2	2625	2587	2434	2078	2100	2024												
3	4375	4312	4056	3464	3500	3374												
4	6124	6037	5679	4850	4901	4724												
5	7874	7762	7302	6235	6301	6073												
6	9624	9486	8924	7621	7701	7423												

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

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	152	270	320	189	259	255												
2	950	1690	2006	1183	1622	1599												
3	2660	4732	5618	3314	4542	4479												
4	5216	9280	11017	6499	8907	8783												
5	8619	15334	18205	10738	14718	14513												
6	12872	22901	27187	16037	21980	21675												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1750	1725	1623	1386	1400	1350												
2	3500	3450	3245	2771	2800	2699												
3	5249	5174	4868	4157	4200	4049												
4	6999	6899	6490	5542	5601	5398												
5	8749	8624	8113	6928	7001	6748												
6	10499	10349	9735	8313	8401	8098												



Расчетный узел: type = "compressor"

Объем бандажной полки (м³): V\_бп = 0

Радиус положения ЦМ бандажной полки (м): R\_бп = 0

Расчет Л на прочность

R0_rotor	area0_rotor	
N0_rotor	σ0_z_rotor	
area_rotor.	area_stator.	
N_rotor	σ_z_rotor	
P1	ρ1	
P2	ρ2	
P3	ρ3	
ca1	cu1	
ca2	cu2	
ca3	cu3	
qx_rotor	qx_stator	
qy_rotor	qy_stator	
Mx_rotor	Mx_stator	
My_rotor	My_stator	
shift_x_rotor	shift_y_rotor	
x0_rotor.	x0_stator.	=
y0_rotor.	y0_stator.	
α_major_rotor.	α_major_stator.	$\chi_{\text{rotor}}(i,z) = \frac{\text{area}_{\text{rotor},i,N_r}}{\text{area}_{\text{rotor},i,1}}$
Ju_rotor.	Ju_stator.	
Jv_rotor.	Jv_stator.	$R0_{\text{rotor}}(i,z) = \frac{1}{\sqrt{1 - \ln(\chi_{\text{rotor}}(i,z))}} \cdot \begin{cases} \sqrt{\text{mean}(R_{\text{st}}(i,1),1,R_{\text{st}}(i,2),1)^2 - \text{mean}(R_{\text{st}}(i,1),N_r,R_{\text{st}}(i,2),N_r)^2 \cdot \ln(\chi_{\text{rotor}}(i,z))} & \text{if type = "compressor"} \\ \sqrt{\text{mean}(R_{\text{st}}(i,2),1,R_{\text{st}}(i,3),1)^2 - \text{mean}(R_{\text{st}}(i,2),N_r,R_{\text{st}}(i,3),N_r)^2 \cdot \ln(\chi_{\text{rotor}}(i,z))} & \text{if type = "turbine"} \end{cases}$
CPx_rotor.	CPx_stator.	
CPy_rotor.	CPy_stator.	$\sigma0_{\text{rotor.max}}(i,z) = \frac{\rho_{\text{blade}i} \cdot \omega^2}{2} \cdot \begin{cases} \left[ \text{mean}(R_{\text{st}}(i,1),N_r,R_{\text{st}}(i,2),N_r)^2 - (R0_{\text{rotor}}(i,z))^2 \right] & \text{if type = "compressor"} \\ \left[ \text{mean}(R_{\text{st}}(i,2),N_r,R_{\text{st}}(i,3),N_r)^2 - (R0_{\text{rotor}}(i,z))^2 \right] & \text{if type = "turbine"} \end{cases}$
CPx_rotor.axis	CPx_stator.axis	
CPy_rotor.axis	CPy_stator.axis	$\left( \rho_{\text{blade}i} \cdot \omega^2 \quad R0_{\text{rotor}}(i,z) \right)$

rotor.axis	stator.axis	
$W_{p_{rotor}}$	$W_{p_{stator}}$	
$M_{\tau_{rotor}}$	$M_{\tau_{stator}}$	
$\tau_{rotor}$	$\tau_{stator}$	
$\varphi_{uv_{rotor}}$	$\varphi_{uv_{stator}}$	
$Mu_{rotor}$	$Mu_{stator}$	
$Mv_{rotor}$	$Mv_{stator}$	
$\varphi_{neutral_{rotor}}$	$\varphi_{neutral_{stator}}$	

$$area0_{rotor}(i, z) = area_{rotor, i, N_r} \cdot \begin{cases} \left( \frac{\sigma0_{rotor, max}(i, z)}{z} \right)^2 & \text{if } z \leq R0_{rotor}(i, z) \\ 1 & \text{otherwise} \end{cases}$$
  

$$N0_{rotor}(i, z) = \rho_{blade, i} \cdot \omega^2 \cdot \begin{cases} \left( \int_z^{mean(R_{st(i, 1), N_r}, R_{st(i, 2), N_r})} area0_{rotor}(i, z) \cdot z \, dz + V_{\phi_{\Pi}} \cdot R_{\phi_{\Pi}} \right) & \text{if type = "compressor"} \\ \left( \int_z^{mean(R_{st(i, 2), N_r}, R_{st(i, 3), N_r})} area0_{rotor}(i, z) \cdot z \, dz + V_{\phi_{\Pi}} \cdot R_{\phi_{\Pi}} \right) & \text{if type = "turbine"} \end{cases}$$
  

$$\sigma0_{z_{rotor}}(i, z) = \frac{N0_{rotor}(i, z)}{area0_{rotor}(i, z)}$$
  

$$area_{rotor, i}(z) = \text{interp}\left(\text{pspline}\left(\text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(area_{rotor, i, i, 1, N_r})^T\right), \text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(area_{rotor, i, i, 1, N_r})^T, z\right)$$
  

$$area_{stator, i}(z) = \text{interp}\left(\text{pspline}\left(\text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(area_{stator, i, i, 1, N_r})^T\right), \text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(area_{stator, i, i, 1, N_r})^T, z\right)$$
  

$$N_{rotor}(i, z) = \rho_{blade, i} \cdot \omega^2 \cdot \begin{cases} \left( \int_z^{mean(R_{st(i, 1), N_r}, R_{st(i, 2), N_r})} area_{rotor, i}(z) \cdot z \, dz + V_{\phi_{\Pi}} \cdot R_{\phi_{\Pi}} \right) & \text{if type = "compressor"} \\ \left( \int_z^{mean(R_{st(i, 2), N_r}, R_{st(i, 3), N_r})} area_{rotor, i}(z) \cdot z \, dz + V_{\phi_{\Pi}} \cdot R_{\phi_{\Pi}} \right) & \text{if type = "turbine"} \end{cases}$$
  

$$\sigma_{z_{rotor}}(i, z) = \frac{N_{rotor}(i, z)}{area_{rotor, i}(z)}$$
  

$$\rho_1(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(\rho, st(i, 1), st(i, 1), 1, N_r)^T\right), \text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(\rho, st(i, 1), st(i, 1), 1, N_r)^T, z\right)$$
  

$$\rho_2(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(\rho, st(i, 2), st(i, 2), 1, N_r)^T\right), \text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(\rho, st(i, 2), st(i, 2), 1, N_r)^T, z\right)$$
  

$$\rho_3(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 3), st(i, 3), 1, N_r)^T, \text{submatrix}(\rho, st(i, 3), st(i, 3), 1, N_r)^T\right), \text{submatrix}(R, st(i, 3), st(i, 3), 1, N_r)^T, \text{submatrix}(\rho, st(i, 3), st(i, 3), 1, N_r)^T, z\right)$$
  

$$P_1(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(P, st(i, 1), st(i, 1), 1, N_r)^T\right), \text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(P, st(i, 1), st(i, 1), 1, N_r)^T, z\right)$$
  

$$P_2(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(P, st(i, 2), st(i, 2), 1, N_r)^T\right), \text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(P, st(i, 2), st(i, 2), 1, N_r)^T, z\right)$$
  

$$P_3(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 3), st(i, 3), 1, N_r)^T, \text{submatrix}(P, st(i, 3), st(i, 3), 1, N_r)^T\right), \text{submatrix}(R, st(i, 3), st(i, 3), 1, N_r)^T, \text{submatrix}(P, st(i, 3), st(i, 3), 1, N_r)^T, z\right)$$
  

$$c_{a1}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(c_a, st(i, 1), st(i, 1), 1, N_r)^T\right), \text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(c_a, st(i, 1), st(i, 1), 1, N_r)^T, z\right)$$
  

$$c_{a2}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(c_a, st(i, 2), st(i, 2), 1, N_r)^T\right), \text{submatrix}(R, st(i, 2), st(i, 2), 1, N_r)^T, \text{submatrix}(c_a, st(i, 2), st(i, 2), 1, N_r)^T, z\right)$$
  

$$c_{a3}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 3), st(i, 3), 1, N_r)^T, \text{submatrix}(c_a, st(i, 3), st(i, 3), 1, N_r)^T\right), \text{submatrix}(R, st(i, 3), st(i, 3), 1, N_r)^T, \text{submatrix}(c_a, st(i, 3), st(i, 3), 1, N_r)^T, z\right)$$
  

$$c_{u1}(i, z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(c_u, st(i, 1), st(i, 1), 1, N_r)^T\right), \text{submatrix}(R, st(i, 1), st(i, 1), 1, N_r)^T, \text{submatrix}(c_u, st(i, 1), st(i, 1), 1, N_r)^T, z\right)$$

$$\begin{aligned}
c_{u2}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, \text{st}(i,2), \text{st}(i,2), 1, N_r\right)^1, \text{submatrix}\left(c_u, \text{st}(i,2), \text{st}(i,2), 1, N_r\right)^1\right), \text{submatrix}\left(R, \text{st}(i,2), \text{st}(i,2), 1, N_r\right)^1, \text{submatrix}\left(c_u, \text{st}(i,2), \text{st}(i,2), 1, N_r\right)^1, z\right) \\
c_{u3}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T, \text{submatrix}\left(c_u, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T\right), \text{submatrix}\left(R, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T, \text{submatrix}\left(c_u, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T, z\right) \\
w_{u1}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, \text{st}(i,1), \text{st}(i,1), 1, N_r\right)^T, \text{submatrix}\left(w_u, \text{st}(i,1), \text{st}(i,1), 1, N_r\right)^T\right), \text{submatrix}\left(R, \text{st}(i,1), \text{st}(i,1), 1, N_r\right)^T, \text{submatrix}\left(w_u, \text{st}(i,1), \text{st}(i,1), 1, N_r\right)^T, z\right) \\
w_{u2}(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(w_u, \text{st}(i,2), \text{st}(i,2), 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(w_u, \text{st}(i,2), \text{st}(i,2), 1, N_r\right)^T, z\right) \\
w_{u3}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T, \text{submatrix}\left(w_u, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T\right), \text{submatrix}\left(R, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T, \text{submatrix}\left(w_u, \text{st}(i,3), \text{st}(i,3), 1, N_r\right)^T, z\right) \\
q_{x_{\text{rotor}}}(i,z) &= -\frac{2\pi z}{Z_{\text{rotor}_i}} \cdot \begin{cases} \left[ \left( P_2(i,z) - P_1(i,z) \right) + \rho_1(i,z) \cdot c_{a1}(i,z) \cdot \left( c_{a2}(i,z) - c_{a1}(i,z) \right) \right] & \text{if type = "compressor"} \\ \left[ \left( P_3(i,z) - P_2(i,z) \right) + \rho_2(i,z) \cdot c_{a2}(i,z) \cdot \left( c_{a3}(i,z) - c_{a2}(i,z) \right) \right] & \text{if type = "turbine"} \end{cases} \\
q_{x_{\text{stator}}}(i,z) &= -\frac{2\pi z}{Z_{\text{stator}_i}} \cdot \begin{cases} \left[ \left( P_3(i,z) - P_2(i,z) \right) + \rho_2(i,z) \cdot c_{a2}(i,z) \cdot \left( c_{a3}(i,z) - c_{a2}(i,z) \right) \right] & \text{if type = "compressor"} \\ \left[ \left( P_2(i,z) - P_1(i,z) \right) + \rho_1(i,z) \cdot c_{a1}(i,z) \cdot \left( c_{a2}(i,z) - c_{a1}(i,z) \right) \right] & \text{if type = "turbine"} \end{cases} \\
q_{y_{\text{rotor}}}(i,z) &= \frac{2\pi z}{Z_{\text{rotor}_i}} \cdot \begin{cases} \left[ \rho_1(i,z) \cdot c_{a1}(i,z) \cdot \left( w_{u2}(i,z) - w_{u1}(i,z) \right) \right] & \text{if type = "compressor"} \\ \left[ \rho_2(i,z) \cdot c_{a2}(i,z) \cdot \left( w_{u3}(i,z) - w_{u2}(i,z) \right) \right] & \text{if type = "turbine"} \end{cases} \\
q_{y_{\text{stator}}}(i,z) &= -\frac{2\pi z}{Z_{\text{stator}_i}} \cdot \begin{cases} \left[ \rho_2(i,z) \cdot c_{a2}(i,z) \cdot \left( c_{u3}(i,z) - c_{u2}(i,z) \right) \right] & \text{if type = "compressor"} \\ \left[ \rho_1(i,z) \cdot c_{a1}(i,z) \cdot \left( c_{u2}(i,z) - c_{u1}(i,z) \right) \right] & \text{if type = "turbine"} \end{cases} \\
M_{x_{\text{rotor}}}(i,z) &= - \int_z \begin{cases} \text{mean}\left(R_{\text{st}(i,1), N_r}, R_{\text{st}(i,2), N_r}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{\text{st}(i,2), N_r}, R_{\text{st}(i,3), N_r}\right) & \text{if type="turbine"} \end{cases} q_{y_{\text{rotor}}}(i,z1) \cdot (z1 - z) dz1 \\
M_{x_{\text{stator}}}(i,z) &= \int_z \begin{cases} \text{mean}\left(R_{\text{st}(i,2), 1}, R_{\text{st}(i,3), 1}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{\text{st}(i,1), 1}, R_{\text{st}(i,2), 1}\right) & \text{if type="turbine"} \end{cases} q_{y_{\text{stator}}}(i,z1) \cdot (z1 - z) dz1 \\
M_{y_{\text{rotor}}}(i,z) &= \int_z \begin{cases} \text{mean}\left(R_{\text{st}(i,1), N_r}, R_{\text{st}(i,2), N_r}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{\text{st}(i,2), N_r}, R_{\text{st}(i,3), N_r}\right) & \text{if type="turbine"} \end{cases} q_{x_{\text{rotor}}}(i,z1) \cdot (z1 - z) dz1 \\
M_{y_{\text{stator}}}(i,z) &= - \int_z \begin{cases} \text{mean}\left(R_{\text{st}(i,2), 1}, R_{\text{st}(i,3), 1}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{\text{st}(i,1), 1}, R_{\text{st}(i,2), 1}\right) & \text{if type="turbine"} \end{cases} q_{x_{\text{stator}}}(i,z1) \cdot (z1 - z) dz1 \\
\int_z^z & \begin{cases} \text{mean}\left(R_{\text{st}(i,1), N_r}, R_{\text{st}(i,2), N_r}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{\text{st}(i,2), N_r}, R_{\text{st}(i,3), N_r}\right) & \text{if type="turbine"} \end{cases} q_{x_{\text{stator}}}(i,z) dz
\end{aligned}$$



$$\left. \begin{aligned} \text{shift\_x}_{\text{rotor}}(i,z) &= \int_z^z \frac{\int_z^z q_{\text{rotor}}(i,z) dz}{N_{\text{rotor}}(i,z)} dz \\ \text{shift\_y}_{\text{rotor}}(i,z) &= z \cdot \int_z^z \frac{\int_z^z \left[ \begin{array}{l} \text{mean}(R_{st(i,1),1}, R_{st(i,2),1}) \quad \text{if type="compressor"} \\ \text{mean}(R_{st(i,2),1}, R_{st(i,3),1}) \quad \text{if type="turbine"} \end{array} \right] dz}{N_{\text{rotor}}(i,z) \cdot z^2} dz \\ x0_{\text{rotor}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(x0_{\text{rotor}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(x0_{\text{rotor}}, i, i, 1, N_r)^T\right) \\ x0_{\text{stator}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(x0_{\text{stator}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(x0_{\text{stator}}, i, i, 1, N_r)^T\right) \\ y0_{\text{rotor}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(y0_{\text{rotor}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(y0_{\text{rotor}}, i, i, 1, N_r)^T\right) \\ y0_{\text{stator}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(y0_{\text{stator}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(y0_{\text{stator}}, i, i, 1, N_r)^T\right) \\ \alpha_{\text{major\_rotor}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(\alpha_{\text{major\_rotor}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(\alpha_{\text{major\_rotor}}, i, i, 1, N_r)^T\right) \\ \alpha_{\text{major\_stator}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(\alpha_{\text{major\_stator}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(\alpha_{\text{major\_stator}}, i, i, 1, N_r)^T\right) \\ Ju_{\text{rotor}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Ju_{\text{rotor}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Ju_{\text{rotor}}, i, i, 1, N_r)^T\right) \\ Ju_{\text{stator}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Ju_{\text{stator}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Ju_{\text{stator}}, i, i, 1, N_r)^T\right) \\ Jv_{\text{rotor}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Jv_{\text{rotor}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Jv_{\text{rotor}}, i, i, 1, N_r)^T\right) \\ Jv_{\text{stator}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Jv_{\text{stator}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(Jv_{\text{stator}}, i, i, 1, N_r)^T\right) \\ CPx_{\text{rotor}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPx_{\text{rotor}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPx_{\text{rotor}}, i, i, 1, N_r)^T\right) \\ CPx_{\text{stator}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPx_{\text{stator}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPx_{\text{stator}}, i, i, 1, N_r)^T\right) \\ CPy_{\text{rotor}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPy_{\text{rotor}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPy_{\text{rotor}}, i, i, 1, N_r)^T\right) \\ CPy_{\text{stator}}(i,z) &= \text{interp}\left(\text{lspline}\left(\text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPy_{\text{stator}}, i, i, 1, N_r)^T\right), \text{submatrix}(R, st(i,2), st(i,2), 1, N_r)^T, \text{submatrix}(CPy_{\text{stator}}, i, i, 1, N_r)^T\right) \\ CPx_{\text{rotor.axis}}(i,z) &= \text{axis}_x(CPx_{\text{rotor}}(i,z), CPy_{\text{rotor}}(i,z), x0_{\text{rotor}}(i,z), y0_{\text{rotor}}(i,z), \alpha_{\text{major\_rotor}}(i,z), 1) \\ CPx_{\text{stator.axis}}(i,z) &= \text{axis}_x(CPx_{\text{stator}}(i,z), CPy_{\text{stator}}(i,z), x0_{\text{stator}}(i,z), y0_{\text{stator}}(i,z), \alpha_{\text{major\_stator}}(i,z), 1) \\ CPy_{\text{rotor.axis}}(i,z) &= \text{axis}_y(CPx_{\text{rotor}}(i,z), CPy_{\text{rotor}}(i,z), x0_{\text{rotor}}(i,z), y0_{\text{rotor}}(i,z), \alpha_{\text{major\_rotor}}(i,z), 1) \\ CPy_{\text{stator.axis}}(i,z) &= \text{axis}_y(CPx_{\text{stator}}(i,z), CPy_{\text{stator}}(i,z), x0_{\text{stator}}(i,z), y0_{\text{stator}}(i,z), \alpha_{\text{major\_stator}}(i,z), 1) \end{aligned} \right.$$

$$\begin{aligned}
W_{p_{\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(W_{p_{\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(W_{p_{\text{rotor.}}}, i, i, 1, N_r\right)^T, z\right) \\
W_{p_{\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(W_{p_{\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(W_{p_{\text{stator.}}}, i, i, 1, N_r\right)^T, z\right) \\
M\tau_{\text{rotor}}(i,z) &= \int_z \begin{cases} \text{mean}\left(R_{\text{st}(i,1), N_r}, R_{\text{st}(i,2), N_r}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{\text{st}(i,2), N_r}, R_{\text{st}(i,3), N_r}\right) & \text{if type="turbine"} \end{cases} \left(q_{x_{\text{rotor}}}(i,z1) \cdot CP_{y_{\text{rotor.axis}}}(i,z1) - q_{y_{\text{rotor}}}(i,z1) \cdot CP_{x_{\text{rotor.axis}}}(i,z1)\right) dz1 \\
M\tau_{\text{stator}}(i,z) &= \int_z \begin{cases} \text{mean}\left(R_{\text{st}(i,2), 1}, R_{\text{st}(i,3), 1}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{\text{st}(i,1), 1}, R_{\text{st}(i,2), 1}\right) & \text{if type="turbine"} \end{cases} \left(q_{x_{\text{stator}}}(i,z1) \cdot CP_{y_{\text{stator.axis}}}(i,z1) - q_{y_{\text{stator}}}(i,z1) \cdot CP_{x_{\text{stator.axis}}}(i,z1)\right) dz1 \\
\tau_{\text{rotor}}(i,z) &= \frac{M\tau_{\text{rotor}}(i,z)}{W_{p_{\text{rotor.}}}(i,z)} \\
\tau_{\text{stator}}(i,z) &= \frac{M\tau_{\text{stator}}(i,z)}{W_{p_{\text{stator.}}}(i,z)} \\
\varphi_{uv_{\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(\frac{\pi}{2} - v_{\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(\frac{\pi}{2} - v_{\text{rotor}}, i, i, 1, N_r\right)^T, z\right) \\
\varphi_{uv_{\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(\frac{\pi}{2} - v_{\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(\frac{\pi}{2} - v_{\text{stator}}, i, i, 1, N_r\right)^T, z\right) \\
Mu_{\text{rotor}}(i,z) &= \text{axis}_x\left(Mx_{\text{rotor}}(i,z), My_{\text{rotor}}(i,z), 0, 0, \varphi_{uv_{\text{rotor}}}(i,z), 1\right) \\
Mu_{\text{stator}}(i,z) &= \text{axis}_x\left(Mx_{\text{stator}}(i,z), My_{\text{stator}}(i,z), 0, 0, \varphi_{uv_{\text{stator}}}(i,z), 1\right) \\
Mv_{\text{rotor}}(i,z) &= \text{axis}_y\left(Mx_{\text{rotor}}(i,z), My_{\text{rotor}}(i,z), 0, 0, \varphi_{uv_{\text{rotor}}}(i,z), 1\right) \\
Mv_{\text{stator}}(i,z) &= \text{axis}_y\left(Mx_{\text{stator}}(i,z), My_{\text{stator}}(i,z), 0, 0, \varphi_{uv_{\text{stator}}}(i,z), 1\right) \\
\varphi_{\text{neutral}_{\text{rotor}}}(i,z) &= \begin{cases} \text{atan}\left(\frac{Mv_{\text{rotor}}(i,z) \cdot Ju_{\text{rotor.}}(i,z)}{Mu_{\text{rotor}}(i,z) \cdot Jv_{\text{rotor.}}(i,z)}\right) & \text{if } Mu_{\text{rotor}}(i,z) \cdot Jv_{\text{rotor.}}(i,z) \neq 0 \\ \frac{\pi}{2} & \text{otherwise} \end{cases} \\
\varphi_{\text{neutral}_{\text{stator}}}(i,z) &= \begin{cases} \text{atan}\left(\frac{Mv_{\text{stator}}(i,z) \cdot Ju_{\text{stator.}}(i,z)}{Mu_{\text{stator}}(i,z) \cdot Jv_{\text{stator.}}(i,z)}\right) & \text{if } Mu_{\text{stator}}(i,z) \cdot Jv_{\text{stator.}}(i,z) \neq 0 \\ \frac{\pi}{2} & \text{otherwise} \end{cases} \\
\left( \begin{array}{cc} R0_{\text{rotor}} & \text{area}0_{\text{rotor}} \\ N0_{\text{rotor}} & \sigma0\_z_{\text{rotor}} \\ \text{area}_{\text{rotor.}} & \text{area}_{\text{stator.}} \\ N_{\text{rotor}} & \sigma\_Z_{\text{rotor}} \end{array} \right)
\end{aligned}$$

	$P_1$	$\rho_1$
	$P_2$	$\rho_2$
	$P_3$	$\rho_3$
	$c_{a1}$	$c_{u1}$
	$c_{a2}$	$c_{u2}$
	$c_{a3}$	$c_{u3}$
	$q_{x_{rotor}}$	$q_{x_{stator}}$
	$q_{y_{rotor}}$	$q_{y_{stator}}$
	$M_{x_{rotor}}$	$M_{x_{stator}}$
	$M_{y_{rotor}}$	$M_{y_{stator}}$
	$shift\_x_{rotor}$	$shift\_y_{rotor}$
	$x0_{rotor.}$	$x0_{stator.}$
	$y0_{rotor.}$	$y0_{stator.}$
	$\alpha\_major_{rotor.}$	$\alpha\_major_{stator.}$
	$J_{u_{rotor.}}$	$J_{u_{stator.}}$
	$J_{v_{rotor.}}$	$J_{v_{stator.}}$
	$CP_{x_{rotor.}}$	$CP_{x_{stator.}}$
	$CP_{y_{rotor.}}$	$CP_{y_{stator.}}$
	$CP_{x_{rotor.axis}}$	$CP_{x_{stator.axis}}$
	$CP_{y_{rotor.axis}}$	$CP_{y_{stator.axis}}$
	$W_{p_{rotor.}}$	$W_{p_{stator.}}$
	$M\tau_{rotor}$	$M\tau_{stator}$
	$\tau_{rotor}$	$\tau_{stator}$
	$\varphi_{uv_{rotor}}$	$\varphi_{uv_{stator}}$
	$M_u_{rotor}$	$M_u_{stator}$
	$M_v_{rotor}$	$M_v_{stator}$
	$\varphi\_neutral_{rotor}$	$\varphi\_neutral_{stator}$

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

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



Наиболее удаленные точки от НЛ (мм):

$$\mathbf{u_{u_{rotor}}^T} =$$

	1	2	3	4	5	6	7	8	9
1	-2.470	-11.992	-9.742						
2	-1.546	-0.806	-0.812						
3	-0.658	-0.928	-0.930						

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

$$\mathbf{v_{u_{rotor}}^T} =$$

	1	2	3
1	3.726	6.036	5.467
2	1.781	2.114	2.028
3	36.463	1.596	1.534

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

$$\mathbf{u_{l_{rotor}}^T} =$$

	1	2	3	4	5	6	7	8	9
1	32.110	31.536	32.240						
2	38.791	39.482	39.493						
3	-0.901	44.262	44.265						

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

$$\mathbf{v_{l_{rotor}}^T} =$$

	1	2	3	4	5	6	7	8	9
1	-3.109	-13.911	-12.177						
2	-1.442	-2.884	-2.490						
3	-44.269	-1.595	-1.338						

$$\cdot 10$$

$$\mathbf{u_{u_{stator}}^T} =$$

	1	2	3	4	5	6	7	8	9
1	-0.048	0.320	0.314						
2	-0.049	-0.024	-0.030						
3	-0.470	-0.012	-0.020						

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

$$\mathbf{v_{u_{stator}}^T} =$$

	1	2	3	4	5	6	7	8	9
1	0.872	1.159	1.080						
2	1.354	1.697	1.630						
3	1.885	2.271	2.209						

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

$$\mathbf{u_{l_{stator}}^T} =$$

	1	2	3	4	5	6	7	8	9
1	19.302	19.265	19.279						
2	21.367	21.319	21.333						
3	23.161	23.104	23.117						

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

$$\mathbf{v_{l_{stator}}^T} =$$

	1	2	3	4	5	6	7	8	9
1	-1.369	-2.566	-2.224						
2	-1.526	-2.974	-2.677						
3	-1.645	-3.298	-3.019						

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

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

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

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

	1	2	3	4	5	6	7	8	9
1	-23.03	-4.57	-3.21						
2	-26.32	-14.61	-12.33						
3	0.00	-0.20	-0.48						

 $\cdot 10^6$

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

	1	2	3
1	1	1	1
2	1	1	1
3	1	1	1

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

	1	2	3	4	5	6	7	8	9
1	23.04	11.01	8.01						
2	22.63	21.35	16.10						
3	0.00	0.21	0.43						

 $\cdot 10^6$

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

	1	2	3
1	1	1	1
2	1	1	1
3	1	1	1

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

	1	2	3	4	5	6	7	8	9
1	0.01	0.40	0.67						
2	28.50	27.45	12.99						
3	45.18	45.57	19.30						

 $\cdot 10^6$

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

	1	2	3
1	1	1	1
2	1	1	1
3	1	1	1

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

	1	2	3	4	5	6	7	8	9
1	-0.01	-0.90	-1.39						
2	-32.34	-49.21	-21.71						
3	-39.98	-68.31	-27.08						

 $\cdot 10^6$

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

	1	2	3
1	1	1	1
2	1	1	1
3	1	1	1



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

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

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

	1	2	3	4	5	6	7	8	9
1	70.19	58.92	56.20						
2	58.09	59.38	55.97						
3	0.00	3.77	6.96						

$\cdot 10^6$

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

	1	2	3	4	5	6	7	8	9
1	0.01	0.41	0.68						
2	28.50	27.45	12.99						
3	45.18	45.58	19.30						

$\cdot 10^6$



Рассматриваемая ступень:

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

$$b_{lim} = \frac{ceil\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 90 \cdot 10^{-3}$$

Расстояния от оси ЛМ до рассматриваемой ступени (м):

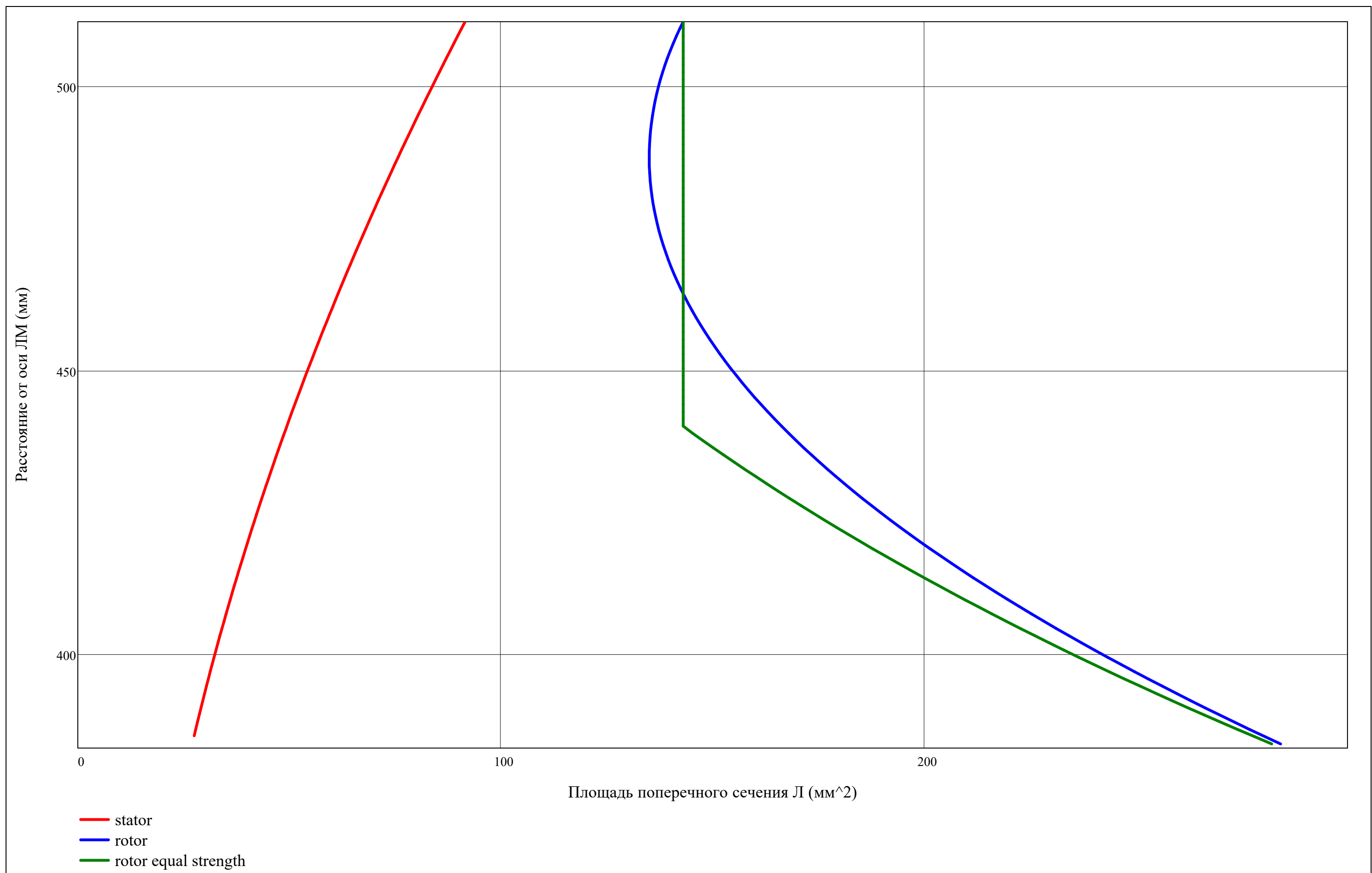
$$R_j = \text{submatrix}\left(R, 2 \cdot j - 1, 2 \cdot j + 1, 1, N_r\right) = \begin{array}{|c|c|c|c|} \hline & 1 & 2 & 3 \\ \hline 1 & 383.4 & 452.0 & 511.4 \\ 2 & 384.9 & 452.6 & 511.4 \\ 3 & 386.3 & 453.2 & 511.4 \\ \hline \end{array} \cdot 10^{-3}$$

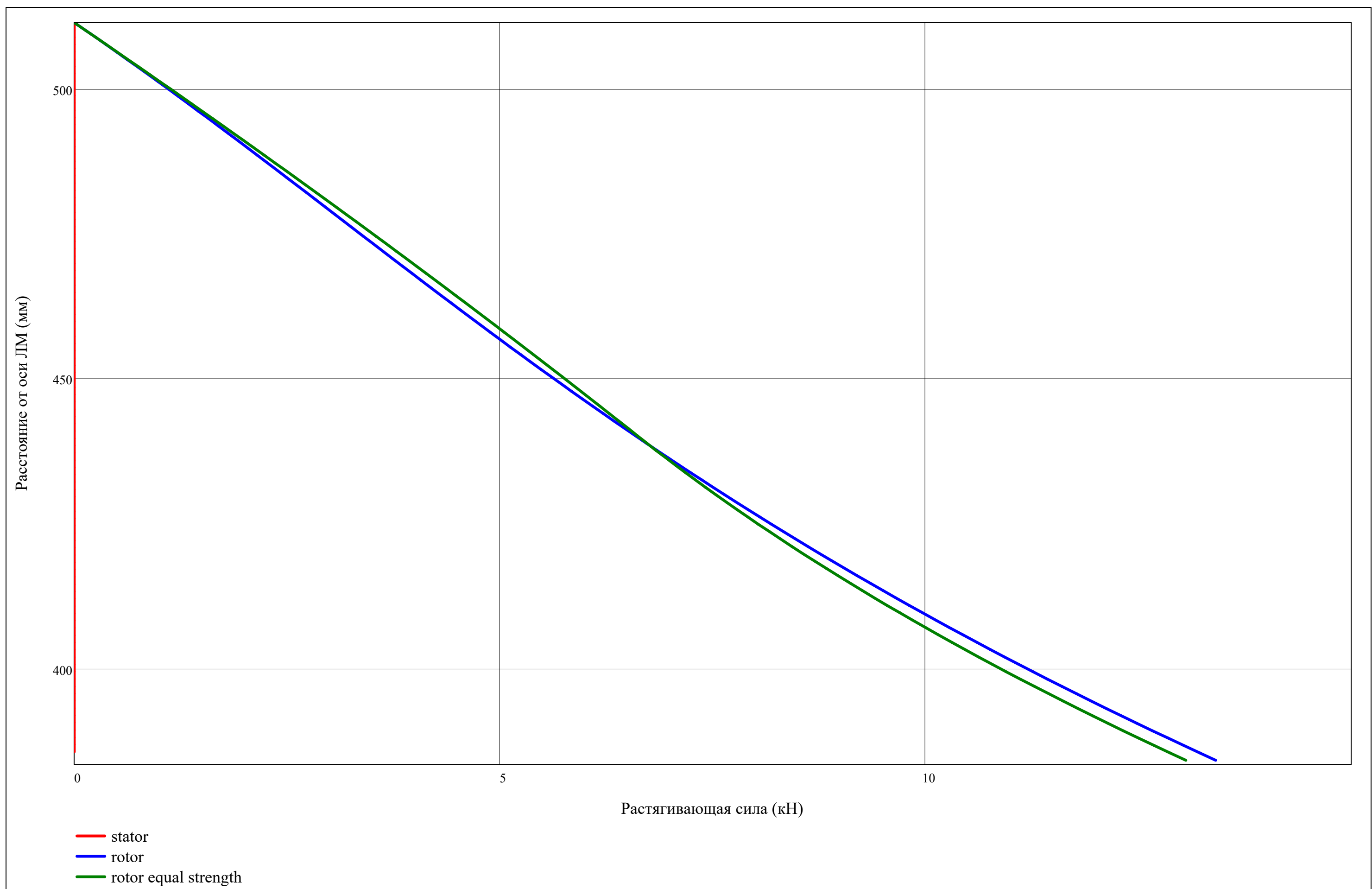
Дискретизация по высоте Л:

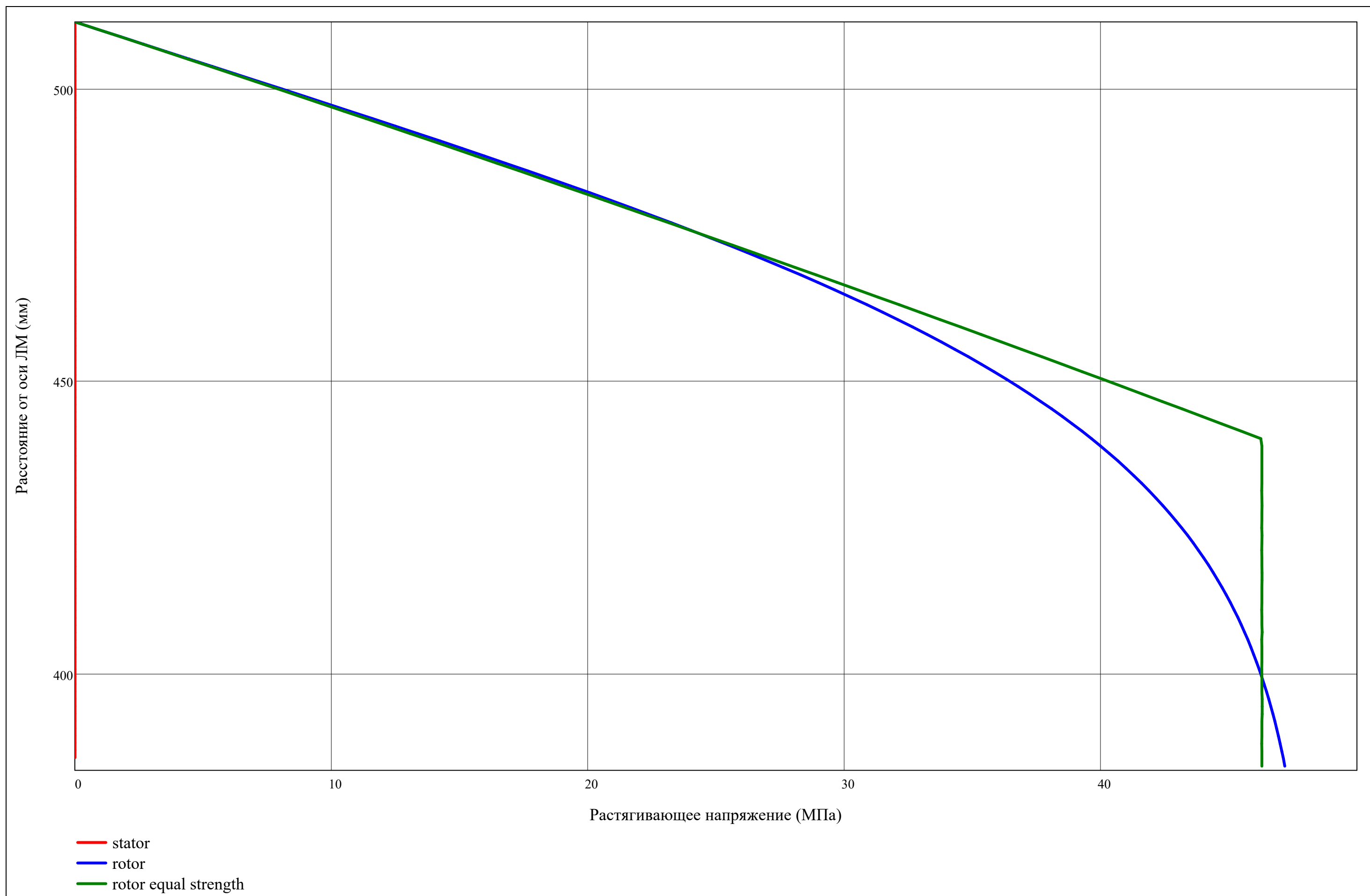
$$z = \min(R_j), \min(R_j) + \frac{\max(R_j) - \min(R_j)}{100} .. \max(R_j)$$

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

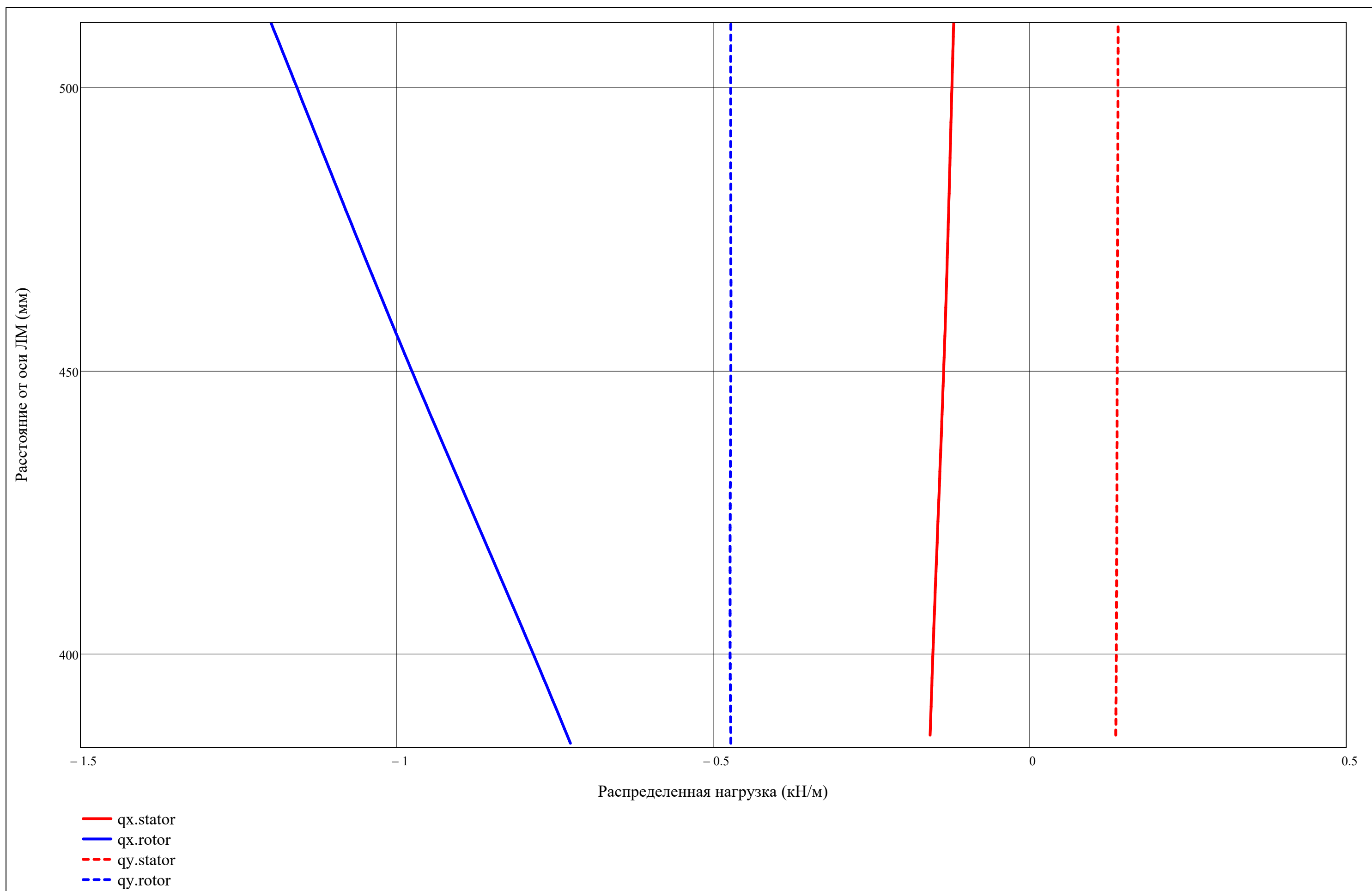
$$z_{stator} = \left\{ \begin{array}{l} \text{mean}\left(R_{j2,1}, R_{j3,1}\right), \text{mean}\left(R_{j2,1}, R_{j3,1}\right) + \frac{\text{mean}\left(R_{j2,N_r}, R_{j3,N_r}\right) - \text{mean}\left(R_{j2,1}, R_{j3,1}\right)}{100} .. \text{mean}\left(R_{j2,N_r}, R_{j3,N_r}\right) \text{ if type = "compressor"}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



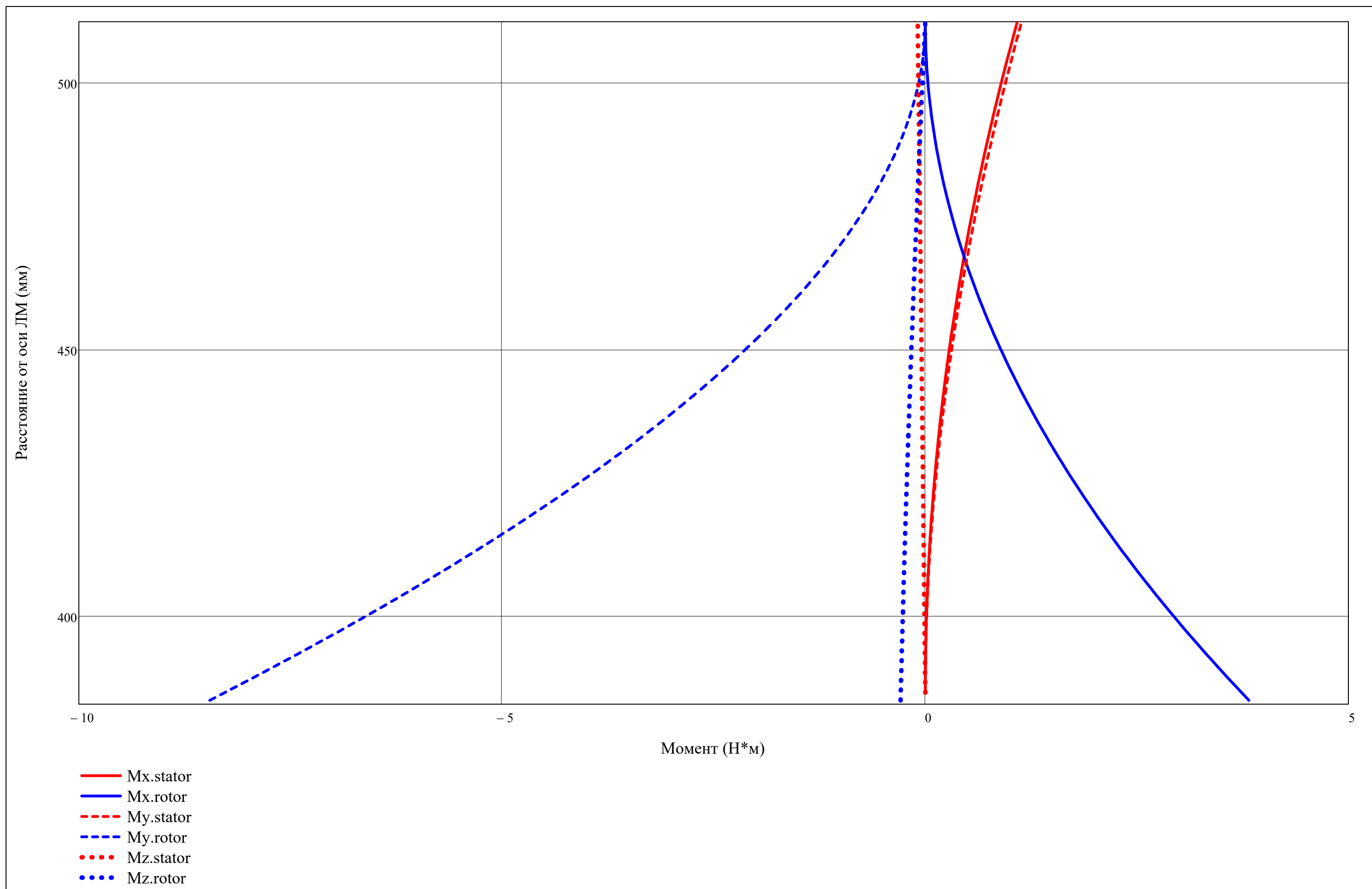


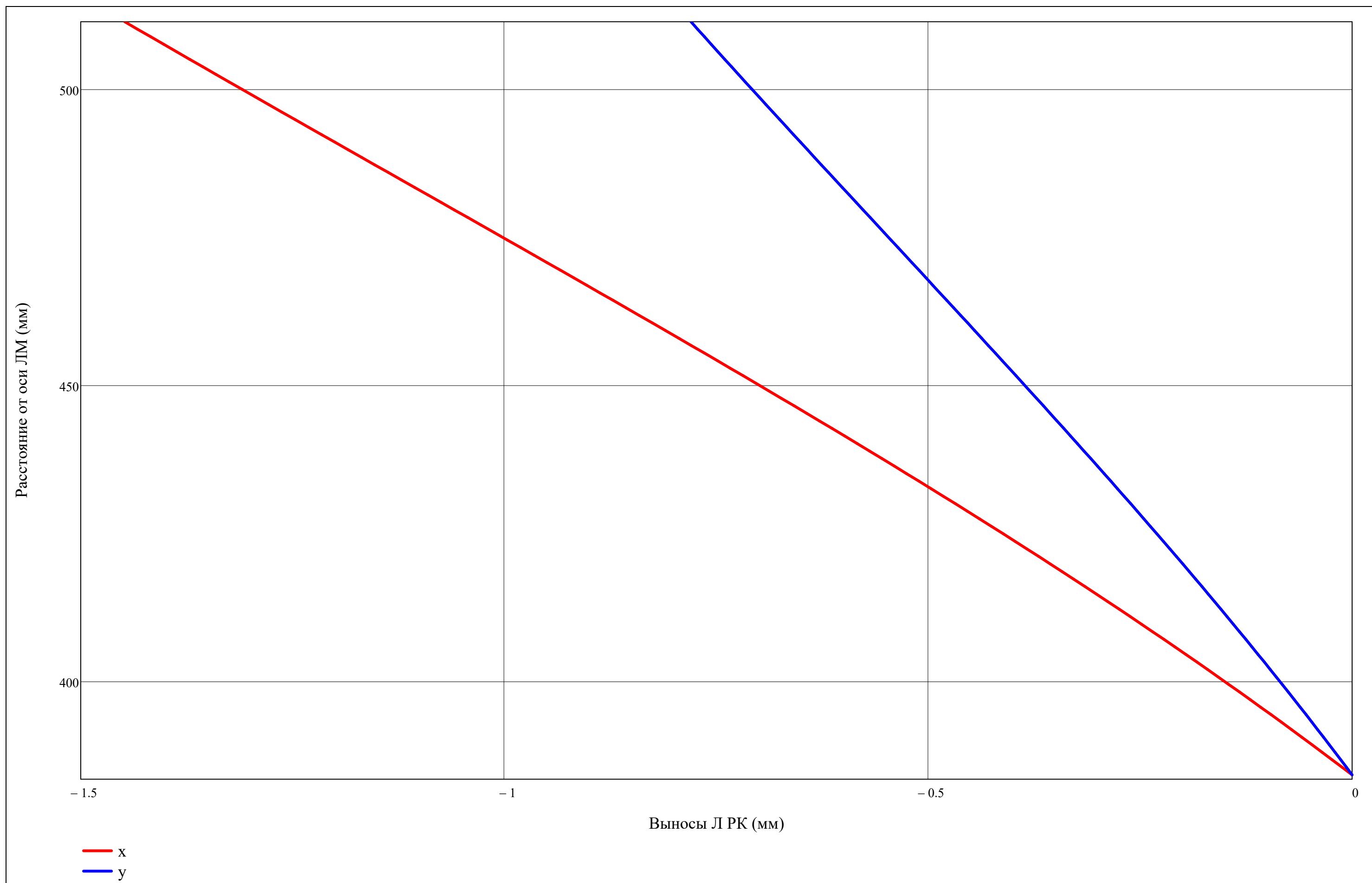


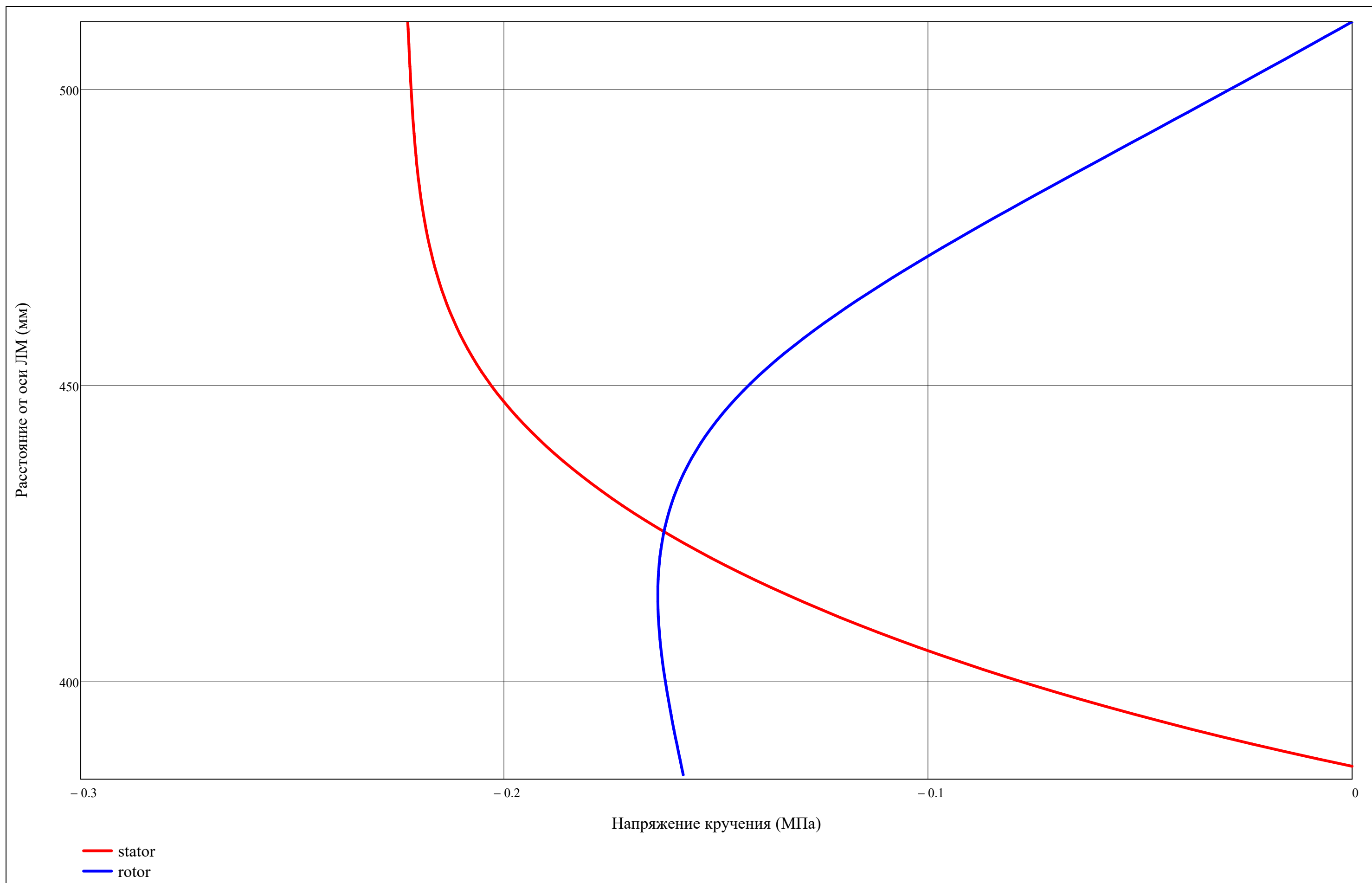


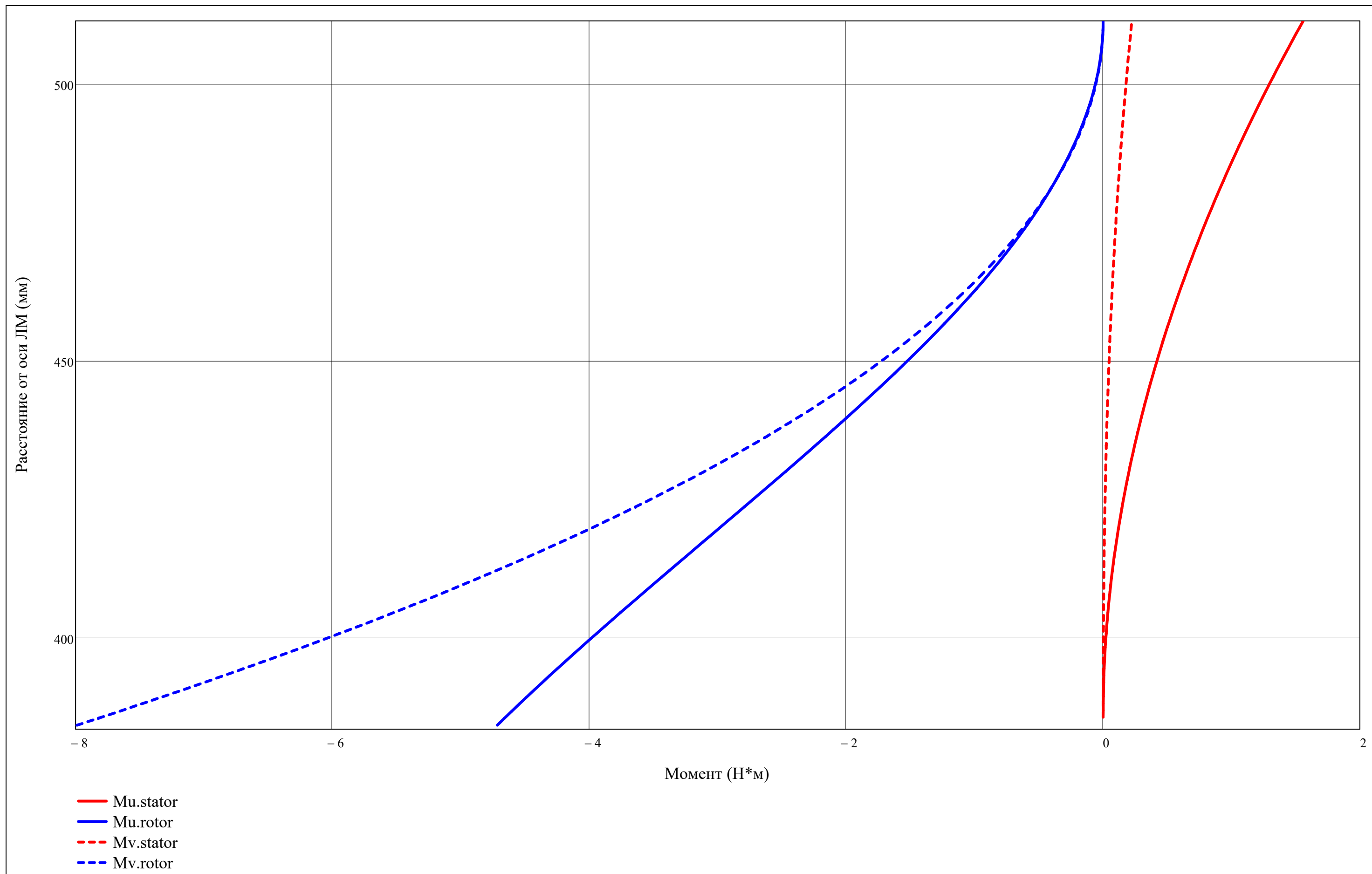


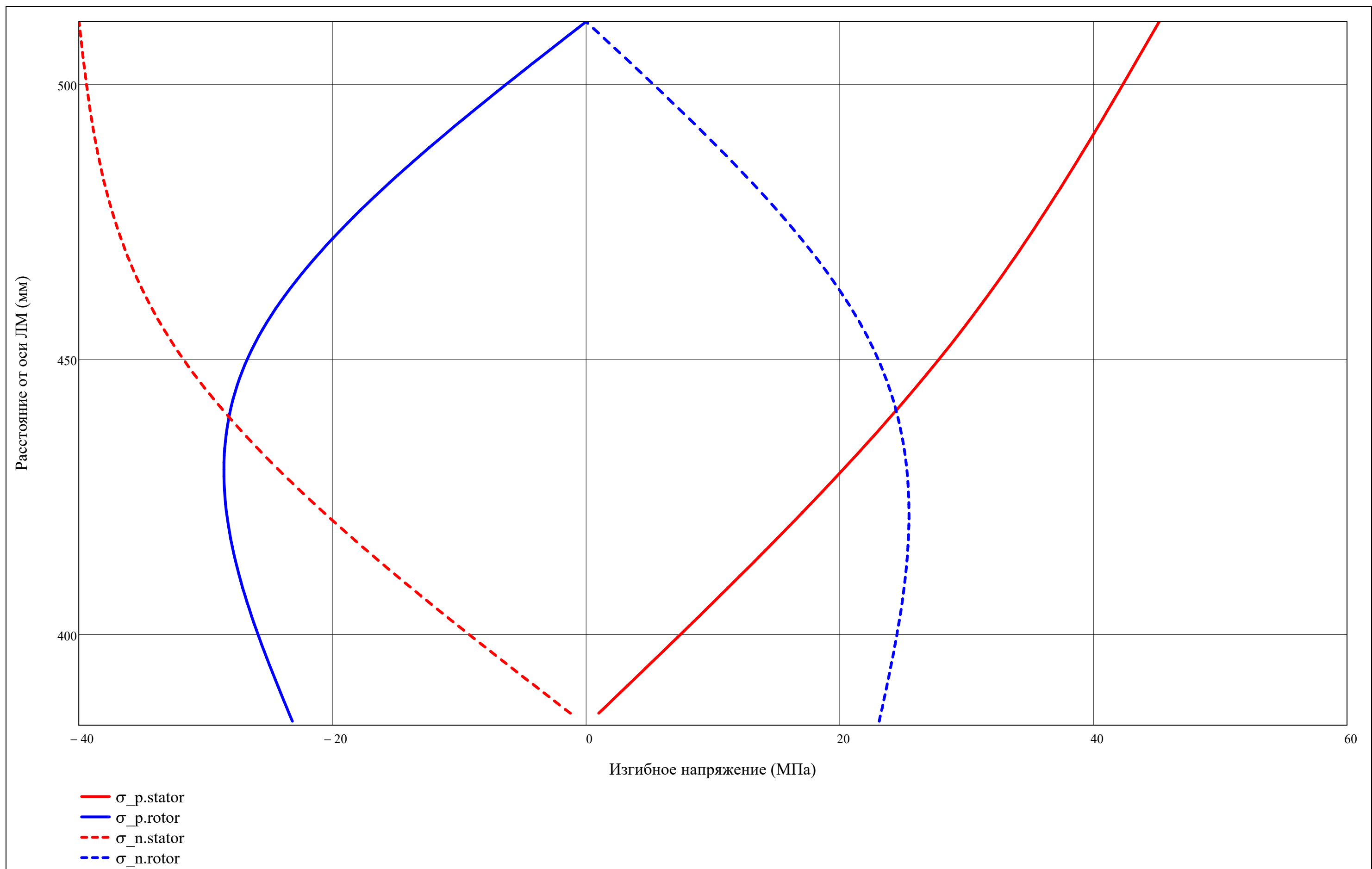


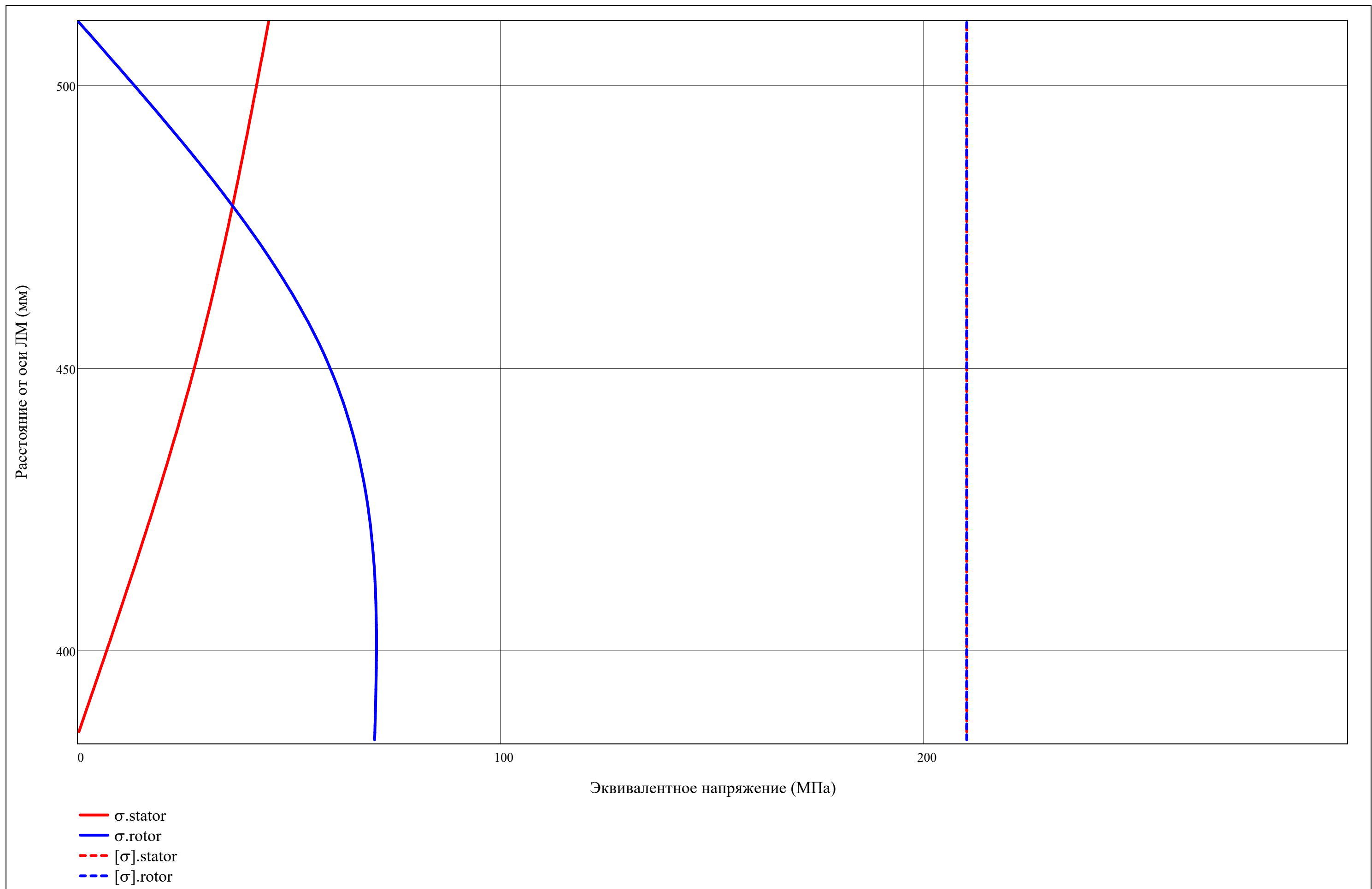












blade

r

=

"rotor"

1

Наиболее удаленные точки от НЛ (мм):

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

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

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

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

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>

=

	1	2
1	-2.47	3.73
2	32.11	-3.11
3	-0.05	0.87
4	19.30	-1.37

·10<sup>-3</sup>

Коэф. запаса:

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

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

=

	1
1	20643.932
2	2.992

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"

otherwise

=

	1
1	3.726
2	-3.109

·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>

=

-23

0

23

-0

·10<sup>6</sup>

Эквивалентные напряжения (Па):

σ<sub>stator<sub>j,r</sub></sub>

σ<sub>rotor<sub>j,r</sub></sub>

=

0

70

·10<sup>6</sup>

v\_p

v\_n

=

x0rotor<sub>j,r</sub>

y0rotor<sub>j,r</sub>

x0stator<sub>j,r</sub>

y0stator<sub>j,r</sub>

if blade = "rotor"

otherwise

=

	1
1	28.047
2	2.012

·10<sup>-3</sup>

chord =

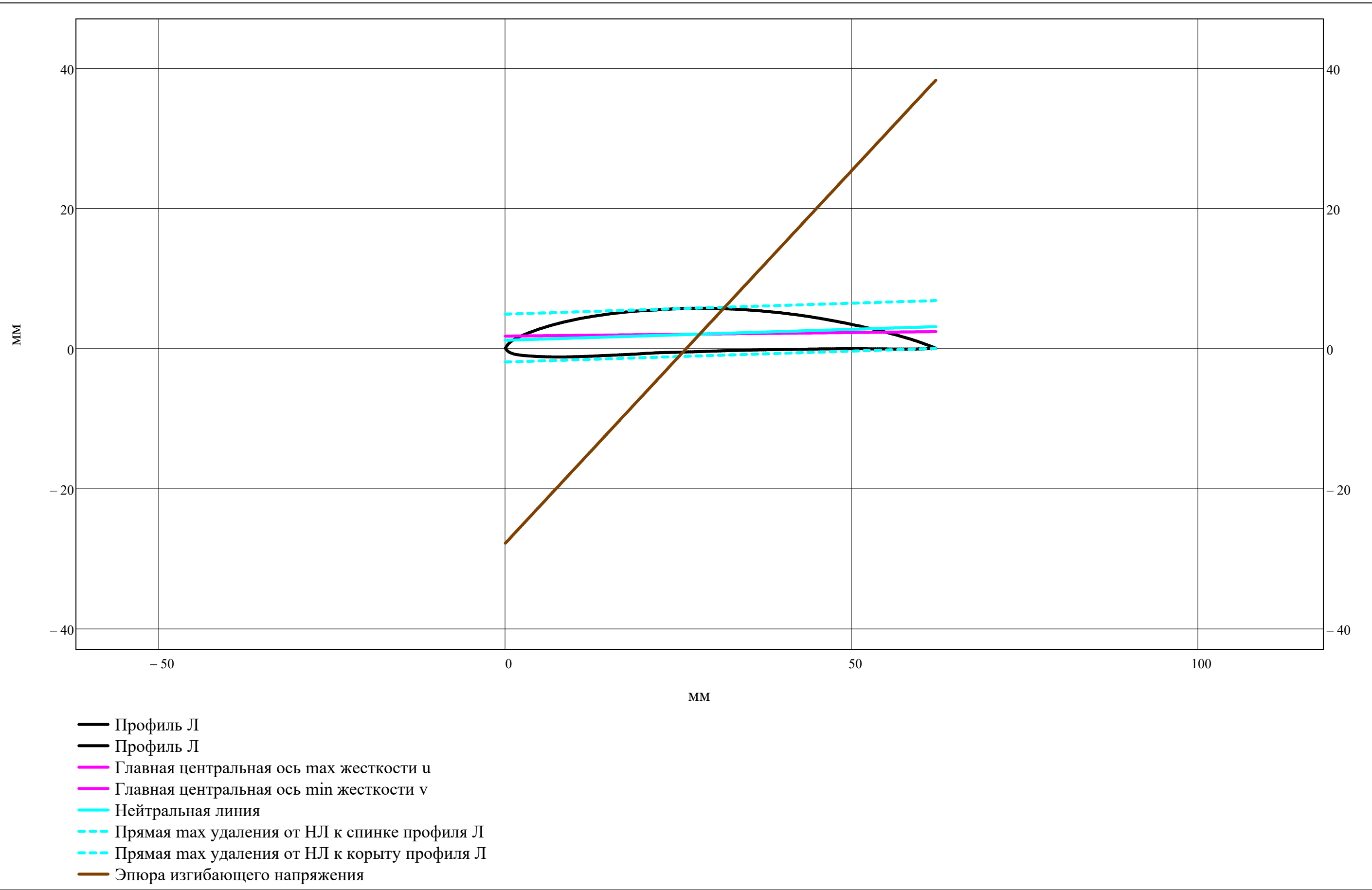
chord<sub>rotor<sub>j,r</sub></sub>

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

if blade = "rotor"

if blade = "stator"

= 62·10<sup>-3</sup>





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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u_{u_{\text{rotor}_{j,r}}} & v_{u_{\text{rotor}_{j,r}}} \\ u_{l_{\text{rotor}_{j,r}}} & v_{l_{\text{rotor}_{j,r}}} \\ u_{u_{\text{stator}_{j,r}}} & v_{u_{\text{stator}_{j,r}}} \\ u_{l_{\text{stator}_{j,r}}} & v_{l_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & -1.55 & 1.78 \\ \hline 2 & 38.79 & -1.44 \\ \hline 3 & -0.05 & 1.35 \\ \hline 4 & 21.37 & -1.53 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{Коэф. запаса: } \begin{pmatrix} \text{safety}_{\text{stator}_{j,r}} \\ \text{safety}_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 7.368 \\ \hline 2 & 3.615 \\ \hline \end{array}$$

$$\begin{pmatrix} v_p \\ v_n \end{pmatrix} = \begin{cases} \begin{pmatrix} v_{u_{\text{rotor}_{j,r}}} \\ v_{l_{\text{rotor}_{j,r}}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v_{u_{\text{stator}_{j,r}}} \\ v_{l_{\text{stator}_{j,r}}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.781 \\ \hline 2 & -1.442 \\ \hline \end{array} \cdot 10^{-3}$$

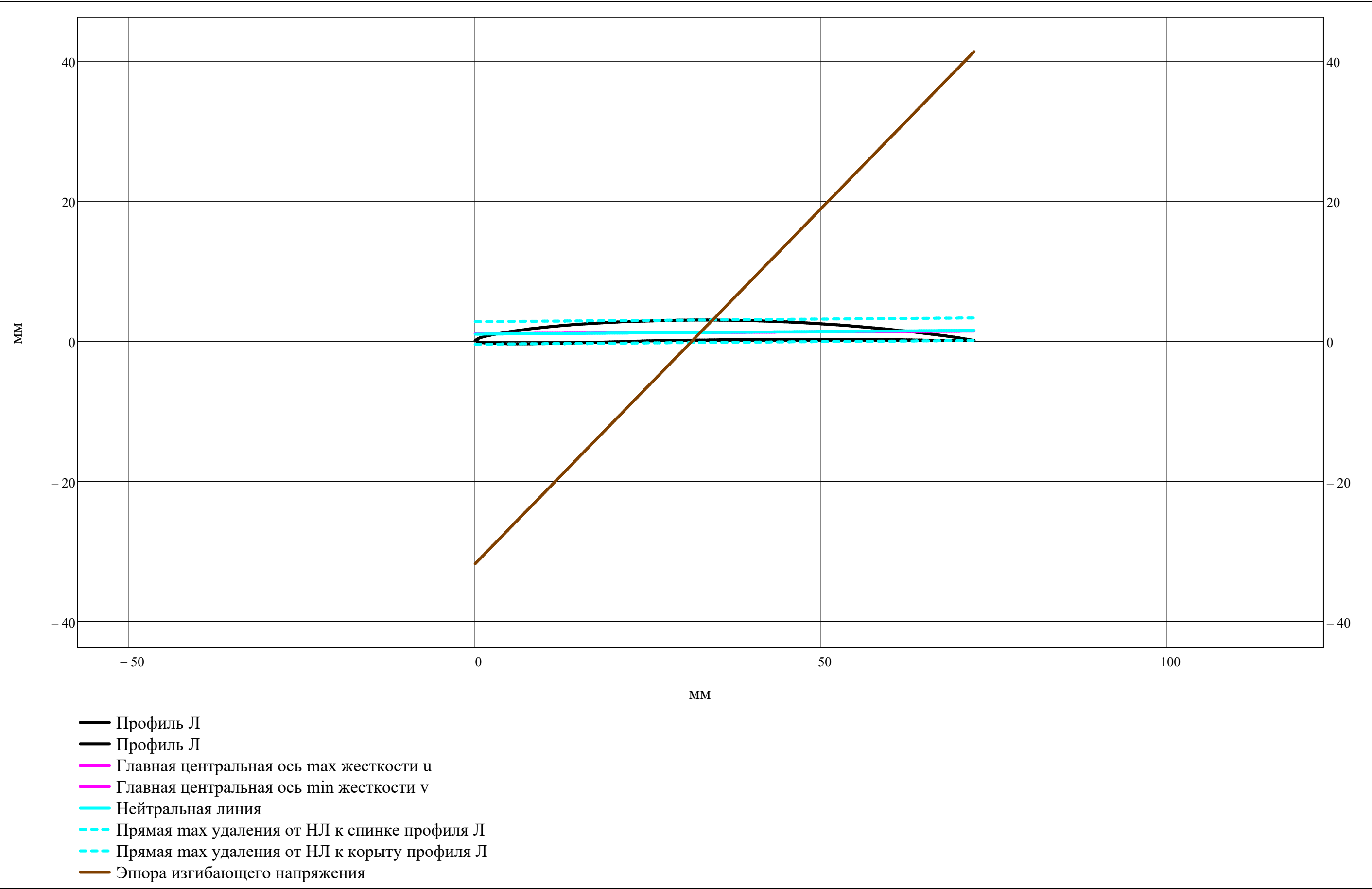
Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma_{p_{\text{rotor}_{j,r}}} & \sigma_{p_{\text{stator}_{j,r}}} \\ \sigma_{n_{\text{rotor}_{j,r}}} & \sigma_{n_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{pmatrix} -26 & 29 \\ 23 & -32 \end{pmatrix} \cdot 10^6$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{\text{stator}_{j,r}} \\ \sigma_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{pmatrix} 29 \\ 58 \end{pmatrix} \cdot 10^6$$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0_{\text{rotor}_{j,r}} \\ y0_{\text{rotor}_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{\text{stator}_{j,r}} \\ y0_{\text{stator}_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 32.549 \\ \hline 2 & 1.147 \\ \hline \end{array} \cdot 10^{-3} \quad \text{chord} = \begin{cases} \text{chord}_{\text{rotor}_{j,r}} & \text{if blade = "rotor"} \\ \text{chord}_{\text{stator}_{j,r}} & \text{if blade = "stator"} \end{cases} = 72 \cdot 10^{-3}$$



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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u_{u_{\text{rotor}_{j,r}}} & v_{u_{\text{rotor}_{j,r}}} \\ u_{l_{\text{rotor}_{j,r}}} & v_{l_{\text{rotor}_{j,r}}} \\ u_{u_{\text{stator}_{j,r}}} & v_{u_{\text{stator}_{j,r}}} \\ u_{l_{\text{stator}_{j,r}}} & v_{l_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & -1.55 & 1.78 \\ \hline 2 & 38.79 & -1.44 \\ \hline 3 & -0.05 & 1.35 \\ \hline 4 & 21.37 & -1.53 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{Коэф. запаса: } \begin{pmatrix} \text{safety}_{\text{stator}_{j,r}} \\ \text{safety}_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 7.368 \\ \hline 2 & 3.615 \\ \hline \end{array}$$

$$\begin{pmatrix} v_p \\ v_n \end{pmatrix} = \begin{cases} \begin{pmatrix} v_{u_{\text{rotor}_{j,r}}} \\ v_{l_{\text{rotor}_{j,r}}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v_{u_{\text{stator}_{j,r}}} \\ v_{l_{\text{stator}_{j,r}}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.354 \\ \hline 2 & -1.526 \\ \hline \end{array} \cdot 10^{-3}$$

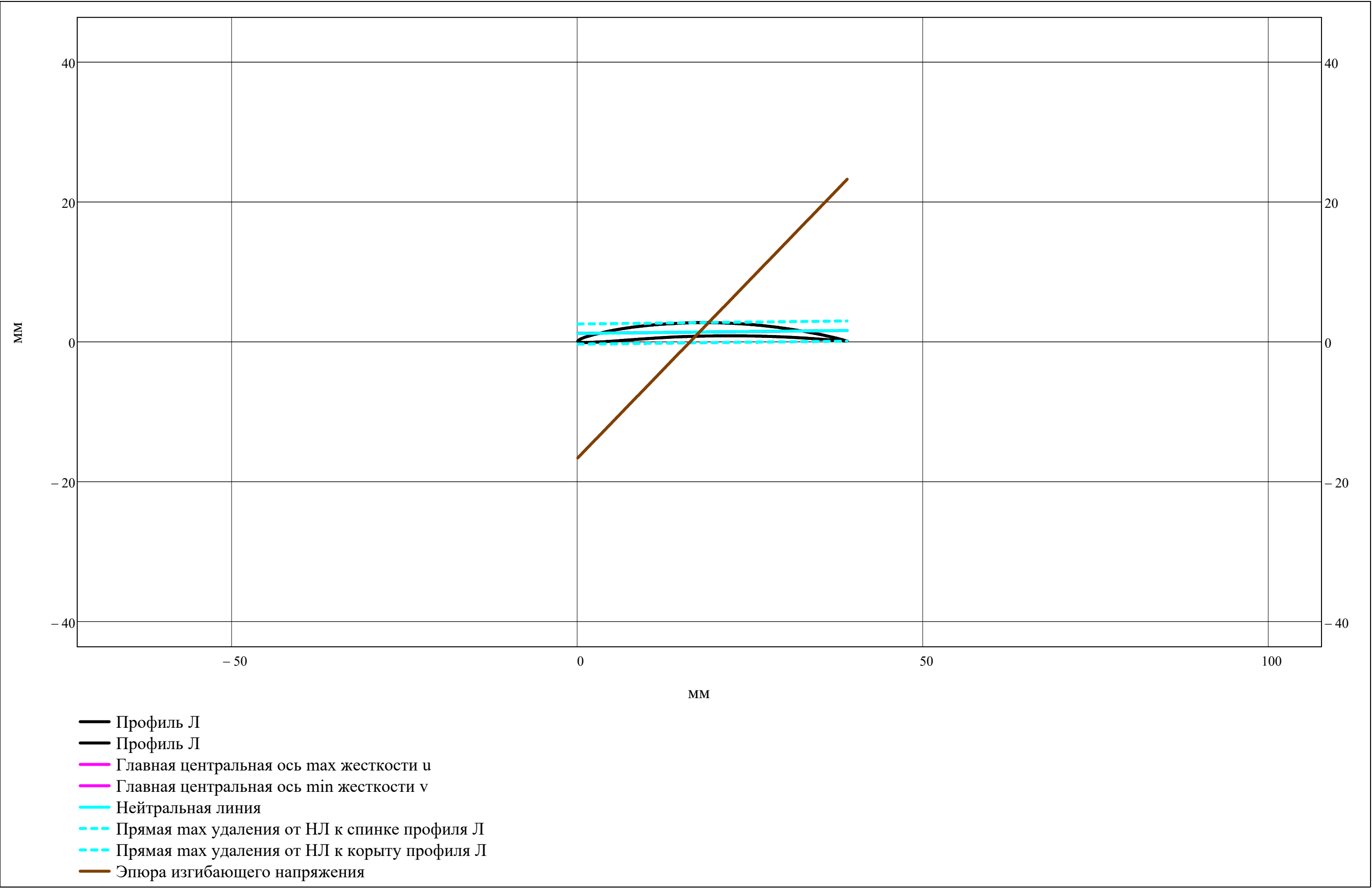
Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma_{p_{\text{rotor}_{j,r}}} & \sigma_{p_{\text{stator}_{j,r}}} \\ \sigma_{n_{\text{rotor}_{j,r}}} & \sigma_{n_{\text{stator}_{j,r}}} \end{pmatrix} = \begin{pmatrix} -26 & 29 \\ 23 & -32 \end{pmatrix} \cdot 10^6$$

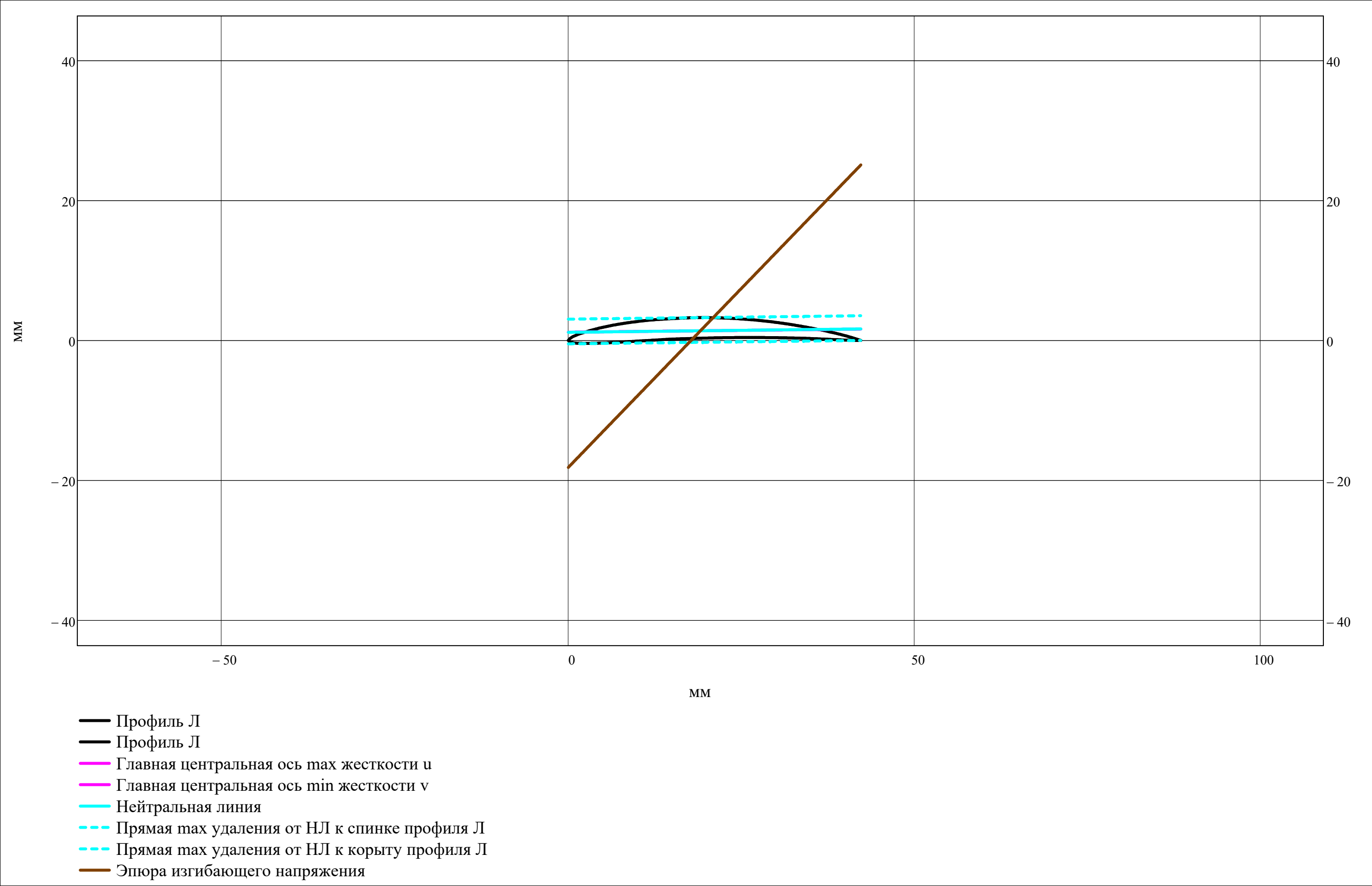
Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{\text{stator}_{j,r}} \\ \sigma_{\text{rotor}_{j,r}} \end{pmatrix} = \begin{pmatrix} 29 \\ 58 \end{pmatrix} \cdot 10^6$$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0_{\text{rotor}_{j,r}} \\ y0_{\text{rotor}_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{\text{stator}_{j,r}} \\ y0_{\text{stator}_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 17.610 \\ \hline 2 & 1.292 \\ \hline \end{array} \cdot 10^{-3} \quad \text{chord} = \begin{cases} \text{chord}_{\text{rotor}_{j,r}} & \text{if blade = "rotor"} \\ \text{chord}_{\text{stator}_{j,r}} & \text{if blade = "stator"} \end{cases} = 39 \cdot 10^{-3}$$









Запас по температуре (K):  $\Delta T_{\text{safety}} = 0$

Выбранный материал Д:  $\text{material\_disk}_i = \begin{cases} \text{"BT23"} & \text{if compressor = "Вл"} \\ \text{"BT6"} & \text{if compressor = "КНД"} \\ \text{"BT9"} & \text{if compressor = "КВД"} \end{cases}$

Плотность материала Д (кг/м^3):

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

Предел длительной прочности Д (Па):

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

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

	1	2	3	4	5	6	7	8	9
1	"BT6"	"BT6"	"BT6"						

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

	1	2	3
1	4430	4430	4430

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

	1	2	3
1	210	210	210

$\cdot 10^6$



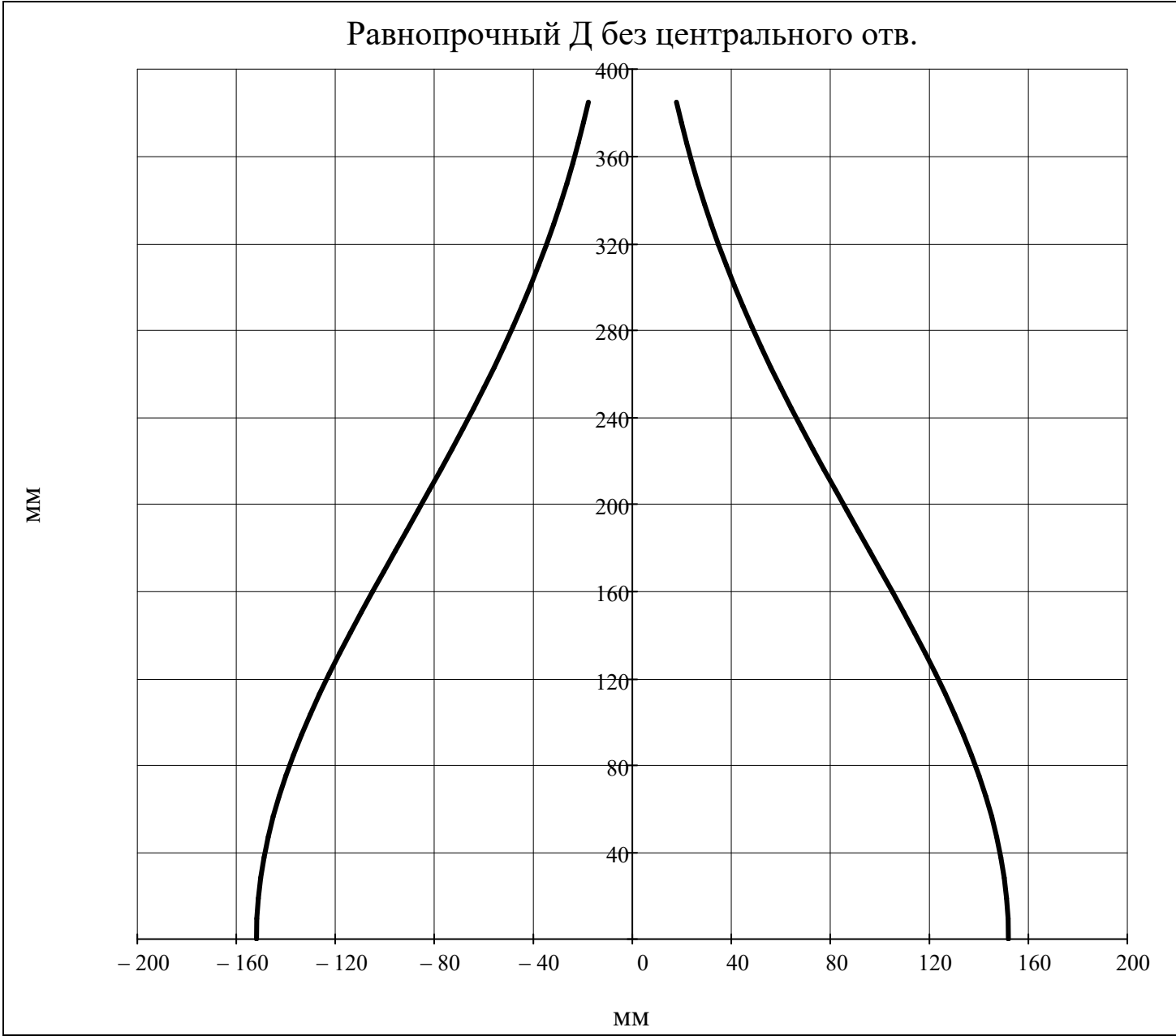
Рассматриваемая ступень:

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

▾ Профилирование равнопрочного Д без центрального отв.

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

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



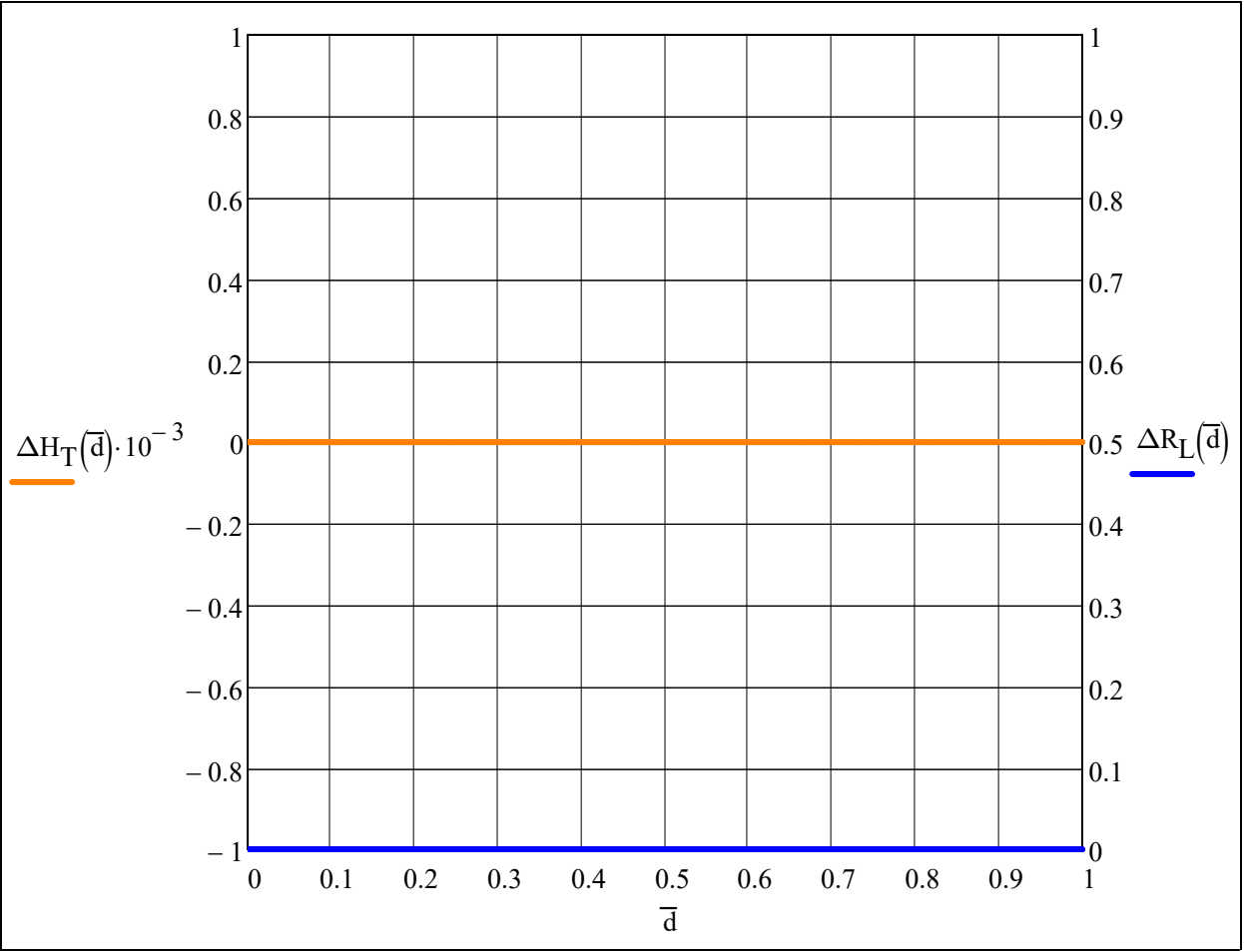
▴ Профилирование равнопрочного Д без центрального отв.

Мах разлика теор. напора ступени и реактивности  
от периферии к корню по высоте Л (Дж/кг)  
[16, с.118-119]:

$$\Delta H_{Tmax} = 0 \cdot 10^3$$

$$\Delta R_{Lmax} = 0.0$$

$$\Delta H_T(\bar{d}) = -\Delta H_{Tmax} \cdot \bar{d} + \Delta H_{Tmax}$$
$$\Delta R_L(\bar{d}) = -\Delta R_{Lmax} \cdot \bar{d} + \Delta R_{Lmax}$$





$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 83.44 \\ 146.22 \\ 87.07 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 90.00 \\ 31.91 \\ 54.79 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{stator.j,r} = 19.79 \cdot ^\circ$$

$$\begin{pmatrix} c_{a_{st(j,1),r}} \\ c_{a_{st(j,2),r}} \\ c_{a_{st(j,3),r}} \end{pmatrix} = \begin{pmatrix} 83.44 \\ 77.29 \\ 71.14 \end{pmatrix}$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 212.81 \\ 213.62 \\ 214.42 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 228.58 \\ 118.25 \\ 178.97 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 21.41 \\ 40.81 \\ 23.42 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{rotor.j,r} = 19.4 \cdot ^\circ$$

$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 83.44 \\ 130.83 \\ 83.02 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 90 \\ 36.21 \\ 58.97 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{stator.j,r} = 19.83 \cdot ^\circ$$

$$\begin{pmatrix} c_{a_{st(j,1),r}} \\ c_{a_{st(j,2),r}} \\ c_{a_{st(j,3),r}} \end{pmatrix} = \begin{pmatrix} 83.44 \\ 77.29 \\ 71.14 \end{pmatrix}$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 250.84 \\ 251.18 \\ 251.52 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 264.35 \\ 164.86 \\ 220.52 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 18.4 \\ 27.96 \\ 18.82 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{rotor.j,r} = 9.56 \cdot ^\circ$$

$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 83.44 \\ 121.25 \\ 80.62 \end{pmatrix}$$

$$\begin{pmatrix} c_{a_{st(j,1),r}} \\ c_{a_{st(j,2),r}} \\ c_{a_{st(j,3),r}} \end{pmatrix} = \begin{pmatrix} 83.44 \\ 77.29 \\ 71.14 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 295.83 \\ 205.48 \\ 255.98 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 90 \\ 39.6 \\ 61.94 \end{pmatrix} \cdot ^\circ$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 283.81 \\ 283.81 \\ 283.81 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 16.38 \\ 22.1 \\ 16.14 \end{pmatrix} \cdot ^\circ$$

$$\epsilon_{stator_{j,r}} = 19.57 \cdot ^\circ$$

$$\epsilon_{rotor_{j,r}} = 5.71 \cdot ^\circ$$

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[illegible]









7	8	9