Параметры расчета

Исходные данные

Коэф. запаса: $safety = 1.3$

Степень двухконтурности: $m2 = 6$

РТ: Воздух $compressor = \text{"КВД"}$

Число Маха: $M = 0$

Геометрическая высота работы (м): $H = 0$

Массовый расход (кг/с): $G = \begin{cases} 35.65 + 213.93 & \text{if } compressor = \text{"Вл"} = 34.81 \\ 35.65 & \text{if } compressor = \text{"КНД"} \\ 34.81 & \text{if } compressor = \text{"КВД"} \end{cases}$

Полная температура на входе в К (К): $T^*_{K1} = \begin{cases} 418.2 & \text{if } compressor = \text{"КВД"} = 418.2 \\ 288.2 & \text{otherwise} \end{cases}$

Полное давление на входе в К (Па): $P^*_{K1} = \begin{cases} 316.2 \cdot 10^3 & \text{if } compressor = \text{"КВД"} = 316.2 \cdot 10^3 \\ 101325 & \text{otherwise} \end{cases}$

Степень повышения давления КВД: $\pi^*_K = \begin{cases} 1.6 & \text{if } compressor = \text{"Вл"} = 9.000 \\ \frac{3.2}{1.6} & \text{if } compressor = \text{"КНД"} \\ 9 & \text{if } compressor = \text{"КВД"} \end{cases}$

Ожидаемый адиабатический КПД ОК: $\eta^*_K = \begin{cases} 0.86 & \text{if compressor = "Вл"} \\ 0.87 & \text{if compressor = "КНД"} \\ 0.88 & \text{if compressor = "КВД"} \end{cases} = 88.00\cdot\%$

Частота вращения ротора (c^{-1}): $\omega = \begin{cases} 1570.8 & \text{if compressor = "КВД"} \\ 555 & \text{otherwise} \end{cases} = 1570.8$

Относ. диаметр корня 1ой ступени [14, с.7]: $\overline{d}_1 = \begin{cases} 0.40 & \text{if compressor = "Вл"} \\ 0.75 & \text{if compressor = "КНД"} \\ 0.65 & \text{if compressor = "КВД"} \end{cases} = 0.65$

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

Частота вращения ротора (об/мин): $n = \frac{60\cdot\omega}{2\cdot\pi} = 15000$

Закон профилирования проточной части (ЗППЧ):

$$ЗППЧ = \begin{pmatrix} \text{"пер" if compressor = "Вл"} & \text{"пер" if compressor = "Вл"} & \text{"пер" if compressor = "Вл"} & \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"кор"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} & \text{"пер"} \\ \text{"пер" if compressor = "КНД"} & \text{"0.96" if compressor = "КНД"} & \text{"0.92" if compressor = "КНД"} & & & & & & & & & & & & \\ \text{"ср" if compressor = "КВД"} & \text{"ср" if compressor = "КВД"} & \text{"кор" if compressor = "КВД"} & & & & & & & & & & & & \end{pmatrix}^T$$

Относ. параметры по относительным ступеням:

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

Тип компрессора	Номер ступени и $\overline{L}_{CT.i}$							
	I	II	III	IV	z_{CP}	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:

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

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

увеличение несущественно увеличивает π

понижение существенно увеличивает π

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

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

[16, с. 234]

увеличение несущественно увеличивает π

увеличение существенно увеличивает π

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

	1	2	3	4	5	6	7	8
1	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700
2	0.990	0.980	0.970	0.960	0.950	0.950	0.950	0.950
3	0.863	0.873	0.888	0.893	0.893	0.888	0.873	0.863
4	0.232	0.222	0.212	0.202	0.192	0.182	0.172	0.162
5	0.267	0.307	0.337	0.347	0.367	0.337	0.307	0.287

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

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

$$0.18 \le \overline{H}_{\sim T}^{T} = (1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1)$$

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

Коэф. теор. напора "средней" ступени [14, с.11]: $\overline{H}_{Tcp} = \dfrac{\sum_{i=1}^{\text{rows}(z_{\sim})} \overline{H}_{\sim T_i}}{\text{rows}(z_{\sim})} = 0.3198$

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

Исходные данные

Распределение основных параметров ОК по ступеням

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

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

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

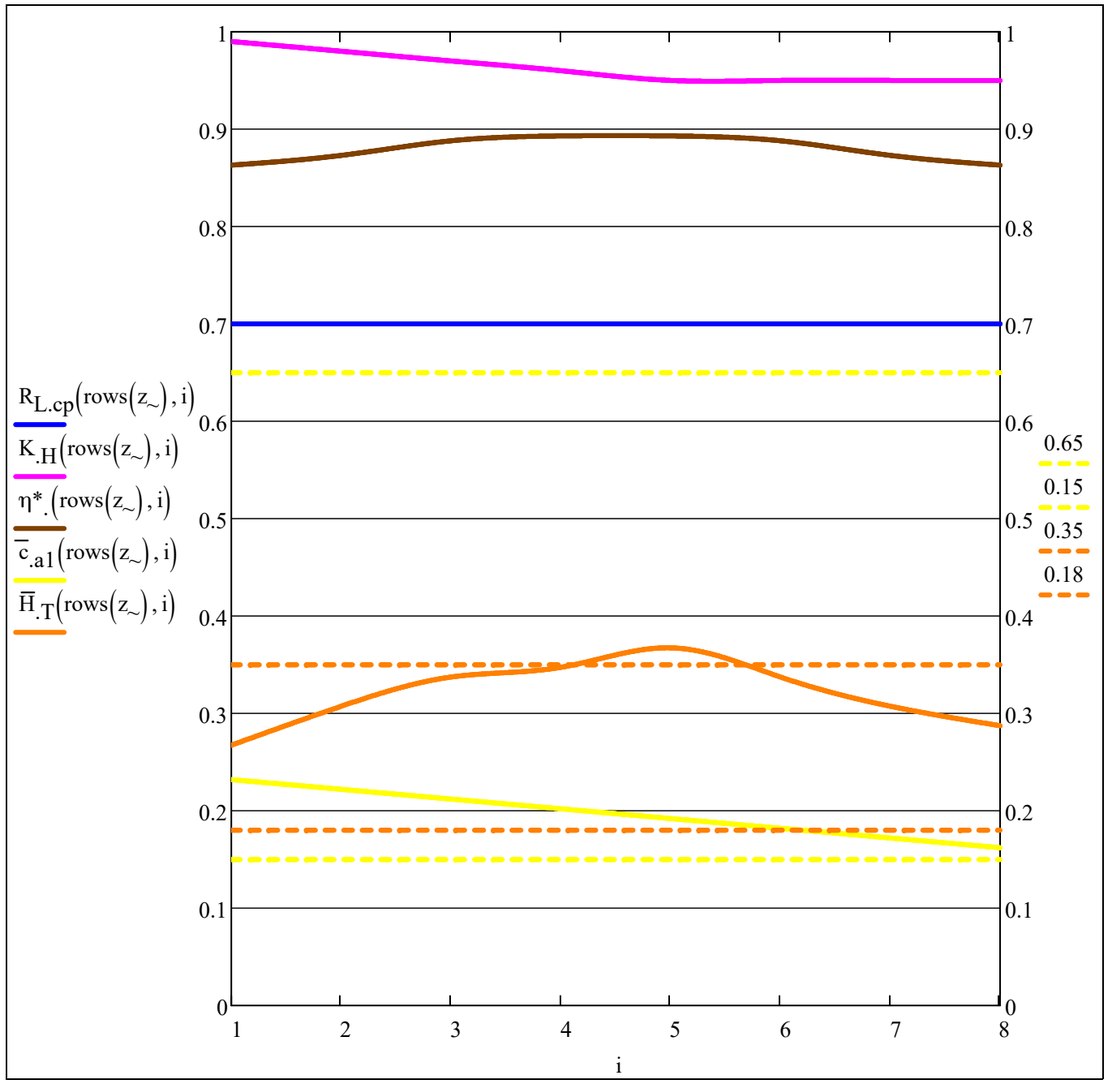
Коэф. расхода: $\overline{c}_{\sim a1}(i) = interp\left(lspline\left(\frac{z_\sim}{rows(z_\sim)}, \overline{c}_{\sim a1}\right), \frac{z_\sim}{rows(z_\sim)}, \overline{c}_{\sim a1}, i\right)$

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

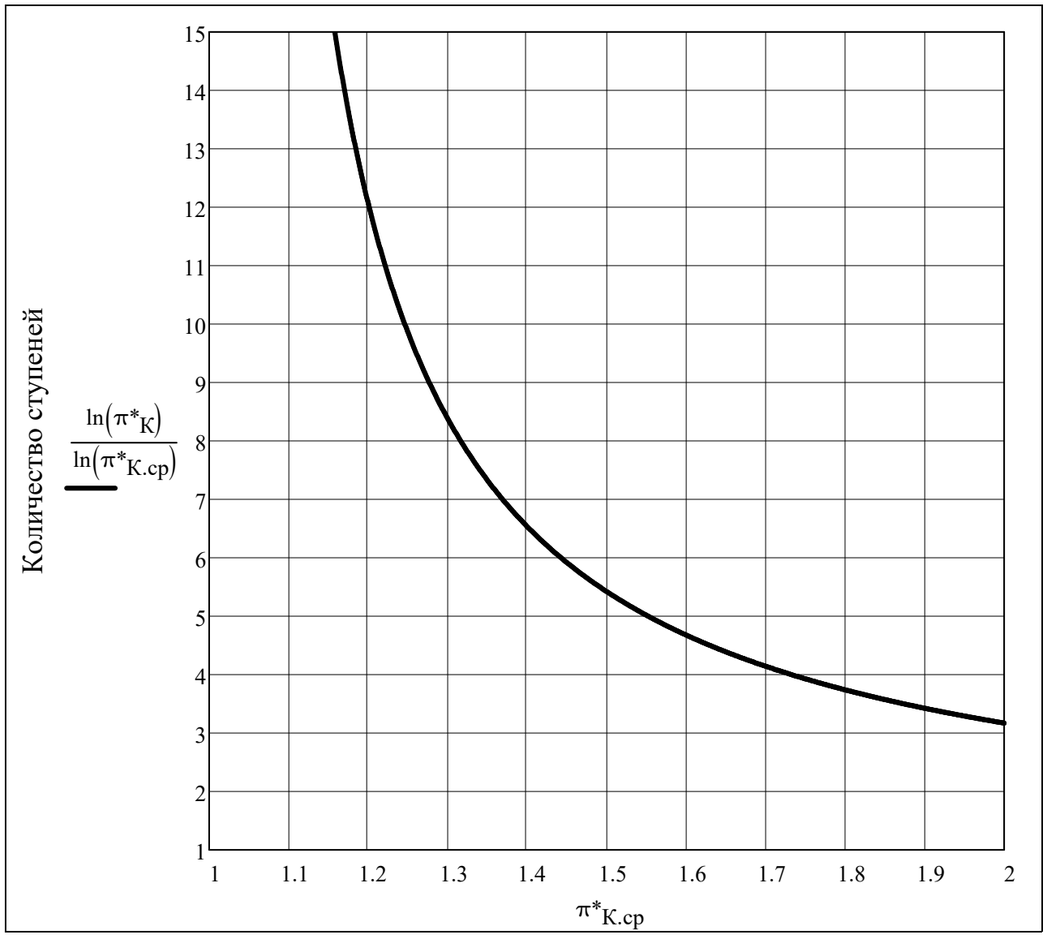
$$\begin{pmatrix} R_{L.cp} \\ K_{.H} \\ \eta^*_{.} \\ \overline{c}_{.a1} \\ \overline{H}_{.T} \end{pmatrix} = \begin{vmatrix} R_{L.cp}(Z,i) = \begin{vmatrix} R_{L\sim cp}\left(\frac{1}{\mathrm{rows}(z_\sim)}\right) & \text{if } i < 1 \\ R_{L\sim cp}(1) & \text{if } i > Z \\ R_{L\sim cp}\left(\frac{i}{Z}\right) & \text{otherwise} \end{vmatrix} \\ K_{.H}(Z,i) = \begin{vmatrix} K_{\sim H}\left(\frac{1}{\mathrm{rows}(z_\sim)}\right) & \text{if } i < 1 \\ K_{\sim H}(1) & \text{if } i > Z \\ K_{\sim H}\left(\frac{i}{Z}\right) & \text{otherwise} \end{vmatrix} \\ \eta^*_{.}(Z,i) = \begin{vmatrix} \eta^*_{\sim}\left(\frac{1}{\mathrm{rows}(z_\sim)}\right) & \text{if } i < 1 \\ \eta^*_{\sim}(1) & \text{if } i > Z \\ \eta^*_{\sim}\left(\frac{i}{Z}\right) & \text{otherwise} \end{vmatrix} \\ \overline{c}_{.a1}(Z,i) = \begin{vmatrix} \overline{c}_{\sim a1}\left(\frac{1}{\mathrm{rows}(z_\sim)}\right) & \text{if } i < 1 \\ \overline{c}_{\sim a1}(1) & \text{if } i > Z \\ \overline{c}_{\sim a1}\left(\frac{i}{Z}\right) & \text{otherwise} \end{vmatrix} \\ \overline{H}_{.T}(Z,i) = \begin{vmatrix} \overline{H}_{\sim T}\left(\frac{1}{\mathrm{rows}(z_\sim)}\right) & \text{if } i < 1 \\ \overline{H}_{\sim T}(1) & \text{if } i > Z \\ \overline{H}_{\sim T}\left(\frac{i}{Z}\right) & \text{otherwise} \end{vmatrix} \\ \left(R_{L.cp} \;\; K_{.H} \;\; \eta^*_{.} \;\; \overline{c}_{.a1} \;\; \overline{H}_{.T}\right)^T \end{vmatrix}$$

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

$$\begin{pmatrix} R_{L.cp}(Z_{temp}, i_{temp}) \\ K_{.H}(Z_{temp}, i_{temp}) \\ \eta^*_{.}(Z_{temp}, i_{temp}) \\ \overline{c}_{.a1}(Z_{temp}, i_{temp}) \\ \overline{H}_{.T}(Z_{temp}, i_{temp}) \end{pmatrix} = \begin{pmatrix} 0.700 \\ 0.950 \\ 0.863 \\ 0.162 \\ 0.287 \end{pmatrix}$$



Распределение основных параметров ОК по ступеням


Количество ступеней
$\frac{\ln(\pi^*_K)}{\ln(\pi^*_{K.cp})}$
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
$\pi^*_{K.cp}$

Нулевые приближения

Показатель адиаьаты перед К []: $k_{K1} = k_{ад}\left(Cp_{воздух}\left(P^*_{K1}, T^*_{K1}\right), R_в\right) = 1.394$

Полное давление после К [Па]: $P^*_{K3} = \pi^*_K \cdot P^*_{K1} = 2846 \cdot 10^3$

$$\begin{pmatrix} iteration_3 \\ T^*_{K3} \\ k_{K3} \end{pmatrix} = \left| \begin{array}{l} iteration_3 = 0 \\ k_{K3} = k_{K1} \\ \text{while } 0 < 1 \\ \quad iteration_3 = iteration_3 + 1 \\ \quad trace\left("iteration.3 = ", num2str\left(iteration_3\right)\right) \\ \quad k_{cp} = mean\left(k_{K1}, k_{K3}\right) \\ \quad T^*_{K3} = T^*_{K1} \cdot \left(1 + \frac{\pi^*_K^{\frac{k_{cp}-1}{k_{cp}}} - 1}{\eta^*_K}\right) \\ \quad Cp_{K3} = Cp_{воздух}\left(P^*_{K3}, T^*_{K3}\right) \\ \quad k'_{K3} = k_{ад}\left(Cp_{K3}, R_в\right) \\ \quad \text{if } \left|eps\left("rel", k_{K3}, k'_{K3}\right)\right| \le epsilon \\ \quad\quad k_{K3} = k'_{K3} \\ \quad\quad \text{break} \\ \quad k_{K3} = k'_{K3} \\ \begin{pmatrix} iteration_3 \\ T^*_{K3} \\ k_{K3} \end{pmatrix} \end{array} \right.$$

Количество итераций []: $iteration_3 = 2$

Полная температура после К [К]: $T^*_{K3} = 805.9$

Показатель адиаьаты после К []: $k_{K3} = 1.354$

Полная плотность перед и после К [кг/м^3]: $\begin{pmatrix} \rho^*_{K1} \\ \rho^*_{K3} \end{pmatrix} = \frac{1}{R_в} \cdot \begin{pmatrix} \frac{P^*_{K1}}{T^*_{K1}} \\ \frac{P^*_{K3}}{T^*_{K3}} \end{pmatrix} = \begin{pmatrix} 2.633 \\ 12.297 \end{pmatrix}$

Критические скорости перед и после К [м/с]: $\begin{pmatrix} a^*_{с.вх} \\ a^*_{с.вых} \end{pmatrix} = \begin{pmatrix} a_{кр}\left(k_{K1}, R_в, T^*_{K1}\right) \\ a_{кр}\left(k_{K3}, R_в, T^*_{K3}\right) \end{pmatrix} = \begin{pmatrix} 373.9 \\ 515.9 \end{pmatrix}$

Ср. показатель адиабаты К []: $k_{cp} = k_{ад}\left(Cp_{воздух.ср}\left(P^*_{K1}, P^*_{K3}, T^*_{K1}, T^*_{K3}\right), R_в\right) = 1.374$

Теоретический напор [Дж/кг]: $H_{TK} = \frac{Cp_{воздух.ср}\left(P^*_{K1}, P^*_{K3}, T^*_{K1}, T^*_{K3}\right) \cdot T^*_{K1} \cdot \left(\pi^*_K^{\frac{k_{cp}-1}{k_{cp}}} - 1\right)}{\eta^*_K} = 410.3 \cdot 10^3$

$$\begin{pmatrix} \text{iteration}_u \\ u_{1пер} \\ Z_{recomend} \\ c_{вх} \\ \lambda_{вх} \\ \rho_{К1} \end{pmatrix} =$$

$\text{iteration}_u = 0$

$\rho_{К1} = \rho^*_{К1}$

while $0 < 1$

$\quad \text{iteration}_u = \text{iteration}_u + 1$

$\quad \text{trace}\left(\text{concat}\left("\text{iteration.u} = " , \text{num2str}\left(\text{iteration}_u\right)\right)\right)$

$$u_{1пер} = \sqrt[3]{\frac{\pi \cdot G \cdot n^2}{900 \cdot \overline{c}_{.a1}(1,0) \cdot \rho_{К1} \cdot \left[1 - \left(\overline{d}_1\right)^2\right]}}$$

$$Z_{recomend} = \max\left(\text{round}\left(\frac{H_{ТК}}{\overline{H}_{Тср} \cdot u_{1пер}^{\ 2}}\right), 1\right)$$

$$c_{вх} = \overline{c}_{.a1}\left(Z_{recomend}, 0\right) \cdot u_{1пер}$$

$$\lambda_{вх} = \frac{c_{вх}}{a^*_{с.вх}}$$

$$\rho'_{К1} = \rho^*_{К1} \cdot ГДФ\left("\rho" , \lambda_{вх} , k_{К1}\right)$$

if $\left|\text{eps}\left("\text{rel}" , \rho'_{К1} , \rho_{К1}\right)\right| \le \text{epsilon}$

$\quad \rho_{К1} = \rho'_{К1}$

$\quad$ break

$\rho_{К1} = \rho'_{К1}$

$$\begin{pmatrix} \text{iteration}_u \\ u_{1пер} \\ Z_{recomend} \\ c_{вх} \\ \lambda_{вх} \\ \rho_{К1} \end{pmatrix}$$

Количество итераций []: $\text{iteration}_u = 2$

Окружная скорость на перифкрии перед К [м/с]: $u_{1пер} = 430.5$

Рекомендуемое количество ступеней []: $Z_{recomend} = 7$

Абс. скорость перед К [м/с]: $c_{вх} = 99.9$

Приведенная скорость перед К []: $\lambda_{вх} = 0.2671$

Плотность перед К [кг/м^3]: $\rho_{К1} = 2.555$

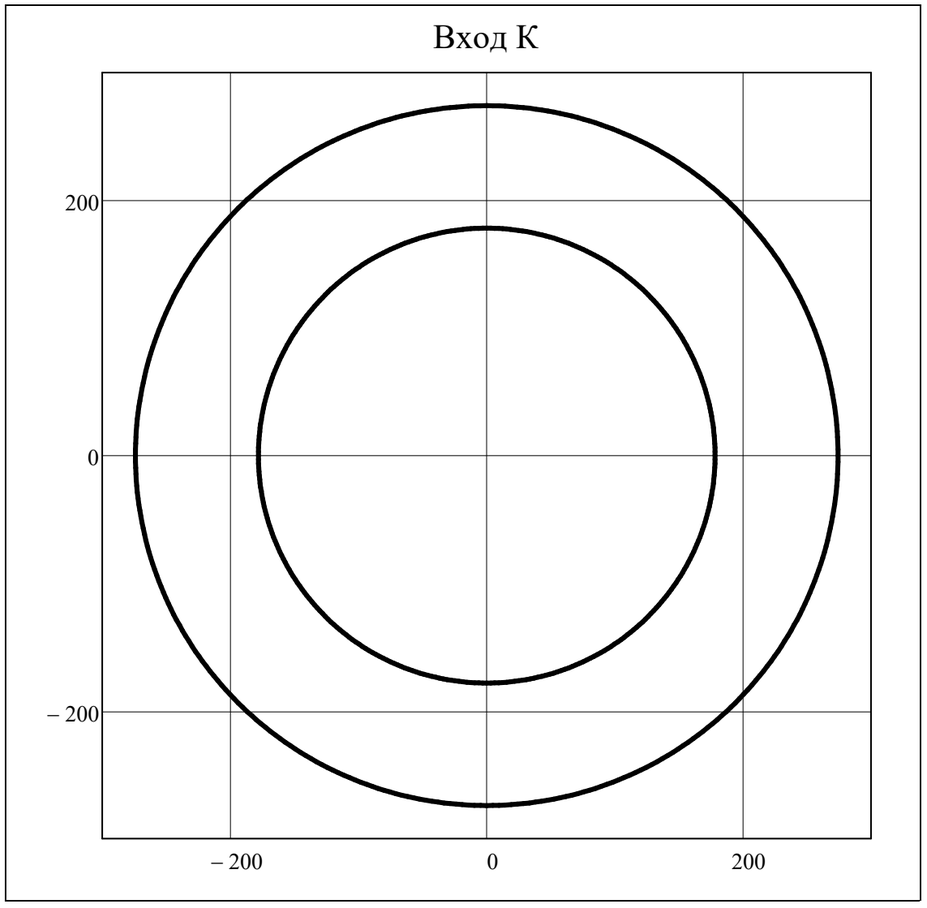
Кольцевая площадь перед К [м^2]: $$F_{вх} = \frac{G \cdot \sqrt{R_в \cdot T^*_{К1}}}{m_q\left(k_{К1}\right) \cdot P^*_{К1} \cdot ГДФ\left("G" , \lambda_{вх} , k_{К1}\right)} = 0.1364$$

$$D'_{пер1} = \frac{2 \cdot u_{1пер}}{\omega} = 548.2 \cdot 10^{-3}$$

Диамтеры перед К [м]: $D'_{ср1} = \overline{r}_{ср}\left(\overline{d}_1\right) \cdot D'_{пер1} = 462.3 \cdot 10^{-3}$

$$D'_{кор1} = \overline{d}_1 \cdot D'_{пер1} = 356.3 \cdot 10^{-3}$$

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



Рекомендуемое количество ступеней []: $Z_{recomend} = 7$

Количество ступеней []:

$$Z = \begin{cases} 1 & \text{if compressor} = \text{"Вл"} \\ 3 & \text{if compressor} = \text{"КНД"} \\ 9 & \text{if compressor} = \text{"КВД"} \end{cases} = 9$$

Нулевые приближения

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

Расчет BHA:

$$\begin{pmatrix} \alpha_{1BHA} & \alpha_{3BHA} \\ \sigma_{BHA} & \sigma_{BHA} \\ \bar{d}_{1BHA} & \bar{d}_{3BHA} \\ T^*_{1BHA} & T^*_{3BHA} \\ P^*_{1BHA} & P^*_{3BHA} \\ \rho^*_{1BHA} & \rho^*_{3BHA} \\ k_{1BHA} & k_{3BHA} \\ a_{кр1BHA} & a_{кр3BHA} \\ \bar{c}_{a1BHA} & \bar{c}_{a3BHA} \\ \bar{c}_{u1BHA} & \bar{c}_{u3BHA} \\ c_{a1BHA} & c_{a3BHA} \\ c_{u1BHA} & c_{u3BHA} \\ c_{1BHA} & c_{3BHA} \\ \lambda_{c1BHA} & \lambda_{c3BHA} \\ F_{1BHA} & F_{3BHA} \\ \varepsilon_{BHA} & \varepsilon_{BHA} \end{pmatrix} =$$

for $r \in av(N_r)$

$\alpha_{1BHA_r} = 90°$

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

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

$T^*_{1BHA_r} = T^*_{К1}$

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

$P^*_{1BHA_r} = P^*_{К1}$

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

$k_{1BHA_r} = k_{ад}\left(Cp_{воздух}\left(P^*_{1BHA_r}, T^*_{1BHA_r}\right), R_в\right)$

$a_{кр1BHA_r} = a_{кр}\left(k_{1BHA_r}, R_в, T^*_{1BHA_r}\right)$

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

$$\bar{c}_{u1BHA_r} = \begin{cases} \bar{r}_{cp}\left(\bar{d}_{1BHA}\right)\cdot\left(1 - R_{L.cp}(Z,0)\right) - \dfrac{\bar{H}_{.T}(Z,0)}{2\cdot\bar{r}_{cp}\left(\bar{d}_{1BHA}\right)} & \text{if } BHA = 1 \\ 0 & \text{otherwise} \end{cases}$$

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

$\sigma_{BHA} = 0.9982$

$submatrix\left(\varepsilon_{BHA}, av(N_r), av(N_r), 1, 1\right) = (22.17)\cdot deg$

$submatrix\left(\alpha_{1BHA}, av(N_r), av(N_r), 1, 1\right) = (90.00)\cdot deg$

$submatrix\left(\alpha_{3BHA}, av(N_r), av(N_r), 1, 1\right) = (67.83)\cdot deg$

$$\begin{pmatrix} \bar{d}_{1BHA} \\ \bar{d}_{3BHA} \end{pmatrix} = \begin{pmatrix} 0.6500 \\ 0.6500 \end{pmatrix} \qquad \begin{pmatrix} F_{1BHA} \\ F_{3BHA} \end{pmatrix} = \begin{pmatrix} 0.1364 \\ 0.1373 \end{pmatrix}$$

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

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

$$\lambda_{c1BHA_r} = \frac{c_{1BHA_r}}{a_{кр1BHA_r}}$$

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

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

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

$$k_{3BHA_r} = k_{ад}\left(Cp_{воздух}\left(P^*3BHA_r, T^*3BHA_r\right), R_в\right)$$

$$a_{кр3BHA_r} = a_{кр}\left(k_{3BHA_r}, R_в, T^*3BHA_r\right)$$

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

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

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

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

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

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

$$\lambda_{c3BHA_r} = \frac{c_{3BHA_r}}{a_{кр3BHA}}$$

$$\text{submatrix}\left(T^*1BHA, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (418.2)$$

$$\text{submatrix}\left(T^*3BHA, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (418.2)$$

$$\text{submatrix}\left(P^*1BHA, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (316.2)\cdot 10^3$$

$$\text{submatrix}\left(P^*3BHA, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (315.6)\cdot 10^3$$

$$\text{submatrix}\left(\rho^*1BHA, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (2.633)$$

$$\text{submatrix}\left(\rho^*3BHA, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (2.628)$$

$$\text{submatrix}\left(k_{1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.394)$$

$$\text{submatrix}\left(k_{3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (1.394)$$

$$\text{submatrix}\left(a_{кр1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (373.9)$$

$$\text{submatrix}\left(a_{кр3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (373.9)$$

$$\text{submatrix}\left(\overline{c}_{a1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.232)$$

$$\text{submatrix}\left(\overline{c}_{a3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.233)$$

$$\text{submatrix}\left(\overline{c}_{u1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.095)$$

$$\text{submatrix}\left(\overline{c}_{u3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.097)$$

$$\text{submatrix}\left(c_{a1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (99.9)$$

$$\text{submatrix}\left(c_{a3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (99.9)$$

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

$$\text{submatrix}\left(c_{u3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (40.7)$$

$$\text{submatrix}\left(c_{1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (99.9)$$

$$\text{submatrix}\left(c_{3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (107.9)$$

$$\text{submatrix}\left(\lambda_{c1BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.267)$$

$$\text{submatrix}\left(\lambda_{c3BHA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (0.288)$$

$$\kappa p3BHA_r$$

$$\begin{pmatrix} F_{1BHA} \\ F_{3BHA} \end{pmatrix} = G\cdot\sqrt{R_B}\cdot\begin{pmatrix} \dfrac{\sqrt{T^*_{1BHA_r}}}{m_q\left(k_{1BHA_r}\right)\cdot P^*_{1BHA_r}\cdot ГДФ\left("G",\lambda_{c1BHA_r},k_{1BHA_r}\right)\cdot\sin\left(\alpha_{1BHA_r}\right)} \\ \dfrac{\sqrt{T^*_{3BHA_r}}}{m_q\left(k_{3BHA_r}\right)\cdot P^*_{3BHA_r}\cdot ГДФ\left("G",\lambda_{c3BHA_r},k_{3BHA_r}\right)\cdot\sin\left(\alpha_{3BHA_r}\right)} \end{pmatrix}$$

$$\varepsilon_{BHA_r} = -1\cdot\left(\alpha_{3BHA_r} - \alpha_{1BHA_r}\right)$$

α_{1BHA}	α_{3BHA}
σ_{BHA}	σ_{BHA}
$\overline{d}_{1BHA}$	$\overline{d}_{3BHA}$
T^*_{1BHA}	T^*_{3BHA}
P^*_{1BHA}	P^*_{3BHA}
ρ^*_{1BHA}	ρ^*_{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}
λ_{c1BHA}	λ_{c3BHA}
F_{1BHA}	F_{3BHA}
ε_{BHA}	ε_{BHA}

Расчет ВНА:

Поступенчатый расчет ОК по ср. ЛТ

R_L π^*
K_H η^*
Cp k
$\overline{H}_T$ H_T
L^* L
T^* T
P^* P
ρ^* ρ
a^*_c $a_{зв}$
λ_c λ_c
F F
D R
$\overline{d}$ h
$\overline{c}_a$ $\overline{c}_u$
c_a c_u
u w_u
c w
M_c M_w
α β
ε_{rotor} ε_{stator}

$$
\begin{aligned}
&r = av(N_r)\\
&T^*_{st(1,1),r} = T^*_{3ВНА_r}\\
&P^*_{st(1,1),r} = P^*_{3ВНА_r}\\
&\rho^*_{st(1,1),r} = \rho^*_{3ВНА_r}\\
&Cp_{st(1,1),r} = Cp_{воздух}\left(P^*_{st(1,1),r}, T^*_{st(1,1),r}\right)\\
&k_{st(1,1),r} = k_{ад}\left(Cp_{st(1,1),r}, R_в\right)\\
&a^*c_{st(1,1),r} = a_{кр}\left(k_{st(1,1),r}, R_в, T^*_{st(1,1),r}\right)\\
&\overline{c}a_{st(1,1),r} = \overline{c}a3ВНА_r\\
&\overline{c}u_{st(1,1),r} = \overline{c}u3ВНА_r\\
&ca_{st(1,1),r} = ca3ВНА_r\\
&u_{st(1,1),N_r} = u1пер\\
&\alpha_{st(1,1),r} = \alpha_{3ВНА_r}\\
&c_{st(1,1),r} = \frac{ca_{st(1,1),r}}{\sin\left(\alpha_{st(1,1),r}\right)}\\
&\lambda c_{st(1,1),r} = \frac{c_{st(1,1),r}}{a^*c_{st(1,1),r}}\\
&F_{st(1,1)} = \frac{G\cdot\sqrt{R_в\cdot T^*_{st(1,1),r}}}{m_q\left(k_{st(1,1),r}\right)\cdot ГДФ\left("G", \lambda c_{st(1,1),r}, k_{st(1,1),r}\right)\cdot\sin\left(\alpha_{st(1,1),r}\right)\cdot P^*_{st(1,1),r}}
\end{aligned}
$$

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

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

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

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

for $i \in 1..Z$

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 $0 < 1$

$$iteration_{12} = iteration_{12} + 1$$

trace(concat(" iteration.12 = " , num2str(iteration$_{12}$)))

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

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

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

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

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

$$Cp_{st(i,2),r} = Cp_{воздух}\left(P^*_{st(i,2),r}, T^*_{st(i,2),r}\right)$$

$k'_2 = k_{ад}\left(Cp_{st(i,2),r}, R_в\right)$

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

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

break

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

$a^*c_{st(i,2),r} = a_{кр}\left(k_{st(i,2),r}, R_в, T^*_{st(i,2),r}\right)$

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

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

$Cp_{st(i,3),r} = Cp_{воздух}\left(P^*_{st(i,3),r}, T^*_{st(i,3),r}\right)$

$k_{st(i,3),r} = k_{ад}\left(Cp_{st(i,3),r}, R_в\right)$

$a^*c_{st(i,3),r} = a_{кр}\left(k_{st(i,3),r}, R_в, T^*_{st(i,3),r}\right)$

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

$iteration_3 = 0$

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

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

$c_{st(i,3),r} = \dfrac{ca_{st(i,3),r}}{\sin\left(\alpha_{st(i,3),r}\right)}$

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

$F_{st(i,3)} = \dfrac{F_{st(i,1)} \cdot m_q\left(k_{st(i,1),r}\right) \cdot ГДФ\left("G", \lambda_{c_{st(i,1),r}}, k_{st(i,1),r}\right) \cdot \sin\left(\alpha_{st(i,1),r}\right) \cdot P^*_{st(i,1),r} \cdot \sqrt{T^*_{st(i,3),r}}}{m_q\left(k_{st(i,3),r}\right) \cdot ГДФ\left("G", \lambda_{c_{st(i,3),r}}, k_{st(i,3),r}\right) \cdot \sin\left(\alpha_{st(i,3),r}\right) \cdot P^*_{st(i,3),r} \sqrt{T^*_{st(i,1),r}}}$

while $0 < 1$

$iteration_3 = iteration_3 + 1$

$trace\left(concat\left("\quad iteration.3 = ", num2str\left(iteration_3\right)\right)\right)$

if $\left(ЗППЧ_i \neq "пер"\right) \wedge \left(ЗППЧ_i \neq "кор"\right) \wedge \left(ЗППЧ_i \neq "ср"\right)$

$D_{st(i,3),N_r} = D_{st(i,1),N_r} \cdot str2num\left(ЗППЧ_i\right)$

$D_{st(i,3),1} = \sqrt{\left(D_{st(i,3),N_r}\right)^2 - \dfrac{4F_{st(i,3)}}{\pi}}$

if $ЗППЧ_i = "пер"$

$$D_{st(i,3),N_r} = D_{st(i,1),N_r}$$

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

if $ЗППЧ_i = "кор"$

$$D_{st(i,3),1} = D_{st(i,1),1}$$

$$D_{st(i,3),N_r} = \sqrt{\left(D_{st(i,3),1}\right)^2 + \frac{4F_{st(i,3)}}{\pi}}$$

if $ЗППЧ_i = "ср"$

$$D_{st(i,3),N_r} = \sqrt{\left(D_{st(i,1),r}\right)^2 + \frac{2F_{st(i,3)}}{\pi}}$$

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

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

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

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

$$\alpha_{st(i,3),r} = \begin{cases} \operatorname{atan}\left(\dfrac{\overline{c}a_{st(i,3),r}}{\overline{c}u_{st(i,3),r}}\right) & \text{if } \operatorname{atan}\left(\dfrac{\overline{c}a_{st(i,3),r}}{\overline{c}u_{st(i,3),r}}\right) \geq 0 \\ \operatorname{atan}\left(\dfrac{\overline{c}a_{st(i,3),r}}{\overline{c}u_{st(i,3),r}}\right) + 2\pi & \text{otherwise} \end{cases}$$

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

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

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

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

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

break if $\left(\left|eps\left("rel",F'_3,F_{st(i,3)}\right)\right| < epsilon\right) \wedge \left(iteration_3 = 0\right)$

$iteration_3 = -1$ if $\left(\left|eps\left("rel",F'_3,F_{st(i,3)}\right)\right| < epsilon\right)$

$F_{st(i,3)} = F'_3$

$\overline{c}a_{st(i,2),r} = \text{mean}\left(\overline{c}a_{st(i,1),r}, \overline{c}a_{st(i,3),r}\right)$

$\text{iteration}_2 = 0$

$F_{st(i,2)} = \text{mean}\left(F_{st(i,1)}, F_{st(i,3)}\right)$

while $0 < 1$

$\text{iteration}_2 = \text{iteration}_2 + 1$

$\text{trace}\left(\text{concat}\left(\text{" iteration.2 = "}, \text{num2str}\left(\text{iteration}_2\right)\right)\right)$

if $\left(ЗППЧ_i \neq \text{"пер"}\right) \wedge \left(ЗППЧ_i \neq \text{"кор"}\right) \wedge \left(ЗППЧ_i \neq \text{"ср"}\right)$

$D_{st(i,2),N_r} = \text{mean}\left(D_{st(i,1),N_r}, D_{st(i,3),N_r}\right)$

$\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}\left(\overline{r}_{cp}\left(\overline{d}_{st(i,1)}\right), \overline{r}_{cp}\left(\overline{d}_{st(i,3)}\right)\right)^2 - 1}$

$D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}\left(\overline{d}_{st(i,2)}\right)$

$D_{st(i,2),1} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$

if $ЗППЧ_i = \text{"пер"}$

$D_{st(i,2),N_r} = D_{st(i,1),N_r}$

$\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}\left(\overline{r}_{cp}\left(\overline{d}_{st(i,1)}\right), \overline{r}_{cp}\left(\overline{d}_{st(i,3)}\right)\right)^2 - 1}$

$D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}\left(\overline{d}_{st(i,2)}\right)$

$D_{st(i,2),1} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$

if $ЗППЧ_i = \text{"кор"}$

$D_{st(i,2),1} = D_{st(i,1),1}$

$\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}\left(\overline{r}_{cp}\left(\overline{d}_{st(i,1)}\right), \overline{r}_{cp}\left(\overline{d}_{st(i,3)}\right)\right)^2 - 1}$

$D_{st(i,2),N_r} = \frac{D_{st(i,2),1}}{\overline{d}_{st(i,2)}}$

$D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}\left(\overline{d}_{st(i,2)}\right)$

if $ЗППЧ_i = \text{"ср"}$

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

$\overline{d}_{st(i,2)} = \sqrt{2 \cdot \text{mean}\left(\overline{r}_{cp}\left(\overline{d}_{st(i,1)}\right), \overline{r}_{cp}\left(\overline{d}_{st(i,3)}\right)\right)^2 - 1}$

$D_{st(i,2),N_r} = \frac{D_{st(i,2),r}}{\overline{r}_{cp}\left(\overline{d}_{st(i,2)}\right)}$

$D_{st(i,2),1} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$

$\left(D \quad \right)^2$

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

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

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

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

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

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

$$F'_2 = \frac{G\cdot\sqrt{R_B\cdot T^*_{st(i,2),r}}}{m_q\left(k_{st(i,2),r}\right)\cdot\Gamma\text{Д}\Phi\left(\text{"G"}, \lambda c_{st(i,2),r}, k_{st(i,2),r}\right)\cdot\sin\left(\alpha_{st(i,2),r}\right)\cdot P^*_{st(i,2),r}}$$

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

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

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

for $a \in 1..3$

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

$$T_{st(i,a),r} = T^*_{st(i,a),r}\cdot\Gamma\text{Д}\Phi\left(\text{"T"}, \lambda c_{st(i,a),r}, k_{st(i,a),r}\right)$$

$$P_{st(i,a),r} = P^*_{st(i,a),r}\cdot\Gamma\text{Д}\Phi\left(\text{"P"}, \lambda c_{st(i,a),r}, k_{st(i,a),r}\right)$$

$$\rho_{st(i,a),r} = \rho^*_{st(i,a),r}\cdot\Gamma\text{Д}\Phi\left(\text{"}\rho\text{"}, \lambda c_{st(i,a),r}, k_{st(i,a),r}\right)$$

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

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

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

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

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

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

$$M\ \ c_{st(i,a),r}$$

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

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

for $radius \in 1..N_r$

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

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

for $i \in 1..Z$

for $a \in 1..3$

for $r \in 1..N_r$

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

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

$$\begin{pmatrix} H_T \\ R_L \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad H_{T.}(r) = \text{interp}\left[\text{pspline}\left[\begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} H_{T_{i,\text{av}(N_r)}} - \frac{\Delta H_T(\overline{d}_{\text{st}(i,2)})}{2} \\ H_{T_{i,\text{av}(N_r)}} \\ H_{T_{i,\text{av}(N_r)}} + \frac{\Delta H_T(\overline{d}_{\text{st}(i,2)})}{2} \end{pmatrix}\right], \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} H_{T_{i,\text{av}(N_r)}} - \frac{\Delta H_T(\overline{d}_{\text{st}(i,2)})}{2} \\ H_{T_{i,\text{av}(N_r)}} \\ H_{T_{i,\text{av}(N_r)}} + \frac{\Delta H_T(\overline{d}_{\text{st}(i,2)})}{2} \end{pmatrix}, r\right] \\ \quad R_{L.}(r) = \text{interp}\left[\text{pspline}\left[\begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} R_{L_{i,\text{av}(N_r)}} - \frac{\Delta R_L(\overline{d}_{\text{st}(i,2)})}{2} \\ R_{L_{i,\text{av}(N_r)}} \\ R_{L_{i,\text{av}(N_r)}} + \frac{\Delta R_L(\overline{d}_{\text{st}(i,2)})}{2} \end{pmatrix}\right], \begin{pmatrix} 1 \\ \text{av}(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} R_{L_{i,\text{av}(N_r)}} - \frac{\Delta R_L(\overline{d}_{\text{st}(i,2)})}{2} \\ R_{L_{i,\text{av}(N_r)}} \\ R_{L_{i,\text{av}(N_r)}} + \frac{\Delta R_L(\overline{d}_{\text{st}(i,2)})}{2} \end{pmatrix}, r\right] \\ \quad \text{for } r \in 1..N_r \\ \quad\quad H_{T_{i,r}} = H_{T.}(r) \\ \quad\quad R_{L_{i,r}} = R_{L.}(r) \\ \begin{pmatrix} H_T \\ R_L \end{pmatrix} \end{array} \right.$$

Поступенчатый расчет ОК по ср. ЛТ

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

Расчет СА:

$$\begin{pmatrix} \alpha_{1CA} & \alpha_{3CA} \\ \sigma_{CA} & \sigma_{CA} \\ \overline{d}_{1CA} & \overline{d}_{3CA} \\ T^*_{1CA} & T^*_{3CA} \\ P^*_{1CA} & P^*_{3CA} \\ \rho^*_{1CA} & \rho^*_{3CA} \\ k_{1CA} & k_{3CA} \\ a_{кр1CA} & a_{кр3CA} \\ \overline{c}_{a1CA} & \overline{c}_{a3CA} \\ \overline{c}_{u1CA} & \overline{c}_{u3CA} \\ c_{a1CA} & c_{a3CA} \\ c_{u1CA} & c_{u3CA} \\ c_{1CA} & c_{3CA} \\ \lambda_{1CA} & \lambda_{3CA} \\ F_{1CA} & F_{3CA} \\ \varepsilon_{CA} & \varepsilon_{CA} \end{pmatrix} =$$

for $r \in av(N_r)$

$\alpha_{1CA_r} = \alpha_{st(Z,3),r}$

$\alpha_{3CA_r} = \begin{cases} 90\cdot° & \text{if } CA = 1 \\ \alpha_{1CA_r} & \text{otherwise} \end{cases}$

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

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

$T^*_{1CA_r} = T^*_{st(Z,3),r}$

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

$P^*_{1CA_r} = P^*_{st(Z,3),r}$

$iterarion_{CA} = 0$

$\sigma_{CA} = 1$

while $0 < 1$

$iterarion_{CA} = iterarion_{CA} + 1$

$trace(concat("iterarion.CA = ", num2str(iterarion_{CA})))$

$P^*_{3CA_r} = P^*_{1CA_r} \cdot \sigma_{CA}$

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

$\sigma_{CA} = 0.9981$

$submatrix(\varepsilon_{CA}, av(N_r), av(N_r), 1, 1) = (36.82)\cdot deg$

$submatrix(\alpha_{1CA}, av(N_r), av(N_r), 1, 1) = (53.18)\cdot deg$

$submatrix(\alpha_{3CA}, av(N_r), av(N_r), 1, 1) = (90.00)\cdot deg$

$$\begin{pmatrix} \overline{d}_{1CA} \\ \overline{d}_{3CA} \end{pmatrix} = \begin{pmatrix} 0.8390 \\ 0.8390 \end{pmatrix} \qquad \begin{pmatrix} F_{1CA} \\ F_{3CA} \end{pmatrix} = \begin{pmatrix} 0.0498 \\ 0.0598 \end{pmatrix}$$

$$\begin{pmatrix} \rho^*3CA_r \end{pmatrix} = \frac{}{R_в}\cdot\left(\frac{P^*3CA_r}{T^*3CA_r}\right)$$

$$\begin{pmatrix} k1CA_r \\ k3CA_r \end{pmatrix} = \begin{pmatrix} k_{ад}\left(Cp_{воздух}\left(P^*1CA_r, T^*1CA_r\right), R_в\right) \\ k_{ад}\left(Cp_{воздух}\left(P^*3CA_r, T^*3CA_r\right), R_в\right) \end{pmatrix}$$

$$\begin{pmatrix} a_{кр}1CA_r \\ a_{кр}3CA_r \end{pmatrix} = \begin{pmatrix} a_{кр}\left(k1CA_r, R_в, T^*1CA_r\right) \\ a_{кр}\left(k3CA_r, R_в, T^*3CA_r\right) \end{pmatrix}$$

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

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

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

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

$$ca1CA_r = \overline{c}a3CA_r \cdot u_{st(Z,3),N_r}$$

$$ca3CA_r = ca1CA_r - \begin{cases} 10 & \text{if } CA = 1 \\ 0 & \text{otherwise} \end{cases}$$

$$\begin{pmatrix} cu1CA_r \\ cu3CA_r \end{pmatrix} = \begin{pmatrix} \frac{ca1CA_r}{\tan\left(\alpha1CA_r\right)} \\ \frac{ca3CA_r}{\tan\left(\alpha3CA_r\right)} \end{pmatrix}$$

$$\begin{pmatrix} c1CA_r \\ c3CA_r \end{pmatrix} = \begin{pmatrix} \frac{ca1CA_r}{\sin\left(\alpha1CA_r\right)} \\ \frac{ca3CA_r}{\sin\left(\alpha3CA_r\right)} \end{pmatrix}$$

$$\begin{pmatrix} \lambda1CA_r \\ \lambda3CA_r \end{pmatrix} = \begin{pmatrix} \frac{c1CA_r}{a_{кр}1CA_r} \\ \frac{c3CA_r}{a_{кр}3CA_r} \end{pmatrix}$$

$$\sigma'_{CA} = \begin{cases} 1 - \text{mean}(0.25, 0.5)\cdot ГДФ\left("\rho", \lambda3CA_r, k3CA_r\right)\cdot\frac{k3CA_r}{k3CA_r + 1}\cdot\left(\lambda3CA_r\right)^2 & \text{if } CA = 1 \end{cases}$$

$\text{submatrix}\left(T^*1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (826.7)$

$\text{submatrix}\left(T^*3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (826.7)$

$\text{submatrix}\left(P^*1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (2841.7)\cdot 10^3$

$\text{submatrix}\left(P^*3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (2836.3)\cdot 10^3$

$\text{submatrix}\left(\rho^*1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (11.972)$

$\text{submatrix}\left(\rho^*3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (11.949)$

$\text{submatrix}\left(k1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (1.352)$

$\text{submatrix}\left(k3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (1.352)$

$\text{submatrix}\left(a_{кр}1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (522.4)$

$\text{submatrix}\left(a_{кр}3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (522.4)$

$\text{submatrix}\left(\overline{c}a1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.162)$

$\text{submatrix}\left(\overline{c}a3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.162)$

$\text{submatrix}\left(\overline{c}u1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.121)$

$\text{submatrix}\left(\overline{c}u3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.000)$

$\text{submatrix}\left(ca1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (58.9)$

$\text{submatrix}\left(ca3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (48.9)$

$\text{submatrix}\left(cu1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (44.1)$

$\text{submatrix}\left(cu3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.0)$

$\text{submatrix}\left(c1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (73.5)$

$\text{submatrix}\left(c3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (48.9)$

$\text{submatrix}\left(\lambda1CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.141)$

$\text{submatrix}\left(\lambda3CA, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.094)$

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

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

$$
\varepsilon_{CA_r} = \alpha_{3CA_r} - \alpha_{1CA_r}
$$

$$
\begin{pmatrix}
\alpha_{1CA} & \alpha_{3CA} \\
\sigma_{CA} & \sigma_{CA} \\
\overline{d}_{1CA} & \overline{d}_{3CA} \\
T^*_{1CA} & T^*_{3CA} \\
P^*_{1CA} & P^*_{3CA} \\
\rho^*_{1CA} & \rho^*_{3CA} \\
k_{1CA} & k_{3CA} \\
a_{кр1CA} & a_{кр3CA} \\
\overline{c}_{a1CA} & \overline{c}_{a3CA} \\
\overline{c}_{u1CA} & \overline{c}_{u3CA} \\
c_{a1CA} & c_{a3CA} \\
c_{u1CA} & c_{u3CA} \\
c_{1CA} & c_{3CA} \\
\lambda_{1CA} & \lambda_{3CA} \\
F_{1CA} & F_{3CA} \\
\varepsilon_{CA} & \varepsilon_{CA}
\end{pmatrix}
$$

Расчет СА:

Результаты поступенчатого расчета по ср. ЛТ

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

$$\overline{\Delta}G = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } a \in 1..3 \\ \quad\quad \overline{\Delta}G_{st(i,a)} = \left| eps\left("rel", G, \rho_{st(i,a),av(N_r)} \cdot c a_{st(i,a),av(N_r)} \cdot F_{st(i,a)}\right)\right| \\ \overline{\Delta}G \end{array} \right.$$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.00	0.00	0.04	0.00	0.03	0.00	0.15	0.00	0.11	0.00	0.08	0.00	0.06	0.00	0.04	0.00	0.02	0.00	0.03

$\cdot\%$

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

	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	1	1	1	1	1	1	1	1	1	1	1	1

Количество ступеней ОК: $Z = 9$

Дискритизация сечений: $ii = 1..2Z + 1$

Дискритизация ступеней: $i = 1..Z$

$\pi^{*T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.392	1.381	1.365	1.319	1.286	1.253	1.203	1.170	1.148						

[16, с 114] $\pi^{*T} \le 1.9 =$

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

Полученная степень повышения полного давления []: $\prod_{i=1}^{Z} \pi^*_i = 9.003$

Степень повышения давления в ЛА: $\pi^*_{ЛА} = \dfrac{P^*_{3CA_{av}(N_r)}}{P^*_{1BHA_{av}(N_r)}} = 8.970$

$\pi^*_{ЛА} \ge \pi^*_К = 0$

$H_T^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	48.71	52.80	56.08	54.57	54.37	52.65	46.34	41.94	38.93						
2	48.71	52.80	56.08	54.57	54.37	52.65	46.34	41.94	38.93						
3	48.71	52.80	56.08	54.57	54.37	52.65	46.34	41.94	38.93						

$\cdot 10^3$

Действительная работа К (Дж/кг): $L_K = \sum_{i=1}^{Z} L_i = 430.1 \cdot 10^3$

Адиабатная работа К [Дж/кг]: $L^*_K = \sum_{i=1}^{Z} L^*_i = 378.5 \cdot 10^3$

Адиабатная КПД К []: $\eta^*_K = \frac{L^*_K}{L_K} = 88.00 \cdot \%$

Мощность К (Вт): $N_K = G \cdot L_K = 14.97 \cdot 10^6$

$\text{submatrix}\left(R_L, 1, Z, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70						

$K_H^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.991	0.982	0.973	0.965	0.955	0.949	0.95	0.95	0.95						

$\eta^{*T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	86.21	87.02	88.35	89.20	89.33	89.23	88.51	87.15	86.30						

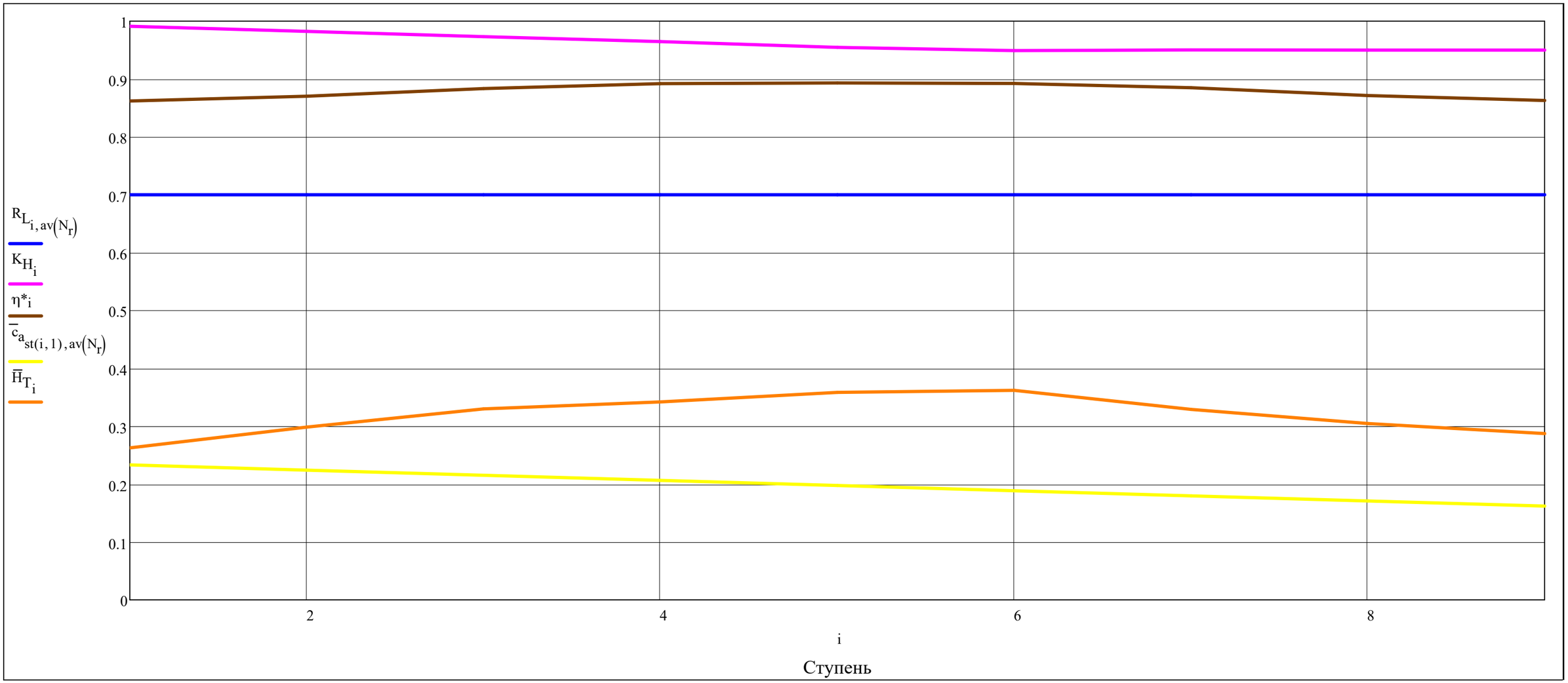
$\cdot\%$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.233	0.229	0.224	0.220	0.215	0.211	0.206	0.202	0.198	0.193	0.189	0.184	0.180	0.175	0.171	0.166	0.162	0.162	0.162	

$\overline{H}_T^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.26	0.30	0.33	0.34	0.36	0.36	0.33	0.30	0.29						



$\text{submatrix}\left(Cp, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1016.2	1024.3	1024.3	1034.0	1034.0	1045.1	1045.1	1056.3	1056.3	1067.5	1067.5	1078.3	1078.3	1087.8	1087.8	1096.2	1096.2	1103.8	1103.8

$\text{submatrix}\left(k, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.394	1.390	1.390	1.384	1.384	1.379	1.379	1.373	1.373	1.368	1.368	1.363	1.363	1.359	1.359	1.355	1.355	1.352	1.352		

$\text{submatrix}\left(T^*, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	418.2	465.7	465.7	516.3	516.3	569.1	569.1	619.5	619.5	668.6	668.6	715.5	715.5	756.3	756.3	792.9	792.9	826.7	826.7		

$\text{submatrix}\left(T, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	412.5	445.9	460.7	496.3	512.1	548.7	565.4	600.3	616.3	650.2	665.9	698.1	712.8	740.9	753.7	778.9	790.4	813.5	824.2		

$\text{submatrix}\left(P^*, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	315.6	439.3	439.3	606.5	606.5	828	828	1091.8	1091.8	1404.5	1404.5	1759.5	1759.5	2117.2	2117.2	2476.2	2476.2	...

$\cdot 10^3$

$\text{submatrix}\left(P, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	300.6	376.3	422.8	526.1	588.5	724.9	808.7	972.5	1071.5	1266.0	1383.0	1604.1	1734.9	1958.5	2089.9	2313.5	2446.6	...

$\cdot 10^3$

$\text{submatrix}\left(\rho^*, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

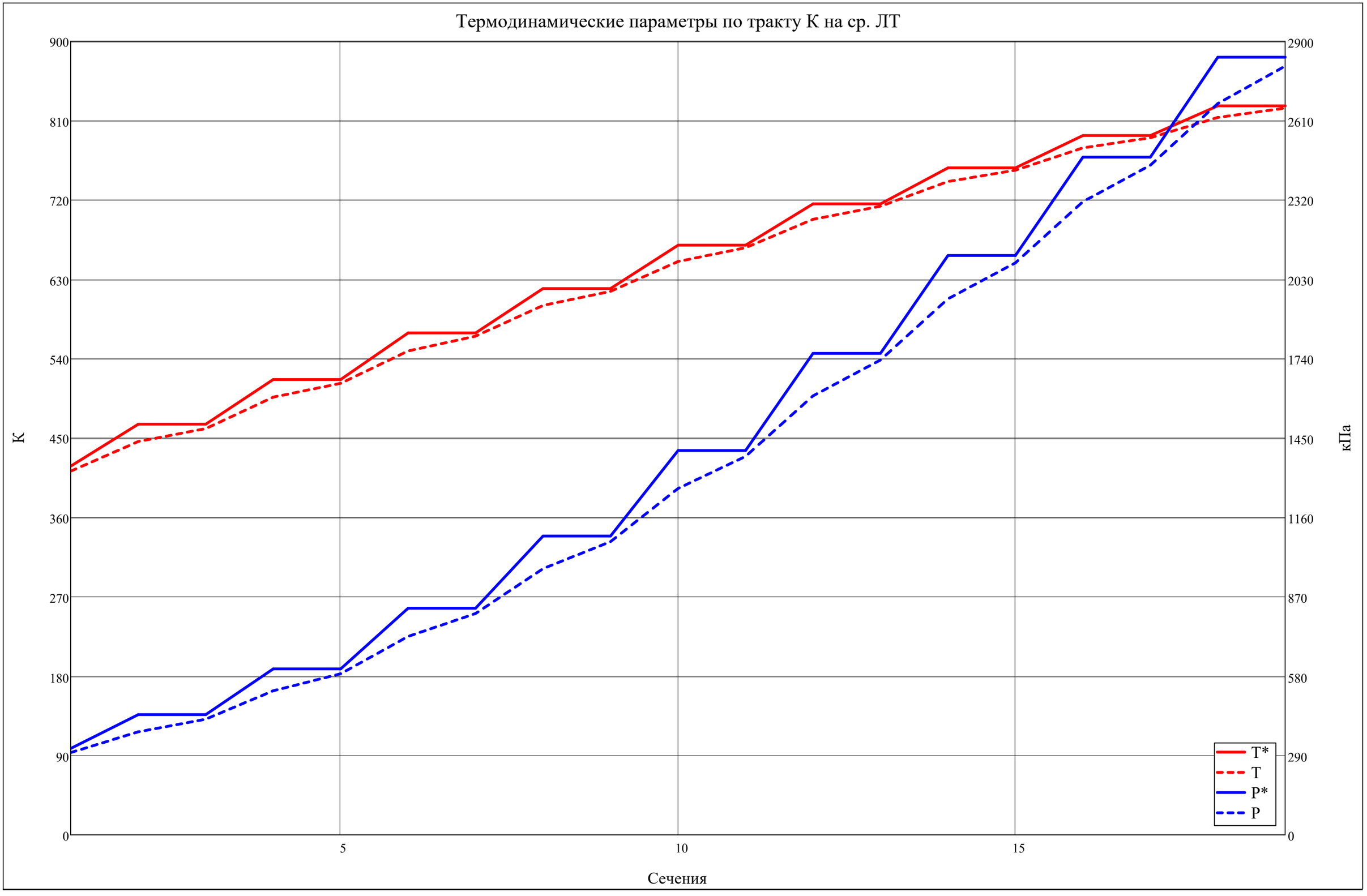
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	2.628	3.285	3.285	4.091	4.091	5.067	5.067	6.138	6.138	7.315	7.315	8.565	8.565	9.75	9.75	10.876	10.876	11.972	11.972

$\text{submatrix}\left(\rho, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	2.538	2.939	3.196	3.691	4.003	4.601	4.981	5.642	6.055	6.781	7.233	8.003	8.477	9.206	9.657	10.344	10.78	11.439	11.871

$k_{cp} = k_{ад}\left(Cp_{воздух.ср}\left(P^*_{st(1,1),\text{av}\left(N_r\right)}, P^*_{st(Z,3),\text{av}\left(N_r\right)}, T^*_{st(1,1),\text{av}\left(N_r\right)}, T^*_{st(Z,3),\text{av}\left(N_r\right)}\right), R_в\right) = 1.373$

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	0.1373	0.1218	0.1155	0.1031	0.098	0.0884	0.0846	0.0775	0.0747	0.069	0.0668	0.0624	0.0608	0.0578	0.0568	0.0547	0.0541	0.0514	0.0498		

$\overline{d}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.6467	0.6726	0.6978	0.7190	0.7397	0.7517	0.7636	0.7734	0.7831	0.7913	0.7995	0.8061	0.8127	0.8173	0.8220	0.8252	0.8284	0.8337	0.8390				

$\overline{d}_{st(Z,3)} = 0.839$ $\overline{d}_{st(Z,3)} \le 0.9 = 1$

$D^T =$

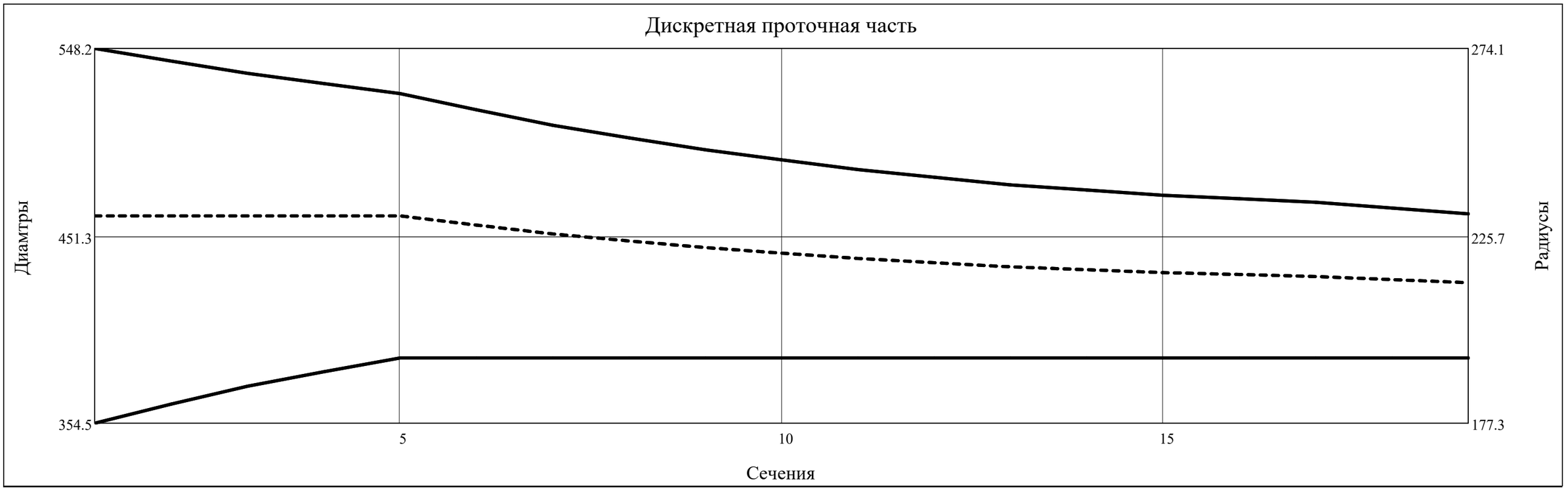
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	354.5	364.3	373.6	381.1	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2	388.2		
2	461.6	461.6	461.6	461.6	461.6	456.9	452.3	448.7	445.3	442.4	439.6	437.4	435.3	433.8	432.3	431.3	430.3	428.7	427.1		
3	548.2	541.7	535.4	530.0	524.8	516.5	508.4	502.0	495.8	490.6	485.6	481.6	477.7	475.0	472.3	470.5	468.7	465.7	462.7		

$\cdot 10^{-3}$

$R^T =$

	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	177.3	182.2	186.8	190.5	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1						
2	230.8	230.8	230.8	230.8	230.8	228.4	226.2	224.4	222.6	221.2	219.8	218.7	217.6	216.9	216.2	215.7	215.2	214.4	213.6						
3	274.1	270.8	267.7	265.0	262.4	258.2	254.2	251.0	247.9	245.3	242.8	240.8	238.9	237.5	236.2	235.2	234.3	232.8	231.4						

$\cdot 10^{-3}$



$h^T =$

	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	96.8	88.7	80.9	74.5	68.3	64.1	60.1	56.9	53.8	51.2	48.7	46.7	44.7	43.4	42.0	41.1	40.2	38.7	37.2						

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	373.9	394.4	394.4	414.9	414.9	435.3	435.3	453.7	453.7	471.0	471.0	486.8	486.8	500.2	500.2	511.9	511.9	522.4	522.4		

$\text{submatrix}\left(a_{3B}, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	406.3	421.8	428.8	444.2	451.2	466.1	473.2	486.5	493.0	505.4	511.4	522.7	528.2	537.6	542.2	550.5	554.5	561.9	565.6		

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	107.9	201.3	100.9	203.3	94.2	206.6	87.7	201.3	81.6	198.3	77.0	193.7	75.9	183.0	75.0	175.2	74.0	170.2	73.5		

$\text{submatrix}\left(w, 1, 2Z, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	334.4	210.2	339.9	202.8	342.8	191	335.8	185.5	331.6	179.8	326	177.1	314.4	181.9	306.1	185.3	300.2	186.8			

$u^T =$

	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	278.4	286.2	293.4	299.3	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9						
2	362.5	362.5	362.5	362.5	362.5	358.8	355.3	352.4	349.7	347.5	345.3	343.6	341.9	340.7	339.6	338.8	338.0	336.7	335.5						
3	430.5	425.4	420.5	416.3	412.2	405.6	399.3	394.3	389.4	385.3	381.4	378.3	375.2	373.1	371.0	369.5	368.1	365.7	363.4						

$c_{a_{st(Z,3),\text{av}\left(N_r\right)}} = 58.88$

$c_{a_{st(Z,3),\text{av}\left(N_r\right)}} \le 130 = 1$

Для КС

$\text{submatrix}\left(c_a, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	99.9	97.3	94.3	91.5	88.8	85.5	82.4	79.6	76.9	74.4	72.0	69.7	67.5	65.4	63.4	61.5	59.6	59.3	58.9		

$\text{submatrix}\left(c_u, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	40.7	176.2	35.9	181.6	31.4	188	29.8	184.8	27.2	183.8	27.3	180.7	34.8	170.9	40.1	164	43.8	159.6	44.1		

$\text{submatrix}\left(w_u, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	319.2	186.3	326.6	181.0	331.1	170.8	325.5	167.6	322.5	163.6	317.9	162.8	307.1	169.8	299.4	174.8	294.2	177.1	291.4		

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

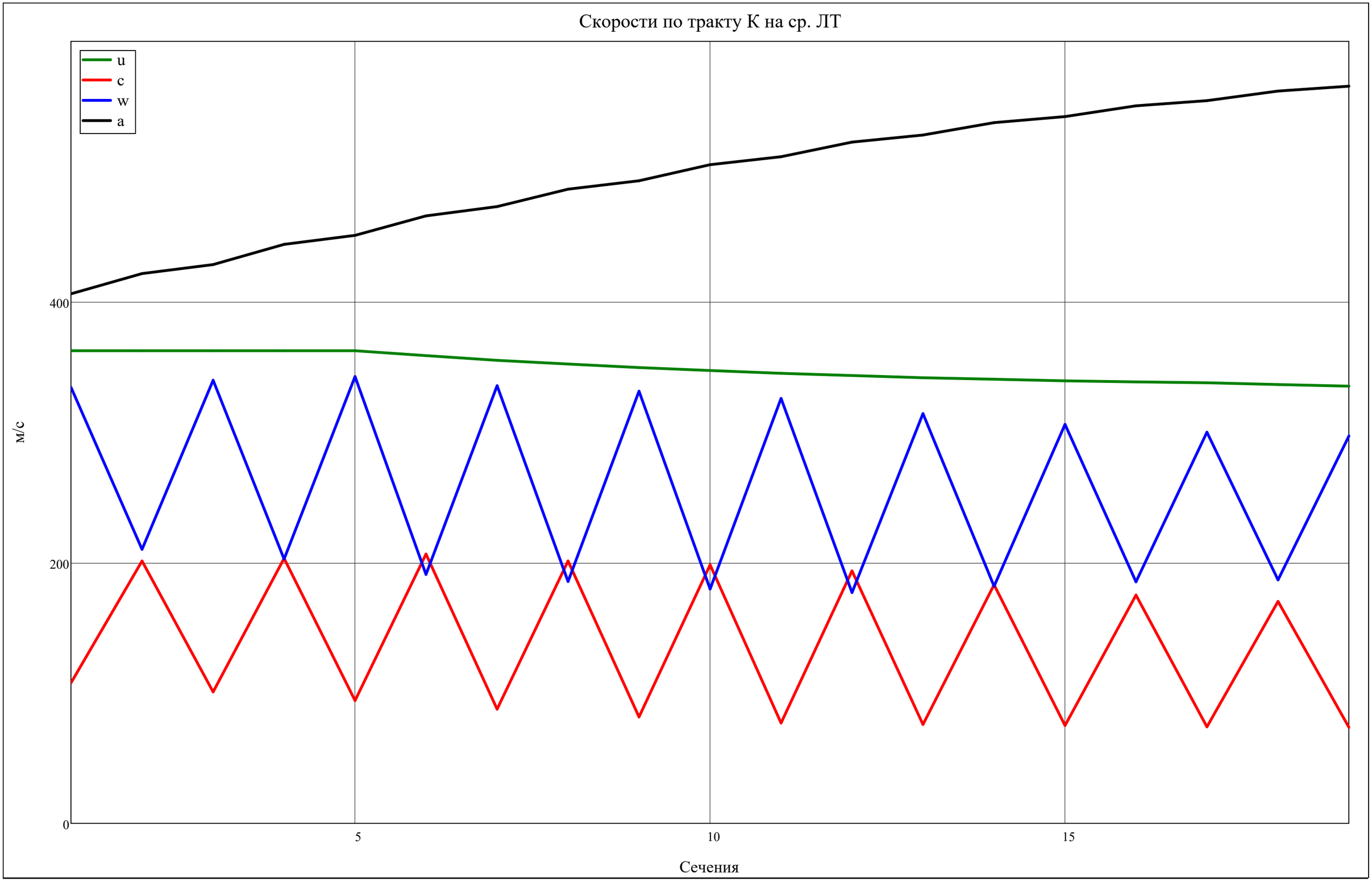
$\text{submatrix}\left(\Delta c_a, 1, Z, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12
1	-2.6	-2.79	-3.22	-2.8	-2.51	-2.27	-2.04	-1.89	-0.38			

$\text{submatrix}\left(\Delta c_a, 1, Z, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T \ge -12 =$

	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	26	27	28	29	30
1	1	1	1	1	1	1	1	1	1																					

Скорости по тракту К на ср. ЛТ



$\text{submatrix}\left(\alpha, 1, 2\cdot Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	67.83	28.90	69.13	26.74	70.50	24.46	70.13	23.31	70.54	22.04	69.20	21.08	62.72	20.94	57.68	20.56	53.70	20.37	53.18		

.∘

$\text{submatrix}\left(\beta, 1, 2\cdot Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	17.38	27.57	16.1	26.82	15.01	26.61	14.21	25.42	13.41	24.45	12.75	23.17	12.39	21.07	11.95	19.39	11.46	18.5	11.42		

.∘

$\text{submatrix}\left(\varepsilon_{\text{rotor}}, 1, Z, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

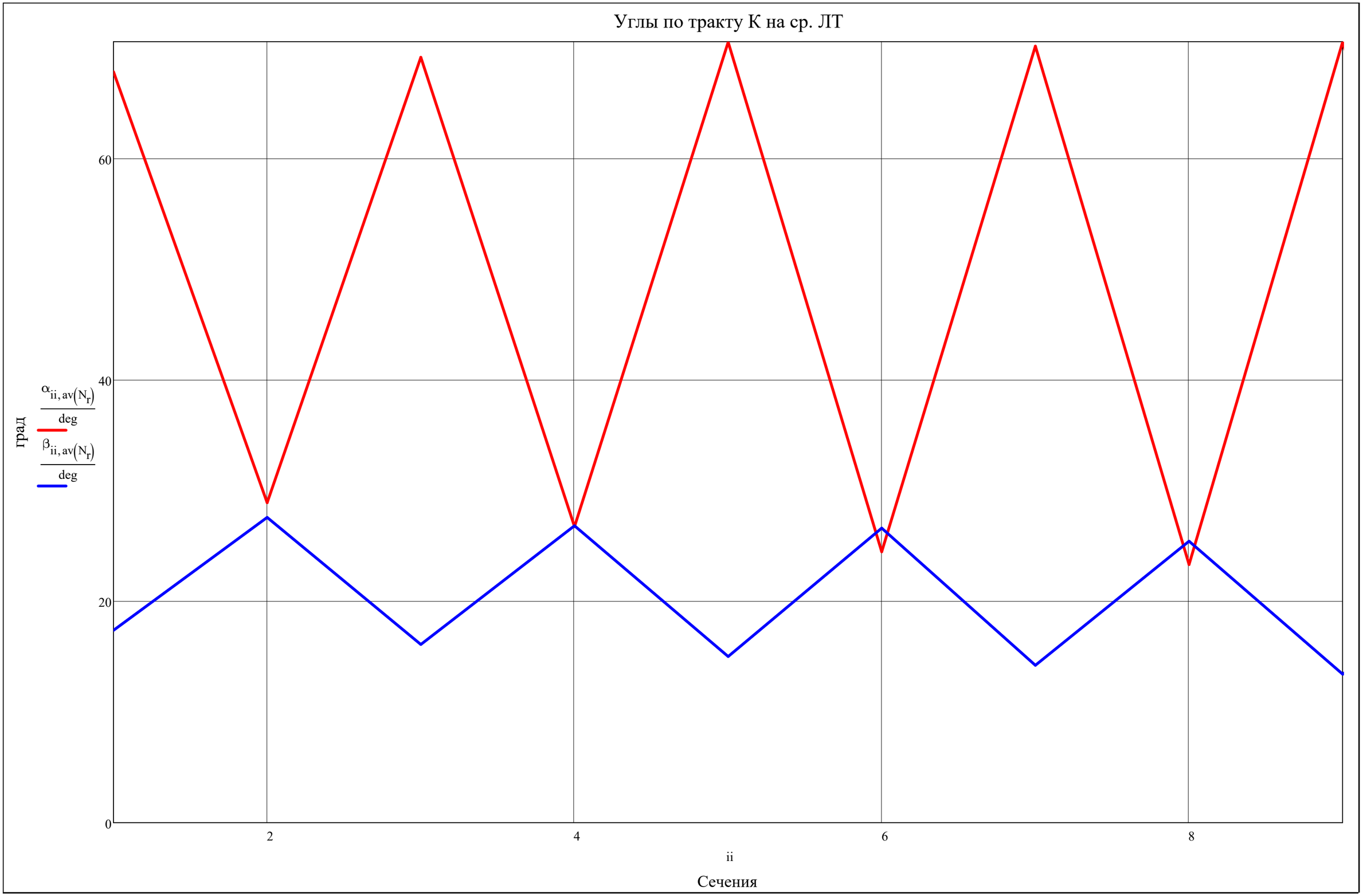
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	10.19	10.72	11.6	11.21	11.04	10.42	8.68	7.44	7.04												

.∘

$\text{submatrix}\left(\varepsilon_{\text{stator}}, 1, Z, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	40.23	43.76	45.67	47.23	47.16	41.64	36.74	33.14	32.81												

.∘


Углы по тракту К на ср. ЛТ
60
40
20
0
2
4
6
8
ii
Сечения
град
$\alpha_{ii,av(N_r)}$ deg
$\beta_{ii,av(N_r)}$ deg

$\text{submatrix}\left(\lambda_c, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.2884	0.5104	0.2559	0.4900	0.2269	0.4746	0.2014	0.4436	0.1798	0.4211	0.1634	0.3979	0.1559	0.3659	0.1500	0.3422	0.1446	0.3259	0.1408

[16, c. 87]

$\text{submatrix}\left(\lambda_c, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T \le 0.85 =$

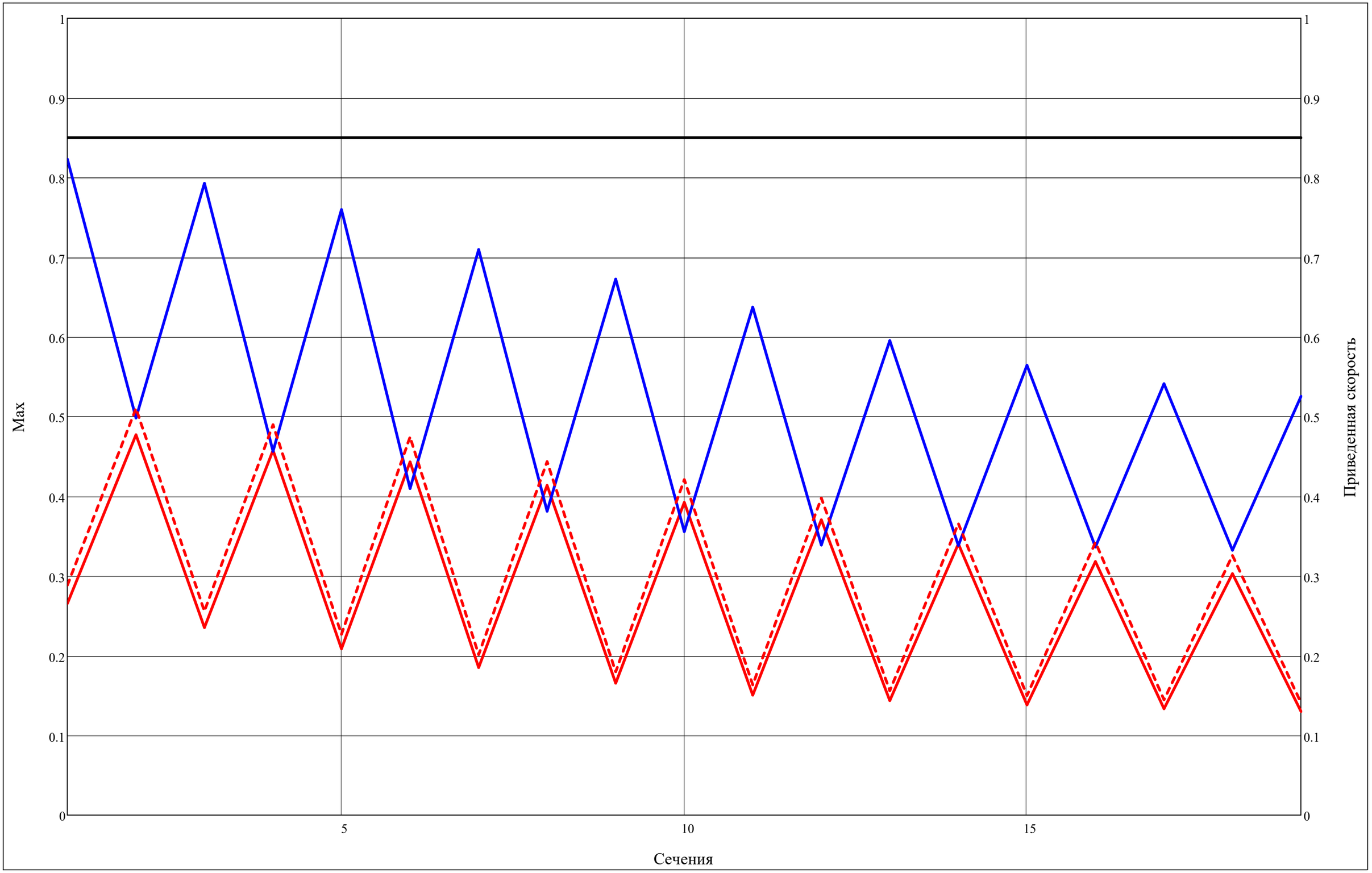
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	...

$\text{submatrix}\left(M_w, 1, 2Z, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.8231	0.4984	0.7928	0.4565	0.7598	0.4098	0.7096	0.3814	0.6726	0.3557	0.6374	0.3388	0.5953	0.3384	0.5645	0.3365	0.5413	0.3324	

$\text{submatrix}\left(M_c, 1, 2Z+1, \text{av}\left(N_r\right), \text{av}\left(N_r\right)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.2655	0.4772	0.2353	0.4577	0.2087	0.4432	0.1853	0.4137	0.1655	0.3924	0.1505	0.3706	0.1437	0.3404	0.1383	0.3182	0.1334	0.3030	0.1300


Max
Приведенная скорость
Сечения
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
10
15

Результаты поступенчатого расчета по ср. ЛТ

Вывод результатов поступенчатого расчета по ср. ЛТ ОК в EXCEL:

Расчет параметров потока по высоте Л

Относ. диаметр корня при увеличении которого меняется з-н профилирования Л
с промежуточного на Ц = const:
с R = const на промежуточный:
[16, с.94-99]

$$\begin{pmatrix} \bar{d}_{m2Ц} \\ \bar{d}_{R2m} \end{pmatrix} = \begin{pmatrix} 0.7 \\ 0.3 \end{pmatrix}$$

$$m := \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad m_i = \left| \begin{array}{ll} -1 & \text{if } \bar{d}_{st(i,1)} \le \bar{d}_{R2m} \\ 1 & \text{if } \bar{d}_{st(i,1)} \ge \bar{d}_{m2Ц} \\ -1 + \dfrac{1-(-1)}{\bar{d}_{m2Ц} - \bar{d}_{R2m}} \cdot \left(\bar{d}_{st(i,1)} - \bar{d}_{R2m} \right) & \text{otherwise} \end{array} \right. \\ m \end{array} \right.$$

$$m_i = \left| \begin{array}{ll} 0.73 & \text{if compressor = "Вл"} \\ m_i & \text{otherwise} \end{array} \right.$$

$m^T =$

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.733	0.989	1.000	1.000	1.000	1.000	1.000	1.000	1.000			

$$\begin{pmatrix} T^*_{1BHA} & T^*_{3BHA} \\ P^*_{1BHA} & P^*_{3BHA} \\ \rho^*_{1BHA} & \rho^*_{3BHA} \\ Cp_{1BHA} & Cp_{3BHA} \\ k_{1BHA} & k_{3BHA} \\ a^*_{c1BHA} & a^*_{c3BHA} \\ c_{u1BHA} & c_{u3BHA} \\ c_{a1BHA} & c_{a3BHA} \\ \alpha_{1BHA} & \alpha_{3BHA} \\ c_{1BHA} & c_{3BHA} \\ \lambda_{c1BHA} & \lambda_{c3BHA} \\ \varepsilon_{BHA} & \varepsilon_{BHA} \end{pmatrix} =$$

for $i \in 1$

for $r \in 1 .. N_r$

$$\begin{pmatrix} T^*_{1BHA_r} \\ T^*_{3BHA_r} \end{pmatrix} = \begin{pmatrix} T^*_{1BHA_{av(N_r)}} \\ T^*_{3BHA_{av(N_r)}} \end{pmatrix}$$

$$\begin{pmatrix} P^*_{1BHA_r} \\ P^*_{3BHA_r} \end{pmatrix} = \begin{pmatrix} P^*_{1BHA_{av(N_r)}} \\ P^*_{3BHA_{av(N_r)}} \end{pmatrix}$$

$$\begin{pmatrix} \rho^*_{1BHA_r} \\ \rho^*_{3BHA_r} \end{pmatrix} = \begin{pmatrix} \rho^*_{1BHA_{av(N_r)}} \\ \rho^*_{3BHA_{av(N_r)}} \end{pmatrix}$$

$$\begin{pmatrix} Cp_{1BHA_r} \\ Cp_{3BHA_r} \end{pmatrix} = \begin{pmatrix} Cp_{воздух}\left(P^*_{1BHA_r}, T^*_{1BHA_r}\right) \\ Cp_{воздух}\left(P^*_{3BHA_r}, T^*_{3BHA_r}\right) \end{pmatrix}$$

$$\begin{pmatrix} k_{1BHA_r} \\ k_{3BHA_r} \end{pmatrix} = \begin{pmatrix} k_{ад}\left(Cp_{1BHA_r}, R_в\right) \\ k_{ад}\left(Cp_{3BHA_r}, R_в\right) \end{pmatrix}$$

$$\begin{pmatrix} a^*_{c1BHA_r} \\ a^*_{c3BHA_r} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{2 \cdot k_{1BHA_r}}{k_{1BHA_r} + 1} \cdot R_в \cdot T^*_{1BHA_r}} \\ \sqrt{\frac{2 \cdot k_{3BHA_r}}{k_{3BHA_r} + 1} \cdot R_в \cdot T^*_{3BHA_r}} \end{pmatrix}$$

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

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

$$\begin{pmatrix} c_{u1BHA_r} \end{pmatrix} \left[\begin{array}{c} c_{u1BHA_{av(N_r)}} \\ \end{array} \right.$$

$$\begin{pmatrix} c_{u1BHA_r} \\ c_{u3BHA_r} \end{pmatrix} = \begin{bmatrix} \dfrac{A}{\left(R_{st(i,1),r}\right)^{m_i}} - \dfrac{B}{\left(R_{st(i,1),r}\right)} & \text{if BHA} = 1 \\ c_{u1BHA_{av}(N_r)} & \text{otherwise} \end{bmatrix}$$

$$\begin{pmatrix} c_{a1BHA_r} \\ c_{a3BHA_r} \end{pmatrix} = \begin{bmatrix} c_{a1BHA_{av}(N_r)} & \\ \text{if BHA} = 1 & \\ \quad \sqrt{\left(c_{a3BHA_{av}(N_r)}\right)^2 - 2\cdot A^2\cdot\left[\left(R_{st(i,1),r}\right)^2 - \left(R_{st(i,1),av(N_r)}\right)^2\right] + 4\cdot A\cdot B\cdot\ln\left(\dfrac{R_{st(i,1),r}}{R_{st(i,1),av(N_r)}}\right)} & \text{if } m_i = -1 \\ \quad \sqrt{\left(c_{a3BHA_{av}(N_r)}\right)^2 - 2\cdot A^2\cdot\ln\left(\dfrac{R_{st(i,1),r}}{R_{st(i,1),av(N_r)}}\right) - 2\cdot A\cdot B\cdot\left(\dfrac{1}{R_{st(i,1),r}} - \dfrac{1}{R_{st(i,1),av(N_r)}}\right)} & \text{if } m_i = 0 \\ \quad \sqrt{\left(c_{a3BHA_{av}(N_r)}\right)^2 + \dfrac{\begin{bmatrix} A\cdot(m_i-1)\cdot\left[-A\cdot(m_i+1)\cdot\left[\dfrac{1}{\left(R_{st(i,1),r}\right)^{2\cdot m_i}} - \dfrac{1}{\left(R_{st(i,1),av(N_r)}\right)^{2\cdot m_i}}\right] \ldots \right. \\ \left. + 2\cdot B\cdot m_i\cdot\left[\dfrac{1}{\left(R_{st(i,1),r}\right)^{m_i+1}} - \dfrac{1}{\left(R_{st(i,1),av(N_r)}\right)^{m_i+1}}\right] \end{bmatrix}}{m_i\cdot(m_i+1)}} & \text{otherwise} \\ c_{a1BHA_{av}(N_r)} & \text{otherwise} \end{bmatrix}$$

$$\begin{pmatrix} \alpha_{1BHA_r} \\ \alpha_{3BHA_r} \end{pmatrix} = \begin{pmatrix} \text{triangle}\left(c_{a1BHA_r}, c_{u1BHA_r}\right) \\ \text{triangle}\left(c_{a3BHA_r}, c_{u3BHA_r}\right) \end{pmatrix}$$

$$\begin{pmatrix} c_{1BHA_r} \\ c_{3BHA_r} \end{pmatrix} = \begin{pmatrix} \dfrac{c_{a1BHA_r}}{\sin\left(\alpha_{1BHA_r}\right)} \\ \dfrac{c_{a3BHA_r}}{\sin\left(\alpha_{3BHA_r}\right)} \end{pmatrix}$$

$$\begin{pmatrix} \lambda_{c1BHA_r} \\ \lambda_{c3BHA_r} \end{pmatrix} = \begin{pmatrix} \dfrac{c_{1BHA_r}}{a^*_{c1BHA_r}} \\ \dfrac{c_{3BHA_r}}{a^*_{c3BHA_r}} \end{pmatrix}$$

$$\varepsilon_{BHA_r} = -1\cdot\left(\alpha_{3BHA_r} - \alpha_{1BHA_r}\right)$$

$$\begin{pmatrix} T^*_{1BHA} & P^*_{1BHA} & \rho^*_{1BHA} & Cp_{1BHA} & k_{1BHA} & a^*_{c1BHA} & c_{u1BHA} & c_{a1BHA} & \alpha_{1BHA} & c_{1BHA} & \lambda_{c1BHA} & \varepsilon_{BHA} \\ T^*_{3BHA} & P^*_{3BHA} & \rho^*_{3BHA} & Cp_{3BHA} & k_{3BHA} & a^*_{c3BHA} & c_{u3BHA} & c_{a3BHA} & \alpha_{3BHA} & c_{3BHA} & \lambda_{c3BHA} & \varepsilon_{BHA} \end{pmatrix}^T$$

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

for $i \in 1 .. Z$

for $a \in 1 .. 3$

for $r \in 1 .. N_r$

$T^*_{st(i,a),r} = T^*_{st(i,a),av(N_r)}$

$P^*_{st(i,a),r} = P^*_{st(i,a),av(N_r)}$

$\rho^*_{st(i,a),r} = \rho^*_{st(i,a),av(N_r)}$

$Cp_{st(i,a),r} = Cp_{воздух}(P^*_{st(i,a),r}, T^*_{st(i,a),r})$

$k_{st(i,a),r} = k_{ад}(Cp_{st(i,a),r}, R_в)$

$$a^*_{c_{st(i,a),r}} = \sqrt{\frac{2 \cdot k_{st(i,a),r}}{k_{st(i,a),r} + 1} \cdot R_в \cdot T^*_{st(i,a),r}}$$

if $\Delta H_{Tmax} = 0$

$$A_{st(i,a)} = \left(1 - R_{L_{i,av(N_r)}}\right) \cdot \omega \cdot \left(R_{st(i,a),av(N_r)}\right)^{m_i+1}$$

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

$$c_{u_{st(i,a),r}} = \begin{cases} c_{u_{st(i,a-1),r}} \cdot \dfrac{R_{st(i,a),r}}{R_{st(i,a-1),r}} + \dfrac{H_{T_{i,av(N_r)}}}{\omega \cdot R_{st(i,a),r}} & \text{if } a = 2 \\ \text{otherwise} \\ \quad \begin{cases} 0 & \text{if } (a = 1) \wedge (i = 1) \wedge (BHA = 0) \\ \dfrac{A_{st(i,a)}}{\left(R_{st(i,a),r}\right)^{m_i}} - \dfrac{B_{st(i,a)}}{\left(R_{st(i,a),r}\right)} & \text{otherwise} \end{cases} \end{cases}$$

$$c_{a_{st(i,a),r}} = \begin{cases} c_{a3BHA_r} & \text{if } (a = 1) \wedge (i = 1) \wedge (BHA = 1) \\ \sqrt{\left(c_{a_{st(i,a),av(N_r)}}\right)^2 - 2 \cdot \left(A_{st(i,a)}\right)^2 \cdot \left[\left(R_{st(i,a),r}\right)^2 - \left(R_{st(i,a),av(N_r)}\right)^2\right] + 4 \cdot A_{st(i,a)} \cdot B_{st(i,a)} \cdot \ln\left(\dfrac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)} \cdot \begin{cases} -1 & \text{if } a = 2 \\ 1 & \text{otherwise} \end{cases} & \text{if } m_i = -1 \\ \sqrt{\left(c_{a_{st(i,a),av(N_r)}}\right)^2 - 2 \cdot \left(A_{st(i,a)}\right)^2 \cdot \ln\left(\dfrac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right) - 2 \cdot A_{st(i,a)} \cdot B_{st(i,a)} \cdot \left(\dfrac{1}{\quad} - \dfrac{1}{\quad}\right)} \cdot \begin{cases} -1 & \text{if } a = 2 \end{cases} & \text{if } m_i = 0 \end{cases}$$

$$\sqrt{\left(\ldots_{st(i,a),av(N_r)}\right) \quad \left(R_{st(i,a),av(N_r)}\right) \quad \left(R_{st(i,a),r} \quad R_{st(i,a),av(N_r)}\right)} \;\Big|\; 1 \quad \text{otherwise}$$

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

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

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

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

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

$$k_{HT} = \frac{H_{T_{i,av(N_r)}} - H_{T_{i,1}}}{R_{st(i,a),av(N_r)} - R_{st(i,a),1}}$$

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

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

$$c_{st(i,a)} = \text{triangle}\left(c_{a\ldots} \ldots\right)$$

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

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

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

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

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

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

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

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

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

for $r \in 1 .. N_r$

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

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

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

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

for $i \in Z$

for $r \in 1 .. N_r$

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

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

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

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

$$
\begin{pmatrix} k_{1CA_r} \\ k_{3CA_r} \end{pmatrix} = \begin{pmatrix} k_{ад}\left(Cp_{1CA_r}, R_в\right) \\ k_{ад}\left(Cp_{3CA_r}, R_в\right) \end{pmatrix}
$$

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

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

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

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

$$\begin{pmatrix} u3CA_r \end{pmatrix} \left(\begin{array}{l} c_{u_{st(i,3),r}} \quad \text{otherwise} \end{array} \right)$$

$$\begin{pmatrix} c_{a1CA_r} \\ c_{a3CA_r} \end{pmatrix} = \left[\begin{array}{l} c_{a_{st(i,3),r}} \\ \left| \begin{array}{l} \text{if } CA = 1 \\ \quad \sqrt{\left(c_{a3CA_{av}(N_r)}\right)^2 - 2\cdot A^2 \cdot \left[\left(R_{st(i,3),r}\right)^2 - \left(R_{st(i,3),av(N_r)}\right)^2 \right] + 4\cdot A\cdot B\cdot \ln\left(\frac{R_{st(i,3),r}}{R_{st(i,3),av(N_r)}}\right)} \quad \text{if } m_i = -1 \\ \quad \sqrt{\left(c_{a3CA_{av}(N_r)}\right)^2 - 2\cdot A^2 \cdot \ln\left(\frac{R_{st(i,3),r}}{R_{st(i,3),av(N_r)}}\right) - 2\cdot A\cdot B\cdot\left(\frac{1}{R_{st(i,3),r}} - \frac{1}{R_{st(i,3),av(N_r)}}\right)} \quad \text{if } m_i = 0 \\ \quad \sqrt{\left(c_{a3CA_{av}(N_r)}\right)^2 + \frac{A\cdot(m_i-1)\cdot\left[-A\cdot(m_i+1)\cdot\left[\frac{1}{\left(R_{st(i,3),r}\right)^{2\cdot m_i}} - \frac{1}{\left(R_{st(i,3),av(N_r)}\right)^{2\cdot m_i}}\right] \ldots + 2\cdot B\cdot m_i\cdot\left[\frac{1}{\left(R_{st(i,3),r}\right)^{m_i+1}} - \frac{1}{\left(R_{st(i,3),av(N_r)}\right)^{m_i+1}}\right]\right]}{m_i\cdot(m_i+1)}} \quad \text{otherwise} \\ c_{a_{st(i,3),r}} \quad \text{otherwise} \end{array} \right. \end{array} \right]$$

$$\begin{pmatrix} \alpha_{1CA_r} \\ \alpha_{3CA_r} \end{pmatrix} = \begin{pmatrix} \text{triangle}\left(c_{a1CA_r}, c_{u1CA_r}\right) \\ \text{triangle}\left(c_{a3CA_r}, c_{u3CA_r}\right) \end{pmatrix}$$

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

$$\begin{pmatrix} \lambda_{c1CA_r} \\ \lambda_{c3CA_r} \end{pmatrix} = \begin{pmatrix} \frac{c_{1CA_r}}{a^*_{c1CA_r}} \\ \frac{c_{3CA_r}}{a^*_{c3CA_r}} \end{pmatrix}$$

$$\varepsilon_{CA_r} = \left(\alpha_{3CA_r} - \alpha_{1CA_r}\right)$$

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

Расчет параметров потока по высоте Л

Результаты расчета параметров потока по высоте Л

$$T^*_{1BHA} = \begin{pmatrix} 418.2 \\ 418.2 \\ 418.2 \end{pmatrix} \qquad T^*_{3BHA} = \begin{pmatrix} 418.2 \\ 418.2 \\ 418.2 \end{pmatrix}$$

$$a^*_{c1BHA} = \begin{pmatrix} 373.95 \\ 373.95 \\ 373.95 \end{pmatrix} \qquad a^*_{c3BHA} = \begin{pmatrix} 373.95 \\ 373.95 \\ 373.95 \end{pmatrix}$$

$$\alpha_{1BHA} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ^\circ \qquad \alpha_{3BHA} = \begin{pmatrix} 66.71 \\ 67.39 \\ 68.13 \end{pmatrix} \cdot ^\circ$$

$$P^*_{1BHA} = \begin{pmatrix} 316.2 \\ 316.2 \\ 316.2 \end{pmatrix} \cdot 10^3 \qquad P^*_{3BHA} = \begin{pmatrix} 315.6 \\ 315.6 \\ 315.6 \end{pmatrix} \cdot 10^3$$

$$c_{1BHA} = \begin{pmatrix} 99.9 \\ 99.9 \\ 99.9 \end{pmatrix} \qquad c_{3BHA} = \begin{pmatrix} 112.6 \\ 108.2 \\ 105.6 \end{pmatrix}$$

$$\varepsilon_{BHA} = \begin{pmatrix} 23.29 \\ 22.61 \\ 21.87 \end{pmatrix} \cdot ^\circ$$

$$\rho^*_{1BHA} = \begin{pmatrix} 2.633 \\ 2.633 \\ 2.633 \end{pmatrix} \qquad \rho^*_{3BHA} = \begin{pmatrix} 2.628 \\ 2.628 \\ 2.628 \end{pmatrix}$$

$$c_{u1BHA} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \qquad c_{u3BHA} = \begin{pmatrix} 44.5 \\ 41.6 \\ 39.3 \end{pmatrix}$$

$$Cp_{1BHA} = \begin{pmatrix} 1016.2 \\ 1016.2 \\ 1016.2 \end{pmatrix} \qquad Cp_{3BHA} = \begin{pmatrix} 1016.2 \\ 1016.2 \\ 1016.2 \end{pmatrix}$$

$$c_{a1BHA} = \begin{pmatrix} 99.9 \\ 99.9 \\ 99.9 \end{pmatrix} \qquad c_{a3BHA} = \begin{pmatrix} 103.5 \\ 99.9 \\ 98.0 \end{pmatrix}$$

$$\lambda_{c1BHA} = \begin{pmatrix} 0.267 \\ 0.267 \\ 0.267 \end{pmatrix} \qquad \lambda_{c3BHA} = \begin{pmatrix} 0.301 \\ 0.289 \\ 0.282 \end{pmatrix}$$

$$k_{1BHA} = \begin{pmatrix} 1.394 \\ 1.394 \\ 1.394 \end{pmatrix} \qquad k_{3BHA} = \begin{pmatrix} 1.394 \\ 1.394 \\ 1.394 \end{pmatrix}$$

$T^{*T} =$

	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	418.2	465.7	465.7	516.3	516.3	569.1	569.1	619.5	619.5	668.6	668.6	715.5	715.5	756.3	756.3	792.9	792.9	826.7	826.7						
2	418.2	465.7	465.7	516.3	516.3	569.1	569.1	619.5	619.5	668.6	668.6	715.5	715.5	756.3	756.3	792.9	792.9	826.7	826.7						
3	418.2	465.7	465.7	516.3	516.3	569.1	569.1	619.5	619.5	668.6	668.6	715.5	715.5	756.3	756.3	792.9	792.9	826.7	826.7						

$T^{T} =$

	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	412.0	436.9	460.4	488.5	511.9	542.2	565.3	594.9	616.2	645.5	665.8	694.0	712.6	737.6	753.5	776.0	790.2	811.0	824.1						
2	412.4	446.0	460.7	496.3	512.1	548.8	565.4	600.4	616.3	650.3	665.9	698.1	712.8	740.9	753.7	779.0	790.4	813.6	824.3						
3	412.7	450.3	460.9	500.3	512.2	552.5	565.5	603.7	616.4	653.3	665.9	700.8	712.9	743.2	753.8	780.9	790.6	815.4	824.4						

$P^{*T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	315.6	439.3	439.3	606.5	606.5	828.0	828.0	1091.8	1091.8	1404.5	1404.5	1759.5	1759.5	2117.2	2117.2	2476.2	2476.2	2841.7	2841.7		
2	315.6	439.3	439.3	606.5	606.5	828.0	828.0	1091.8	1091.8	1404.5	1404.5	1759.5	1759.5	2117.2	2117.2	2476.2	2476.2	2841.7	2841.7		
3	315.6	439.3	439.3	606.5	606.5	828.0	828.0	1091.8	1091.8	1404.5	1404.5	1759.5	1759.5	2117.2	2117.2	2476.2	2476.2	2841.7	2841.7		

$\cdot 10^{3}$

$P^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	299.3	349.8	421.7	496.9	587.7	694.1	807.9	940.5	1070.8	1232.1	1382.2	1569.2	1733.6	1925.3	2088.1	2281.0	2444.2	2640.3	2807.9		
2	300.5	376.4	422.8	526.1	588.5	725.5	808.7	973.0	1071.5	1266.4	1383.0	1604.5	1734.9	1958.9	2089.9	2313.8	2446.6	2672.7	2810.2		
3	301.2	389.7	423.3	541.3	589.0	743.5	809.2	992.7	1071.9	1288.1	1383.5	1627.6	1735.8	1981.5	2091.2	2336.2	2448.2	2695.2	2811.8		

$\cdot 10^{3}$

$\rho^{*T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	2.628	3.285	3.285	4.091	4.091	5.067	5.067	6.138	6.138	7.315	7.315	8.565	8.565	9.750	9.750	10.876	10.876	11.972	11.972		
2	2.628	3.285	3.285	4.091	4.091	5.067	5.067	6.138	6.138	7.315	7.315	8.565	8.565	9.750	9.750	10.876	10.876	11.972	11.972		
3	2.628	3.285	3.285	4.091	4.091	5.067	5.067	6.138	6.138	7.315	7.315	8.565	8.565	9.750	9.750	10.876	10.876	11.972	11.972		

$\rho^{T} =$

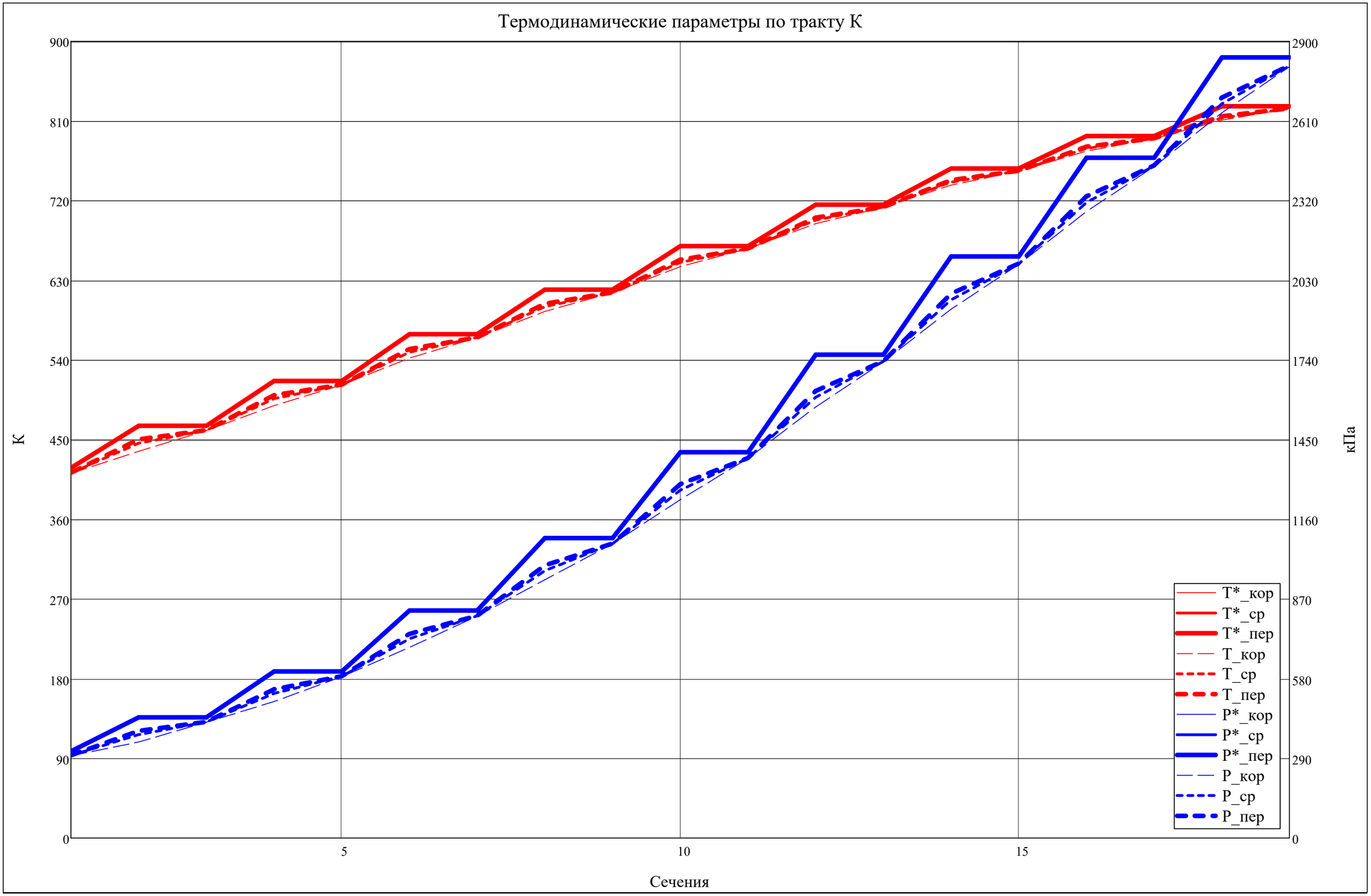
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	2.530	2.788	3.190	3.542	3.999	4.458	4.977	5.506	6.052	6.648	7.230	7.875	8.472	9.091	9.651	10.236	10.772	11.338	11.866		
2	2.537	2.940	3.196	3.691	4.003	4.604	4.981	5.644	6.055	6.782	7.233	8.004	8.477	9.207	9.657	10.345	10.780	11.441	11.873		
3	2.542	3.014	3.199	3.768	4.005	4.686	4.983	5.727	6.056	6.867	7.235	8.089	8.480	9.285	9.661	10.419	10.785	11.512	11.878		

$Cp^{T} =$

	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	1016	1024	1024	1034	1034	1045	1045	1056	1056	1068	1068	1078	1078	1088	1088	1096	1096	1104	1104						
2	1016	1024	1024	1034	1034	1045	1045	1056	1056	1068	1068	1078	1078	1088	1088	1096	1096	1104	1104						
3	1016	1024	1024	1034	1034	1045	1045	1056	1056	1068	1068	1078	1078	1088	1088	1096	1096	1104	1104						

$k^{T} =$

	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	1.394	1.390	1.390	1.384	1.384	1.379	1.379	1.373	1.373	1.368	1.368	1.363	1.363	1.359	1.359	1.355	1.355	1.352	1.352						
2	1.394	1.390	1.390	1.384	1.384	1.379	1.379	1.373	1.373	1.368	1.368	1.363	1.363	1.359	1.359	1.355	1.355	1.352	1.352						
3	1.394	1.390	1.390	1.384	1.384	1.379	1.379	1.373	1.373	1.368	1.368	1.363	1.363	1.359	1.359	1.355	1.355	1.352	1.352						


Термодинамические параметры по тракту К
К
кПа
900
810
720
630
540
450
360
270
180
90
0
2900
2610
2320
2030
1740
1450
1160
870
580
290
0
5
10
15
Сечения
T*_кор
T*_ср
T*_пер
T_кор
T_ср
T_пер
P*_кор
P*_ср
P*_пер
P_кор
P_ср
P_пер

a^{*T}_{c} =

	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	373.9	394.4	394.4	414.9	414.9	435.3	435.3	453.7	453.7	471.0	471.0	486.8	486.8	500.2	500.2	511.9	511.9	522.4	522.4						
2	373.9	394.4	394.4	414.9	414.9	435.3	435.3	453.7	453.7	471.0	471.0	486.8	486.8	500.2	500.2	511.9	511.9	522.4	522.4						
3	373.9	394.4	394.4	414.9	414.9	435.3	435.3	453.7	453.7	471.0	471.0	486.8	486.8	500.2	500.2	511.9	511.9	522.4	522.4						

$a_{зв}^{T}$ =

	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	406.0	417.5	428.6	440.7	451.1	463.3	473.1	484.3	493.0	503.5	511.4	521.1	528.1	536.4	542.2	549.5	554.5	561.0	565.5						
2	406.3	421.8	428.8	444.2	451.2	466.1	473.2	486.6	493.0	505.4	511.4	522.7	528.2	537.6	542.2	550.5	554.5	561.9	565.6						
3	406.4	423.9	428.8	446.0	451.2	467.7	473.2	487.9	493.0	506.6	511.4	523.7	528.2	538.4	542.3	551.2	554.6	562.5	565.6						

c^{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	112.6	243.0	104.2	239.8	96.3	237.2	89.4	228.0	83.0	222.3	78.3	215.2	77.9	201.9	77.5	192.3	76.9	185.9	75.3						
2	108.2	201.0	100.9	203.3	94.2	206.0	87.7	200.8	81.6	198.0	77.0	193.5	75.9	182.8	75.0	175.0	74.0	169.9	72.7						
3	105.6	177.6	99.2	182.2	93.0	186.3	86.6	182.8	80.7	181.2	76.1	178.0	74.5	168.9	73.3	162.2	71.9	157.9	70.8						

w^{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	255.8	131.6	266.6	120.6	281.9	119.6	282.5	121.1	284.3	121.0	283.3	122.9	274.4	131.4	267.9	137.3	263.2	141.7	264.7						
2	336.1	210.4	339.9	202.8	342.8	191.6	335.8	186.0	331.6	180.1	326.0	177.4	314.4	182.2	306.1	185.4	300.2	187.1	298.7						
3	403.3	286.5	400.6	274.2	394.7	255.0	381.8	243.1	373.0	232.3	363.8	225.5	350.1	227.0	340.2	227.9	333.3	227.2	329.4						

u^{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	278.4	286.2	293.4	299.3	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9	304.9						
2	362.5	362.5	362.5	362.5	362.5	358.8	355.3	352.4	349.7	347.5	345.3	343.6	341.9	340.7	339.6	338.8	338.0	336.7	335.5						
3	430.5	425.4	420.5	416.3	412.2	405.6	399.3	394.3	389.4	385.3	381.4	378.3	375.2	373.1	371.0	369.5	368.1	365.7	363.4						

c_{a}^{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	103.5	111.3	94.4	92.0	88.8	85.5	82.4	79.6	76.9	74.4	72.0	69.7	67.5	65.4	63.4	61.5	59.6	59.3	58.9						
2	99.9	97.3	94.3	91.5	88.8	85.5	82.4	79.6	76.9	74.4	72.0	69.7	67.5	65.4	63.4	61.5	59.6	59.3	58.9						
3	98.0	89.6	94.2	91.2	88.8	85.5	82.4	79.6	76.9	74.4	72.0	69.7	67.5	65.4	63.4	61.5	59.6	59.3	58.9						

c_{u}^{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	44.5	216.0	44.1	221.4	37.4	221.3	34.7	213.7	31.2	209.5	31.0	203.6	39.0	191.0	44.7	182.2	48.6	176.2	46.9						
2	41.6	175.9	35.9	181.6	31.4	187.4	29.8	184.4	27.2	183.5	27.3	180.5	34.8	170.7	40.1	163.8	43.8	159.3	42.6						
3	39.3	153.3	31.1	157.7	27.6	165.5	26.5	164.6	24.4	165.2	24.7	163.7	31.7	155.7	36.7	150.1	40.2	146.4	39.3						

w_{u}^{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
1	233.9	70.2	249.3	77.9	267.6	83.6	270.2	91.3	273.7	95.5	274.0	101.3	265.9	113.9	260.3	122.7	256.4	128.7	258.0					
2	321.0	186.6	326.6	181.0	331.1	171.4	325.5	168.1	322.5	164.0	317.9	163.1	307.1	170.0	299.4	174.9	294.2	177.5	292.8					
3	391.2	272.1	389.3	258.6	384.6	240.2	372.8	229.7	365.0	220.1	356.6	214.5	343.5	217.3	334.3	219.5	327.9	219.3	324.1					

$$\Delta c_a = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } a \in 2..3 \\ \quad\quad \text{for } r \in 1..N_r \\ \quad\quad\quad \Delta c_{a_{st(i,a),r}} = c_{a_{st(i,a),r}} - c_{a_{st(i,a-1),r}} \\ \Delta c_a \end{array} \right.$$

$\Delta c_a^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0.00	7.83	-16.91	-2.36	-3.28	-3.22	-3.10	-2.80	-2.72	-2.51	-2.46	-2.27	-2.23	-2.04	-2.02	-1.89	-1.87	-0.38	-0.38		
2	0.00	-2.60	-3.01	-2.79	-2.73	-3.22	-3.10	-2.80	-2.72	-2.51	-2.46	-2.27	-2.23	-2.04	-2.02	-1.89	-1.87	-0.38	-0.38		
3	0.00	-8.41	4.66	-3.01	-2.45	-3.22	-3.10	-2.80	-2.72	-2.51	-2.46	-2.27	-2.23	-2.04	-2.02	-1.89	-1.87	-0.38	-0.38		

[16, c. 81]

$\Delta c_a^T \geq -25 =$

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

$R_L^T =$

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.5386	0.5520	0.5759	0.5927	0.6054	0.6153	0.6229	0.6280	0.6314			
2	0.7000	0.7000	0.6967	0.6974	0.6978	0.6983	0.6990	0.6994	0.6990			
3	0.7749	0.7743	0.7639	0.7592	0.7552	0.7519	0.7495	0.7478	0.7457			

$R_L^T \geq 0 =$

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

Скорости по тракту К

600
400
200
0

м/с

5
10
15

Сечения

a_кор
a_ср
a_пер
c_кор
c_ср
c_пер
w_кор
w_ср
w_пер
u_кор
u_ср
u_пер

$\alpha^T =$

	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	66.71	27.26	64.95	22.57	67.17	21.14	67.17	20.44	67.94	19.56	66.72	18.89	59.97	18.91	54.84	18.65	50.84	18.58	51.47						
2	67.39	28.94	69.13	26.74	70.50	24.54	70.13	23.36	70.54	22.08	69.20	21.11	62.72	20.97	57.68	20.58	53.70	20.41	54.10						
3	68.13	30.29	71.71	30.05	72.70	27.34	72.18	25.83	72.39	24.24	71.02	23.05	64.84	22.78	59.93	22.29	56.00	22.03	56.25						

$.^\circ$

$\beta^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	23.86	57.77	20.74	49.75	18.35	45.64	16.97	41.11	15.70	37.94	14.72	34.53	14.23	29.86	13.69	26.62	13.09	24.72	12.85		
2	17.29	27.53	16.10	26.82	15.01	26.52	14.21	25.36	13.41	24.41	12.75	23.14	12.39	21.04	11.95	19.37	11.46	18.46	11.37		
3	14.06	18.22	13.60	19.43	13.00	19.60	12.47	19.12	11.90	18.68	11.41	18.00	11.11	16.75	10.74	15.66	10.31	15.12	10.30		

$.^\circ$

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

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

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

$\varepsilon_{rotor}^T =$

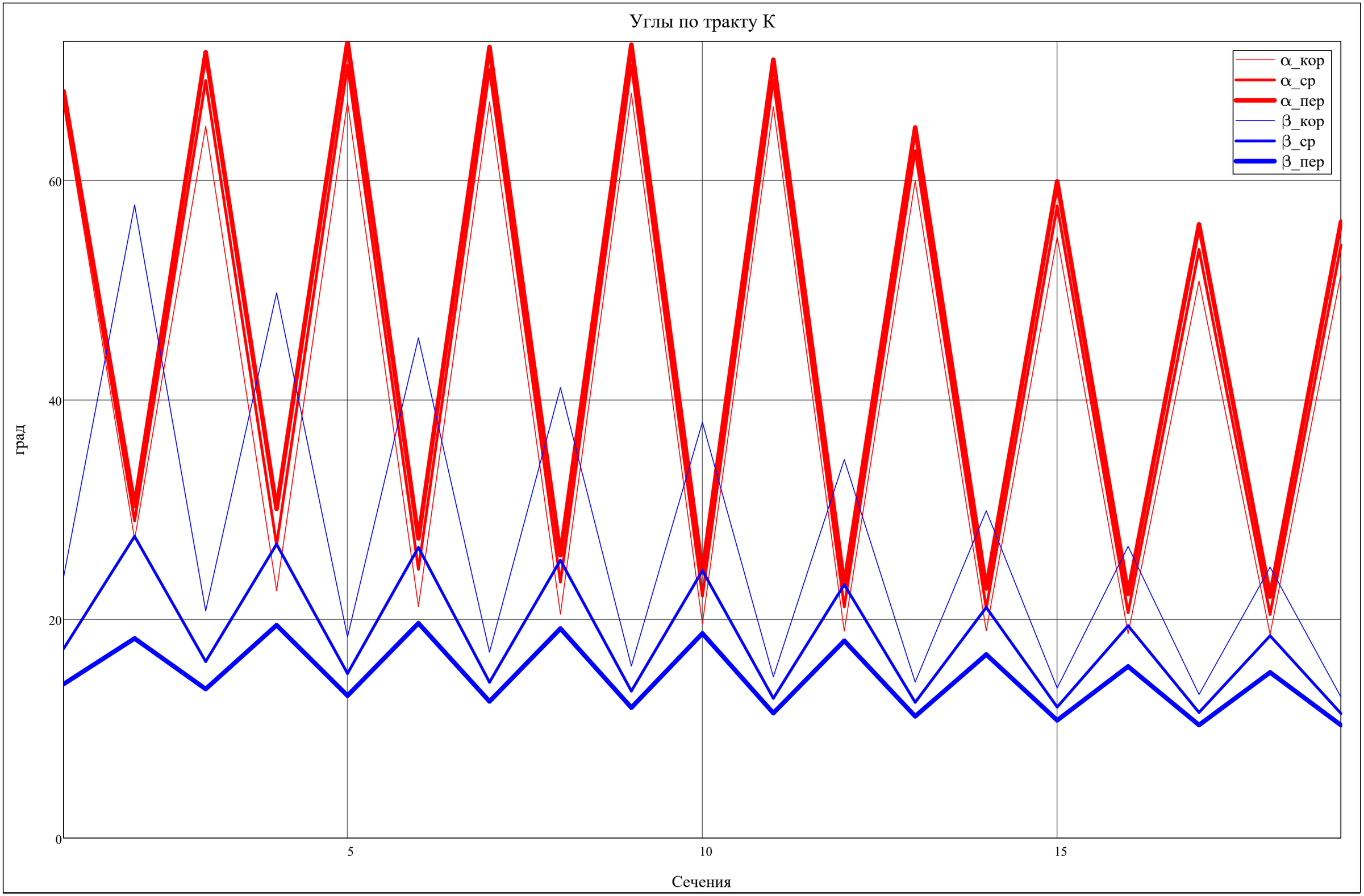
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	33.91	29.01	27.29	24.14	22.24	19.81	15.63	12.93	11.63						
2	10.25	10.72	11.51	11.14	10.99	10.38	8.66	7.42	7.01						
3	4.16	5.82	6.61	6.65	6.78	6.59	5.64	4.92	4.81						

$.^\circ$

$\varepsilon_{stator}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	38.38	41.87	47.52	47.71	49.08	48.10	40.53	35.16	32.89						
2	37.26	41.21	46.92	47.37	48.87	48.14	41.09	36.00	33.70						
3	36.52	40.26	46.04	46.74	48.39	47.91	41.32	36.50	34.22						

$.^\circ$


Углы по тракту К
α_кор
α_ср
α_пер
β_кор
β_ср
β_пер
60
40
20
0
град
5
10
15
Сечения

$\lambda_c^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.3012	0.6161	0.2642	0.5779	0.2321	0.5451	0.2055	0.5025	0.1829	0.4720	0.1663	0.4421	0.1600	0.4036	0.1550	0.3757	0.1502	0.3559	0.1441				
2	0.2893	0.5098	0.2559	0.4900	0.2269	0.4733	0.2014	0.4426	0.1798	0.4204	0.1634	0.3974	0.1559	0.3654	0.1500	0.3419	0.1446	0.3253	0.1391				
3	0.2823	0.4503	0.2516	0.4390	0.2240	0.4279	0.1989	0.4029	0.1779	0.3848	0.1616	0.3656	0.1531	0.3377	0.1465	0.3169	0.1405	0.3024	0.1355				

[16, c. 87]

$\lambda_c^T \leq 0.85 =$

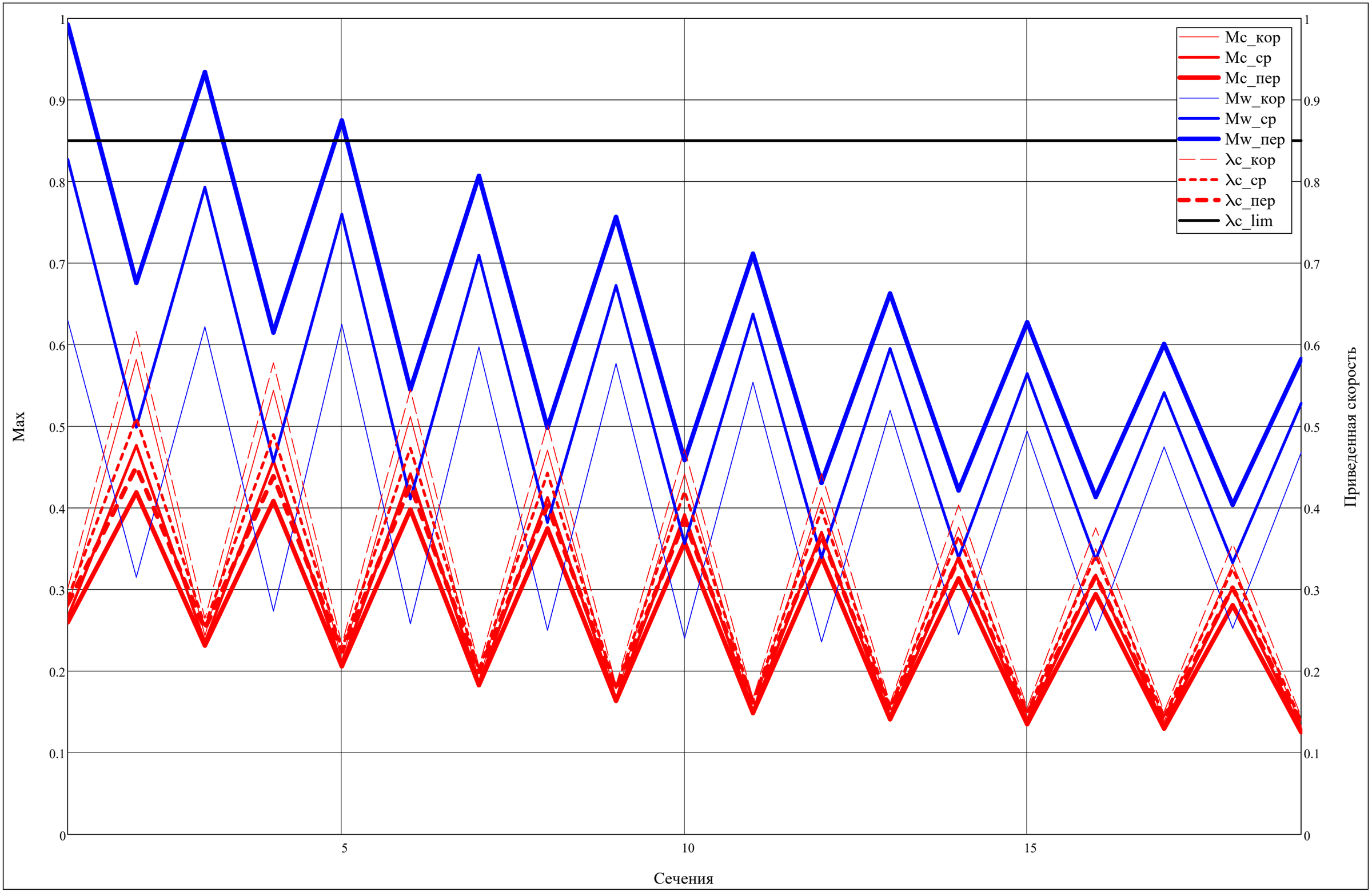
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

$M_c^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.2774	0.5820	0.2431	0.5441	0.2135	0.5120	0.1891	0.4708	0.1684	0.4415	0.1532	0.4130	0.1475	0.3763	0.1430	0.3500	0.1387	0.3314	0.1331				
2	0.2663	0.4766	0.2353	0.4577	0.2087	0.4419	0.1853	0.4128	0.1655	0.3918	0.1505	0.3701	0.1437	0.3400	0.1383	0.3179	0.1334	0.3024	0.1285				
3	0.2597	0.4189	0.2314	0.4084	0.2060	0.3982	0.1830	0.3747	0.1637	0.3578	0.1488	0.3398	0.1411	0.3137	0.1351	0.2942	0.1297	0.2808	0.1252				

$M_w^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.6299	0.3151	0.6220	0.2736	0.6249	0.2582	0.5972	0.2501	0.5768	0.2404	0.5539	0.2359	0.5195	0.2449	0.4941	0.2498	0.4747	0.2525	0.4680				
2	0.8274	0.4989	0.7928	0.4565	0.7598	0.4110	0.7096	0.3822	0.6726	0.3563	0.6374	0.3393	0.5953	0.3388	0.5645	0.3369	0.5413	0.3329	0.5281				
3	0.9923	0.6758	0.9341	0.6149	0.8747	0.5451	0.8069	0.4983	0.7565	0.4586	0.7114	0.4307	0.6628	0.4215	0.6274	0.4135	0.6009	0.4039	0.5824				


Mc_кор
Mc_ср
Mc_пер
Mw_кор
Mw_ср
Mw_пер
λc_кор
λc_ср
λc_пер
λc_lim
Max
Приведенная скорость
Сечения
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
10
15

$$T^*_{1CA} = \begin{pmatrix} 826.7 \\ 826.7 \\ 826.7 \end{pmatrix} \qquad T^*_{3CA} = \begin{pmatrix} 826.7 \\ 826.7 \\ 826.7 \end{pmatrix}$$

$$P^*_{1CA} = \begin{pmatrix} 2841.7 \\ 2841.7 \\ 2841.7 \end{pmatrix} \cdot 10^3 \qquad P^*_{3CA} = \begin{pmatrix} 2836.3 \\ 2836.3 \\ 2836.3 \end{pmatrix} \cdot 10^3$$

$$\rho^*_{1CA} = \begin{pmatrix} 11.972 \\ 11.972 \\ 11.972 \end{pmatrix} \qquad \rho^*_{3CA} = \begin{pmatrix} 11.949 \\ 11.949 \\ 11.949 \end{pmatrix}$$

$$Cp_{1CA} = \begin{pmatrix} 1103.8 \\ 1103.8 \\ 1103.8 \end{pmatrix} \qquad Cp_{3CA} = \begin{pmatrix} 1103.8 \\ 1103.8 \\ 1103.8 \end{pmatrix}$$

$$k_{1CA} = \begin{pmatrix} 1.352 \\ 1.352 \\ 1.352 \end{pmatrix} \qquad k_{3CA} = \begin{pmatrix} 1.352 \\ 1.352 \\ 1.352 \end{pmatrix}$$

$$a^*_{c1CA} = \begin{pmatrix} 522.4 \\ 522.4 \\ 522.4 \end{pmatrix} \qquad a^*_{c3CA} = \begin{pmatrix} 522.4 \\ 522.4 \\ 522.4 \end{pmatrix}$$

$$c_{1CA} = \begin{pmatrix} 75.3 \\ 72.7 \\ 70.8 \end{pmatrix} \qquad c_{3CA} = \begin{pmatrix} 48.9 \\ 48.9 \\ 48.9 \end{pmatrix}$$

$$c_{u1CA} = \begin{pmatrix} 46.9 \\ 42.6 \\ 39.3 \end{pmatrix} \qquad c_{u3CA} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix}$$

$$c_{a1CA} = \begin{pmatrix} 58.9 \\ 58.9 \\ 58.9 \end{pmatrix} \qquad c_{a3CA} = \begin{pmatrix} 48.9 \\ 48.9 \\ 48.9 \end{pmatrix}$$

$$\alpha_{1CA} = \begin{pmatrix} 51.47 \\ 54.10 \\ 56.25 \end{pmatrix} \cdot ^\circ \qquad \alpha_{3CA} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ^\circ$$

$$\varepsilon_{CA} = \begin{pmatrix} 38.53 \\ 35.90 \\ 33.75 \end{pmatrix} \cdot ^\circ$$

$$\lambda_{c1CA} = \begin{pmatrix} 0.144 \\ 0.139 \\ 0.136 \end{pmatrix} \qquad \lambda_{c3CA} = \begin{pmatrix} 0.094 \\ 0.094 \\ 0.094 \end{pmatrix}$$

Результаты расчета параметров потока по высоте Л

Вывод результатов расчета параметров потока по высоте Л

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

Построение треугольников скоростей в 3х сечениях

$$\Delta_c(v,i,j,r) = \begin{cases} \tan\left(\alpha_{st(i,j),r}\right)\cdot v & \text{if } \left(\tan\left(\alpha_{st(i,j),r}\right) \geq 0 \wedge -\left|c_{st(i,j),r}\cdot\cos\left(\alpha_{st(i,j),r}\right)\right| \leq v \leq 0\right) \\ \tan\left(\alpha_{st(i,j),r}\right)\cdot v & \text{if } \left(\tan\left(\alpha_{st(i,j),r}\right) < 0 \wedge 0 \leq v \leq \left|c_{st(i,j),r}\cdot\cos\left(\alpha_{st(i,j),r}\right)\right|\right) \end{cases}$$

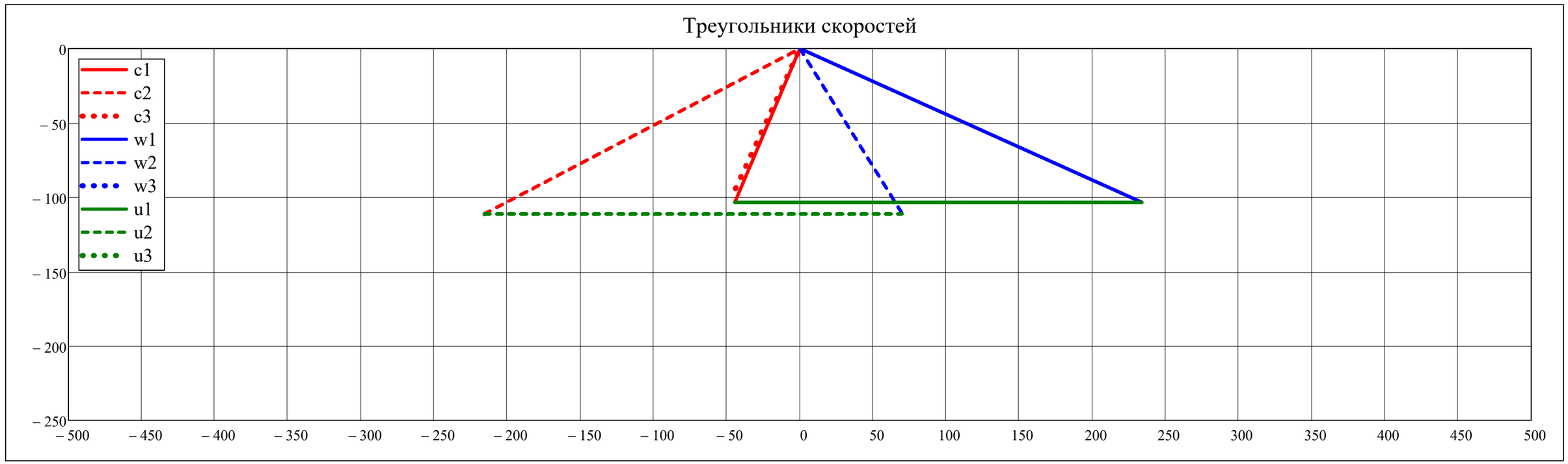
$$\Delta_w(v,i,j,r) = \begin{cases} -\tan\left(\beta_{st(i,j),r}\right)\cdot v & \text{if } \left(-\tan\left(\beta_{st(i,j),r}\right) \geq 0\right) \wedge \left(-\left|w_{st(i,j),r}\cdot\cos\left(\beta_{st(i,j),r}\right)\right| \leq v \leq 0\right) \wedge (j \neq 3) \\ -\tan\left(\beta_{st(i,j),r}\right)\cdot v & \text{if } \left(-\tan\left(\beta_{st(i,j),r}\right) < 0\right) \wedge \left(0 \leq v \leq \left|w_{st(i,j),r}\cdot\cos\left(\beta_{st(i,j),r}\right)\right|\right) \wedge (j \neq 3) \end{cases}$$

$$\Delta_u(v,i,j,r) = \begin{cases} -c_{a_{st(i,j),r}} & \text{if } \left(-c_{st(i,j),r}\cdot\cos\left(\alpha_{st(i,j),r}\right) \leq v \leq w_{st(i,j),r}\cdot\cos\left(\beta_{st(i,j),r}\right)\right) \wedge (j \neq 3) \\ \text{NaN} & \text{otherwise} \end{cases}$$

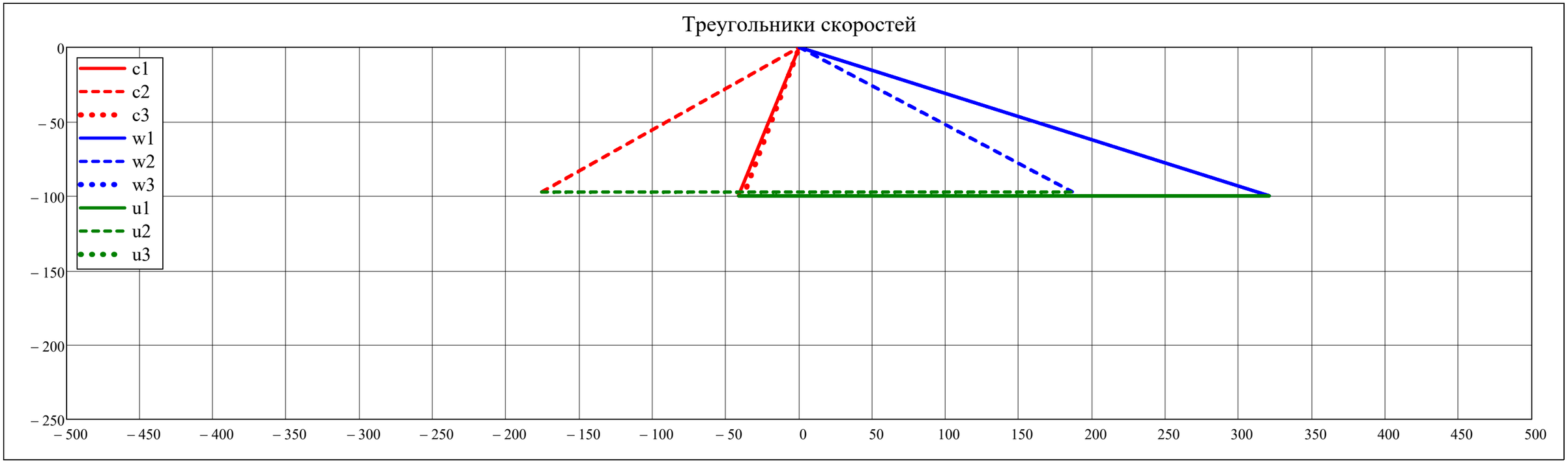
$$v_{lim} = \text{ceil}\left(\frac{\max(c,w,u)}{10^2}\right)\cdot 10^2 = 500$$

Дискретизация скорости: $v = -v_{lim}, -v_{lim} + \frac{v_{lim}}{3000} .. v_{lim}$

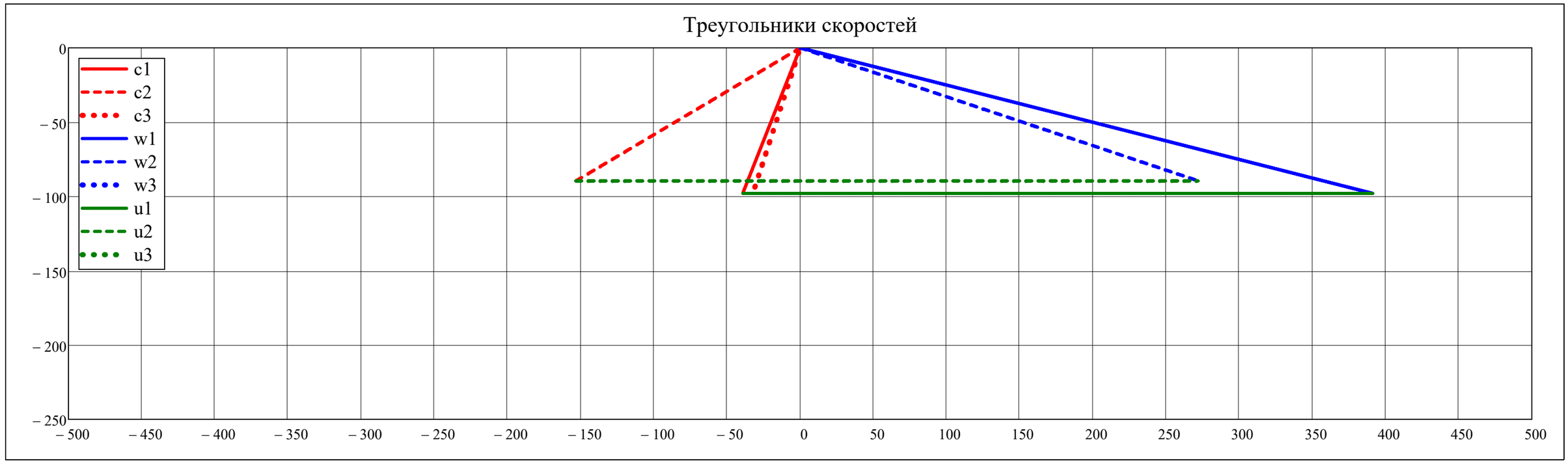
r = 1


Треугольники скоростей
c1
c2
c3
w1
w2
w3
u1
u2
u3
0
– 50
– 100
– 150
– 200
– 250
– 500
– 450
– 400
– 350
– 300
– 250
– 200
– 150
– 100
– 50
0
50
100
150
200
250
300
350
400
450
500

$\underset{\sim}{r} = av(N_r)$



$\underset{\sim}{r} = N_r$



Построение треугольников скоростей в 3х сечениях

Определение степени повышения полного давлеия по 2ум контурам

$$\begin{pmatrix} F_I & F_{II} \\ D2 & R2 \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } a \in 1..3 \\ \quad\quad \rho_{.}(z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(\rho, st(i,a), st(i,a), 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(\rho, st(i,a), st(i,a), 1, N_r\right)^T, z\right) \\ \quad\quad c_{a.}(z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(c_a, st(i,a), st(i,a), 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(c_a, st(i,a), st(i,a), 1, N_r\right)^T, z\right) \\ \quad\quad R2 = \sqrt{\frac{\left(R_{st(i,a),N_r}\right)^2 + m2 \cdot \left(R_{st(i,a),1}\right)^2}{1 + m2}} \\ \quad\quad R2_{st(i,a)} = \text{root}\left[\frac{\rho_{.}(R2) \cdot c_{a.}(R2) \cdot \pi \cdot \left[\left(R_{st(i,a),N_r}\right)^2 - (R2)^2\right]}{\rho_{.}(R2) \cdot c_{a.}(R2) \cdot \pi \cdot \left[(R2)^2 - \left(R_{st(i,a),1}\right)^2\right]} - m2, R2\right] \\ \quad\quad D2_{st(i,a)} = 2 \cdot R2_{st(i,a)} \\ \quad\quad \begin{pmatrix} F_{II_{st(i,a)}} \\ F_{I_{st(i,a)}} \end{pmatrix} = \pi \cdot \begin{bmatrix} \left(R_{st(i,a),N_r}\right)^2 - \left(R2_{st(i,a)}\right)^2 \\ \left(R2_{st(i,a)}\right)^2 - \left(R_{st(i,a),1}\right)^2 \end{bmatrix} \\ \begin{pmatrix} F_I & F_{II} \\ D2 & R2 \end{pmatrix} \end{array} \right.$$

Кольцевые площади (м^2):

$\text{stack}\left(F_I^T, F_{II}^T, F^T\right) =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.0196	0.0180	0.0165	0.0152	0.0140	0.0130	0.0121	0.0114	0.0107	0.0101	0.0095	0.0091	0.0087	0.0084	0.0081	0.0079	0.0077	0.0074	0.0071
2	0.1177	0.1082	0.0990	0.0914	0.0840	0.0781	0.0726	0.0682	0.0640	0.0606	0.0573	0.0547	0.0522	0.0504	0.0487	0.0476	0.0464	0.0445	0.0427
3	0.1373	0.1218	0.1155	0.1031	0.0980	0.0884	0.0846	0.0775	0.0747	0.0690	0.0668	0.0624	0.0608	0.0578	0.0568	0.0547	0.0541	0.0514	0.0498

Радиус и диаметр двухконтурности (м):

$\text{stack}\left(R2^T, D2^T\right) =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	194.1	197.3	200.4	202.9	205.3	204.5	203.8	203.2	202.7	202.2	201.8	201.5	201.1	200.9	200.7	200.5	200.4	200.1	199.9
2	388.1	394.6	400.7	405.7	410.5	409.0	407.6	406.4	405.3	404.5	403.6	402.9	402.2	401.8	401.3	401.0	400.7	400.2	399.7

$\cdot 10^{-3}$

$$\begin{pmatrix} \pi^*_{II} \\ \pi^*_{I} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } a \in 1 \\ \quad\quad Cp_{\cdot}(z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(Cp, st(i,a), st(i,a), 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(Cp, st(i,a), st(i,a), 1, N_r\right)^T, z\right) \\ \quad\quad k_{\cdot}(z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(k, st(i,a), st(i,a), 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(k, st(i,a), st(i,a), 1, N_r\right)^T, z\right) \\ \quad\quad T^*_{\cdot}(z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(T^*, st(i,a), st(i,a), 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(T^*, st(i,a), st(i,a), 1, N_r\right)^T, z\right) \\ \quad\quad H_{T\cdot}(z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(H_T, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,a), st(i,a), 1, N_r\right)^T, \text{submatrix}\left(H_T, i, i, 1, N_r\right)^T, z\right) \\ \quad\quad \pi^*_{II_i} = \left| \begin{array}{l} 1 \quad \text{if } m2 = 0 \\ \dfrac{2\cdot\pi}{F_{II_{st(i,a)}}} \cdot \displaystyle\int_{R2_{st(i,a)}}^{R_{st(i,a),N_r}} \left(1 + \frac{K_{H_i}\cdot\eta^*_i\cdot H_{T\cdot}(r)}{Cp_{\cdot}(r)\cdot T^*_{\cdot}(r)}\right)^{\frac{k_{\cdot}(r)}{k_{\cdot}(r)-1}} \cdot r\,dr \quad \text{otherwise} \end{array} \right. \\ \quad\quad \pi^*_{I_i} = \left| \begin{array}{l} \dfrac{2\cdot\pi}{F_{I_{st(i,a)}}} \cdot \displaystyle\int_{R_{st(i,a),1}}^{R2_{st(i,a)}} \left(1 + \frac{K_{H_i}\cdot\eta^*_i\cdot H_{T\cdot}(r)}{Cp_{\cdot}(r)\cdot T^*_{\cdot}(r)}\right)^{\frac{k_{\cdot}(r)}{k_{\cdot}(r)-1}} \cdot r\,dr \end{array} \right. \\ \begin{pmatrix} \pi^*_{II} \\ \pi^*_{I} \end{pmatrix} \end{array} \right.$$

$\text{stack}\left(\pi^*_I{}^T, \pi^*_{II}{}^T\right) =$

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.392	1.381	1.365	1.319	1.286	1.253	1.203	1.170	1.148			
2	1.392	1.381	1.365	1.319	1.286	1.253	1.203	1.170	1.148			

$$\prod_{i=1}^{Z} \pi^*_{I_i} = 9.003$$

$$\prod_{i=1}^{Z} \pi^*_{II_i} = 9.003$$

Определение степени повышения полного давлеия по 2ум контурам

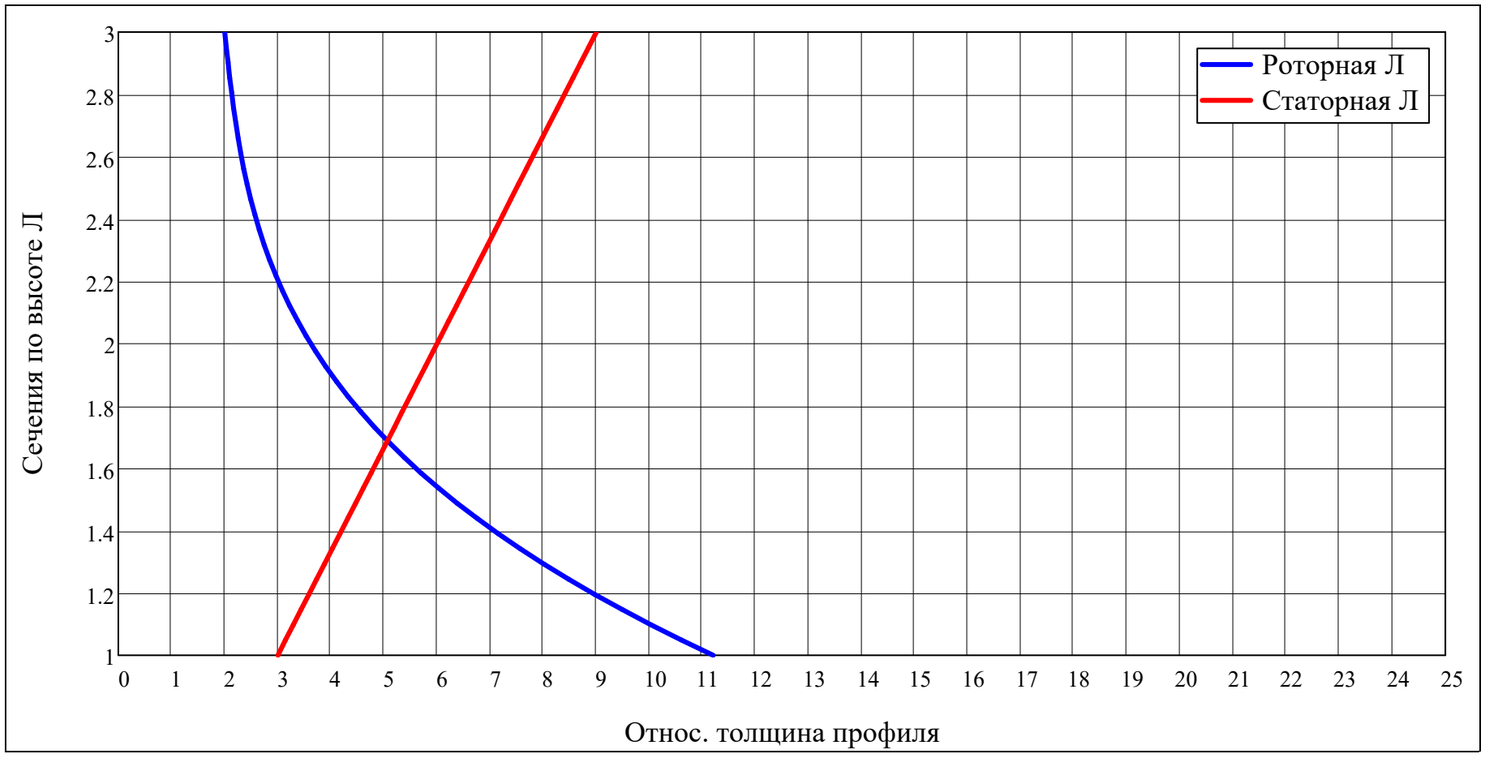
Относ. толщины и радиусы профилей

Относ. толщины Л РК и СА:

$$\overline{c}_{rotor.}(r) = \text{interp}\left[\text{cspline}\left[\begin{pmatrix}1\\ \text{av}(N_r)\\ N_r\end{pmatrix}, \begin{pmatrix}12 + \begin{cases}4 & \text{if compressor = "Вл"}\\ -4 & \text{if compressor = "КНД"}\\ -0.8 & \text{otherwise}\end{cases}\\ 3 + \begin{cases}1.65 & \text{if compressor = "Вл"}\\ 0 & \text{if compressor = "КНД"}\\ 0.62 & \text{otherwise}\end{cases}\\ 2\end{pmatrix}\%\right], \begin{pmatrix}1\\ \text{av}(N_r)\\ N_r\end{pmatrix}, \begin{pmatrix}12 + \begin{cases}4 & \text{if compressor = "Вл"}\\ -4 & \text{if compressor = "КНД"}\\ -0.8 & \text{otherwise}\end{cases}\\ 3 + \begin{cases}1.65 & \text{if compressor = "Вл"}\\ 0 & \text{if compressor = "КНД"}\\ 0.62 & \text{otherwise}\end{cases}\\ 2\end{pmatrix}\%, r\right]$$

$$\overline{c}_{stator.}(r) = \text{interp}\left[\text{cspline}\left[\begin{pmatrix}1\\ \text{av}(N_r)\\ N_r\end{pmatrix}, \begin{pmatrix}3\\ 6\\ 9\end{pmatrix}\%\right], \begin{pmatrix}1\\ \text{av}(N_r)\\ N_r\end{pmatrix}, \begin{pmatrix}3\\ 6\\ 9\end{pmatrix}\%, r\right]$$

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



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

$\overline{c}_{BHA} =$

	1
1	3.00
2	6.00
3	9.00

$\cdot\%$

$$\begin{pmatrix} \overline{c}_{stator} \\ \overline{c}_{rotor} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } r \in 1..N_r \\ \quad\quad \begin{pmatrix} \overline{c}_{stator_{i,r}} \\ \overline{c}_{rotor_{i,r}} \end{pmatrix} = \begin{pmatrix} \overline{c}_{stator.}(r) \\ \overline{c}_{rotor.}(r) \end{pmatrix} \\ \begin{pmatrix} \overline{c}_{stator} \\ \overline{c}_{rotor} \end{pmatrix} \end{array} \right.$$

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

	1	2	3	4	5	6	7	8	9
1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
3	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00

$\cdot\%$

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

	1	2	3	4	5	6	7	8	9
1	11.20	11.20	11.20	11.20	11.20	11.20	11.20	11.20	11.20
2	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62
3	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

$\cdot\%$

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

$\overline{c}_{CA} =$

	1
1	3.00
2	6.00
3	9.00

$\cdot\%$

$$\begin{pmatrix} \overline{r\_inlet}_{BHA} \\ \overline{r\_outlet}_{BHA} \end{pmatrix} = \left| \begin{array}{l} \text{for } r \in 1 .. N_r \qquad \text{if } BHA = 1 \\ \quad \begin{pmatrix} \overline{r\_inlet}_{BHA_r} \\ \overline{r\_outlet}_{BHA_r} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c}_{stator.}(r) \\ \begin{pmatrix} \overline{r\_inlet}_{BHA} \\ \overline{r\_outlet}_{BHA} \end{pmatrix} \end{array} \right.$$

$$\begin{pmatrix} \overline{r\_inlet}_{CA} \\ \overline{r\_outlet}_{CA} \end{pmatrix} = \left| \begin{array}{l} \text{for } r \in 1 .. N_r \qquad \text{if } CA = 1 \\ \quad \begin{pmatrix} \overline{r\_inlet}_{CA_r} \\ \overline{r\_outlet}_{CA_r} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c}_{stator.}(r) \\ \begin{pmatrix} \overline{r\_inlet}_{CA} \\ \overline{r\_outlet}_{CA} \end{pmatrix} \end{array} \right.$$

$$\begin{pmatrix} \overline{r\_inlet}_{rotor} & \overline{r\_inlet}_{stator} \\ \overline{r\_outlet}_{rotor} & \overline{r\_outlet}_{stator} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1 .. Z \\ \quad \text{for } r \in 1 .. N_r \\ \quad\quad \left| \begin{array}{l} \begin{pmatrix} \overline{r\_inlet}_{stator_{i,r}} \\ \overline{r\_outlet}_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} 0.10 \\ 0.05 \end{pmatrix} \cdot \overline{c}_{stator.}(r) \\ \begin{pmatrix} \overline{r\_inlet}_{rotor_{i,r}} \\ \overline{r\_outlet}_{rotor_{i,r}} \end{pmatrix} = \begin{pmatrix} 0.10 \\ 0.05 \end{pmatrix} \cdot \overline{c}_{rotor.}(r) \end{array} \right. \\ \begin{pmatrix} \overline{r\_inlet}_{rotor} & \overline{r\_inlet}_{stator} \\ \overline{r\_outlet}_{rotor} & \overline{r\_outlet}_{stator} \end{pmatrix} \end{array} \right.$$

$\overline{r\_inlet}_{BHA} =$

	1
1	0.600
2	1.200
3	1.800

$\cdot\%$

$\overline{r\_inlet}_{CA} =$

	1
1	0.600
2	1.200
3	1.800

$\cdot\%$

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

	1	2	3	4	5	6	7	8	9
1	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
2	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600
3	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900	0.900

$\cdot\%$

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

	1	2	3	4	5	6	7	8	9
1	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120
2	0.362	0.362	0.362	0.362	0.362	0.362	0.362	0.362	0.362
3	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200

$\cdot\%$

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

	1	2	3	4	5	6	7	8	9
1	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
2	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
3	0.450	0.450	0.450	0.450	0.450	0.450	0.450	0.450	0.450

$\cdot\%$

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

	1	2	3	4	5	6	7	8	9
1	0.560	0.560	0.560	0.560	0.560	0.560	0.560	0.560	0.560
2	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181
3	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100

$\cdot\%$

$\overline{r\_outlet}_{BHA} =$

	1
1	0.300
2	0.600
3	0.900

$\cdot\%$

$\overline{r\_outlet}_{CA} =$

	1
1	0.300
2	0.600
3	0.900

Относ. толщины и радиусы профилей

Распределение параметров по высоте Л

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

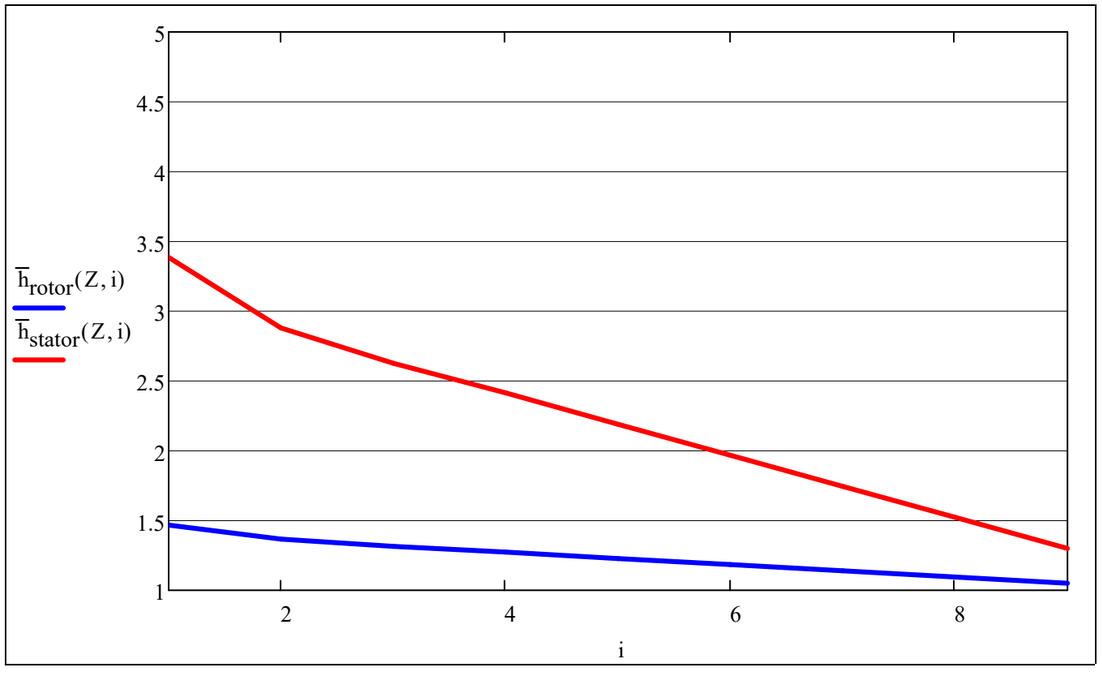
$$\overline{h}_{\sim rotor} = (2 \;\; 1.9 \;\; 1.85 \;\; 1.8 \;\; 1.75 \;\; 1.7 \;\; 1.65 \;\; 1.6)^T + \begin{cases} 1.1 & \text{if compressor = "Вл"} \\ -0.1 & \text{if compressor = "КНД"} \\ -0.55 & \text{if compressor = "КВД"} \end{cases}$$

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

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

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

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



Для компрессора газогенератора

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

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

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

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

[16, с. 83-84]

Распределение параметров по высоте Л

Парусность: $\begin{pmatrix} sail_{rotor} \\ sail_{stator} \end{pmatrix} = \begin{pmatrix} 1.3 \\ 1.2 \end{pmatrix}$

Расчет длин хорд по высоте Л

$chord_{BHA} =$ for $i \in 1$ if $BHA = 1$

$chord_{BHA_{av}(N_r)} = \dfrac{h_{st(i,1)}}{\overline{h}_{stator}(Z,0)}$

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

for $r \in 1..N_r$

$b_{BHAкор} = \dfrac{chord_{BHA_{av}(N_r)} \cdot sail}{sail_{stator} - 1 + sail}$

$b_{BHAпер} = b_{BHAкор} \cdot sail_{stator}$

$b_{BHA.}(z) = interp\left[cspline\left[\begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{BHAкор} \\ chord_{BHA_{av}(N_r)} \\ b_{BHAпер} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{BHAкор} \\ chord_{BHA_{av}(N_r)} \\ b_{BHAпер} \end{pmatrix}, z\right]$

$chord_{BHA_r} = b_{BHA.}(R_{st(i,1),r})$

$chord_{BHA}$

$$\left(\text{chord}_{rotor}\ \ \text{chord}_{stator}\right) = \text{for}\ \ i \in 1..Z$$

$$\begin{pmatrix} \text{chord}_{rotor_{i,av(N_r)}} \\ \text{chord}_{stator_{i,av(N_r)}} \end{pmatrix} = \begin{pmatrix} \dfrac{\text{mean}\left(h_{st(i,1)}, h_{st(i,2)}\right)}{\overline{h}_{rotor}(Z,i)} \\ \dfrac{\text{mean}\left(h_{st(i,2)}, h_{st(i,3)}\right)}{\overline{h}_{stator}(Z,i)} \end{pmatrix}$$

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

$$\text{for}\ \ r \in 1..N_r$$

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

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

$$\begin{pmatrix} b_{РКпер} \\ b_{НАпер} \end{pmatrix} = \begin{pmatrix} b_{РКкор} \cdot \text{sail}_{rotor} \\ b_{НАкор} \cdot \text{sail}_{stator} \end{pmatrix}$$

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

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

$$\text{chord}_{rotor_{i,r}} = \text{chord}_{rotor.}\left(R_{st(i,2),r}\right)$$

$$\text{chord}_{stator_{i,r}} = \text{chord}_{stator.}\left(R_{st(i,2),r}\right)$$

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

$\mathrm{chord}_{CA} =$ for $i \in Z$ if $CA = 1$

$\mathrm{chord}_{CA_{av}(N_r)} = \dfrac{h_{st(i,3)}}{\overline{h}_{stator}(Z, Z+1)}$

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

for $r \in 1 .. N_r$

$b_{CAкор} = \dfrac{\mathrm{chord}_{CA_{av}(N_r)} \cdot sail}{sail_{stator} - 1 + sail}$

$b_{CAпер} = b_{CAкор} \cdot sail_{stator}$

$b_{CA.}(z) = \mathrm{interp}\left[\mathrm{cspline}\left[\begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CAкор} \\ \mathrm{chord}_{CA_{av}(N_r)} \\ b_{CAпер} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CAкор} \\ \mathrm{chord}_{CA_{av}(N_r)} \\ b_{CAпер} \end{pmatrix}, z\right]$

$\mathrm{chord}_{CA_r} = b_{CA.}\left(R_{st(i,1),r}\right)$

chord_{CA}

Расчет длин хорд по высоте Л

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

$\bar{x}_f = 0.5$

Определение количества Л РК и НА

$$\begin{pmatrix} \varepsilon_{BHA(b/t)=1} \\ Z_{BHA} \\ r\_inlet_{BHA} \\ r\_outlet_{BHA} \\ t_{BHA} \\ i_{BHA} \\ m_{BHA} \\ \theta_{BHA} \\ \delta_{BHA} \\ \chi_{BHA} \\ \upsilon_{BHA} \\ R_{СЛ.BHA} \\ K_{BHA} \\ D_{BHA} \end{pmatrix} = \left| \begin{array}{l} \text{if } BHA = 1 \\ \quad \left| \begin{array}{l} \text{for } r \in av(N_r) \\ \quad \left| \begin{array}{l} \varepsilon_{BHA(b/t)=1_r} = \varepsilon_{(b/t)=1}\left(\alpha_{3BHA_r}\right) \\ b/t_{BHA_r} = b/t=1\left(\dfrac{\varepsilon_{BHA_r}}{\varepsilon_{BHA(b/t)=1_r}}\right) \\ t_{BHA_r} = \dfrac{chord_{BHA_r}}{b/t_{BHA_r}} \\ Z_{BHA} = \left| \begin{array}{l} round\left(\dfrac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right) \text{ if } mod\left(round\left(\dfrac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right),2\right) = 0 \\ round\left(\dfrac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right) + 1 \text{ otherwise} \end{array} \right. \end{array} \right. \\ \text{for } r \in 1..N_r \\ \quad \left| \begin{array}{l} \left(r\_inlet_{BHA_r} \; r\_outlet_{BHA_r}\right) = chord_{BHA_r} \cdot \left(\bar{r}\_inlet_{BHA_r} \; \bar{r}\_outlet_{BHA_r}\right) \\ t_{BHA_r} = \dfrac{D_{st(1,1),r}}{Z_{BHA}} \\ i_{BHA_r} = 2.5 \cdot \left(\dfrac{chord_{BHA_r}}{t_{BHA_r}} - 2\right) \cdot ° \\ m_{BHA} = 0.23 \cdot \left(2 \cdot \bar{x}_f\right)^2 + 0.18 - \dfrac{0.002}{\quad} \cdot \left(\alpha_{3BHA}\right) \end{array} \right. \end{array} \right. \end{array} \right.$$

$$\theta_{BHA_r} = \frac{\varepsilon_{BHA_r} - i_{BHA_r}}{1 - m_{BHA_r} \cdot \sqrt{\frac{t_{BHA_r}}{chord_{BHA_r}}}}$$

$$\delta_{BHA_r} = m_{BHA_r} \cdot \theta_{BHA_r} \cdot \sqrt{\frac{t_{BHA_r}}{chord_{BHA_r}}}$$

$$\chi_{BHA_r} = \theta_{BHA_r} \cdot \frac{1 + 2 \cdot \left(1 - 2 \cdot \overline{x}_f\right)}{2}$$

$$\upsilon_{BHA_r} = \chi_{BHA_r} + \alpha_{1BHA_r} + i_{BHA_r}$$

$$R_{СЛ.BHA_r} = \frac{chord_{BHA_r}}{2 \cdot \sin\left(0.5 \cdot \theta_{BHA_r}\right)}$$

$$K_{BHA_r} = \frac{c_{a3BHA_r}}{c_{a1BHA_r}}$$

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

$$\left(\varepsilon_{BHA(b/t)=1} \quad Z_{BHA} \quad r\_inlet_{BHA} \quad r\_outlet_{BHA} \quad t_{BHA} \quad i_{BHA} \quad m_{BHA} \quad \theta_{BHA} \quad \delta_{BHA} \quad \chi_{BHA} \quad \upsilon_{BHA} \quad R_{СЛ.BHA} \quad K_{BHA} \quad D_{BHA}\right)^T$$

$$
\begin{pmatrix}
\varepsilon_{PK(b/t)=1} & \varepsilon_{HA(b/t)=1} \\
Z_{rotor} & Z_{stator} \\
r\_inlet_{rotor} & r\_inlet_{stator} \\
r\_outlet_{rotor} & r\_outlet_{stator} \\
t_{rotor} & t_{stator} \\
i_{rotor} & i_{stator} \\
m_{rotor} & m_{stator} \\
\theta_{rotor} & \theta_{stator} \\
\delta_{rotor} & \delta_{stator} \\
\chi_{rotor} & \chi_{stator} \\
\upsilon_{rotor} & \upsilon_{stator} \\
R_{СЛ.rotor} & R_{СЛ.stator} \\
K_{rotor} & K_{stator} \\
D_{rotor} & D_{stator} \\
\zeta_{rotor} & \zeta_{stator} \\
quality_{rotor} & quality_{stator} \\
\eta_{stage} & \eta_{stage}
\end{pmatrix}
=
\left|
\begin{array}{l}
\text{for } i \in 1..Z \\
\quad \text{for } r \in av\left(N_r\right) \\
\quad\quad \begin{pmatrix} \varepsilon_{PK(b/t)=1_{i,r}} \\ \varepsilon_{HA(b/t)=1_{i,r}} \end{pmatrix} = \begin{pmatrix} \varepsilon_{(b/t)=1}\left(\beta_{st(i,2),r}\right) \\ \varepsilon_{(b/t)=1}\left(\alpha_{st(i,3),r}\right) \end{pmatrix} \\
\quad\quad \begin{pmatrix} b/t_{PK_{i,r}} \\ b/t_{HA_{i,r}} \end{pmatrix} = \begin{pmatrix} b/t=1\left(\dfrac{\varepsilon_{rotor_{i,r}}}{\varepsilon_{PK(b/t)=1_{i,r}}}\right) \\ b/t=1\left(\dfrac{\varepsilon_{stator_{i,r}}}{\varepsilon_{HA(b/t)=1_{i,r}}}\right) \end{pmatrix} \\
\quad\quad \begin{pmatrix} t_{rotor_{i,r}} \\ t_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \dfrac{chord_{rotor_{i,r}}}{b/t_{PK_{i,r}}} \\ \dfrac{chord_{stator_{i,r}}}{b/t_{HA_{i,r}}} \end{pmatrix} \\
\quad\quad Z_{stator_i} = \left|
\begin{array}{ll}
round\left(\dfrac{\pi \cdot mean\left(D_{st(i,2),r}, D_{st(i,3),r}\right)}{t_{stator_{i,r}}}\right) & \text{if } mod\left(round\left(\dfrac{\pi \cdot mean\left(D_{st(i,2),r}, D_{st(i,3),r}\right)}{t_{stator_{i,r}}}\right), 2\right) = 0 \\
round\left(\dfrac{\pi \cdot mean\left(D_{st(i,2),r}, D_{st(i,3),r}\right)}{t_{stator_{i,r}}}\right) + 1 & \text{otherwise}
\end{array}
\right. \\
\quad\quad Z_{rotor_i} = \left|
\begin{array}{l}
Z_{rotor_i} = round\left(\dfrac{\pi \cdot mean\left(D_{st(i,1),r}, D_{st(i,2),r}\right)}{t_{rotor_{i,r}}}\right) \\
\text{while } gcd\left(Z_{rotor_i}, Z_{stator_i}\right) \neq 1 \\
\quad Z_{rotor_i} = Z_{rotor_i} + 1
\end{array}
\right.
\end{array}
\right.
$$

for $r \in 1 .. N_r$

$$\begin{pmatrix} r\_inlet_{stator_{i,r}} & r\_outlet_{stator_{i,r}} \\ r\_inlet_{rotor_{i,r}} & r\_outlet_{rotor_{i,r}} \end{pmatrix} = \begin{pmatrix} \overline{r}\_inlet_{stator_{i,r}} \cdot chord_{stator_{i,r}} & \overline{r}\_outlet_{stator_{i,r}} \cdot chord_{stator_{i,r}} \\ \overline{r}\_inlet_{rotor_{i,r}} \cdot chord_{rotor_{i,r}} & \overline{r}\_outlet_{rotor_{i,r}} \cdot chord_{rotor_{i,r}} \end{pmatrix}$$

$$\begin{pmatrix} t_{rotor_{i,r}} \\ t_{stator_{i,r}} \end{pmatrix} = \pi \cdot \begin{pmatrix} \frac{mean\left(D_{st(i,1),r}, D_{st(i,2),r}\right)}{Z_{rotor_i}} \\ \frac{mean\left(D_{st(i,2),r}, D_{st(i,3),r}\right)}{Z_{stator_i}} \end{pmatrix}$$

$$\begin{pmatrix} i_{rotor_{i,r}} \\ i_{stator_{i,r}} \end{pmatrix} = 2.5 \cdot \begin{pmatrix} \frac{chord_{rotor_{i,r}}}{t_{rotor_{i,r}}} - 1 \\ \frac{chord_{stator_{i,r}}}{t_{stator_{i,r}}} - 2 \end{pmatrix} .^{\circ}$$

$$\begin{pmatrix} m_{rotor_{i,r}} \\ m_{stator_{i,r}} \end{pmatrix} = 0.23 \cdot \left(2 \cdot \overline{x}_f\right)^2 + 0.18 - \frac{0.002}{deg} \cdot \begin{pmatrix} \beta_{st(i,2),r} \\ \alpha_{st(i,3),r} \end{pmatrix}$$

$$\begin{pmatrix} \theta_{rotor_{i,r}} \\ \theta_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \frac{\varepsilon_{rotor_{i,r}} - i_{rotor_{i,r}}}{1 - m_{rotor_{i,r}} \cdot \sqrt{\frac{t_{rotor_{i,r}}}{chord_{rotor_{i,r}}}}} \\ \frac{\varepsilon_{stator_{i,r}} - i_{stator_{i,r}}}{1 - m_{stator_{i,r}} \cdot \sqrt{\frac{t_{stator_{i,r}}}{chord_{stator_{i,r}}}}} \end{pmatrix}$$

$$\begin{pmatrix} \delta_{rotor_{i,r}} \\ \delta_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} m_{rotor_{i,r}} \cdot \theta_{rotor_{i,r}} \cdot \sqrt{\frac{t_{rotor_{i,r}}}{chord_{rotor_{i,r}}}} \\ m_{stator_{i,r}} \cdot \theta_{stator_{i,r}} \cdot \sqrt{\frac{t_{stator_{i,r}}}{chord_{stator_{i,r}}}} \end{pmatrix}$$

$$\begin{pmatrix} \chi_{rotor_{i,r}} \\ \chi_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \theta_{rotor_{i,r}} \\ \theta_{stator_{i,r}} \end{pmatrix} \cdot \frac{1 + 2 \cdot \left(1 - 2 \cdot \overline{x}_f\right)}{2}$$

$$\begin{pmatrix} \upsilon_{rotor_{i,r}} \\ \upsilon_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \chi_{rotor_{i,r}} + \beta_{st(i,1),r} + i_{rotor_{i,r}} \\ \chi_{stator_{i,r}} + \alpha_{st(i,2),r} + i_{stator_{i,r}} \end{pmatrix}$$

$$\begin{pmatrix} chord_{rotor_{i,r}} \end{pmatrix}$$

$$\begin{pmatrix} R_{СЛ.rotor_{i,r}} \\ R_{СЛ.stator_{i,r}} \end{pmatrix} = \frac{1}{2}\cdot\begin{pmatrix} \frac{chord_{rotor_{i,r}}}{\sin\left(0.5\cdot\theta_{rotor_{i,r}}\right)} \\ \frac{chord_{stator_{i,r}}}{\sin\left(0.5\cdot\theta_{stator_{i,r}}\right)} \end{pmatrix}$$

$$\begin{pmatrix} K_{rotor_{i,r}} \\ K_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \frac{c_{a_{st(i,2),r}}}{c_{a_{st(i,1),r}}} \\ \frac{c_{a_{st(i,3),r}}}{c_{a_{st(i,2),r}}} \end{pmatrix}$$

$$\begin{pmatrix} D_{rotor_{i,r}} \\ D_{stator_{i,r}} \end{pmatrix} = \begin{bmatrix} \left(1 - K_{rotor_{i,r}}\cdot\frac{\sin\left(\beta_{st(i,1),r}\right)}{\sin\left(\left|\beta_{st(i,2),r}\right|\right)}\right) + \left(\frac{1}{\tan\left(\beta_{st(i,1),r}\right)} - K_{rotor_{i,r}}\cdot\frac{1}{\tan\left(\beta_{st(i,2),r}\right)}\right)\cdot\frac{\sin\left(\beta_{st(i,1),r}\right)}{2\cdot\frac{chord_{rotor_{i,r}}}{t_{rotor_{i,r}}}} \\ \left(1 - K_{stator_{i,r}}\cdot\frac{\sin\left(\alpha_{st(i,2),r}\right)}{\sin\left(\alpha_{st(i,3),r}\right)}\right) + \left(\frac{1}{\tan\left(\alpha_{st(i,2),r}\right)} - K_{stator_{i,r}}\cdot\frac{1}{\tan\left(\alpha_{st(i,3),r}\right)}\right)\cdot\frac{\sin\left(\alpha_{st(i,2),r}\right)}{2\cdot\frac{chord_{stator_{i,r}}}{t_{stator_{i,r}}}} \end{bmatrix}$$

$$\begin{pmatrix} \zeta_{rotor_{i,r}} \\ \zeta_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \frac{\zeta\bullet\sin(\beta3)/(2b/t)\left(D_{rotor_{i,r}}\right)\cdot 2\cdot\frac{chord_{rotor_{i,r}}}{t_{rotor_{i,r}}}}{\sin\left(\beta_{st(i,2),r}\right)} \\ \frac{\zeta\bullet\sin(\beta3)/(2b/t)\left(D_{stator_{i,r}}\right)\cdot 2\cdot\frac{chord_{stator_{i,r}}}{t_{stator_{i,r}}}}{\sin\left(\alpha_{st(i,3),r}\right)} \end{pmatrix}$$

$$\begin{pmatrix} \beta cp_{i,r} \\ \alpha cp_{i,r} \end{pmatrix} = \begin{pmatrix} \operatorname{atan}\left(\frac{c_{a_{st(i,1),r}}}{\operatorname{mean}\left(w_{u_{st(i,1),r}}, w_{u_{st(i,2),r}}\right)}\right) \\ \operatorname{atan}\left(\frac{c_{a_{st(i,2),r}}}{\operatorname{mean}\left(c_{u_{st(i,2),r}}, c_{u_{st(i,3),r}}\right)}\right) \end{pmatrix}$$

$$\begin{pmatrix} quality_{rotor_{i,r}} \\ quality_{stator_{i,r}} \end{pmatrix} = \begin{bmatrix} \frac{2}{\zeta_{rotor_{i,r}}}\cdot\left(\frac{1}{\tan\left(\beta_{st(i,1),r}\right)} - \frac{1}{\tan\left(\beta_{st(i,2),r}\right)}\right)\cdot\left(\frac{\sin\left(\beta_{st(i,1),r}\right)}{\sin\left(\beta cp_{i,r}\right)}\right)^2 - \frac{1}{\tan\left(\beta cp_{i,r}\right)} \\ \frac{2}{\zeta_{stator_{i,r}}}\cdot\left(\frac{1}{\tan\left(\alpha_{st(i,2),r}\right)} - \frac{1}{\tan\left(\alpha_{st(i,3),r}\right)}\right)\cdot\left(\frac{\sin\left(\alpha_{st(i,2),r}\right)}{\sin\left(\alpha cp_{i,r}\right)}\right)^2 - \frac{1}{\tan\left(\alpha cp_{i,r}\right)} \end{bmatrix}$$

$$\begin{bmatrix} \left(\frac{c_{a_{st(i,1),r}}}{u_{st(i,1),r}}\right)^2 + \left(R_{L_{i,r}}\right)^2 & \left(\frac{c_{a_{st(i,2),r}}}{u_{st(i,2),r}}\right)^2 + \left(1 - R_{L_{i,r}}\right)^2 \end{bmatrix}$$

$$\eta_{stage_{i,r}} = 1 - \left[\frac{\left(c_{a_{st(i,1),r}} \cdot \frac{c_{a_{st(i,1),r}}}{u_{st(i,1),r}} + R_{L_{i,r}} \right)}{quality_{rotor_{i,r}}} + \frac{\left(c_{a_{st(i,2),r}} \cdot \frac{c_{a_{st(i,2),r}}}{u_{st(i,2),r}} + \left(1 - R_{L_{i,r}}\right) \right)}{quality_{stator_{i,r}}} \right]$$

$$\begin{pmatrix} \varepsilon_{PK(b/t)=1} & Z_{rotor} & r\_inlet_{rotor} & r\_outlet_{rotor} & t_{rotor} & i_{rotor} & m_{rotor} & \theta_{rotor} & \delta_{rotor} & \chi_{rotor} & \upsilon_{rotor} & R_{СЛ.rotor} & K_{rotor} & D_{rotor} & \zeta_{rotor} & quality_{rotor} & \eta_{stage} \\ \varepsilon_{HA(b/t)=1} & Z_{stator} & r\_inlet_{stator} & r\_outlet_{stator} & t_{stator} & i_{stator} & m_{stator} & \theta_{stator} & \delta_{stator} & \chi_{stator} & \upsilon_{stator} & R_{СЛ.stator} & K_{stator} & D_{stator} & \zeta_{stator} & quality_{stator} & \eta_{stage} \end{pmatrix}^{T}$$

$$
\begin{pmatrix} \varepsilon_{CA(b/t)=1} \\ Z_{CA} \\ r\_inlet_{CA} \\ r\_outlet_{CA} \\ t_{CA} \\ i_{CA} \\ m_{CA} \\ \theta_{CA} \\ \delta_{CA} \\ \chi_{CA} \\ \upsilon_{CA} \\ R_{СЛ.CA} \\ K_{CA} \\ D_{CA} \end{pmatrix} =
$$

if $CA = 1$

for $r \in av(N_r)$

$\varepsilon_{CA(b/t)=1_r} = \varepsilon_{(b/t)=1}(\alpha_{3CA_r})$

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

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

$Z_{CA} = \begin{cases} round\left(\frac{\pi \cdot D_{st(Z,3),r}}{t_{CA_r}}\right) & \text{if } mod\left(round\left(\frac{\pi \cdot D_{st(Z,3),r}}{t_{CA_r}}\right), 2\right) = 0 \\ round\left(\frac{\pi \cdot D_{st(Z,3),r}}{t_{CA_r}}\right) + 1 & \text{otherwise} \end{cases}$

for $r \in 1 .. N_r$

$\left(r\_inlet_{CA_r} \quad r\_outlet_{CA_r}\right) = chord_{CA_r} \cdot \left(\overline{r}\_inlet_{CA_r} \quad \overline{r}\_outlet_{CA_r}\right)$

$t_{CA_r} = \frac{D_{st(Z,3),r}}{Z_{CA}}$

$i_{CA_r} = 2.5 \cdot \left(\frac{chord_{CA_r}}{t_{CA_r}} - 2\right) \cdot °$

$m_{CA_r} = 0.23 \cdot \left(2 \cdot \overline{x}_f\right)^2 + 0.18 - \frac{0.002}{deg} \cdot \left(\alpha_{3CA_r}\right)$

$\theta_{CA_r} = \frac{\varepsilon_{CA_r} - i_{CA_r}}{1 - m_{CA_r} \cdot \sqrt{\frac{t_{CA_r}}{chord_{CA_r}}}}$

$$\delta_{CA_r} = m_{CA_r} \cdot \theta_{CA_r} \cdot \sqrt{\frac{t_{CA_r}}{chord_{CA_r}}}$$

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

$$\upsilon_{CA_r} = \chi_{CA_r} + \alpha_{1CA_r} + i_{CA_r}$$

$$R_{СЛ.CA_r} = \frac{chord_{CA_r}}{2 \cdot \sin\left(0.5 \cdot \theta_{CA_r}\right)}$$

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

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

$$\left(\varepsilon_{CA(b/t)=1} \; Z_{CA} \; r\_inlet_{CA} \; r\_outlet_{CA} \; t_{CA} \; i_{CA} \; m_{CA} \; \theta_{CA} \; \delta_{CA} \; \chi_{CA} \; \upsilon_{CA} \; R_{СЛ.CA} \; K_{CA} \; D_{CA}\right)^T$$

Определение количества Л РК и НА

Результаты расчета количества Л и параметров решеток РК и НА

$\text{chord}_{BHA} =$

	1
1	26.42
2	29.35
3	31.71

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	54.30	48.94	43.38	39.63	36.89	34.80	33.42	32.84	32.50						
2	63.23	56.88	50.34	45.95	42.75	40.30	38.68	38.00	37.59						
3	70.59	63.63	56.39	51.52	47.96	45.24	43.45	42.69	42.25						

$\cdot 10^{-3}$

Длина хорды Л (м):

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	22.57	22.38	21.37	20.71	20.64	21.02	22.16	24.19	26.45						
2	25.05	24.80	23.66	22.92	22.82	23.24	24.49	26.72	29.22						
3	27.09	26.86	25.64	24.86	24.77	25.23	26.59	29.02	31.75						

$\cdot 10^{-3}$

$\text{chord}_{CA} =$

	1
1	25.80
2	28.65
3	30.96

$\cdot 10^{-3}$

$\text{r\_inlet}_{BHA} =$

	1
1	0.16
2	0.35
3	0.57

$\cdot 10^{-3}$

$\text{r\_outlet}_{BHA} =$

	1
1	0.08
2	0.18
3	0.29

$\cdot 10^{-3}$

Радисы входных и выходных кромок профилей Л (мм):

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

	1	2	3	4	5	6	7	8	9
1	0.61	0.55	0.49	0.44	0.41	0.39	0.37	0.37	0.36
2	0.23	0.21	0.18	0.17	0.15	0.15	0.14	0.14	0.14
3	0.14	0.13	0.11	0.10	0.10	0.09	0.09	0.09	0.08

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	0.30	0.27	0.24	0.22	0.21	0.19	0.19	0.18	0.18
2	0.11	0.10	0.09	0.08	0.08	0.07	0.07	0.07	0.07
3	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.08
2	0.15	0.15	0.14	0.14	0.14	0.14	0.15	0.16	0.18
3	0.24	0.24	0.23	0.22	0.22	0.23	0.24	0.26	0.29

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04
2	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.09
3	0.12	0.12	0.12	0.11	0.11	0.11	0.12	0.13	0.14

$\cdot 10^{-3}$

$\text{r\_inlet}_{CA} =$

	1
1	0.15
2	0.34
3	0.56

$\cdot 10^{-3}$

$\text{r\_outlet}_{CA} =$

	1
1	0.08
2	0.17
3	0.28

$\cdot 10^{-3}$

$\varepsilon_{BHA(b/t)=1_{av(N_r)}} = 23.47 \cdot °$

$submatrix\left(\varepsilon_{PK(b/t)=1}, 1, Z, av(N_r), av(N_r)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7.41	7.26	7.19	6.95	6.76	6.52	6.16	5.91	5.78						

$\cdot °$

Угол поворота потока:

$submatrix\left(\varepsilon_{HA(b/t)=1}, 1, Z, av(N_r), av(N_r)\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	24.31	24.97	24.80	24.99	24.35	21.16	18.75	16.73	16.93						

$\cdot °$

$\varepsilon_{CA(b/t)=1_{av(N_r)}} = 33.67 \cdot °$

$\frac{chord_{BHA}}{t_{BHA}} =$

	1
1	3.429
2	2.924
3	2.661

$\left(\frac{chord_{rotor}}{t_{rotor}}\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2.068	2.353	2.810	2.827	2.813	2.653	1.891	1.427	1.306						
2	1.875	2.236	2.757	2.825	2.851	2.720	1.955	1.485	1.365						
3	1.773	2.167	2.724	2.824	2.879	2.769	2.003	1.528	1.410						

Густота решетки:

$\left(\frac{chord_{stator}}{t_{stator}}\right)^T =$

	1	2	3	4	5	6	7	8	9
1	2.765	3.185	4.661	4.620	5.551	9.240	7.776	7.179	5.249
2	2.453	2.941	4.406	4.439	5.403	9.087	7.703	7.147	5.260
3	2.273	2.788	4.237	4.314	5.298	8.974	7.648	7.122	5.268

$\frac{chord_{CA}}{t_{CA}} =$

	1
1	3.455
2	3.488
3	3.479

$Z_{BHA} = 46$

$Z_{rotor}^T =$

	1	2	3	4	5	6	7	8	9
1	43	57	79	87	93	93	69	53	49

Количество Л:

$Z_{stator}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	142	172	266	272	328	536	428	362	242						

Значения округляются до целого в большую сторону так, чтобы при разъемном корпусе количество Л НА было четным, а количества Л РК и НА были взаимно простыми

$Z_{CA} = 52$

$$t_{BHA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 7.71 \\ \hline 2 & 10.04 \\ \hline 3 & 11.92 \\ \hline \end{array} \cdot 10^{-3}$$

$$t_{rotor}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 26.26 & 20.80 & 15.44 & 14.02 & 13.11 & 13.11 & 17.68 & 23.01 & 24.89 & & & & & & \\ \hline 2 & 33.73 & 25.44 & 18.26 & 16.27 & 14.99 & 14.81 & 19.78 & 25.60 & 27.54 & & & & & & \\ \hline 3 & 39.81 & 29.36 & 20.70 & 18.24 & 16.66 & 16.34 & 21.69 & 27.94 & 29.95 & & & & & & \\ \hline \end{array} \cdot 10^{-3}$$

Шаг решетки (м):

$$t_{stator}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 8.16 & 7.03 & 4.59 & 4.48 & 3.72 & 2.28 & 2.85 & 3.37 & 5.04 & & & & & & \\ \hline 2 & 10.21 & 8.43 & 5.37 & 5.16 & 4.22 & 2.56 & 3.18 & 3.74 & 5.56 & & & & & & \\ \hline 3 & 11.91 & 9.63 & 6.05 & 5.76 & 4.68 & 2.81 & 3.48 & 4.08 & 6.03 & & & & & & \\ \hline \end{array} \cdot 10^{-3}$$

$$t_{CA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 7.47 \\ \hline 2 & 8.21 \\ \hline 3 & 8.90 \\ \hline \end{array} \cdot 10^{-3}$$

$$i_{BHA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 3.572 \\ \hline 2 & 2.311 \\ \hline 3 & 1.652 \\ \hline \end{array} \cdot^{\circ}$$

$$i_{rotor}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 2.669 & 3.383 & 4.524 & 4.567 & 4.533 & 4.133 & 2.227 & 1.067 & 0.764 & & & & & & \\ \hline 2 & 2.187 & 3.089 & 4.392 & 4.561 & 4.628 & 4.301 & 2.388 & 1.211 & 0.913 & & & & & & \\ \hline 3 & 1.932 & 2.918 & 4.309 & 4.560 & 4.697 & 4.423 & 2.508 & 1.319 & 1.026 & & & & & & \\ \hline \end{array} \cdot^{\circ}$$

Угол атаки:

$$i_{stator}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 1.913 & 2.964 & 6.651 & 6.549 & 8.876 & 18.099 & 14.440 & 12.946 & 8.122 & & & & & & \\ \hline 2 & 1.132 & 2.354 & 6.015 & 6.098 & 8.508 & 17.717 & 14.258 & 12.866 & 8.150 & & & & & & \\ \hline 3 & 0.684 & 1.970 & 5.593 & 5.785 & 8.244 & 17.436 & 14.121 & 12.805 & 8.170 & & & & & & \\ \hline \end{array} \cdot^{\circ}$$

$$i_{CA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 3.639 \\ \hline 2 & 3.721 \\ \hline 3 & 3.698 \\ \hline \end{array} \cdot^{\circ}$$

Коэф. формы ср. линии профиля:

$m_{BHA} =$

	1
1	0.2766
2	0.2752
3	0.2737

$m_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.2945	0.3105	0.3187	0.3278	0.3341	0.3409	0.3503	0.3568	0.3606						
2	0.3549	0.3564	0.3570	0.3593	0.3612	0.3637	0.3679	0.3713	0.3731						
3	0.3736	0.3711	0.3708	0.3718	0.3726	0.3740	0.3765	0.3787	0.3798						

$m_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.2801	0.2757	0.2757	0.2741	0.2766	0.2901	0.3003	0.3083	0.3071						
2	0.2717	0.2690	0.2697	0.2689	0.2716	0.2846	0.2946	0.3026	0.3018						
3	0.2666	0.2646	0.2656	0.2652	0.2680	0.2803	0.2901	0.2980	0.2975						

$m_{CA} =$

	1
1	0.2300
2	0.2300
3	0.2300

Угол изгиба ср. линии профиля:

$\theta_{BHA} =$

	1
1	23.18
2	24.19
3	24.29

$.^{\circ}$

$\theta_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	39.28	32.14	28.11	24.32	22.12	19.83	17.98	16.92	15.87						
2	10.88	10.02	9.07	8.37	8.10	7.80	8.50	8.92	8.95						
3	3.10	3.88	2.96	2.69	2.67	2.79	4.27	5.19	5.56						

$.^{\circ}$

$\theta_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	43.86	46.01	46.85	47.17	45.55	33.17	29.23	25.11	28.60						
2	43.71	46.09	46.93	47.31	45.70	33.59	30.02	26.09	29.42						
3	43.53	45.50	46.44	46.95	45.44	33.62	30.39	26.68	29.93						

$.^{\circ}$

$\theta_{CA} =$

	1
1	39.82
2	36.69
3	34.27

$.^{\circ}$

$$\delta_{BHA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 3.462 \\ \hline 2 & 3.893 \\ \hline 3 & 4.076 \\ \hline \end{array} .^{\circ}$$

$$\delta_{rotor}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 8.044 & 6.504 & 5.345 & 4.741 & 4.406 & 4.150 & 4.580 & 5.052 & 5.008 \\ \hline 2 & 2.820 & 2.387 & 1.950 & 1.789 & 1.732 & 1.721 & 2.238 & 2.719 & 2.858 \\ \hline 3 & 0.868 & 0.979 & 0.666 & 0.595 & 0.586 & 0.628 & 1.136 & 1.589 & 1.778 \\ \hline \end{array} .^{\circ}$$

Угол отставания:

$$\delta_{stator}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 7.387 & 7.106 & 5.982 & 6.016 & 5.347 & 3.165 & 3.149 & 2.889 & 3.833 \\ \hline 2 & 7.584 & 7.228 & 6.031 & 6.038 & 5.339 & 3.171 & 3.187 & 2.953 & 3.871 \\ \hline 3 & 7.696 & 7.210 & 5.993 & 5.995 & 5.290 & 3.146 & 3.188 & 2.979 & 3.880 \\ \hline \end{array} .^{\circ}$$

$$\delta_{CA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 4.926 \\ \hline 2 & 4.519 \\ \hline 3 & 4.226 \\ \hline \end{array} .^{\circ}$$

$$\upsilon_{BHA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 105.16 \\ \hline 2 & 104.40 \\ \hline 3 & 103.80 \\ \hline \end{array} .^{\circ}$$

$$\upsilon_{rotor}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 46.18 & 40.19 & 36.93 & 33.69 & 31.29 & 28.76 & 25.45 & 23.22 & 21.79 \\ \hline 2 & 24.91 & 24.20 & 23.93 & 22.96 & 22.09 & 20.95 & 19.03 & 17.63 & 16.85 \\ \hline 3 & 17.54 & 18.46 & 18.79 & 18.37 & 17.93 & 17.23 & 15.75 & 14.65 & 14.11 \\ \hline \end{array} .^{\circ}$$

Угол установки Л:

$$\upsilon_{stator}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 51.10 & 48.54 & 51.21 & 50.58 & 51.21 & 53.57 & 47.96 & 44.15 & 41.01 \\ \hline 2 & 51.93 & 52.14 & 54.02 & 53.11 & 53.43 & 55.63 & 50.24 & 46.49 & 43.27 \\ \hline 3 & 52.74 & 54.77 & 56.15 & 55.09 & 55.20 & 57.30 & 52.10 & 48.43 & 45.17 \\ \hline \end{array} .^{\circ}$$

$$\upsilon_{CA} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 75.02 \\ \hline 2 & 76.17 \\ \hline 3 & 77.09 \\ \hline \end{array} .^{\circ}$$

$$R_{СЛ.ВНА} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 65.77 \\ \hline 2 & 70.03 \\ \hline 3 & 75.35 \\ \hline \end{array} \cdot 10^{-3}$$

$$R_{СЛ.rotor}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 80.77 & 88.42 & 89.30 & 94.08 & 96.17 & 101.05 & 106.93 & 111.63 & 117.69 & & & & & & \\ \hline 2 & 333.47 & 325.78 & 318.31 & 314.82 & 302.80 & 296.09 & 260.85 & 244.20 & 240.89 & & & & & & \\ \hline 3 & 1306.64 & 939.04 & 1090.02 & 1098.07 & 1030.28 & 927.48 & 583.29 & 471.73 & 435.47 & & & & & & \\ \hline \end{array} \cdot 10^{-3}$$

Радиус дуги ср. линии (м):

$$R_{СЛ.stator}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 30.22 & 28.63 & 26.88 & 25.89 & 26.66 & 36.83 & 43.90 & 55.64 & 53.55 & & & & & & \\ \hline 2 & 33.64 & 31.68 & 29.70 & 28.56 & 29.39 & 40.21 & 47.27 & 59.20 & 57.54 & & & & & & \\ \hline 3 & 36.52 & 34.73 & 32.52 & 31.20 & 32.07 & 43.63 & 50.73 & 62.91 & 61.46 & & & & & & \\ \hline \end{array} \cdot 10^{-3}$$

$$R_{СЛ.СА} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 37.88 \\ \hline 2 & 45.51 \\ \hline 3 & 52.53 \\ \hline \end{array} \cdot 10^{-3}$$

$$K_{ВНА} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 1.0359 \\ \hline 2 & 1.0000 \\ \hline 3 & 0.9808 \\ \hline \end{array}$$

$$K_{rotor}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 1.0757 & 0.9750 & 0.9637 & 0.9661 & 0.9673 & 0.9684 & 0.9698 & 0.9702 & 0.9936 & & & & & & \\ \hline 2 & 0.9740 & 0.9704 & 0.9637 & 0.9661 & 0.9673 & 0.9684 & 0.9698 & 0.9702 & 0.9936 & & & & & & \\ \hline 3 & 0.9142 & 0.9680 & 0.9637 & 0.9661 & 0.9673 & 0.9684 & 0.9698 & 0.9702 & 0.9936 & & & & & & \\ \hline \end{array}$$

Фактор диффузорности решетки:

$$K_{stator}^{T} = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}\hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 0.8481 & 0.9644 & 0.9637 & 0.9659 & 0.9670 & 0.9680 & 0.9692 & 0.9695 & 0.9937 & & & & & & \\ \hline 2 & 0.9691 & 0.9701 & 0.9637 & 0.9659 & 0.9670 & 0.9680 & 0.9692 & 0.9695 & 0.9937 & & & & & & \\ \hline 3 & 1.0520 & 0.9732 & 0.9637 & 0.9659 & 0.9670 & 0.9680 & 0.9692 & 0.9695 & 0.9937 & & & & & & \\ \hline \end{array}$$

$$K_{СА} = \begin{array}{|c|c|}\hline & 1 \\ \hline 1 & 0.8302 \\ \hline 2 & 0.8302 \\ \hline 3 & 0.8302 \\ \hline \end{array}$$

$D_{BHA} =$

	1
1	-0.1928
2	-0.1544
3	-0.1308

$D_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.6404	0.6843	0.6917	0.6833	0.6858	0.6809	0.6676	0.6675	0.6475						
2	0.4805	0.4993	0.5256	0.5291	0.5407	0.5433	0.5321	0.5311	0.5192						
3	0.3730	0.3907	0.4212	0.4296	0.4446	0.4506	0.4416	0.4405	0.4337						

Диффузорность решетки:

$D_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.6991	0.7188	0.7073	0.7226	0.7200	0.6794	0.6625	0.6485	0.6615						
2	0.6401	0.6624	0.6613	0.6819	0.6842	0.6492	0.6360	0.6251	0.6375						
3	0.5925	0.6177	0.6231	0.6474	0.6533	0.6226	0.6124	0.6040	0.6160						

$D_{CA} =$

	1
1	0.4407
2	0.4115
3	0.3896

$D_{BHA} \le 0.6 =$

	1
1	1
2	1
3	1

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

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

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

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

$D_{CA} \le 0.6 =$

	1
1	1
2	1
3	1

$\zeta_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.1570	0.2300	0.3005	0.3197	0.3431	0.3452	0.2678	0.2245	0.2055						
2	0.1475	0.1929	0.2643	0.2859	0.3120	0.3159	0.2386	0.1955	0.1803						
3	0.1404	0.1716	0.2383	0.2608	0.2870	0.2925	0.2196	0.1781	0.1660						

Коэф. потерь полного давления:

$\zeta_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.2392	0.2892	0.4074	0.4223	0.5074	0.7833	0.6592	0.6117	0.4634						
2	0.1685	0.2162	0.3234	0.3485	0.4311	0.6770	0.5769	0.5405	0.4131						
3	0.1302	0.1734	0.2694	0.2979	0.3763	0.5990	0.5153	0.4864	0.3741						

$quality_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	9.264	6.101	4.625	4.403	4.163	4.256	6.054	7.639	8.907						
2	9.020	7.083	5.063	4.726	4.388	4.462	6.642	8.629	10.166						
3	6.616	7.281	5.146	4.751	4.386	4.445	6.787	8.970	10.690						

Качество профилей решеток РК и НА:

$quality_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	4.944	4.613	2.981	2.888	2.187	0.788	1.194	1.371	2.456						
2	7.583	6.028	3.825	3.565	2.693	1.147	1.545	1.706	2.807						
3	10.095	7.312	4.583	4.178	3.146	1.453	1.847	1.995	3.121						

КПД элементарной ступени: $\eta_{stage}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	73.97	67.95	57.82	56.04	50.83	37.74	48.01	52.64	61.06						
2	75.29	69.62	59.59	57.02	52.20	42.65	52.42	57.11	63.86						
3	67.36	67.58	58.02	55.32	51.02	43.70	53.56	58.57	64.53						

$\cdot\%$

Результаты расчета количества Л и параметров решеток РК и НА

Вывод параметров решеток

Подключение симметричного профиля

$EXCEL_{AIRFOIL.subsonic}$ = ...\A40.xlsx

$X/B_{subsonic} = submatrix(EXCEL_{AIRFOIL.subsonic}, 2, rows(EXCEL_{AIRFOIL.subsonic}), ORIGIN+0, ORIGIN+0)$

$Y/B_{subsonic} = submatrix(EXCEL_{AIRFOIL.subsonic}, 2, rows(EXCEL_{AIRFOIL.subsonic}), ORIGIN+1, ORIGIN+1)$

Предел использования дозвукового профиля: $M_{lim} = 0.95$

$EXCEL_{AIRFOIL.supersonic}$ = ...\Емин сверхзвуковой профиль.xlsx

$X/B_{supersonic} = submatrix(EXCEL_{AIRFOIL.supersonic}, 2, rows(EXCEL_{AIRFOIL.supersonic}), ORIGIN+0, ORIGIN+0)$

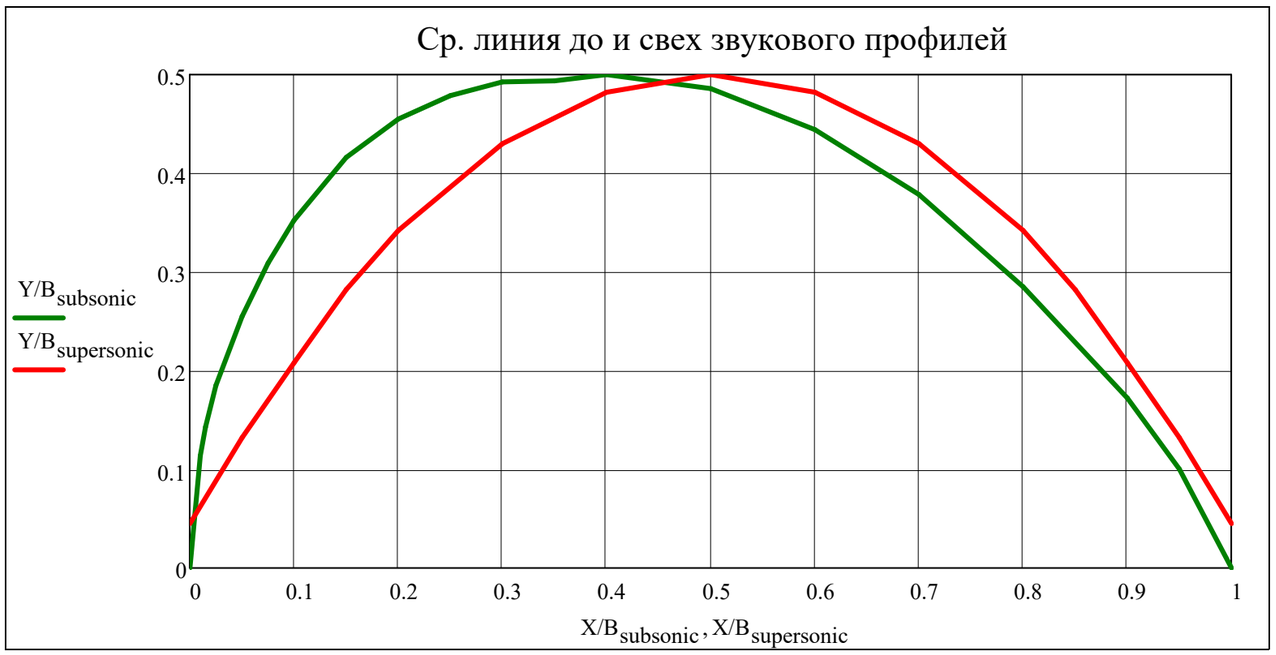
$Y/B_{supersonic} = submatrix(EXCEL_{AIRFOIL.supersonic}, 2, rows(EXCEL_{AIRFOIL.supersonic}), ORIGIN+1, ORIGIN+1)$

$augment(X/B_{subsonic}, Y/B_{subsonic})^T =$

	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

$augment(X/B_{supersonic}, Y/B_{supersonic})^T =$

	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

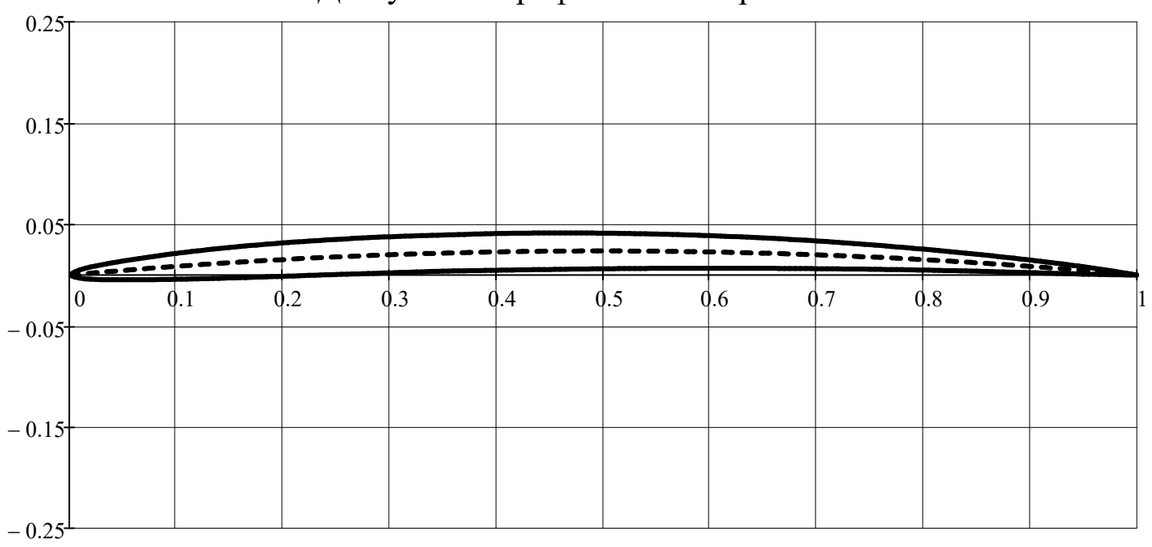


$$AIRFOIL_{subsonic}(x, line, \overline{c}, \theta) = \begin{cases} interp\left(cspline\left(X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right) + Y/B_{subsonic}\cdot\overline{c}\right), X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right) + Y/B_{subsonic}\cdot\overline{c}, x\right) & \text{if } line = "+" \\ interp\left(cspline\left(X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right)\right), X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right), x\right) & \text{if } line = "0" \\ interp\left(cspline\left(X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right) - Y/B_{subsonic}\cdot\overline{c}\right), X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right) - Y/B_{subsonic}\cdot\overline{c}, x\right) & \text{if } line = "-" \\ NaN & \text{otherwise} \end{cases}$$

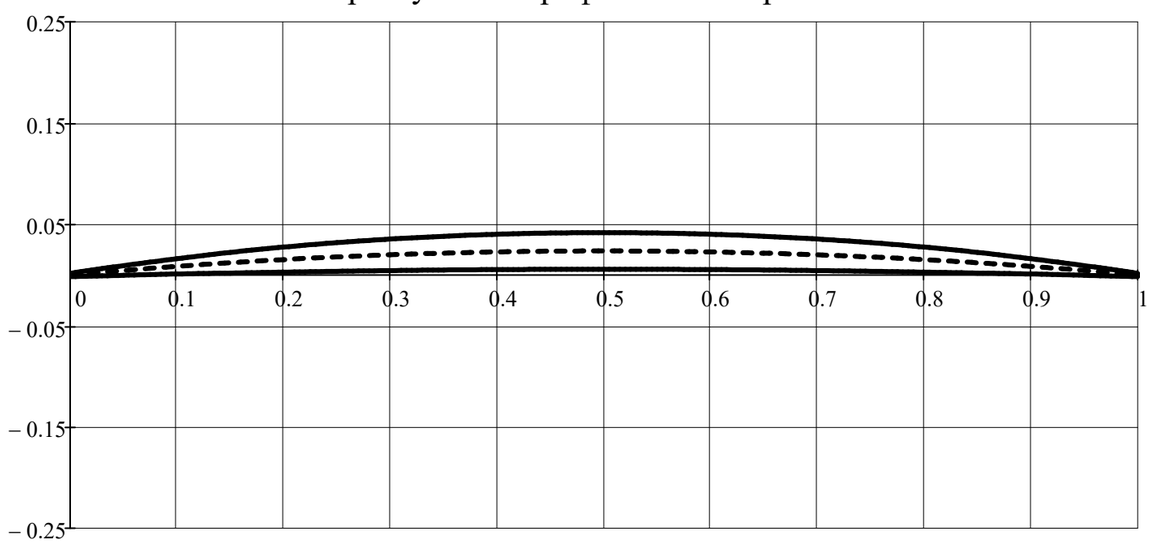
$$AIRFOIL_{supersonic}(x, line, \overline{c}, \theta) = \begin{cases} interp\left(cspline\left(X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic}, \theta\right) + Y/B_{supersonic}\cdot\overline{c}\right), X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic}, \theta\right) + Y/B_{supersonic}\cdot\overline{c}, x\right) & \text{if } line = "+" \\ interp\left(cspline\left(X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic}, \theta\right)\right), X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic}, \theta\right), x\right) & \text{if } line = "0" \\ interp\left(cspline\left(X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic}, \theta\right) - Y/B_{supersonic}\cdot\overline{c}\right), X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic}, \theta\right) - Y/B_{supersonic}\cdot\overline{c}, x\right) & \text{if } line = "-" \\ NaN & \text{otherwise} \end{cases}$$

$x = 0, 0.005 .. 1$ $j = 1$

Дозвуковой профиль РК на ср. сечении



Сверхзвуковой профиль РК на ср. сечении



Подключение симметричного профиля

Определение относительных геометрических характеристик сечений Л

Результат расчета абсолютных геометрических характеристик сечений Л

Определение абсолютных геометрических характеристик сечений Л

Результат расчета абсолютных геометрических характеристик сечений Л

$l\_upper_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	23.18	23.08	22.20	21.53	21.49	21.86	22.82	24.75	27.01
2	25.94	25.81	24.82	24.06	24.02	24.43	25.48	27.63	30.13
3	28.32	28.23	27.19	26.39	26.36	26.83	27.99	30.35	33.09

$\cdot 10^{-3}$

$l\_upper_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	57.05	51.08	45.18	41.12	38.19	35.93	34.35	33.67	33.28
2	63.57	57.20	50.64	46.22	42.99	40.51	38.86	38.15	37.74
3	70.65	63.73	56.50	51.62	48.06	45.32	43.52	42.75	42.31

$\cdot 10^{-3}$

$l\_lower_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	22.86	22.73	21.83	21.16	21.12	21.49	22.48	24.44	26.69
2	25.25	25.07	24.02	23.27	23.21	23.62	24.75	26.92	29.40
3	27.26	27.07	25.93	25.15	25.08	25.54	26.82	29.21	31.92

$\cdot 10^{-3}$

$l\_lower_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	54.63	49.22	43.62	39.86	37.11	35.02	33.67	33.11	32.78
2	63.27	56.92	50.38	45.99	42.78	40.32	38.71	38.03	37.62
3	70.59	63.64	56.40	51.53	47.97	45.25	43.46	42.70	42.25

$\cdot 10^{-3}$

$area_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	11.18	10.99	10.02	9.42	9.35	9.70	10.77	12.84	15.36
2	27.53	26.99	24.56	23.05	22.86	23.70	26.31	31.33	37.47
3	48.29	47.48	43.29	40.67	40.38	41.90	46.55	55.45	66.34

$\cdot 10^{-6}$

$area_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	241.50	196.22	154.13	128.65	111.50	99.19	91.49	88.34	86.51
2	105.86	85.66	67.10	55.91	48.38	42.99	39.62	38.23	37.42
3	69.81	59.22	46.51	38.82	33.65	29.93	27.61	26.66	26.11

$\cdot 10^{-6}$

$Sx_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	16.3	17.4	17.3	15.8	16.1	16.7	16.4	18.4	22.5
2	43.3	46.6	46.3	42.5	43.4	45.1	44.8	50.8	62.0
3	80.5	86.7	86.8	80.3	82.3	86.1	86.5	99.0	121.2

$\cdot 10^{-9}$

$Sx_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	747.9	467.3	305.7	205.9	153.0	114.2	79.7	62.5	54.5
2	114.2	87.0	64.8	47.7	37.9	30.0	22.1	17.9	16.4
3	35.0	36.5	28.8	22.2	18.2	14.9	11.3	9.3	8.8

$\cdot 10^{-9}$

$Sy_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	114.0	111.1	96.7	88.1	87.1	92.1	107.8	140.2	183.5
2	311.4	302.3	262.4	238.6	235.6	248.8	291.0	378.1	494.4
3	590.8	575.9	501.3	456.6	451.7	477.4	559.0	726.8	951.1

$\cdot 10^{-9}$

$Sy_{rotor}^{T} =$

	1	2	3	4	5	6	7	8
1	5922.2	4337.1	3019.5	2302.6	1857.8	1558.9	1380.9	1310.1
2	3023.0	2200.4	1525.6	1160.3	934.2	782.5	692.2	656.1
3	2464.0	1701.5	1184.6	903.4	728.9	611.6	541.8	...

$\cdot 10^{-9}$

$x0_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	10.19	10.11	9.65	9.36	9.32	9.50	10.01	10.92	11.95
2	11.31	11.20	10.68	10.35	10.31	10.50	11.06	12.07	13.20
3	12.23	12.13	11.58	11.23	11.19	11.39	12.01	13.11	14.34

$\cdot 10^{-3}$

$x0_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	24.52	22.10	19.59	17.90	16.66	15.72	15.09	14.83	14.68
2	28.56	25.69	22.74	20.75	19.31	18.20	17.47	17.16	16.98
3	35.29	28.73	25.47	23.27	21.66	20.43	19.62	19.28	19.08

$\cdot 10^{-3}$

$y0_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	1.46	1.59	1.73	1.68	1.72	1.72	1.52	1.43	1.46
2	1.57	1.73	1.89	1.85	1.90	1.90	1.70	1.62	1.66
3	1.67	1.83	2.00	1.97	2.04	2.06	1.86	1.79	1.83

$\cdot 10^{-3}$

$y0_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	3.10	2.38	1.98	1.60	1.37	1.15	0.87	0.71	0.63
2	1.08	1.02	0.97	0.85	0.78	0.70	0.56	0.47	0.44
3	0.50	0.62	0.62	0.57	0.54	0.50	0.41	0.35	0.34

$\cdot 10^{-3}$

$Jx_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	27	31	33	29	31	32	28	29	37
2	79	92	99	89	93	97	87	95	120
3	165	191	205	186	196	207	192	217	276

$\cdot 10^{-12}$

$Jx_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	3086	1581	887	516	346	236	154	121	107
2	169	119	82	54	40	29	18	14	12
3	27	31	23	16	13	10	6	5	4

$\cdot 10^{-12}$

$Jy_{stator}^{T} =$

	1	2	3	4	5	6	7	8
1	1486	1437	1194	1054	1039	1119	1381	1959
2	4507	4332	3587	3159	3107	3340	4117	5838
3	9246	8937	7428	6559	6464	6960	8589	...

$\cdot 10^{-12}$

$Jy_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	185803	122653	75683	52727	39605	31344	26667	24859	23840
2	110446	72318	44378	30808	23074	18218	15472	14406	13798
3	105911	62553	38598	26891	20199	15986	13600	12678	12159

$\cdot 10^{-12}$

$Jxy_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	173	183	173	154	156	165	170	209	279
2	509	543	514	457	465	492	515	637	851
3	1023	1093	1044	937	957	1020	1080	1349	1807

$\cdot 10^{-12}$

$Jxy_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	19065	10739	6227	3832	2650	1866	1251	964	831
2	3392	2324	1532	1029	760	567	401	320	290
3	1235	1091	764	536	410	316	230	187	175

$\cdot 10^{-12}$

$Jx0_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	2.64	2.98	3.12	2.77	2.88	2.99	2.70	2.98	3.81
2	10.43	11.45	11.41	10.19	10.50	11.04	10.84	12.93	17.07
3	30.53	32.24	30.74	27.60	28.28	30.11	31.78	40.23	54.59

$\cdot 10^{-12}$

$Jx0_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	769.58	467.90	280.92	186.70	136.53	104.68	84.86	77.08	73.11
2	46.01	30.88	19.78	13.46	10.00	7.64	5.95	5.24	4.93
3	9.56	8.08	5.38	3.77	2.87	2.23	1.73	1.51	1.43

$\cdot 10^{-12}$

$Jy0_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	325	314	261	230	227	244	301	428	612
2	984	946	783	690	679	729	899	1275	1823
3	2019	1952	1622	1432	1412	1520	1876	2662	3810

$\cdot 10^{-12}$

$Jy0_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	40578	26786	16528	11515	8649	6845	5824	5429	5207
2	24117	15792	9691	6727	5039	3978	3379	3146	3013
3	18949	13659	8428	5872	4411	3491	2970	2768	2655

$\cdot 10^{-12}$

$Jxy0_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	6.57	6.93	6.54	5.80	5.88	6.21	6.45	7.94	10.62
2	19.34	20.58	19.41	17.26	17.52	18.55	19.50	24.21	32.39
3	38.83	41.39	39.38	35.30	36.03	38.40	40.84	51.17	68.63

$\cdot 10^{-12}$

$Jxy0_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	724.29	408.89	237.27	146.44	101.33	71.41	47.91	36.95	31.86
2	130.09	89.09	58.72	39.46	29.15	21.74	15.39	12.28	11.11
3	0.00	41.85	29.31	20.56	15.74	12.11	8.82	7.16	6.72

$\cdot 10^{-12}$

$\alpha\_major_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	1.17	1.28	1.45	1.46	1.50	1.47	1.24	1.07	1.00
2	1.14	1.26	1.44	1.45	1.50	1.48	1.26	1.10	1.03
3	1.12	1.23	1.42	1.44	1.49	1.48	1.27	1.12	1.05

$\cdot^{\circ}$

$\alpha\_major_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	1.04	0.89	0.84	0.74	0.68	0.61	0.48	0.40	0.36
2	0.31	0.32	0.35	0.34	0.33	0.31	0.26	0.22	0.21
3	0.00	0.18	0.20	0.20	0.20	0.20	0.17	0.15	0.15

$\cdot^{\circ}$

$Ju_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	2.50	2.82	2.95	2.63	2.73	2.83	2.56	2.84	3.62
2	10.04	11.00	10.92	9.75	10.04	10.56	10.41	12.47	16.48
3	29.77	31.35	29.77	26.71	27.35	29.12	30.87	39.23	53.33

$\cdot 10^{-12}$

$Jv_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	325	314	261	230	227	244	302	428	613
2	985	946	784	690	679	730	899	1275	1823
3	2020	1953	1623	1433	1413	1521	1877	2663	3811

$\cdot 10^{-12}$

$Juv_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00
2	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	-0.00	0.00

$\cdot 10^{-12}$

$Jp_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	327	317	264	233	230	247	304	431	616
2	995	957	795	700	689	740	910	1288	1840
3	2050	1984	1653	1460	1440	1550	1908	2702	3864

$\cdot 10^{-12}$

$Wp_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	26.3	25.6	22.3	20.3	20.1	21.2	24.8	32.3	42.3
2	71.9	69.8	60.6	55.1	54.4	57.5	67.2	87.3	114.2
3	137.1	133.7	116.4	106.0	104.8	110.8	129.8	168.7	220.8

$\cdot 10^{-9}$

$Ju_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	756.40	461.54	277.45	184.80	135.33	103.92	84.46	76.82	72.91
2	45.31	30.38	19.43	13.23	9.83	7.52	5.88	5.19	4.89
3	9.56	7.95	5.28	3.70	2.81	2.18	1.70	1.49	1.41

$\cdot 10^{-12}$

$Jv_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	40591	26793	16532	11517	8651	6846	5824	5429	5207
2	24118	15792	9691	6727	5039	3978	3379	3146	3013
3	18949	13659	8429	5872	4411	3491	2970	2768	2655

$\cdot 10^{-12}$

$Juv_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	-0.00	-0.00	0.00	0.00	0.00
3	0.00	-0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00

$\cdot 10^{-12}$

$Jp_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	41348	27254	16809	11702	8786	6950	5909	5506	5280
2	24163	15822	9710	6741	5049	3986	3385	3151	3018
3	18958	13667	8434	5876	4414	3493	2971	2770	2656

$\cdot 10^{-12}$

$Wp_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	1381.2	1011.5	704.2	537.0	433.3	363.6	322.0	305.5	296.1
2	696.5	507.0	351.5	267.3	215.2	180.3	159.5	151.2	146.4
3	537.1	391.7	272.7	207.9	167.8	140.8	124.7	118.3	114.7

$\cdot 10^{-9}$

$stiffness_{stator}^{T} =$

	1	2	3	4	5	6	7	8
1	1.25	1.21	1.00	0.88	0.87	0.94	1.16	1.64
2	15.13	14.54	12.04	10.60	10.43	11.21	13.82	19.59
3	69.81	67.47	56.08	49.52	48.81	52.55	64.85	...

$\cdot 10^{-12}$

$stiffness_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	2172.53	1434.14	884.93	616.52	463.09	366.50	311.81	290.67	278.76
2	134.92	88.34	54.21	37.63	28.19	22.25	18.90	17.60	16.85
3	32.12	23.32	14.39	10.03	7.53	5.96	5.07	4.73	4.53

$\cdot 10$

$CPx_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	7.900	7.833	7.479	7.250	7.224	7.359	7.756	8.465	9.259
2	8.767	8.680	8.280	8.021	7.988	8.134	8.570	9.352	10.227
3	9.480	9.400	8.975	8.700	8.669	8.830	9.307	10.158	11.111

$\cdot 10^{-3}$

$CPx_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	19.004	17.130	15.182	13.871	12.913	12.179	11.697	11.494	11.374
2	22.131	19.908	17.620	16.083	14.962	14.104	13.540	13.300	13.157
3	24.705	22.269	19.737	18.032	16.787	15.833	15.206	14.942	14.786

$\cdot 10^{-3}$

$CPy_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

$\cdot 10^{-3}$

$CPy_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

$\cdot 10^{-3}$

Результат расчета абсолютных геометрических характеристик сечений Л

Вывод результатов расчета геометрических хар-к сечений Л

Профилирование решеток

Абс. координаты профиля:

$$\text{Airfoil}(\text{type}, x, \text{line}, i, r) = \begin{cases} \text{if type} = \text{"BHA"} \\ \quad \begin{cases} \text{AIRFOIL}_{\text{subsonic}}\left(x, \text{line}, \overline{c}_{\text{BHA}_r}, \varepsilon_{\text{BHA}_r}\right) & \text{if } M_{c_{st(1,1),r}} < M_{\text{lim}} \\ \text{AIRFOIL}_{\text{supersonic}}\left(x, \text{line}, \overline{c}_{\text{BHA}_r}, \varepsilon_{\text{BHA}_r}\right) & \text{otherwise} \end{cases} \\ \text{if type} = \text{"rotor"} \\ \quad \begin{cases} \text{AIRFOIL}_{\text{subsonic}}\left(x, \text{line}, \overline{c}_{\text{rotor}_{i,r}}, \varepsilon_{\text{rotor}_{i,r}}\right) & \text{if } M_{w_{st(i,1),r}} < M_{\text{lim}} \\ \text{AIRFOIL}_{\text{supersonic}}\left(x, \text{line}, \overline{c}_{\text{rotor}_{i,r}}, \varepsilon_{\text{rotor}_{i,r}}\right) & \text{otherwise} \end{cases} \\ \text{if type} = \text{"stator"} \\ \quad \begin{cases} \text{AIRFOIL}_{\text{subsonic}}\left(x, \text{line}, \overline{c}_{\text{stator}_{i,r}}, \varepsilon_{\text{stator}_{i,r}}\right) & \text{if } M_{c_{st(i,2),r}} < M_{\text{lim}} \\ \text{AIRFOIL}_{\text{supersonic}}\left(x, \text{line}, \overline{c}_{\text{stator}_{i,r}}, \varepsilon_{\text{stator}_{i,r}}\right) & \text{otherwise} \end{cases} \\ \text{if type} = \text{"CA"} \\ \quad \begin{cases} \text{AIRFOIL}_{\text{subsonic}}\left(x, \text{line}, \overline{c}_{\text{CA}_r}, \varepsilon_{\text{CA}_r}\right) & \text{if } M_{c_{st(Z,3),r}} < M_{\text{lim}} \\ \text{AIRFOIL}_{\text{supersonic}}\left(x, \text{line}, \overline{c}_{\text{CA}_r}, \varepsilon_{\text{CA}_r}\right) & \text{otherwise} \end{cases} \end{cases}$$

Профилирование решеток

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

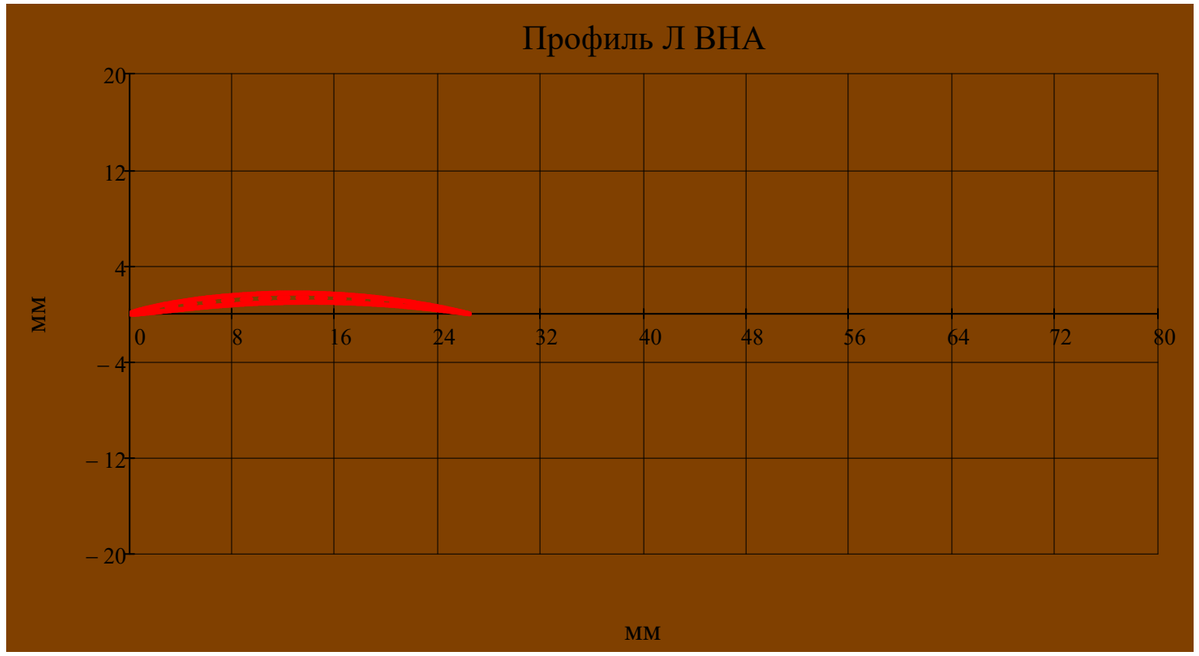
Построение профилей Л РК и НА

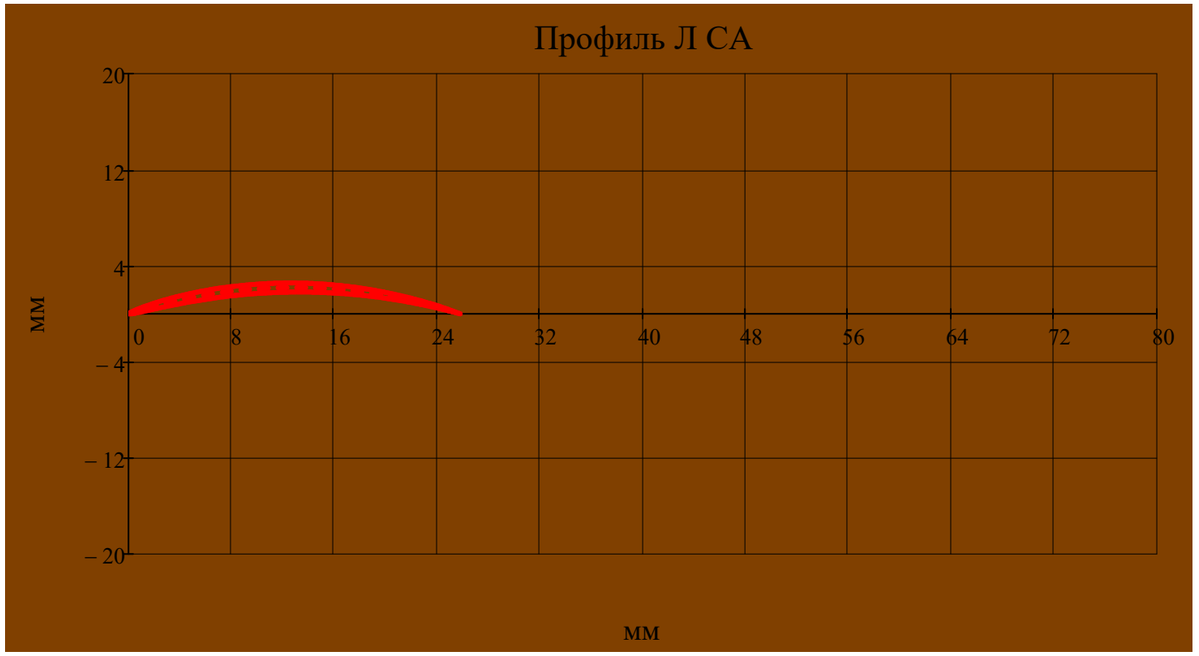
$$AXLE0(type, x, i, r) = \begin{cases} \dfrac{y0_{rotor_{i,r}}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}}\right) \cdot \left(x - \dfrac{x0_{rotor_{i,r}}}{chord_{rotor_{i,r}}}\right) & \text{if } type = \text{"rotor"} \\ \dfrac{y0_{stator_{i,r}}}{chord_{stator_{i,r}}} + \tan\left(\alpha\_major_{stator_{i,r}}\right) \cdot \left(x - \dfrac{x0_{stator_{i,r}}}{chord_{stator_{i,r}}}\right) & \text{if } type = \text{"stator"} \\ \text{NaN} & \text{otherwise} \end{cases}$$

$$AXLE90(type, x, i, r) = \begin{cases} \dfrac{y0_{rotor_{i,r}}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}} + \dfrac{\pi}{2}\right) \cdot \left(x - \dfrac{x0_{rotor_{i,r}}}{chord_{rotor_{i,r}}}\right) & \text{if } (type = \text{"rotor"}) \wedge \left|\alpha\_major_{rotor_{i,r}}\right| \geq 1 \cdot ° \\ \dfrac{y0_{stator_{i,r}}}{chord_{stator_{i,r}}} + \tan\left(\alpha\_major_{stator_{i,r}} + \dfrac{\pi}{2}\right) \cdot \left(x - \dfrac{x0_{stator_{i,r}}}{chord_{stator_{i,r}}}\right) & \text{if } (type = \text{"stator"}) \wedge \left|\alpha\_major_{stator_{i,r}}\right| \geq 1 \cdot ° \\ \text{NaN} & \text{otherwise} \end{cases}$$

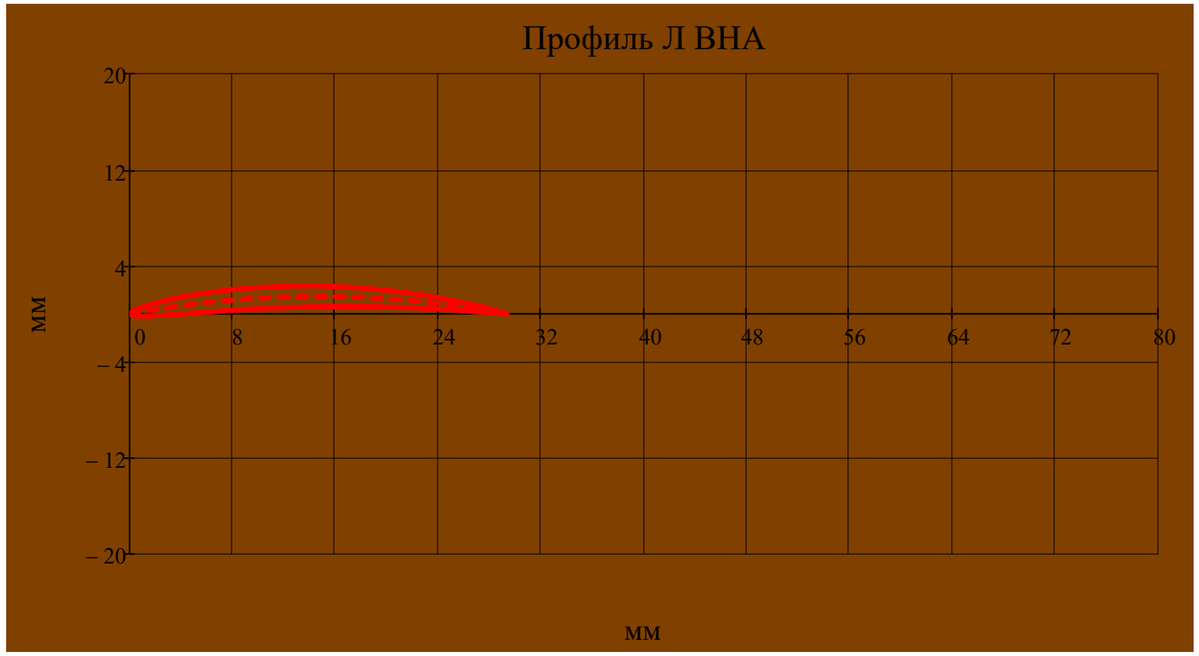
$$b_{lim} = \frac{ceil\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 80 \cdot 10^{-3}$$

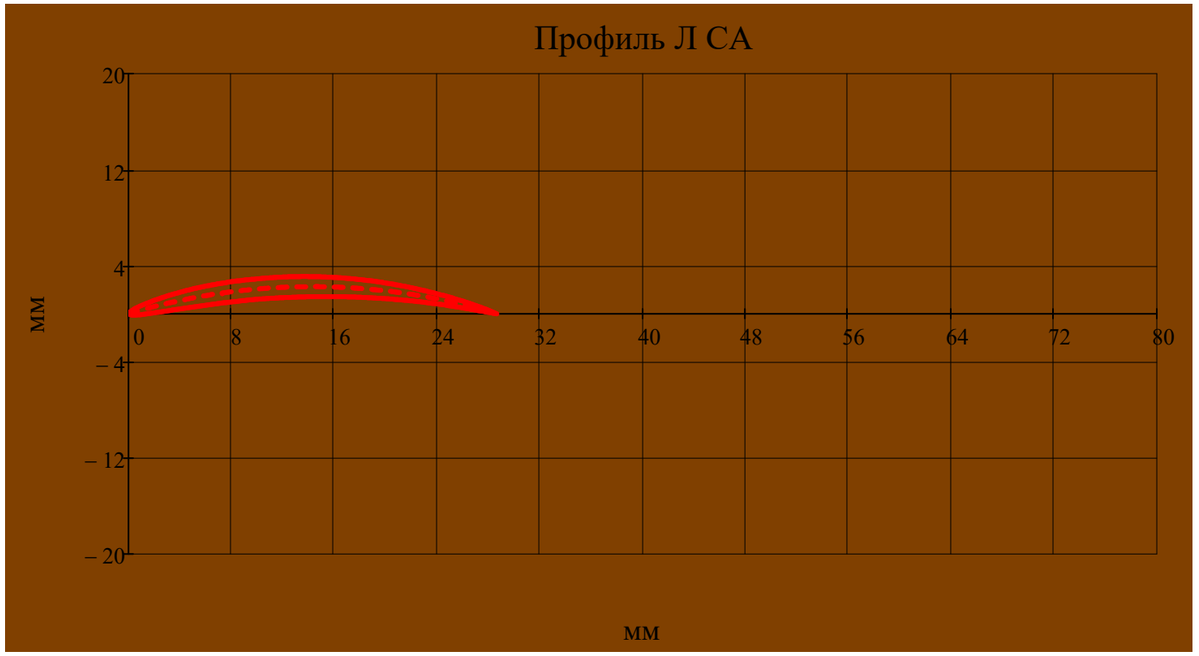
r = 1


Профиль Л ВНА
20
12
4
– 4
– 12
– 20
мм
0
8
16
24
32
40
48
56
64
72
80
мм

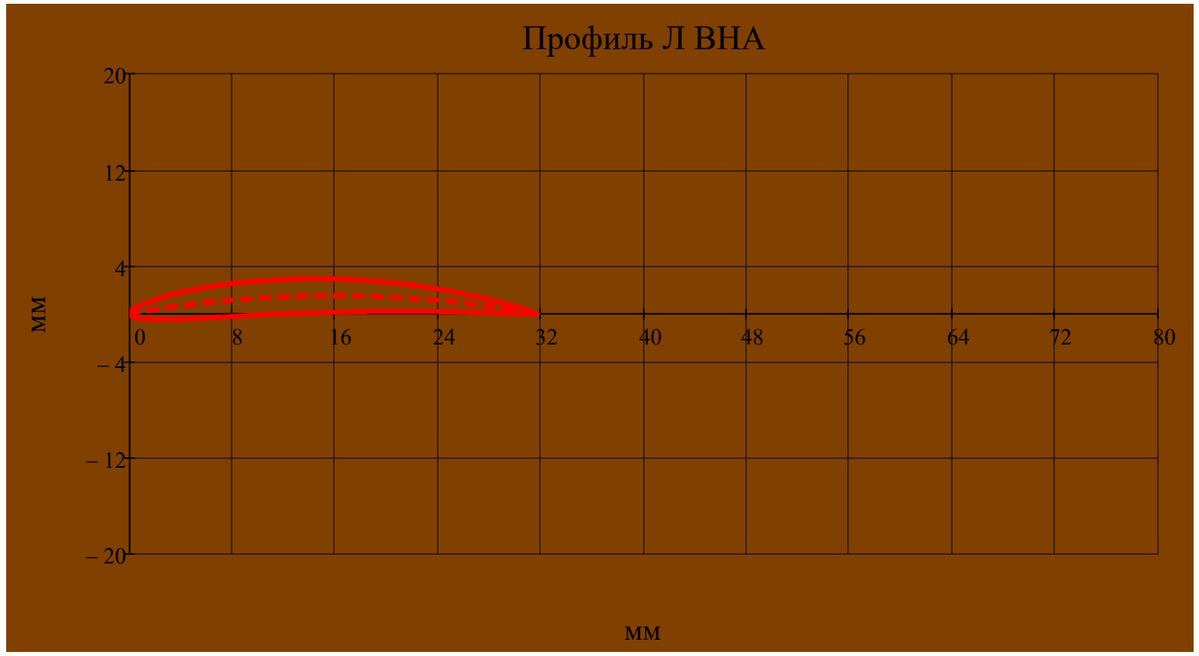

Профиль Л СА
20
12
4
– 4
– 12
– 20
мм
0
8
16
24
32
40
48
56
64
72
80
мм

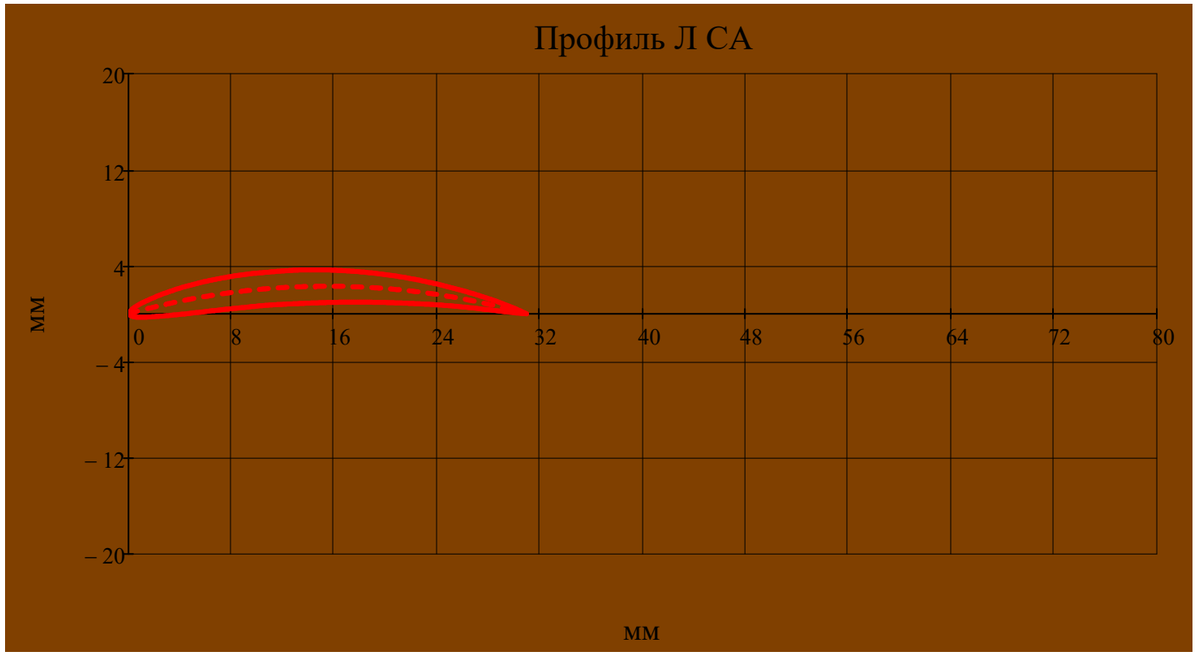
$\underset{\sim}{r} = av(N_r)$



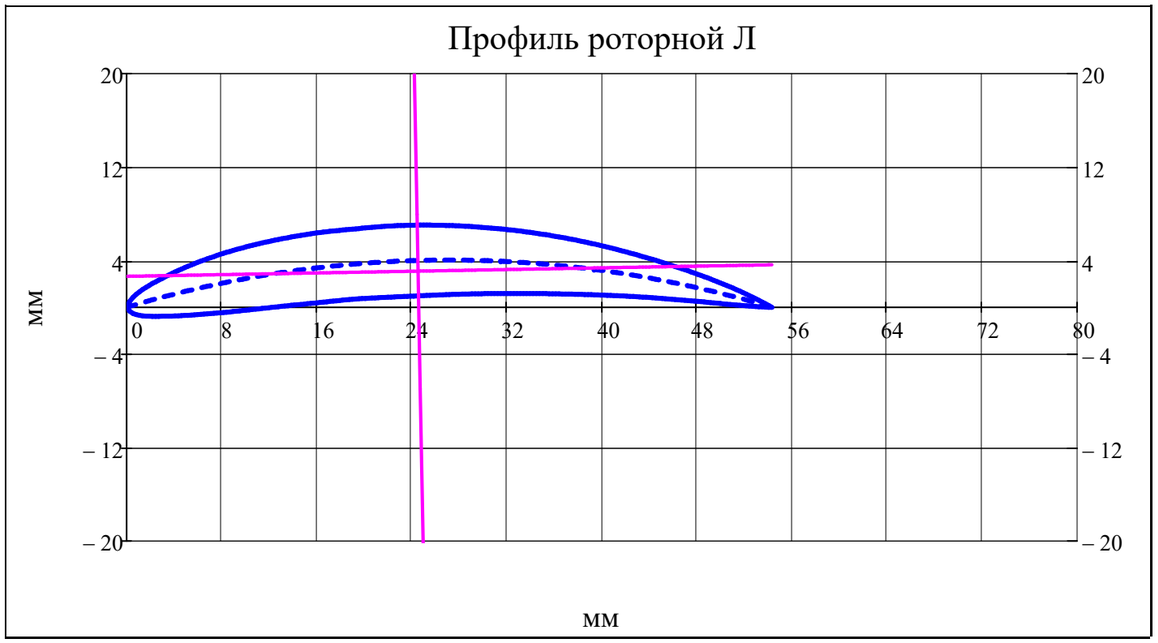


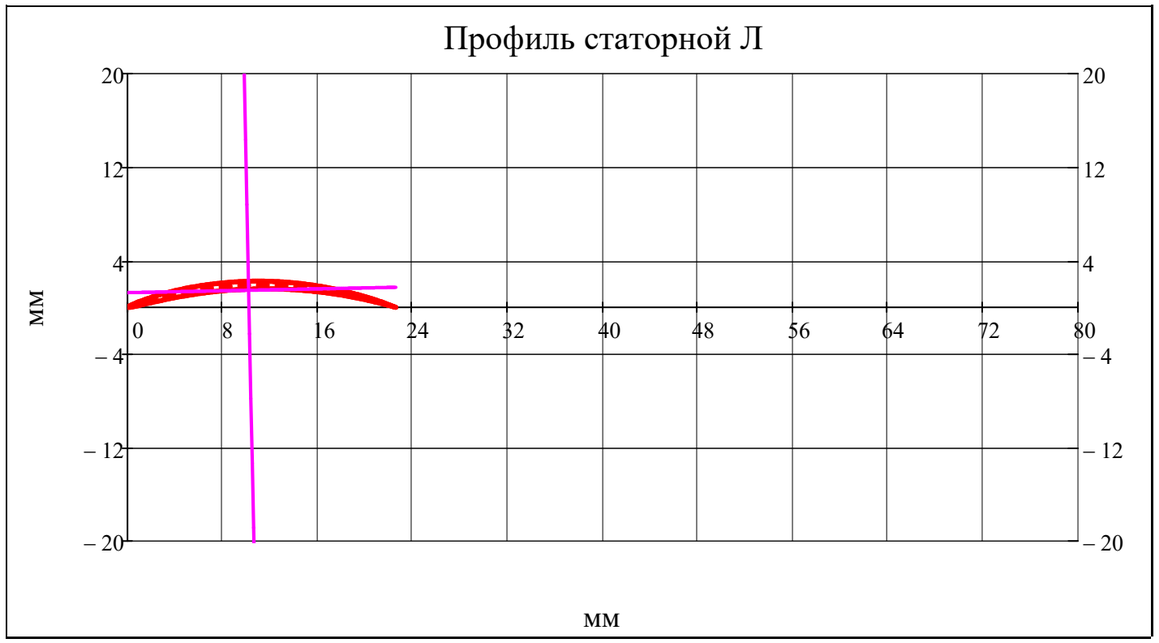
$\underset{\sim}{r} = N_r$



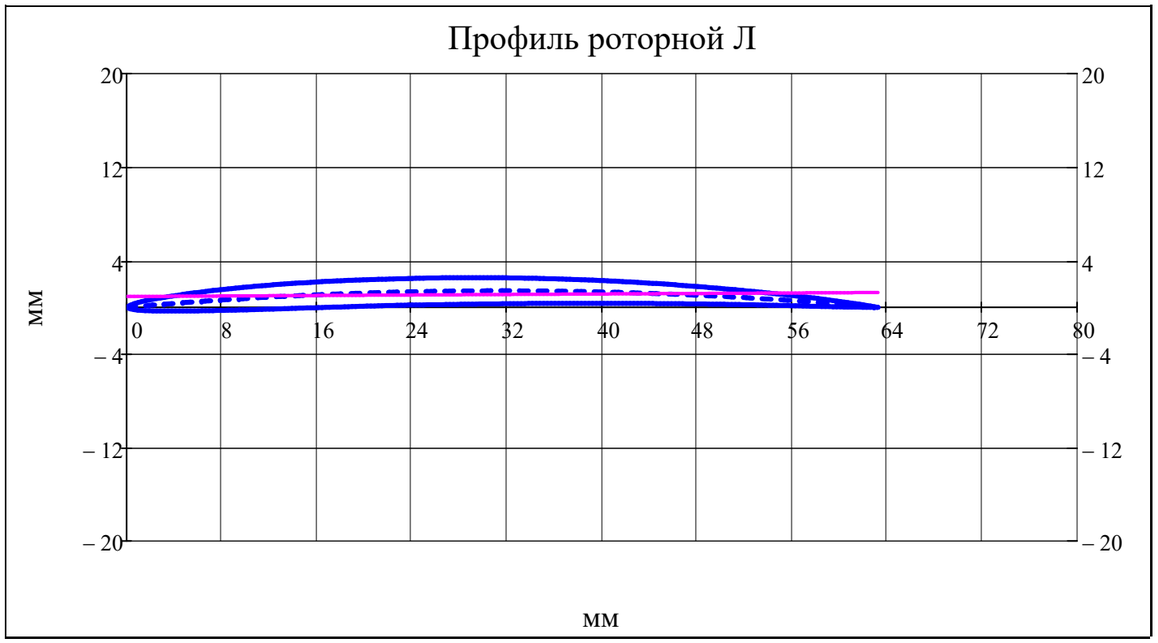


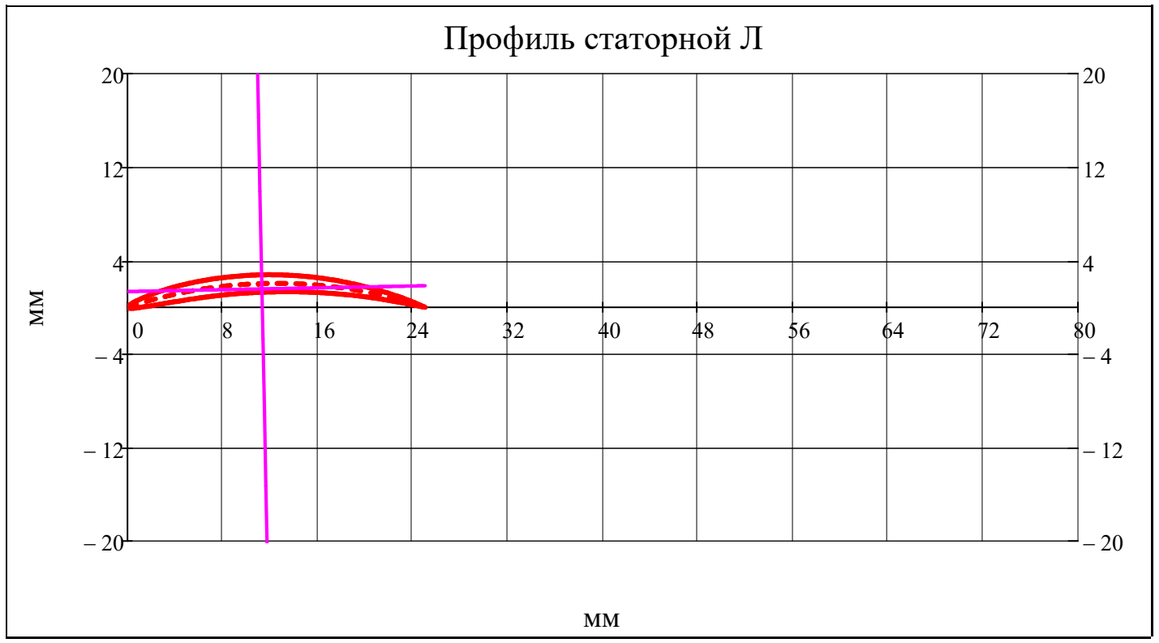
$r_{\Lambda V} = 1$


Профиль роторной Л
20
12
4
– 4
– 12
– 20
0
8
16
24
32
40
48
56
64
72
80
мм
мм

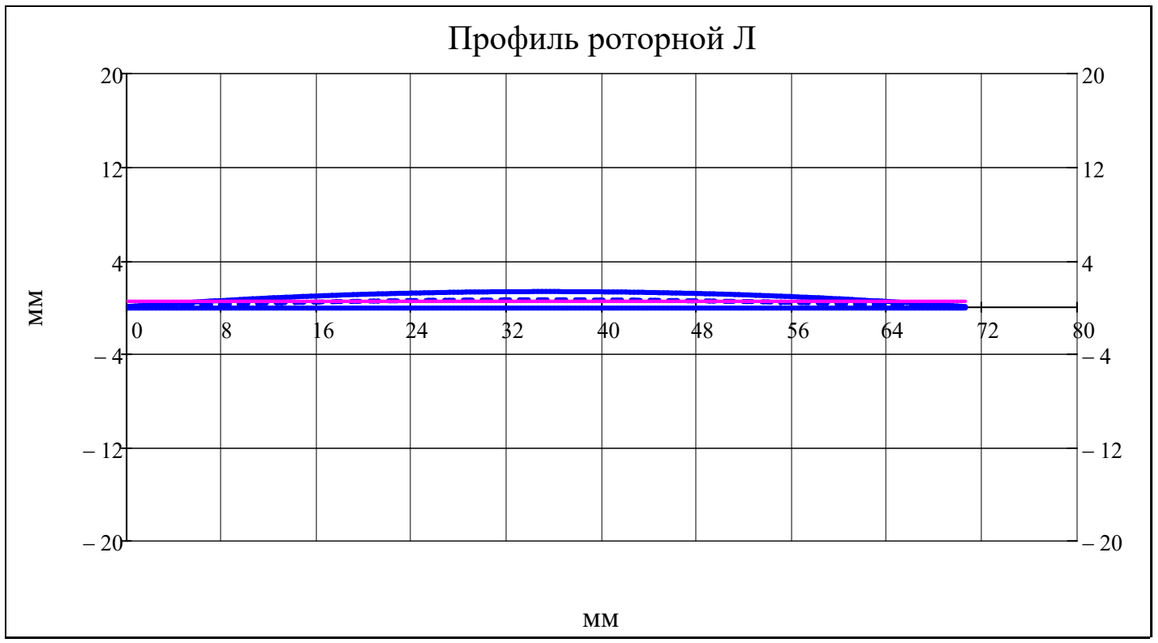

Профиль статорной Л
20
12
4
– 4
– 12
– 20
0
8
16
24
32
40
48
56
64
72
80
мм
мм

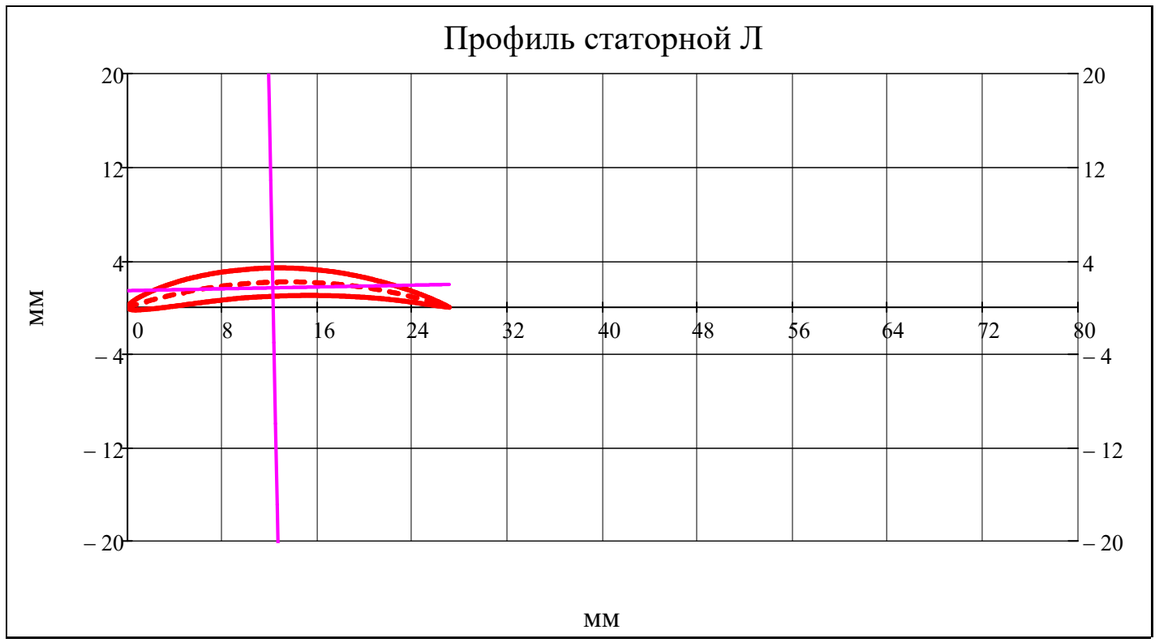
$\underset{\sim}{r} = av(N_r)$





$r_{\approx} = N_r$





Построение профилей Л РК и НА

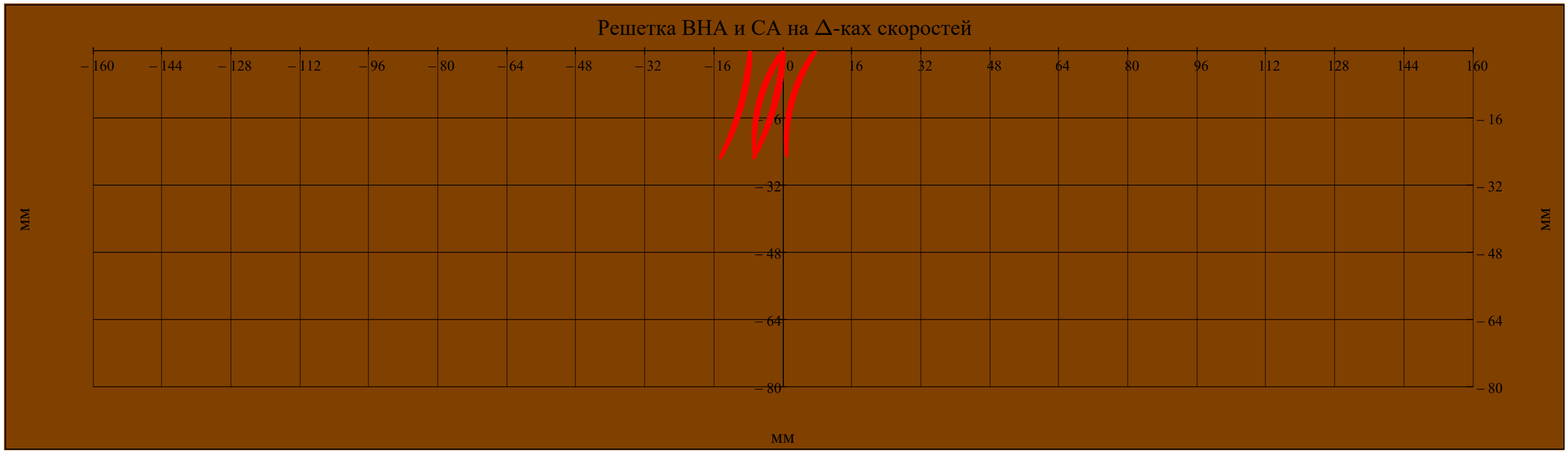
Вывод координат для построения профиля Л

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

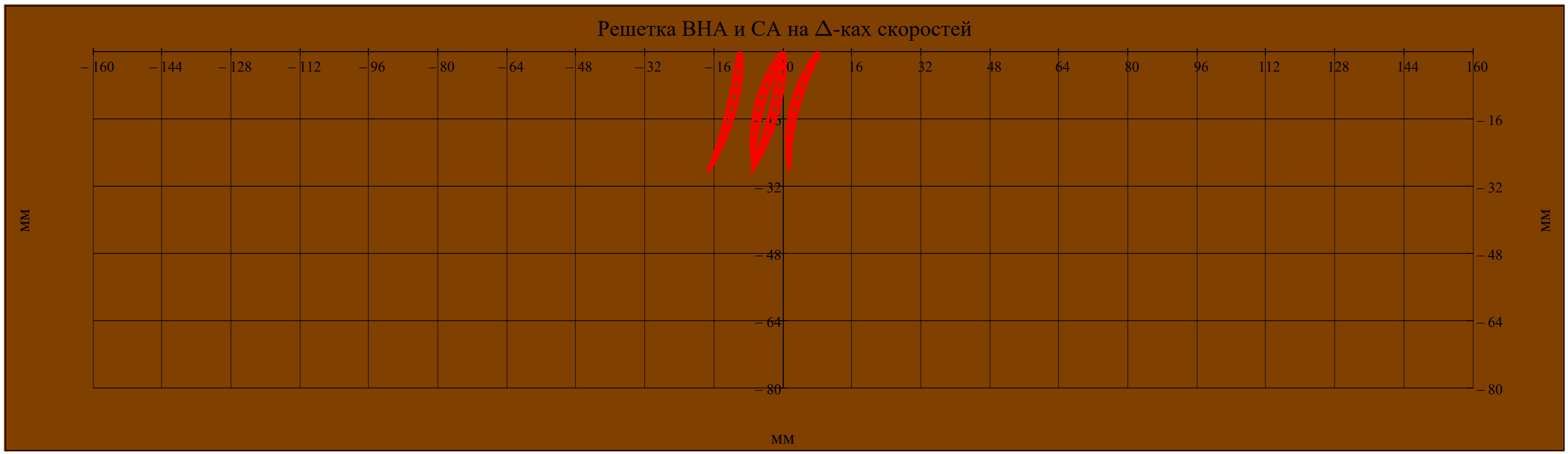
$$b_{lim} = \frac{\operatorname{ceil}\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right)\cdot 10^2\right)}{10^2} = 80\cdot 10^{-3}$$

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

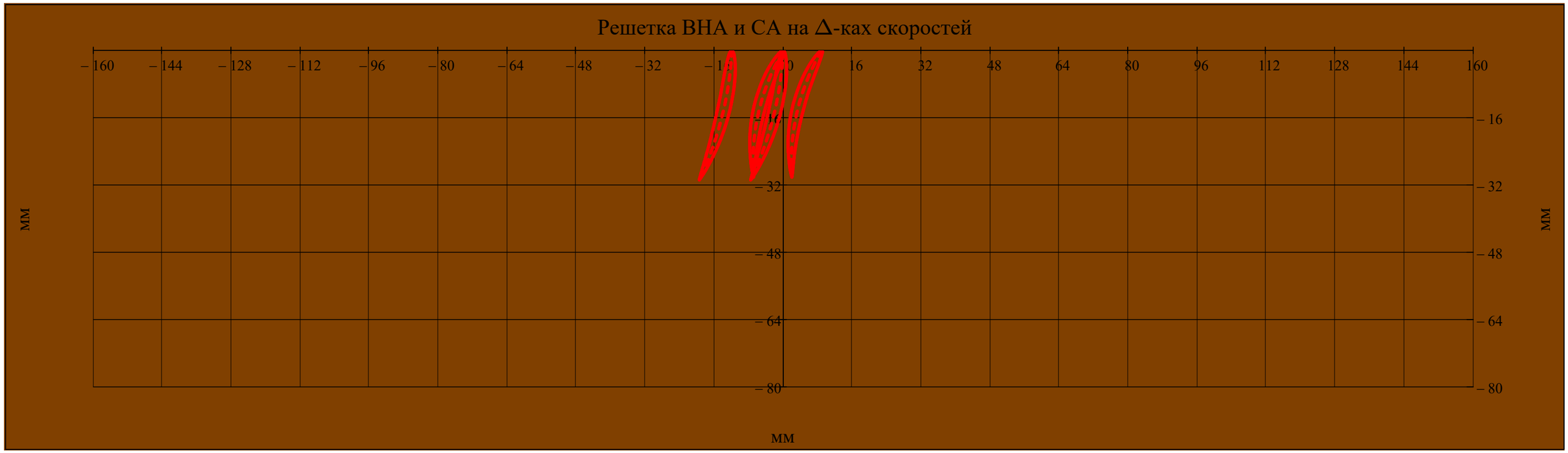
$r = 1$



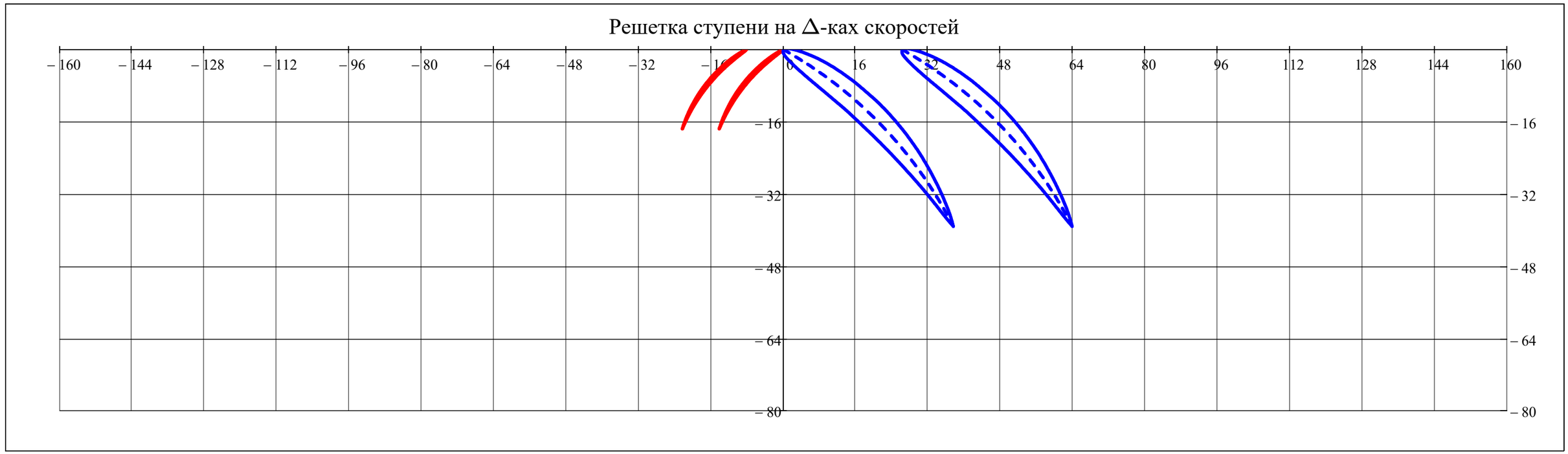
$\underset{\sim}{r} = av(N_r)$



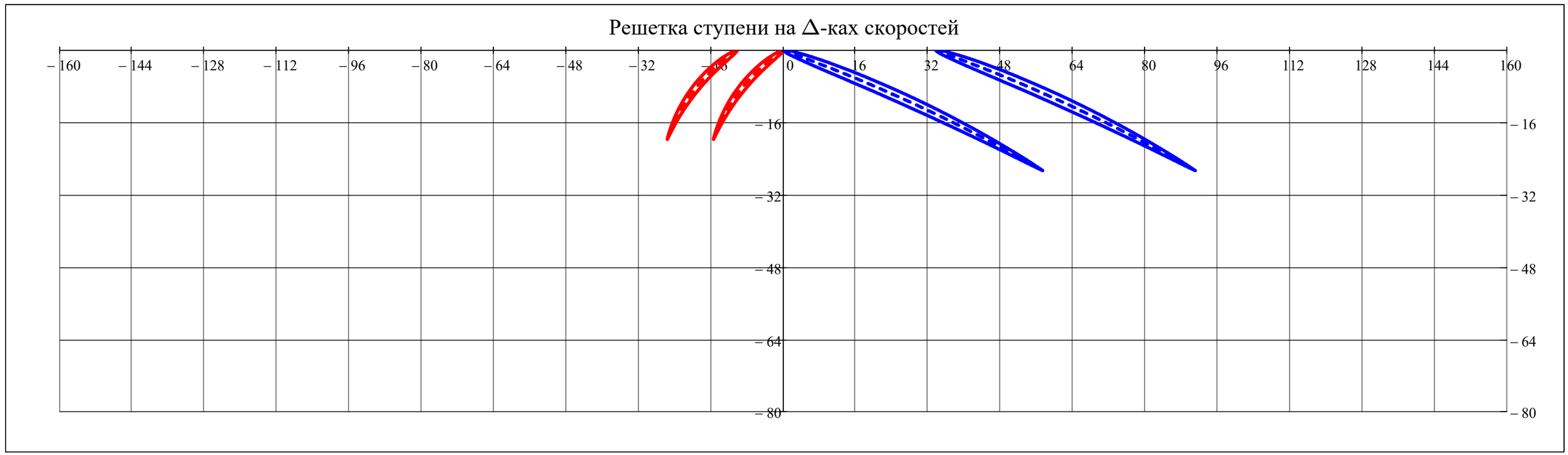
$r \approx N_r$


Решетка ВНА и СА на Δ-ках скоростей
– 160
– 144
– 128
– 112
– 96
– 80
– 64
– 48
– 32
16
32
48
64
80
96
112
128
144
160
– 16
– 32
– 48
– 64
– 80
мм
мм

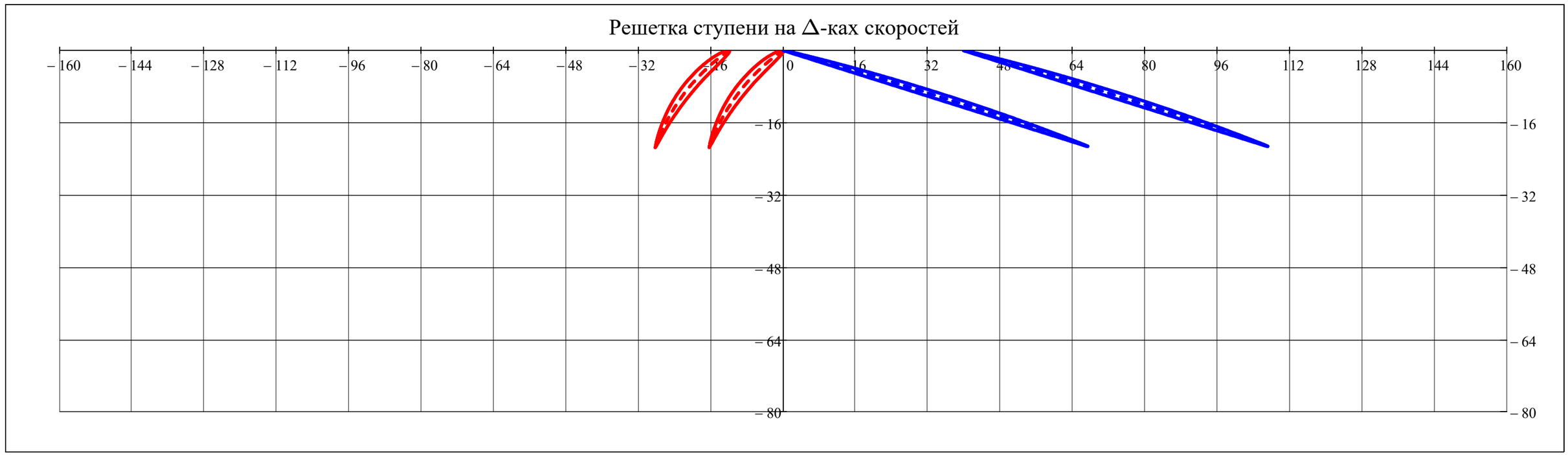
r = 1


Решетка ступени на Δ-ках скоростей
– 160
– 144
– 128
– 112
– 96
– 80
– 64
– 48
– 32
– 16
0
16
32
48
64
80
96
112
128
144
160
– 16
– 32
– 48
– 64
– 80

$\underset{\sim}{r} = av(N_r)$



$r = N_r$



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

Вывод данных по построению профиля Л rotor и stator на треугольниках скоростей

Радиальные и осевые зазоры и длина К

Радиальный зазор (м) [с.64 казаджан]: $\overline{\Delta}r = 0.0025$

$0.0015 \le \overline{\Delta}r \le 0.0035 = 1$

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

$\Delta_r^T =$

	1	2	3	4	5	6	7	8	9
1	1.35	1.33	1.29	1.25	1.23	1.20	1.19	1.18	1.16

$\cdot 10^{-3}$

Относительный осевой зазор () [16, с. 245]: $\overline{\Delta}a = 0.17$

$0.1 \le \overline{\Delta}a \le 0.2 = 1$

Осевой зазор (м): $\Delta a_i = \overline{\Delta}a \cdot chord_{rotor_{i,av}(N_r)}$

$\Delta a^T =$

	1	2	3	4	5	6	7	8	9
1	10.75	9.67	8.56	7.81	7.27	6.85	6.58	6.46	6.39

$\cdot 10^{-3}$

Односторонний осевой зазор (м):

$\frac{\Delta a^T}{2} =$

	1	2	3	4	5	6	7	8	9
1	5.37	4.83	4.28	3.91	3.63	3.43	3.29	3.23	3.20

$\cdot 10^{-3}$

Длина ОК (м):

$$Length = \left[\begin{array}{l} \Delta a_1 + \begin{cases} chord_{BHA_{av}(N_r)} \cdot \sin\left(\upsilon_{BHA_{av}(N_r)}\right) & \text{if } BHA = 1 \quad ... \\ 0 \quad \text{otherwise} \end{cases} \\ + \sum_{i=1}^{Z} \left(chord_{rotor_{i,av}(N_r)} \cdot \sin\left(\upsilon_{rotor_{i,av}(N_r)}\right) \right) + 2 \cdot \sum_{i=1}^{Z} \Delta a_i + \sum_{i=1}^{Z} \left(chord_{stator_{i,av}(N_r)} \cdot \sin\left(\upsilon_{stator_{i,av}(N_r)}\right) \right) ... \\ + \begin{cases} chord_{CA_{av}(N_r)} \cdot \sin\left(\upsilon_{CA_{av}(N_r)}\right) & \text{if } CA = 1 \quad + \Delta a_Z \\ 0 \quad \text{otherwise} \end{cases} \end{array} \right] = 540.4 \cdot 10^{-3}$$

Радиальные и осевые зазоры и длина К

Проточная часть

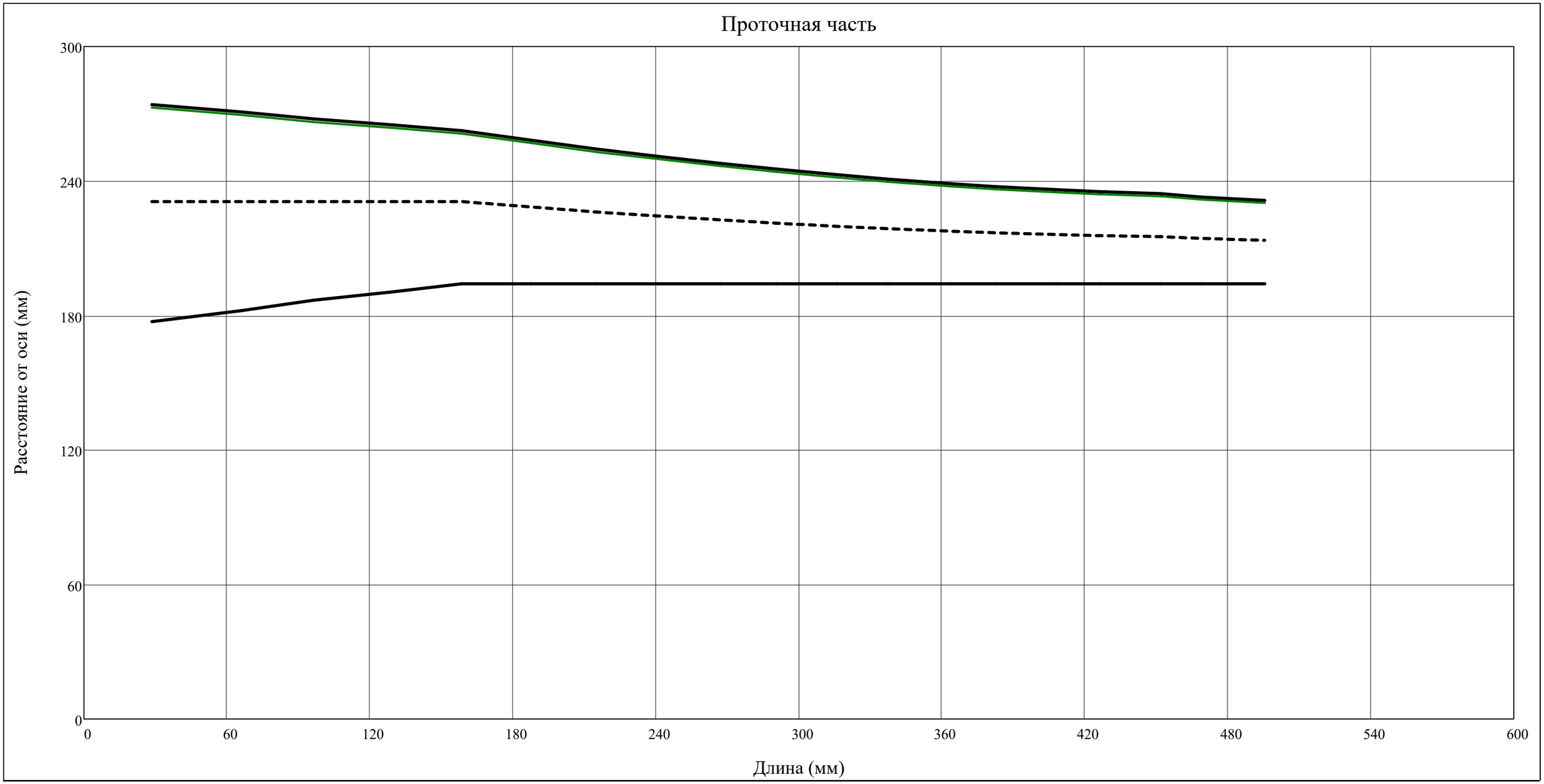
$$\begin{pmatrix} x_{ПЧ} \\ y_{ПЧпер} \\ y_{ПЧср} \\ y_{ПЧкор} \\ y_{Лпер} \end{pmatrix} = \left| \begin{array}{l} c = 1 \\ x_{ПЧ_c} = \begin{cases} chord_{BHA_{av(N_r)}} \cdot \sin\left(\upsilon_{BHA_{av(N_r)}}\right) & \text{if } BHA = 1 \\ 0 & \text{otherwise} \end{cases} \\ y_{ПЧпер_c} = R_{st(c,1),N_r} \\ y_{Лпер_c} = y_{ПЧпер_c} - \Delta_{r_c} \\ y_{ПЧср_c} = R_{st(c,1),av(N_r)} \\ y_{ПЧкор_c} = R_{st(c,1),ORIGIN} \\ \text{for } i \in 1..Z \\ \quad c = c + 1 \\ \quad x_{ПЧ_c} = x_{ПЧ_{c-1}} + 0.5\cdot\Delta a_i + chord_{rotor_{i,av(N_r)}} \cdot \sin\left(\upsilon_{rotor_{i,av(N_r)}}\right) + 0.5\cdot\Delta a_i \\ \quad \begin{pmatrix} y_{ПЧпер_c} \\ y_{ПЧср_c} \\ y_{ПЧкор_c} \end{pmatrix} = \begin{pmatrix} R_{st(i,2),N_r} \\ R_{st(i,2),av(N_r)} \\ R_{st(i,2),ORIGIN} \end{pmatrix} \\ \quad y_{Лпер_c} = y_{ПЧпер_c} - \Delta_{r_i} \\ \quad c = c + 1 \\ \quad x_{ПЧ_c} = x_{ПЧ_{c-1}} + 0.5\cdot\Delta a_i + chord_{stator_{i,av(N_r)}} \cdot \sin\left(\upsilon_{stator_{i,av(N_r)}}\right) + 0.5\cdot\Delta a_i \\ \quad \begin{pmatrix} y_{ПЧпер_c} \\ y_{ПЧср_c} \\ y_{ПЧкор_c} \end{pmatrix} = \begin{pmatrix} R_{st(i,3),N_r} \\ R_{st(i,3),av(N_r)} \\ R_{st(i,3),ORIGIN} \end{pmatrix} \\ \quad y_{Лпер_c} = y_{ПЧпер_c} - \Delta_{r_i} \\ \left(x_{ПЧ} \;\; y_{ПЧпер} \;\; y_{ПЧср} \;\; y_{ПЧкор} \;\; y_{Лпер}\right)^T \end{array} \right.$$

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

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

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

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



Проточная часть

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

Поперечная часть ступени

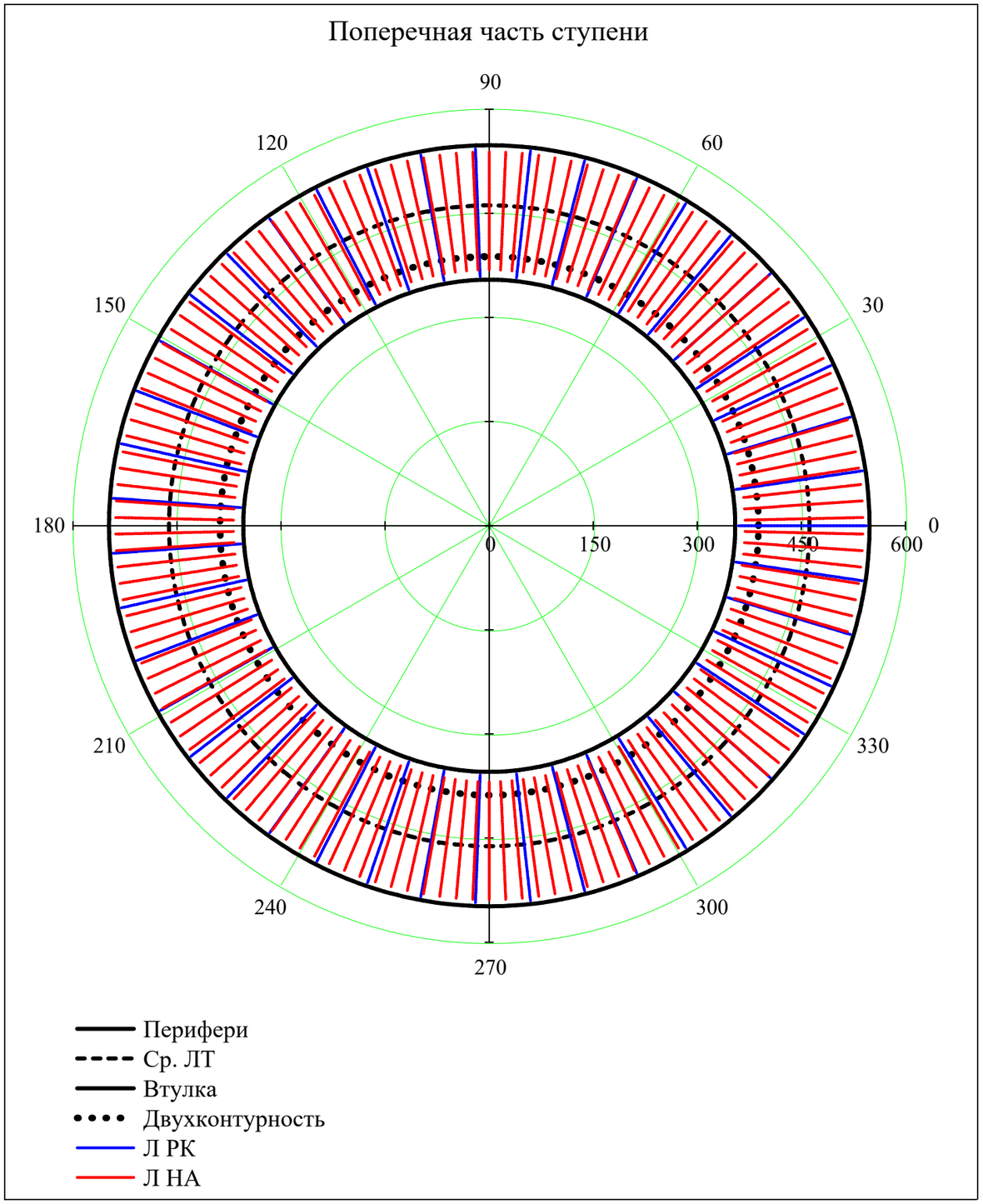
$r = \min(D), \min(D) + \frac{\max(D) - \min(D)}{N_{dis}} .. \max(D)$

$i_{rotor} = 1 .. Z_{rotor_j}$

$i_{stator} = 1 .. Z_{stator_j}$

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

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



Поперечная часть ступени

Выбор материала Л

Запас по температуре (К): $\Delta T_{safety} = 50$

Выбранный материал Л:

$$material\_blade_i = \begin{cases} \text{"ЖС-6К"} & \text{if } 1123 \le T^*_{st(i,2),av(N_r)} + \Delta T_{safety} \\ \text{"ВТ41"} & \text{if } 873 \le T^*_{st(i,2),av(N_r)} + \Delta T_{safety} < 1123 \\ \text{"ВТ25"} & \text{if } 753 \le T^*_{st(i,2),av(N_r)} + \Delta T_{safety} < 873 \\ \text{"ВТ9"} & \text{otherwise} \end{cases}$$

$$material\_blade_i = \begin{cases} \text{"ВТ23"} & \text{if } compressor = \text{"Вл"} \\ \text{"ВТ6"} & \text{if } compressor = \text{"КНД"} \\ material\_blade_i & \text{otherwise} \end{cases}$$

Плотность материала Л (кг/м^3):

$$\rho\_blade_i = \begin{cases} 8393 & \text{if } material\_blade_i = \text{"ЖС-6К"} \\ 7900 & \text{if } material\_blade_i = \text{"ВТ41"} \\ 4500 & \text{if } material\_blade_i = \text{"ВТ25"} \\ 4570 & \text{if } material\_blade_i = \text{"ВТ23"} \\ 4510 & \text{if } material\_blade_i = \text{"ВТ9"} \\ 4430 & \text{if } material\_blade_i = \text{"ВТ6"} \\ NaN & \text{otherwise} \end{cases}$$

Коэф. формы: $k_n = 6.8$

Модуль Юнга I рода материала Л (Па): $E\_blade = 210 \cdot 10^9$

Предел длительной прочности Л РК (Па):

$$\sigma\_blade\_long_i = 10^6 \cdot \begin{cases} 125 & \text{if } material\_blade_i = \text{"ЖС-6К"} \\ 123 & \text{if } material\_blade_i = \text{"ВТ41"} \\ 150 & \text{if } material\_blade_i = \text{"ВТ25"} \\ 230 & \text{if } material\_blade_i = \text{"ВТ23"} \\ 200 & \text{if } material\_blade_i = \text{"ВТ9"} \\ 210 & \text{if } material\_blade_i = \text{"ВТ6"} \\ NaN & \text{otherwise} \end{cases}$$

Коэф. Пуассона материала Л (): $\mu\_steel = 0.3$

$material\_blade^T =$

	1	2	3	4	5	6	7	8	9
1	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ25"	"ВТ25"	"ВТ25"	"ВТ41"

$\rho\_blade^T =$

	1	2	3	4	5	6	7	8	9
1	4510	4510	4510	4510	4510	4500	4500	4500	7900

$\sigma\_blade\_long^T =$

	1	2	3	4	5	6	7	8	9
1	200.0	200.0	200.0	200.0	200.0	150.0	150.0	150.0	123.0

$\cdot 10^6$

Выбор материала Л

Расчет собственных частот колебаний Л

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

for $i \in 1 .. Z$

for $r \in av(N_r)$

for $mode \in 1 .. 6$

$\nu0_{\text{изг.stator}_{i,mode}} = \nu0_{\text{изгиб}}(mode, mean(h_{st(i,2)}, h_{st(i,3)}), E\_blade, \rho\_blade_i, area_{stator_{i,r}}, Ju_{stator_{i,r}})$

$\nu0_{\text{изг.rotor}_{i,mode}} = \nu0_{\text{изгиб}}(mode, mean(h_{st(i,1)}, h_{st(i,2)}), E\_blade, \rho\_blade_i, area_{rotor_{i,r}}, Ju_{rotor_{i,r}})$

$\nu0_{\text{угл.stator}_{i,mode}} = \nu0_{\text{угл}}(mode, 0, mean(h_{st(i,2)}, h_{st(i,3)}), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{stator_{i,r}}, Jp_{stator_{i,r}})$

$\nu0_{\text{угл.rotor}_{i,mode}} = \nu0_{\text{угл}}(mode, 0, mean(h_{st(i,1)}, h_{st(i,2)}), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{rotor_{i,r}}, Jp_{rotor_{i,r}})$

$\nu0_{\text{угл.stator\_bondage}_{i,mode}} = \nu0_{\text{угл}}(mode, 1, mean(h_{st(i,2)}, h_{st(i,3)}), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{stator_{i,r}}, Jp_{stator_{i,r}})$

$\nu0_{\text{угл.rotor\_bondage}_{i,mode}} = \nu0_{\text{угл}}(mode, 1, mean(h_{st(i,1)}, h_{st(i,2)}), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{rotor_{i,r}}, Jp_{rotor_{i,r}})$

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

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	1539	1826	2097	2353	2606	2851	3056	3212	2597	852	1018	1194	1352	1506	1660	1796	1903	1513
2	4617	5479	6290	7060	7819	8553	9167	9635	7790	2557	3053	3582	4055	4519	4979	5389	5710	4540
3	7694	9131	10483	11767	13031	14255	15278	16059	12983	4261	5088	5970	6758	7532	8298	8982	9516	7567
4	10772	12784	14677	16474	18243	19956	21389	22482	18177	5966	7124	8358	9461	10544	11617	12575	13322	10594
5	13850	16436	18870	21180	23456	25658	27500	28906	23370	7670	9159	10746	12164	13557	14936	16168	17129	13621
6	16927	20089	23063	25887	28668	31360	33611	35329	28563	9375	11194	13135	14867	16570	18256	19761	20935	16648

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	321	478	660	811	1015	1221	1318	1457	1326	290	377	469	543	625	703	759	814	669
2	2011	2998	4137	5085	6360	7653	8260	9134	8312	1820	2362	2938	3402	3916	4407	4755	5103	4195
3	5630	8395	11585	14241	17810	21430	23131	25578	23275	5095	6614	8226	9528	10967	12341	13316	14290	11749
4	11042	16464	22719	27927	34926	42026	45362	50160	45645	9992	12970	16132	18685	21507	24202	26114	28024	23040
5	18245	27205	37541	46147	57711	69443	74956	82885	75423	16511	21431	26657	30875	35538	39992	43151	46307	38071
6	27248	40629	56066	68918	86189	103709	111943	123783	112640	24658	32006	39811	46109	53074	59725	64444	69156	56857

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	3078	3653	4193	4707	5212	5702	6111	6423	5193	1705	2035	2388	2703	3013	3319	3593	3806	3027
2	6155	7305	8387	9414	10425	11404	12222	12847	10387	3409	4071	4776	5406	6025	6638	7186	7613	6054
3	9233	10958	12580	14120	15637	17106	18333	19270	15580	5114	6106	7164	8109	9038	9958	10779	11419	9081
4	12311	14610	16773	18827	20850	22807	24444	25694	20773	6818	8141	9552	10813	12051	13277	14372	15225	12108
5	15389	18263	20967	23534	26062	28509	30555	32117	25967	8523	10177	11941	13516	15063	16596	17965	19032	15135
6	18466	21915	25160	28241	31275	34211	36666	38541	31160	10227	12212	14329	16219	18076	19915	21558	22838	18162

Расчет собственных частот колебаний Л

Вывод результатов расчета собственных частот колебаний Л

Расчетный узел: $type = "compressor"$

Объем бандажной полки ($м^3$): $V_{бп} = 0$

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

Расчет Л на прочность

$$\begin{pmatrix} R0_{rotor} & area0_{rotor} \\ N0_{rotor} & \sigma0\_z_{rotor} \\ area_{rotor.} & area_{stator.} \\ N_{rotor} & \sigma\_z_{rotor} \\ P_1 & \rho_1 \\ P_2 & \rho_2 \\ P_3 & \rho_3 \\ c_{a1} & c_{u1} \\ c_{a2} & c_{u2} \\ c_{a3} & c_{u3} \\ qx_{rotor} & qx_{stator} \\ qy_{rotor} & qy_{stator} \\ Mx_{rotor} & Mx_{stator} \\ My_{rotor} & My_{stator} \\ shift\_x_{rotor} & shift\_y_{rotor} \\ x0_{rotor.} & x0_{stator.} \\ y0_{rotor.} & y0_{stator.} \\ \alpha\_major_{rotor.} & \alpha\_major_{stator.} \\ Ju_{rotor.} & Ju_{stator.} \\ Jv_{rotor.} & Jv_{stator.} \\ CPx_{rotor.} & CPx_{stator.} \\ CPy_{rotor.} & CPy_{stator.} \\ CPx_{rotor.axis} & CPx_{stator.axis} \\ CPy_{rotor.axis} & CPy_{stator.axis} \end{pmatrix} = \begin{cases} \chi_{rotor}(i,z) = \dfrac{area_{rotor_{i,N_r}}}{area_{rotor_{i,1}}} \\ R0_{rotor}(i,z) = \dfrac{1}{\sqrt{1-\ln\left(\chi_{rotor}(i,z)\right)}} \cdot \begin{cases} \sqrt{mean\left(R_{st(i,1),1}, R_{st(i,2),1}\right)^2 - mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)^2 \cdot \ln\left(\chi_{rotor}(i,z)\right)} & \text{if } type = "compressor" \\ \sqrt{mean\left(R_{st(i,2),1}, R_{st(i,3),1}\right)^2 - mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)^2 \cdot \ln\left(\chi_{rotor}(i,z)\right)} & \text{if } type = "turbine" \end{cases} \\ \sigma0_{rotor.max}(i,z) = \dfrac{\rho\_blade_i \cdot \omega^2}{2} \cdot \begin{cases} \left[mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)^2 - \left(R0_{rotor}(i,z)\right)^2\right] & \text{if } type = "compressor" \\ \left[mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)^2 - \left(R0_{rotor}(i,z)\right)^2\right] & \text{if } type = "turbine" \end{cases} \\ \left(\quad \rho\_blade_i \cdot \omega^2 \quad \int_{}^{R0_{rotor}(i,z)} \right. \end{cases}$$

$$\begin{pmatrix} \varphi\_rotor.axis & \varphi\_stator.axis \\ Wp_{rotor.} & Wp_{stator.} \\ M\tau_{rotor} & M\tau_{stator} \\ \tau_{rotor} & \tau_{stator} \\ \varphi\_uv_{rotor} & \varphi\_uv_{stator} \\ Mu_{rotor} & Mu_{stator} \\ Mv_{rotor} & Mv_{stator} \\ \varphi\_neutral_{rotor} & \varphi\_neutral_{stator} \end{pmatrix}$$

$$area0_{rotor}(i,z) = area_{rotor_{i,N_r}} \cdot \begin{cases} e^{\left(\overline{\sigma 0_{rotor.max}(i,z)} \cdot \int_z z\,dz\right)} & \text{if } z \le R0_{rotor}(i,z) \\ 1 & \text{otherwise} \end{cases}$$

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

$$\sigma 0\_z_{rotor}(i,z) = \frac{N0_{rotor}(i,z)}{area0_{rotor}(i,z)}$$

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

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

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

$$\sigma\_z_{rotor}(i,z) = \frac{N_{rotor}(i,z)}{area_{rotor.}(i,z)}$$

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

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

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

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

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

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

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

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

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

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

$$c_{u2}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^{1}, \mathrm{submatrix}\left(c_u, st(i,2), st(i,2), 1, N_r\right)^{1}\right), \mathrm{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^{1}, \mathrm{submatrix}\left(c_u, st(i,2), st(i,2), 1, N_r\right)^{1}, z\right)$$

$$c_{u3}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R, st(i,3), st(i,3), 1, N_r\right)^{T}, \mathrm{submatrix}\left(c_u, st(i,3), st(i,3), 1, N_r\right)^{T}\right), \mathrm{submatrix}\left(R, st(i,3), st(i,3), 1, N_r\right)^{T}, \mathrm{submatrix}\left(c_u, st(i,3), st(i,3), 1, N_r\right)^{T}, z\right)$$

$$w_{u1}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^{T}, \mathrm{submatrix}\left(w_u, st(i,1), st(i,1), 1, N_r\right)^{T}\right), \mathrm{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^{T}, \mathrm{submatrix}\left(w_u, st(i,1), st(i,1), 1, N_r\right)^{T}, z\right)$$

$$w_{u2}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^{T}, \mathrm{submatrix}\left(w_u, st(i,2), st(i,2), 1, N_r\right)^{T}\right), \mathrm{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^{T}, \mathrm{submatrix}\left(w_u, st(i,2), st(i,2), 1, N_r\right)^{T}, z\right)$$

$$w_{u3}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R, st(i,3), st(i,3), 1, N_r\right)^{T}, \mathrm{submatrix}\left(w_u, st(i,3), st(i,3), 1, N_r\right)^{T}\right), \mathrm{submatrix}\left(R, st(i,3), st(i,3), 1, N_r\right)^{T}, \mathrm{submatrix}\left(w_u, st(i,3), st(i,3), 1, N_r\right)^{T}, z\right)$$

$$qx_{rotor}(i,z) = -\frac{2\pi z}{Z_{rotor_i}} \cdot \begin{cases} \left[\left(P_2(i,z) - P_1(i,z)\right) + \rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(c_{a2}(i,z) - c_{a1}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\left(P_3(i,z) - P_2(i,z)\right) + \rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(c_{a3}(i,z) - c_{a2}(i,z)\right)\right] & \text{if type = "turbine"} \end{cases}$$

$$qx_{stator}(i,z) = -\frac{2\pi z}{Z_{stator_i}} \cdot \begin{cases} \left[\left(P_3(i,z) - P_2(i,z)\right) + \rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(c_{a3}(i,z) - c_{a2}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\left(P_2(i,z) - P_1(i,z)\right) + \rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(c_{a2}(i,z) - c_{a1}(i,z)\right)\right] & \text{if type = "turbine"} \end{cases}$$

$$qy_{rotor}(i,z) = \frac{2\pi z}{Z_{rotor_i}} \cdot \begin{cases} \left[\rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(w_{u2}(i,z) - w_{u1}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(w_{u3}(i,z) - w_{u2}(i,z)\right)\right] & \text{if type = "turbine"} \end{cases}$$

$$qy_{stator}(i,z) = -\frac{2\pi z}{Z_{stator_i}} \cdot \begin{cases} \left[\rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(c_{u3}(i,z) - c_{u2}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(c_{u2}(i,z) - c_{u1}(i,z)\right)\right] & \text{if type = "turbine"} \end{cases}$$

$$Mx_{rotor}(i,z) = -\int_z \begin{cases} \mathrm{mean}\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right) & \text{if type="turbine"} \end{cases} qy_{rotor}(i,z1)\cdot(z1 - z)\,dz1$$

$$Mx_{stator}(i,z) = \int_z \begin{cases} \mathrm{mean}\left(R_{st(i,2),1}, R_{st(i,3),1}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,1),1}, R_{st(i,2),1}\right) & \text{if type="turbine"} \end{cases} qy_{stator}(i,z1)\cdot(z1 - z)\,dz1$$

$$My_{rotor}(i,z) = \int_z \begin{cases} \mathrm{mean}\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right) & \text{if type="turbine"} \end{cases} qx_{rotor}(i,z1)\cdot(z1 - z)\,dz1$$

$$My_{stator}(i,z) = -\int_z \begin{cases} \mathrm{mean}\left(R_{st(i,2),1}, R_{st(i,3),1}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,1),1}, R_{st(i,2),1}\right) & \text{if type="turbine"} \end{cases} qx_{stator}(i,z1)\cdot(z1 - z)\,dz1$$

$$\int^{z} \int \begin{cases} \mathrm{mean}\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right) & \text{if type="turbine"} \end{cases} qx_{\ldots}(i,z)\,dz$$

$$\text{shift\_x}_{\text{rotor}}(i,z) = \int_z \frac{qx_{\text{rotor}}(i,z)\,dz}{N_{\text{rotor}}(i,z)}\,dz$$

$$\text{shift\_y}_{\text{rotor}}(i,z) = z\cdot\int_z \frac{\left(qy_{\text{rotor}}(i,z)\cdot z\right)dz}{N_{\text{rotor}}(i,z)\cdot z^2}\,dz$$

$$x0_{\text{rotor.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(x0_{\text{rotor}},i,i,1,N_r\right)^T\right),\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(x0_{\text{rotor}},i,i,1,N_r\right)^T,z\right)$$

$$x0_{\text{stator.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(x0_{\text{stator}},i,i,1,N_r\right)^T\right),\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(x0_{\text{stator}},i,i,1,N_r\right)^T,z\right)$$

$$y0_{\text{rotor.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(y0_{\text{rotor}},i,i,1,N_r\right)^T\right),\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(y0_{\text{rotor}},i,i,1,N_r\right)^T,z\right)$$

$$y0_{\text{stator.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(y0_{\text{stator}},i,i,1,N_r\right)^T\right),\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(y0_{\text{stator}},i,i,1,N_r\right)^T,z\right)$$

$$\alpha\_major_{\text{rotor.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(\alpha\_major_{\text{rotor}},i,i,1,N_r\right)^T\right),\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(\alpha\_major_{\text{rotor}},i,i,1,N_r\right)^T\right.$$

$$\alpha\_major_{\text{stator.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(\alpha\_major_{\text{stator}},i,i,1,N_r\right)^T\right),\text{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\text{submatrix}\left(\alpha\_major_{\text{stator}},i,i,1,N_r\right.\right.$$

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

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

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

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

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

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

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

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

$$CPx_{\text{rotor.axis}}(i,z) = \text{axis}_x\left(CPx_{\text{rotor.}}(i,z),CPy_{\text{rotor.}}(i,z),x0_{\text{rotor.}}(i,z),y0_{\text{rotor.}}(i,z),\alpha\_major_{\text{rotor.}}(i,z),1\right)$$

$$CPx_{\text{stator.axis}}(i,z) = \text{axis}_x\left(CPx_{\text{stator.}}(i,z),CPy_{\text{stator.}}(i,z),x0_{\text{stator.}}(i,z),y0_{\text{stator.}}(i,z),\alpha\_major_{\text{stator.}}(i,z),1\right)$$

$$CPy_{\text{rotor.axis}}(i,z) = \text{axis}_y\left(CPx_{\text{rotor.}}(i,z),CPy_{\text{rotor.}}(i,z),x0_{\text{rotor.}}(i,z),y0_{\text{rotor.}}(i,z),\alpha\_major_{\text{rotor.}}(i,z),1\right)$$

$$CPy_{\text{stator.axis}}(i,z) = \text{axis}_y\left(CPx_{\text{stator.}}(i,z),CPy_{\text{stator.}}(i,z),x0_{\text{stator.}}(i,z),y0_{\text{stator.}}(i,z),\alpha\_major_{\text{stator.}}(i,z),1\right)$$

$$Wp_{rotor.}(i,z) = interp\left(lspline\left(submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(Wp_{rotor},i,i,1,N_r\right)^T\right),submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(Wp_{rotor},i,i,1,N_r\right)^T,z\right)$$

$$Wp_{stator.}(i,z) = interp\left(lspline\left(submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(Wp_{stator},i,i,1,N_r\right)^T\right),submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(Wp_{stator},i,i,1,N_r\right)^T,z\right)$$

$$M\tau_{rotor}(i,z) = \int_z \begin{cases} mean\left(R_{st(i,1),N_r},R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ mean\left(R_{st(i,2),N_r},R_{st(i,3),N_r}\right) & \text{if type="turbine"} \end{cases} \left(qx_{rotor}(i,z1)\cdot CPy_{rotor.axis}(i,z1) - qy_{rotor}(i,z1)\cdot CPx_{rotor.axis}(i,z1)\right) dz1$$

$$M\tau_{stator}(i,z) = \int_z \begin{cases} mean\left(R_{st(i,2),1},R_{st(i,3),1}\right) & \text{if type="compressor"} \\ mean\left(R_{st(i,1),1},R_{st(i,2),1}\right) & \text{if type="turbine"} \end{cases} \left(qx_{stator}(i,z1)\cdot CPy_{stator.axis}(i,z1) - qy_{stator}(i,z1)\cdot CPx_{stator.axis}(i,z1)\right) dz1$$

$$\tau_{rotor}(i,z) = \frac{M\tau_{rotor}(i,z)}{Wp_{rotor.}(i,z)}$$

$$\tau_{stator}(i,z) = \frac{M\tau_{stator}(i,z)}{Wp_{stator.}(i,z)}$$

$$\varphi\_uv_{rotor}(i,z) = interp\left(lspline\left(submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(\frac{\pi}{2}-\upsilon_{rotor},i,i,1,N_r\right)^T\right),submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(\frac{\pi}{2}-\upsilon_{rotor},i,i,1,N_r\right)^T,z\right)$$

$$\varphi\_uv_{stator}(i,z) = interp\left(lspline\left(submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(\frac{\pi}{2}-\upsilon_{stator},i,i,1,N_r\right)^T\right),submatrix\left(R,st(i,2),st(i,2),1,N_r\right)^T,submatrix\left(\frac{\pi}{2}-\upsilon_{stator},i,i,1,N_r\right)^T,z\right)$$

$$Mu_{rotor}(i,z) = axis_x\left(Mx_{rotor}(i,z),My_{rotor}(i,z),0,0,\varphi\_uv_{rotor}(i,z),1\right)$$

$$Mu_{stator}(i,z) = axis_x\left(Mx_{stator}(i,z),My_{stator}(i,z),0,0,\varphi\_uv_{stator}(i,z),1\right)$$

$$Mv_{rotor}(i,z) = axis_y\left(Mx_{rotor}(i,z),My_{rotor}(i,z),0,0,\varphi\_uv_{rotor}(i,z),1\right)$$

$$Mv_{stator}(i,z) = axis_y\left(Mx_{stator}(i,z),My_{stator}(i,z),0,0,\varphi\_uv_{stator}(i,z),1\right)$$

$$\varphi\_neutral_{rotor}(i,z) = \begin{cases} atan\left(\frac{Mv_{rotor}(i,z)\cdot Ju_{rotor.}(i,z)}{Mu_{rotor}(i,z)\cdot Jv_{rotor.}(i,z)}\right) & \text{if } Mu_{rotor}(i,z)\cdot Jv_{rotor.}(i,z) \neq 0 \\ \frac{\pi}{2} & \text{otherwise} \end{cases}$$

$$\varphi\_neutral_{stator}(i,z) = \begin{cases} atan\left(\frac{Mv_{stator}(i,z)\cdot Ju_{stator.}(i,z)}{Mu_{stator}(i,z)\cdot Jv_{stator.}(i,z)}\right) & \text{if } Mu_{stator}(i,z)\cdot Jv_{stator.}(i,z) \neq 0 \\ \frac{\pi}{2} & \text{otherwise} \end{cases}$$

$$\begin{pmatrix} R0_{rotor} & area0_{rotor} \\ N0_{rotor} & \sigma0\_z_{rotor} \\ area_{rotor.} & area_{stator.} \\ N_{rotor} & \sigma\_z_{rotor} \end{pmatrix}$$

P_1	ρ_1
P_2	ρ_2
P_3	ρ_3
c_{a1}	c_{u1}
c_{a2}	c_{u2}
c_{a3}	c_{u3}
qx_{rotor}	qx_{stator}
qy_{rotor}	qy_{stator}
Mx_{rotor}	Mx_{stator}
My_{rotor}	My_{stator}
$shift\_x_{rotor}$	$shift\_y_{rotor}$
$x0_{rotor.}$	$x0_{stator.}$
$y0_{rotor.}$	$y0_{stator.}$
$\alpha\_major_{rotor.}$	$\alpha\_major_{stator.}$
$Ju_{rotor.}$	$Ju_{stator.}$
$Jv_{rotor.}$	$Jv_{stator.}$
$CPx_{rotor.}$	$CPx_{stator.}$
$CPy_{rotor.}$	$CPy_{stator.}$
$CPx_{rotor.axis}$	$CPx_{stator.axis}$
$CPy_{rotor.axis}$	$CPy_{stator.axis}$
$Wp_{rotor.}$	$Wp_{stator.}$
$M\tau_{rotor}$	$M\tau_{stator}$
τ_{rotor}	τ_{stator}
φ_uv_{rotor}	φ_uv_{stator}
Mu_{rotor}	Mu_{stator}
Mv_{rotor}	Mv_{stator}
$\varphi\_neutral_{rotor}$	$\varphi\_neutral_{stator}$

Расчет Л на прочность

$$\text{neutral\_line}(\text{type},x,i,r) = \begin{cases} \dfrac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \tan\left(\left(\alpha\_\text{major}_{\text{rotor}_{i,r}} + \varphi\_\text{neutral}_{\text{rotor}}\left(i, R_{\text{st}(i,2),r}\right)\right)\right)\cdot\left(x - \dfrac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if type = "rotor"} \\ \dfrac{y0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}} + \tan\left(\left(\alpha\_\text{major}_{\text{stator}_{i,r}} + \varphi\_\text{neutral}_{\text{stator}}\left(i, R_{\text{st}(i,2),r}\right)\right)\right)\cdot\left(x - \dfrac{x0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}}\right) & \text{if type = "stator"} \end{cases}$$

$$\text{epure}(\text{type},x,i,r) = \begin{cases} \dfrac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \dfrac{-1}{\tan\left(\alpha\_\text{major}_{\text{rotor}_{i,r}} + \varphi\_\text{neutral}_{\text{rotor}}\left(i, R_{\text{st}(i,2),r}\right) - \dfrac{\pi}{4}\right)}\cdot\left(x - \dfrac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if type = "rotor"} \\ \dfrac{y0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}} + \dfrac{-1}{\tan\left(\alpha\_\text{major}_{\text{stator}_{i,r}} + \varphi\_\text{neutral}_{\text{stator}}\left(i, R_{\text{st}(i,2),r}\right) - \dfrac{\pi}{4}\right)}\cdot\left(x - \dfrac{x0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}}\right) & \text{if type = "stator"} \end{cases}$$

Определение координат точек профиля Л, наиболее удаленных от НЛ

Наиболее удаленные точки от НЛ (мм):

$u\_u_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	-2.547	-2.080	-2.107	-1.590	-1.605	-1.621	-1.641	-1.652	-1.659
2	-0.725	-0.724	-0.723	-0.724	-0.724	-0.725	-0.727	-1.361	-1.361
3	0.000	-0.818	-0.817	-0.817	-0.817	-0.817	-0.818	-0.818	-0.818

$\cdot 10^{-3}$

$v\_u_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	4.006	3.850	3.795	3.707	3.653	3.586	3.474	3.401	3.366
2	1.463	1.478	1.503	1.491	1.486	1.467	1.413	1.375	1.362
3	0.845	0.908	0.935	0.936	0.941	0.934	0.901	0.876	0.872

$\cdot 10^{-3}$

$u\_l_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	29.509	29.617	29.649	29.138	28.068	26.997	-12.640	-9.373	-9.369
2	34.666	34.665	34.664	34.665	34.665	34.666	-21.609	-20.343	-19.710
3	23.293	38.705	38.704	38.704	38.704	38.704	38.705	-24.823	-24.822

$\cdot 10^{-3}$

$v\_l_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	-5.036	-4.050	-3.697	-3.228	-2.970	-2.690	-2.694	-2.726	-2.749
2	-1.331	-1.388	-1.487	-1.437	-1.415	-1.335	-1.158	-1.117	-1.106
3	-0.582	-0.819	-0.929	-0.935	-0.952	-0.925	-0.791	-0.730	-0.725

$\cdot 10^{-3}$

$u\_u_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	0.206	0.209	-1.564	-1.570	-1.618	-1.584	-1.326	-1.146	-1.070
2	-0.014	-0.009	-0.001	-0.000	0.003	0.003	-0.008	-0.014	-0.017
3	-0.276	-0.268	-0.257	-0.256	-0.252	-0.250	-0.264	-0.273	-0.278

$\cdot 10^{-3}$

$v\_u_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	0.766	0.804	10.237	10.237	10.240	10.238	10.225	10.217	10.214
2	1.210	1.258	1.328	1.333	1.351	1.342	1.257	1.194	1.166
3	1.703	1.752	1.829	1.838	1.859	1.853	1.767	1.703	1.673

$\cdot 10^{-3}$

$u\_l_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	12.342	12.335	-2.137	-2.146	-2.210	-2.164	-1.812	-1.567	-1.464
2	13.697	13.687	13.669	13.668	13.662	13.661	13.685	13.698	13.704
3	14.811	14.799	14.779	14.776	14.769	14.766	14.793	14.808	14.815

$\cdot 10^{-3}$

$v\_l_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	-1.735	-1.903	-12.327	-12.327	-12.324	-12.326	-12.341	-12.351	-12.354
2	-1.876	-2.094	-2.411	-2.435	-2.522	-2.500	-2.102	-1.826	-1.699
3	-2.005	-2.237	-2.588	-2.627	-2.733	-2.729	-2.319	-2.032	-1.891

$\cdot 10^{-3}$

$$\begin{pmatrix} \sigma\_p_{rotor} & \sigma\_n_{rotor} \\ \sigma\_p_{stator} & \sigma\_n_{stator} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } r \in 1..N_r \\ \quad \begin{pmatrix} \sigma\_p_{rotor_{i,r}} & \sigma\_n_{rotor_{i,r}} \\ \sigma\_p_{stator_{i,r}} & \sigma\_n_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \frac{Mu_{rotor}(i, R_{st(i,2),r})}{Ju_{rotor_{i,r}}} \cdot v\_u_{rotor_{i,r}} - \frac{Mv_{rotor}(i, R_{st(i,2),r})}{Jv_{rotor_{i,r}}} \cdot u\_u_{rotor_{i,r}} & \frac{Mu_{rotor}(i, R_{st(i,2),r})}{Ju_{rotor_{i,r}}} \cdot v\_l_{rotor_{i,r}} - \frac{Mv_{rotor}(i, R_{st(i,2),r})}{Jv_{rotor_{i,r}}} \cdot u\_l_{rotor_{i,r}} \\ \frac{Mu_{stator}(i, R_{st(i,2),r})}{Ju_{stator_{i,r}}} \cdot v\_u_{stator_{i,r}} - \frac{Mv_{stator}(i, R_{st(i,2),r})}{Jv_{stator_{i,r}}} \cdot u\_u_{stator_{i,r}} & \frac{Mu_{stator}(i, R_{st(i,2),r})}{Ju_{stator_{i,r}}} \cdot v\_l_{stator_{i,r}} - \frac{Mv_{stator}(i, R_{st(i,2),r})}{Jv_{stator_{i,r}}} \cdot u\_l_{stator_{i,r}} \end{pmatrix} \\ \begin{pmatrix} \sigma\_p_{rotor} & \sigma\_n_{rotor} \\ \sigma\_p_{stator} & \sigma\_n_{stator} \end{pmatrix} \end{array} \right.$$

$$\begin{pmatrix} \sigma\_p_{rotor.} & \sigma\_p_{stator.} \\ \sigma\_n_{rotor.} & \sigma\_n_{stator.} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \sigma\_p_{rotor.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{rotor}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{rotor}, i, i, 1, N_r\right)^T, z\right) \\ \quad \sigma\_p_{stator.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{stator}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{stator}, i, i, 1, N_r\right)^T, z\right) \\ \quad \sigma\_n_{rotor.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{rotor}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{rotor}, i, i, 1, N_r\right)^T, z\right) \\ \quad \sigma\_n_{stator.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{stator}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{stator}, i, i, 1, N_r\right)^T, z\right) \\ \begin{pmatrix} \sigma\_p_{rotor.} & \sigma\_p_{stator.} \\ \sigma\_n_{rotor.} & \sigma\_n_{stator.} \end{pmatrix} \end{array} \right.$$

$\sigma\_p_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	-24.59	-35.43	-47.02	-62.63	-78.53	-98.25	-143.38	-184.44	-193.90
2	-66.85	-75.01	-90.36	-110.97	-132.28	-160.03	-230.81	-296.24	-315.96
3	-0.34	-0.29	-1.04	-0.93	-0.85	-0.74	-0.57	-0.38	-1.16

$\cdot 10^{6}$

$\sigma\_p_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	0.55	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	83.95	58.73	39.85	38.94	28.76	14.34	14.90	12.68	12.98
3	134.64	98.88	68.11	67.27	50.49	25.15	24.90	20.35	20.51

$\cdot 10^{6}$

$\sigma\_p_{rotor}^{T} \le 70 \cdot 10^{6} =$

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

$\sigma\_p_{stator}^{T} \le 70 \cdot 10^{6} =$

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

$\sigma\_n_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	38.31	45.18	54.66	64.61	74.69	85.27	103.32	140.76	151.40
2	63.68	73.61	93.21	111.30	130.92	151.20	184.57	235.46	251.55
3	0.24	0.27	1.06	0.95	0.88	0.74	0.51	0.31	0.95

$\cdot 10^{6}$

$\sigma\_n_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9
1	-1.25	-0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	-132.36	-99.95	-74.49	-73.17	-55.40	-27.72	-25.65	-19.85	-19.28
3	-162.26	-130.36	-100.17	-99.90	-77.32	-38.87	-34.05	-25.17	-23.91

$\cdot 10^{6}$

$\sigma\_n_{rotor}^{T} \le 70 \cdot 10^{6} =$

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

$\sigma\_n_{stator}^{T} \le 70 \cdot 10^{6} =$

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

$$\begin{pmatrix}\sigma_{rotor}\\ \sigma_{stator}\end{pmatrix} = \left|\begin{array}{l}\text{for } i \in 1..Z\\ \quad \text{for } r \in 1..N_r\\ \quad\left|\begin{array}{l}\sigma_{rotor_{i,r}} = \sqrt{\left(\sigma\_z_{rotor}\left(i, R_{st(i,2),r}\right) + \max\left(\sigma\_p_{rotor_{i,r}}, \sigma\_n_{rotor_{i,r}}\right)\right)^2 + \tau_{rotor}\left(i, R_{st(i,2),r}\right)^2}\\ \sigma_{stator_{i,r}} = \sqrt{\left(0 + \max\left(\sigma\_p_{stator_{i,r}}, \sigma\_n_{stator_{i,r}}\right)\right)^2 + \tau_{stator}\left(i, R_{st(i,2),r}\right)^2}\end{array}\right.\\ \begin{pmatrix}\sigma_{rotor}\\ \sigma_{stator}\end{pmatrix}\end{array}\right.$$

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

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

	1	2	3	4	5	6	7	8	9
1	152.77	142.09	138.21	137.27	139.06	143.07	156.39	190.65	233.81
2	153.13	150.11	160.35	169.30	182.06	196.87	226.18	274.33	316.42
3	5.14	4.21	7.12	5.48	4.42	3.43	2.30	1.52	4.37

$\cdot 10^6$

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

	1	2	3	4	5	6	7	8	9
1	0.57	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	83.95	58.74	39.86	38.95	28.78	14.35	14.91	12.68	12.99
3	134.64	98.88	68.12	67.28	50.50	25.15	24.91	20.35	20.52

$\cdot 10^6$

$$\begin{pmatrix} safety_{rotor} \\ safety_{stator} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } r \in 1..N_r \\ \quad\quad safety_{rotor_{i,r}} = \begin{cases} \dfrac{\sigma\_blade\_long_i}{\sigma_{rotor_{i,r}}} & \text{if } \sigma_{rotor_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{cases} \\ \quad\quad safety_{stator_{i,r}} = \begin{cases} \dfrac{\sigma\_blade\_long_i}{\sigma_{stator_{i,r}}} & \text{if } \sigma_{stator_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{cases} \\ \begin{pmatrix} safety_{rotor} \\ safety_{stator} \end{pmatrix} \end{array} \right.$$

$safety_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9
1	1.31	1.41	1.45	1.46	1.44	1.05	0.96	0.79	0.53
2	1.31	1.33	1.25	1.18	1.10	0.76	0.66	0.55	0.39
3	38.90	47.54	28.09	36.53	45.26	43.76	65.24	98.98	28.13

$safety_{rotor}^{T} \geq safety =$

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

$safety_{stator}^{T} =$

	1	2	3	4	5
1	352.11	562.93	000000000000000000000000000000	000000000000000000000000000000	000000000000000000000000000000
2	2.38	3.4	5.02	5.13	6.95
3	1.49	2.02	2.94	2.97	...

$safety_{stator}^{T} \geq safety =$

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

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

$b_{lim} = \dfrac{\operatorname{ceil}\left(\max\left(\text{chord}_{\text{rotor}_{j,N_r}}, \text{chord}_{\text{stator}_{j,N_r}}\right)\cdot 10^2\right)}{10^2} = 80\cdot 10^{-3}$

Расстояния от оси ЛМ до рассматриваемой ступени (м): $Rj = \text{submatrix}\left(R, 2\cdot j - 1, 2\cdot j + 1, 1, N_r\right) =$

	1	2	3
1	177.3	230.8	274.1
2	182.2	230.8	270.8
3	186.8	230.8	267.7

$\cdot 10^{-3}$

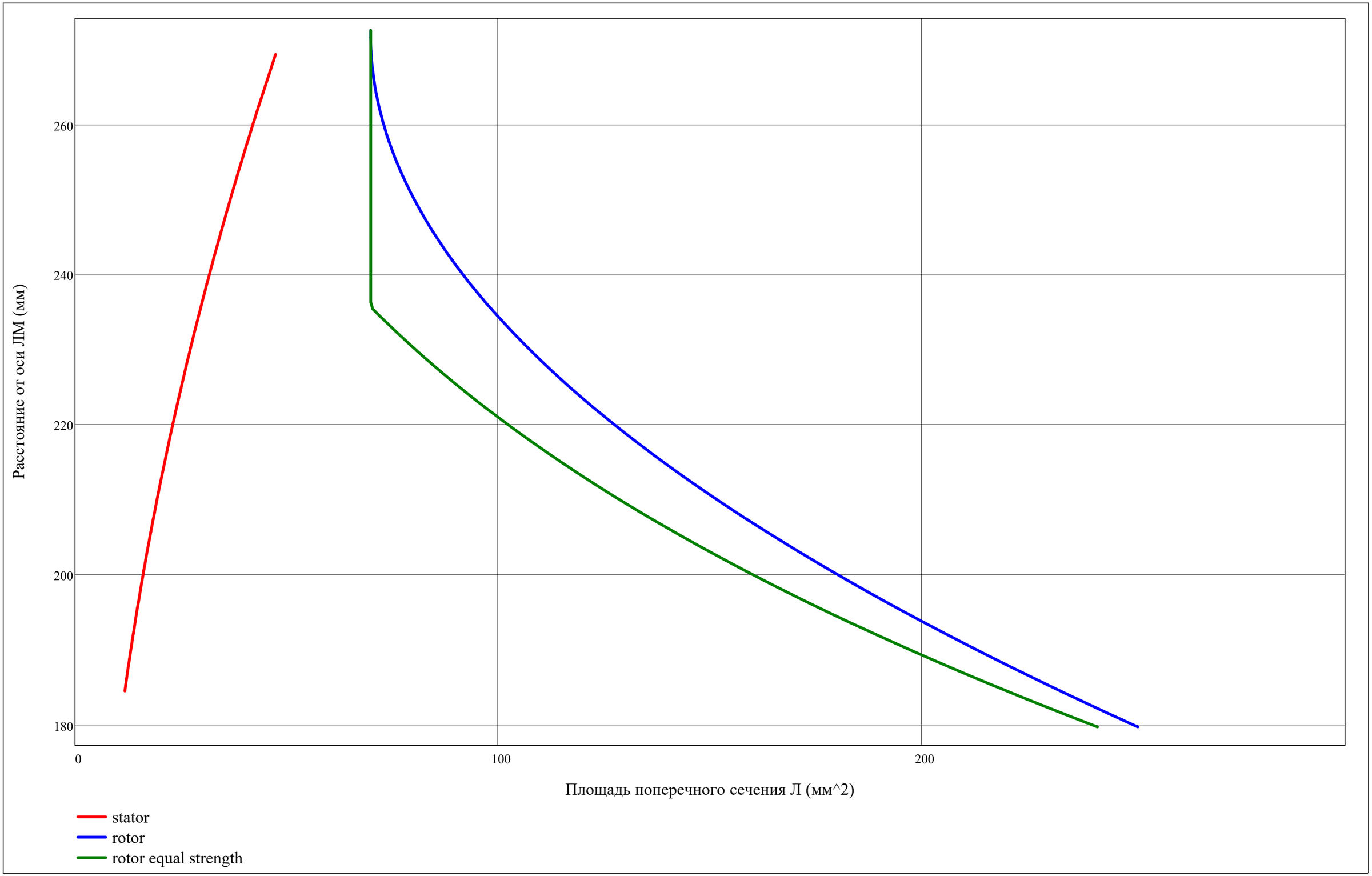
Дискретизация по высоте Л:

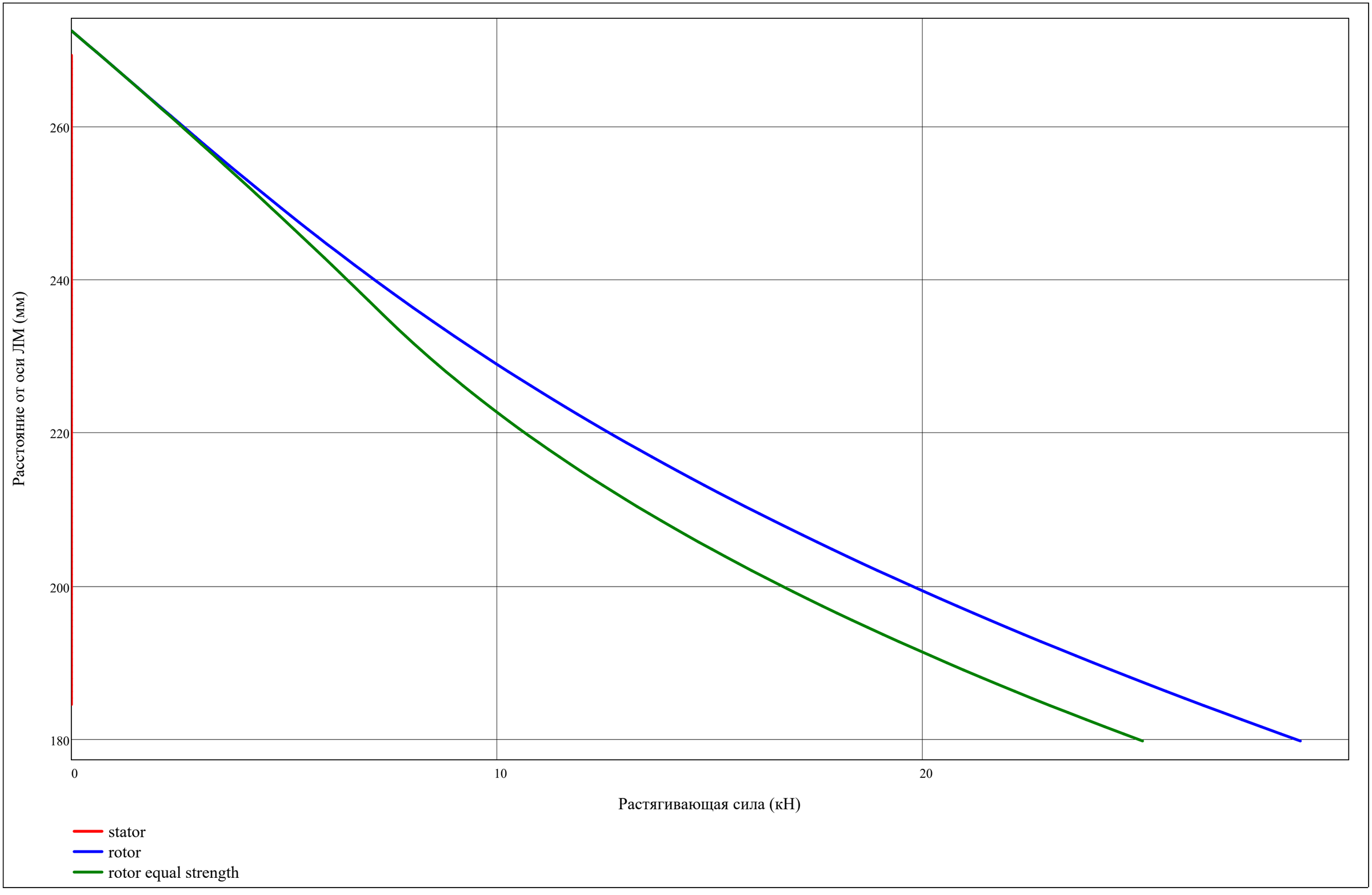
$z = \min(Rj), \min(Rj) + \dfrac{\max(Rj) - \min(Rj)}{100} .. \max(Rj)$

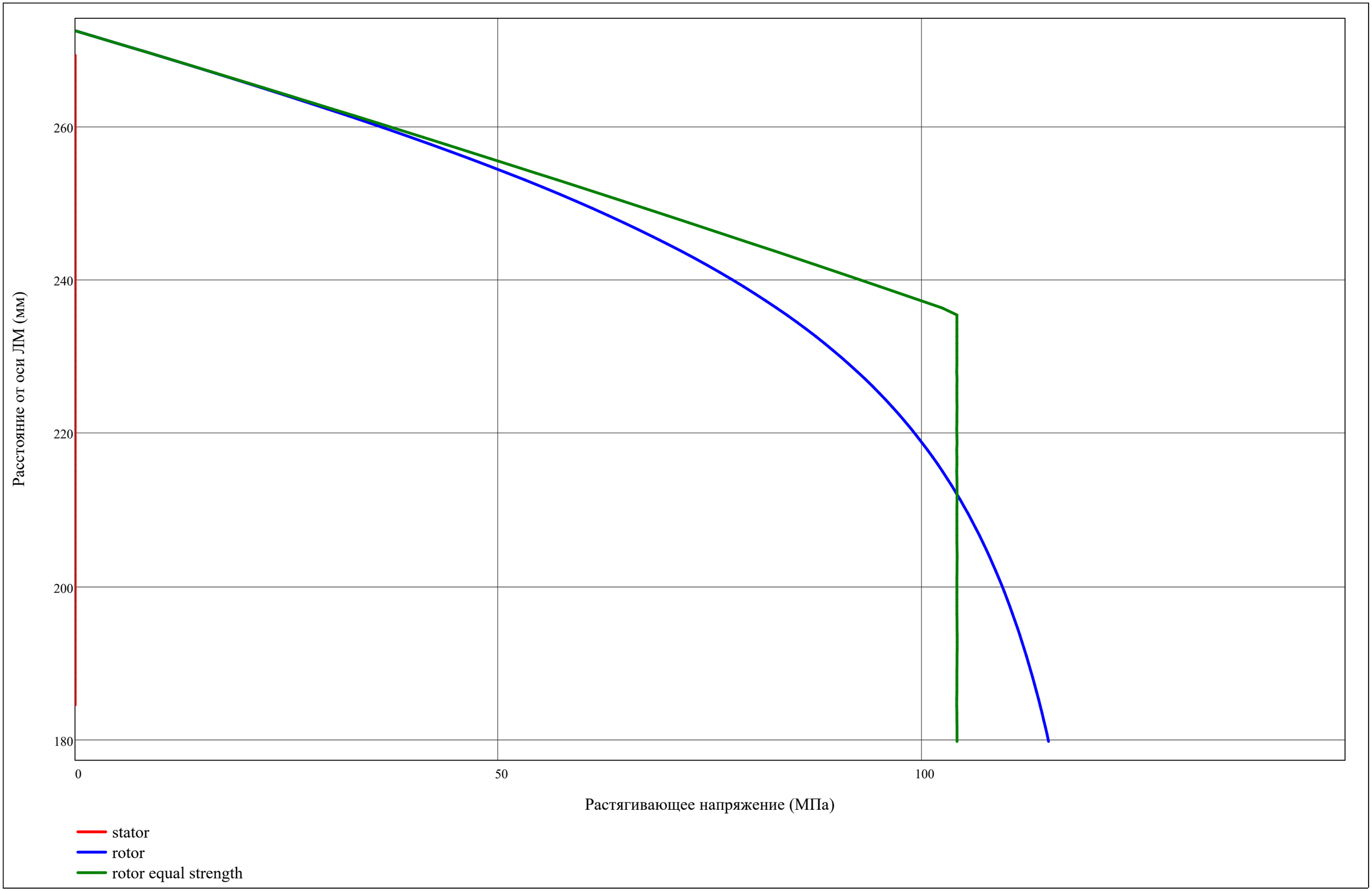
$z_{rotor} = \begin{cases} \text{mean}\left(Rj_{1,1}, Rj_{2,1}\right), \text{mean}\left(Rj_{1,1}, Rj_{2,1}\right) + \dfrac{\text{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) - \text{mean}\left(Rj_{1,1}, Rj_{2,1}\right)}{100} .. \text{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) & \text{if type = "compressor"} \\ \text{mean}\left(Rj_{2,1}, Rj_{3,1}\right), \text{mean}\left(Rj_{2,1}, Rj_{3,1}\right) + \dfrac{\text{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) - \text{mean}\left(Rj_{2,1}, Rj_{3,1}\right)}{100} .. \text{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) & \text{if type = "turbine"} \end{cases}$

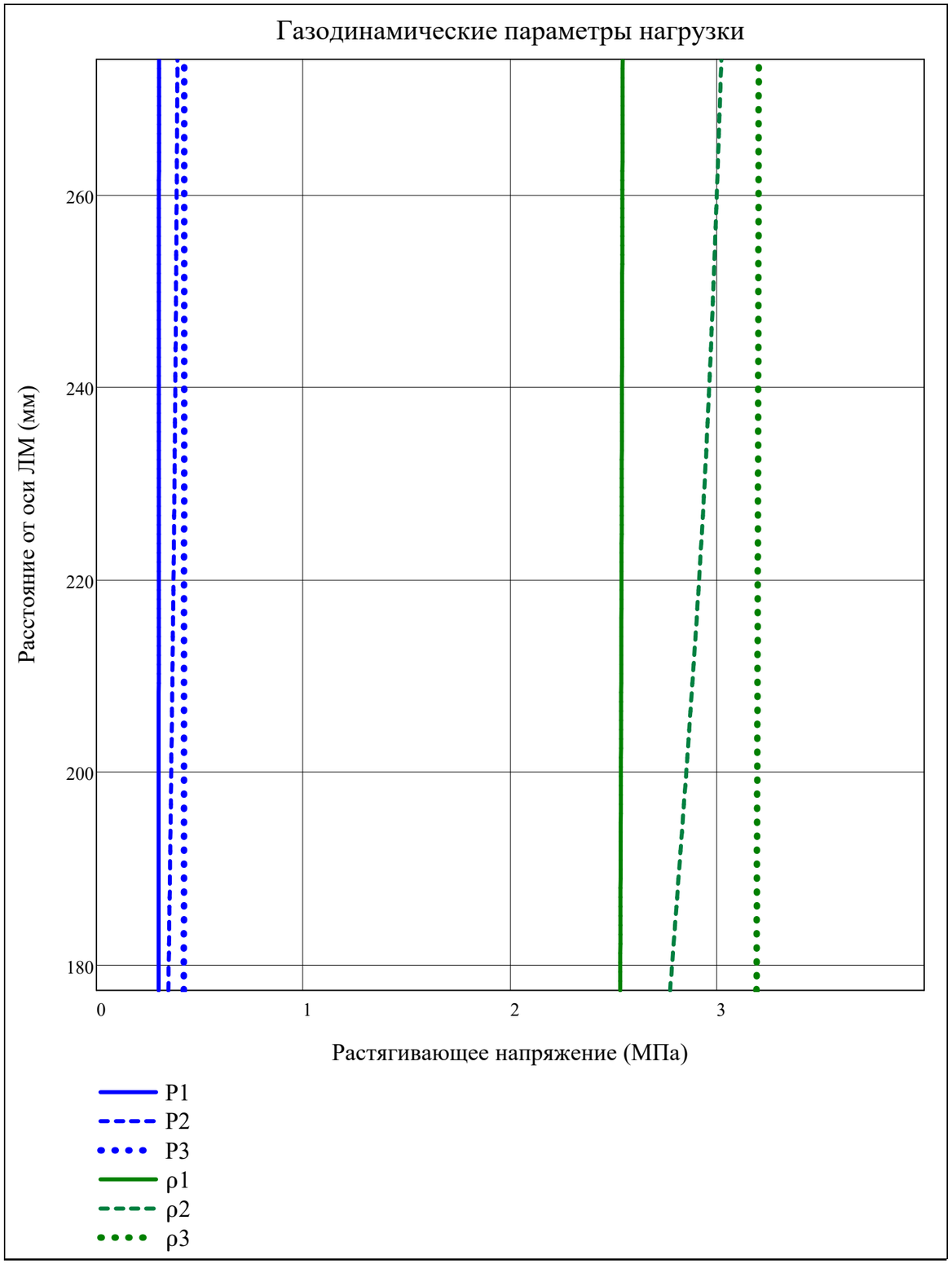
$z_{stator} = \begin{cases} \text{mean}\left(Rj_{2,1}, Rj_{3,1}\right), \text{mean}\left(Rj_{2,1}, Rj_{3,1}\right) + \dfrac{\text{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) - \text{mean}\left(Rj_{2,1}, Rj_{3,1}\right)}{100} .. \text{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) & \text{if type = "compressor"} \\ \text{mean}\left(Rj_{1,1}, Rj_{2,1}\right), \text{mean}\left(Rj_{1,1}, Rj_{2,1}\right) + \dfrac{\text{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) - \text{mean}\left(Rj_{1,1}, Rj_{2,1}\right)}{100} .. \text{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) & \text{if type = "turbine"} \end{cases}$

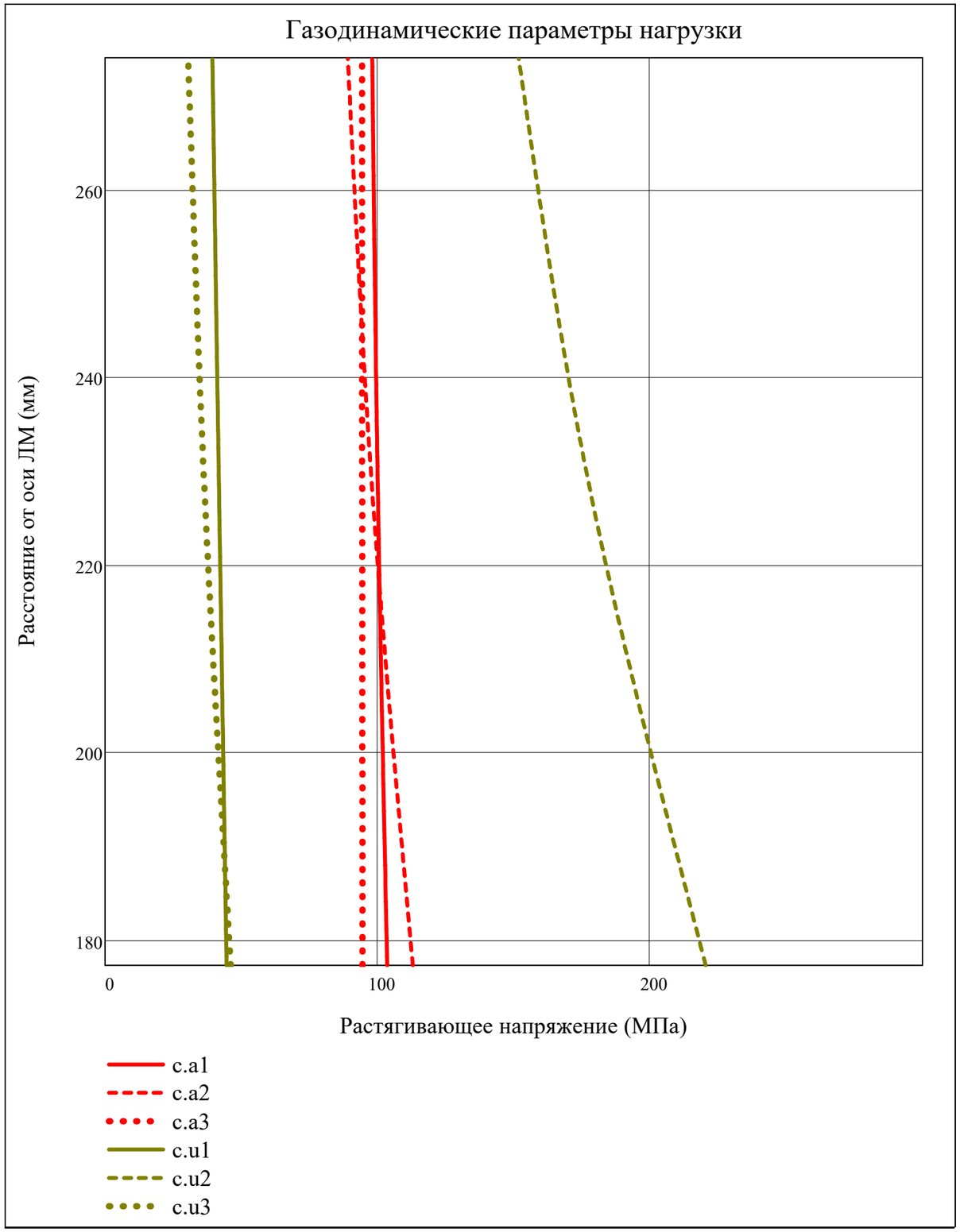
Результаты расчета на прочность Л

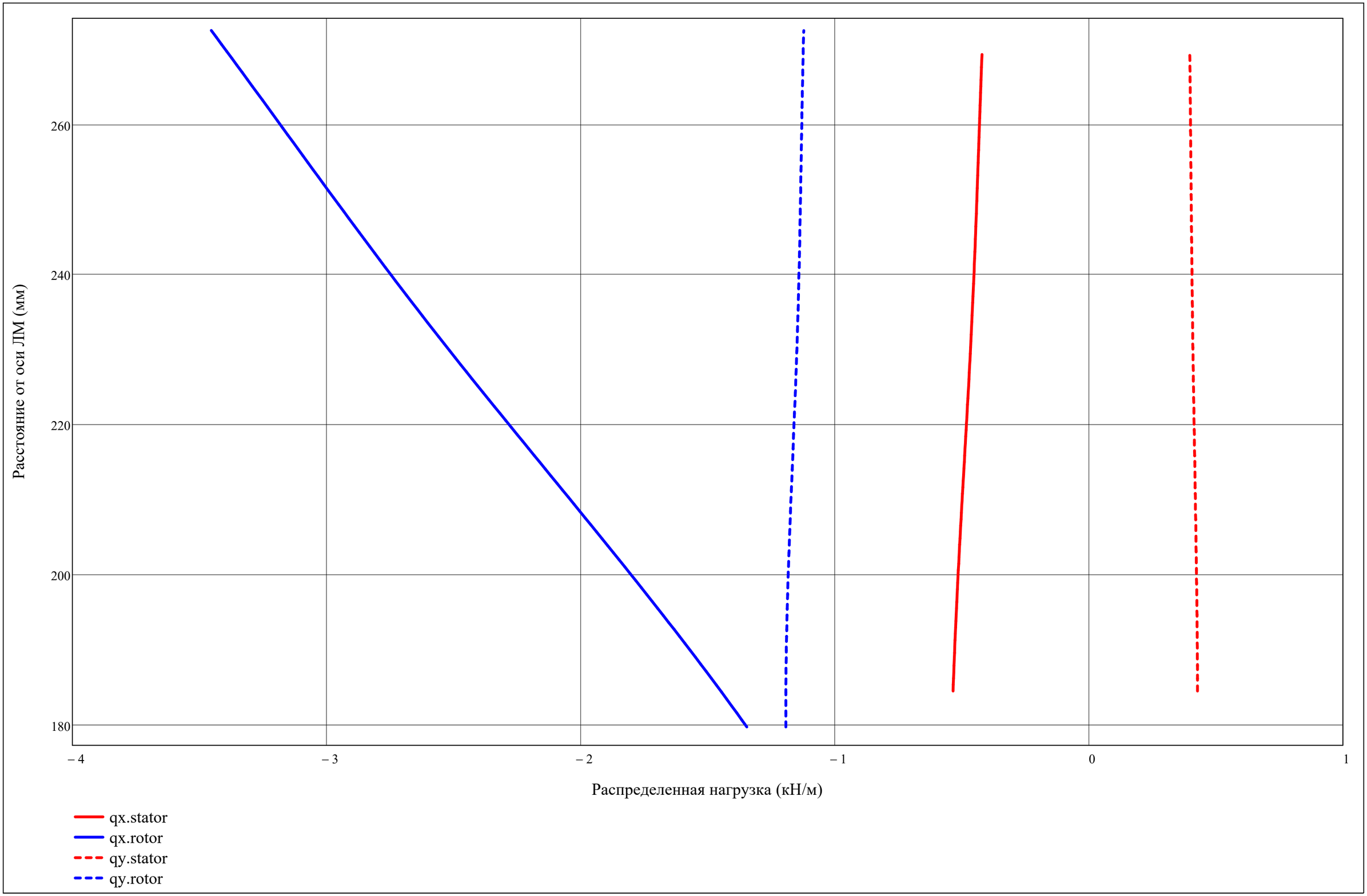

260
240
220
200
180
0
100
200
Расстояние от оси ЛМ (мм)
Площадь поперечного сечения Л (мм^2)
stator
rotor
rotor equal strength

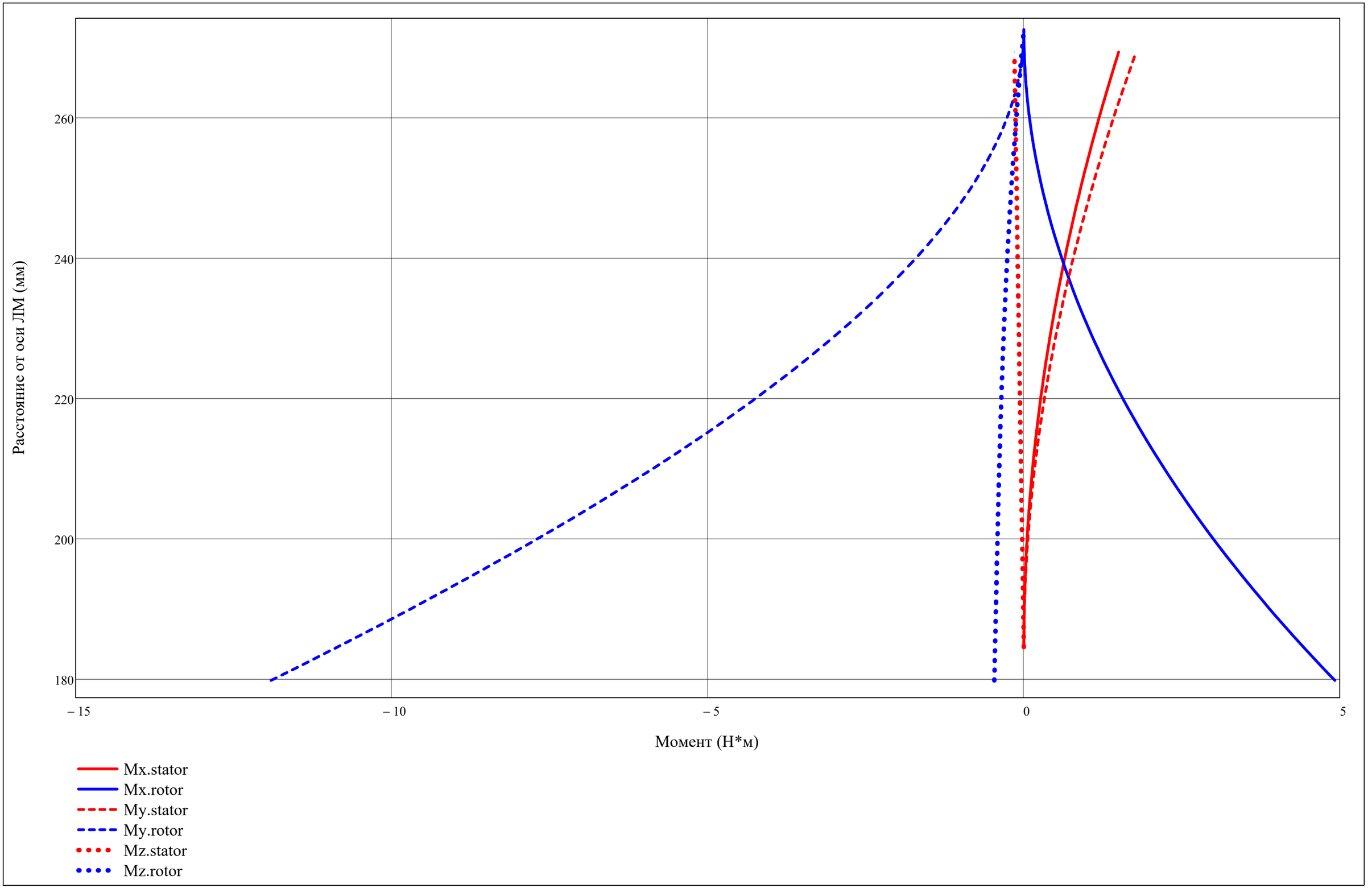

260
240
220
200
180
0
10
20
Расстояние от оси ЛМ (мм)
Растягивающая сила (кН)
stator
rotor
rotor equal strength

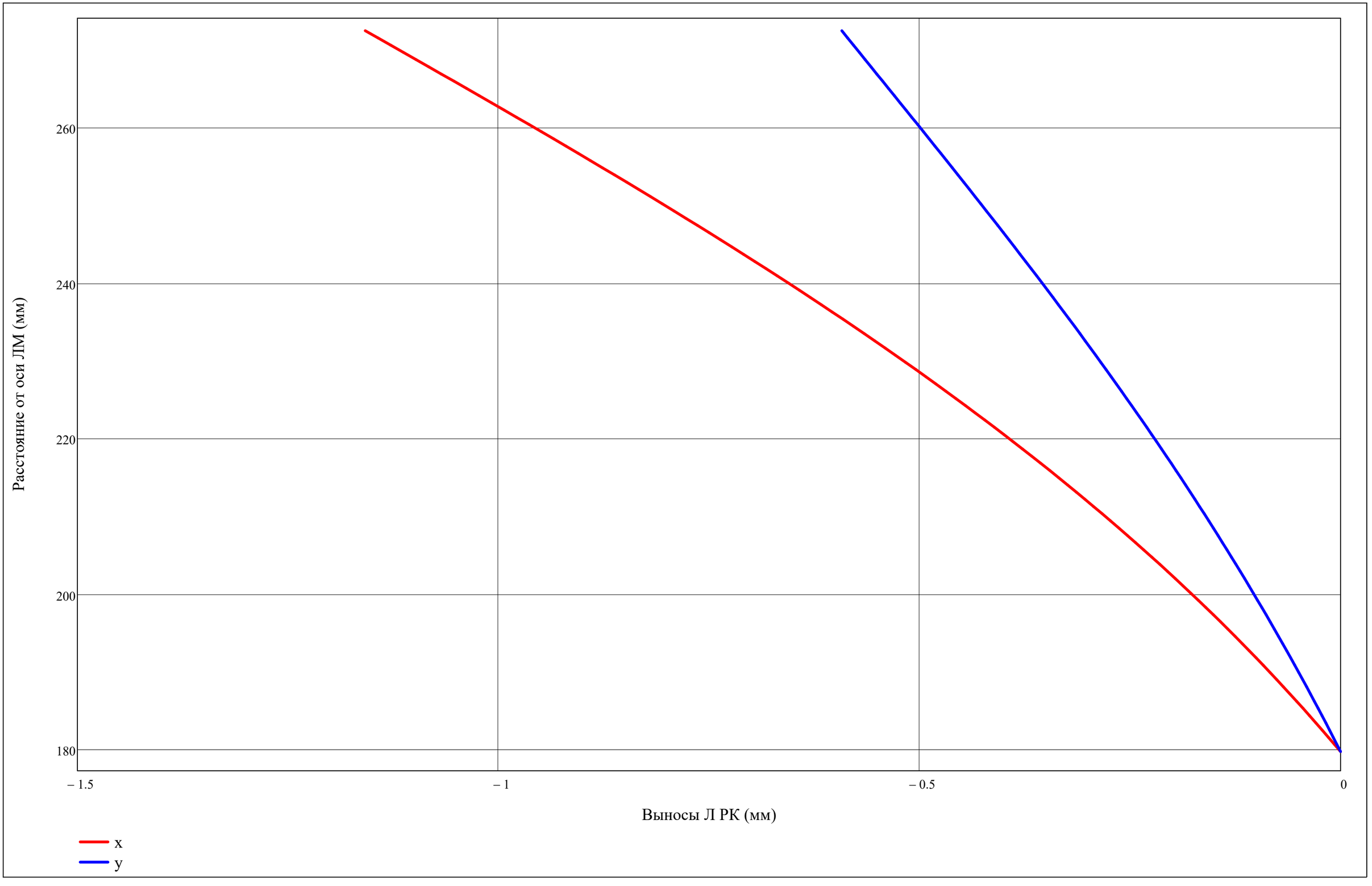

260
240
220
200
180
0
50
100
Расстояние от оси ЛМ (мм)
Растягивающее напряжение (МПа)
stator
rotor
rotor equal strength

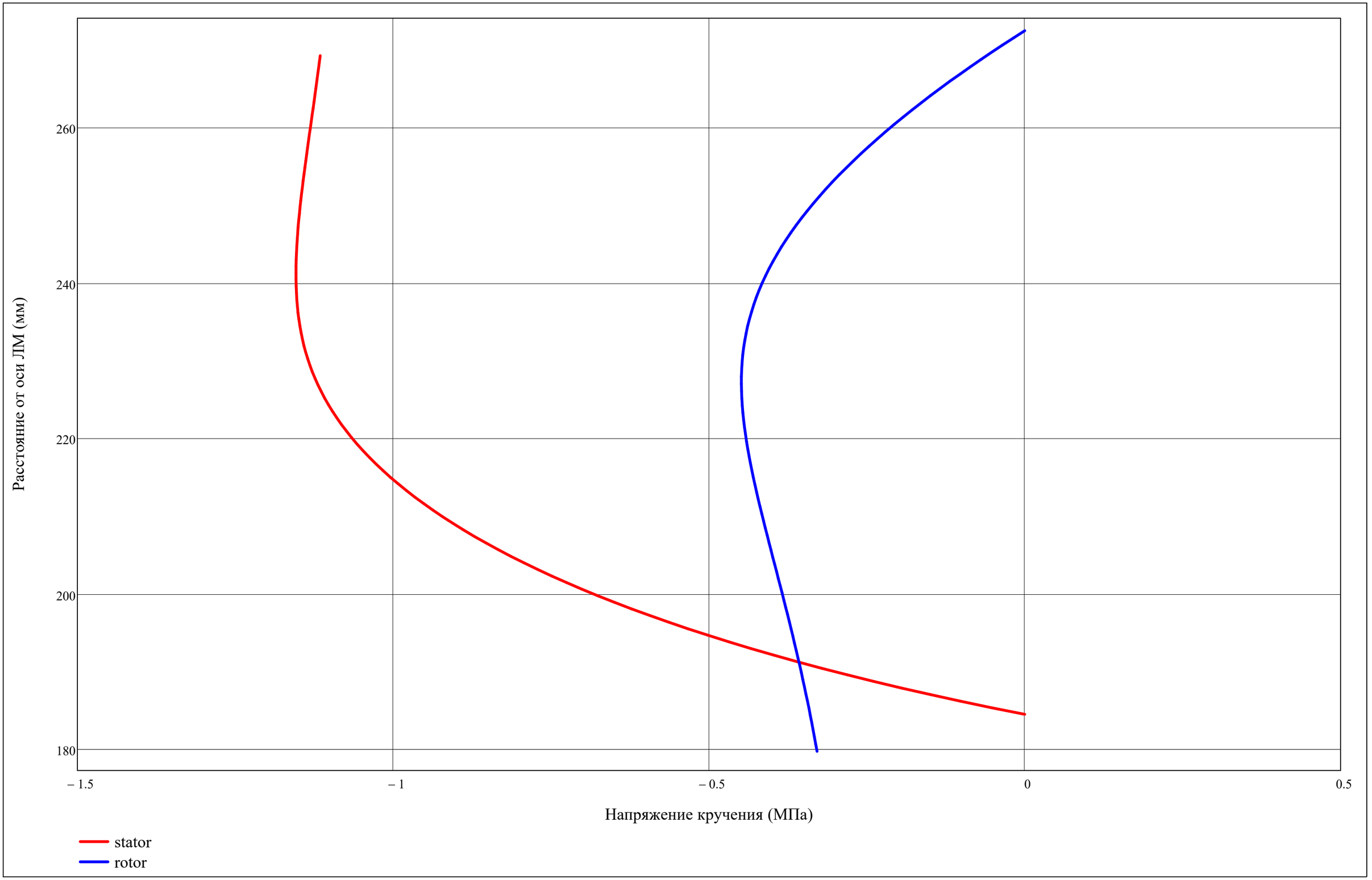

Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
260
240
220
200
180
0
1
2
3
Растягивающее напряжение (МПа)
P1
P2
P3
ρ1
ρ2
ρ3

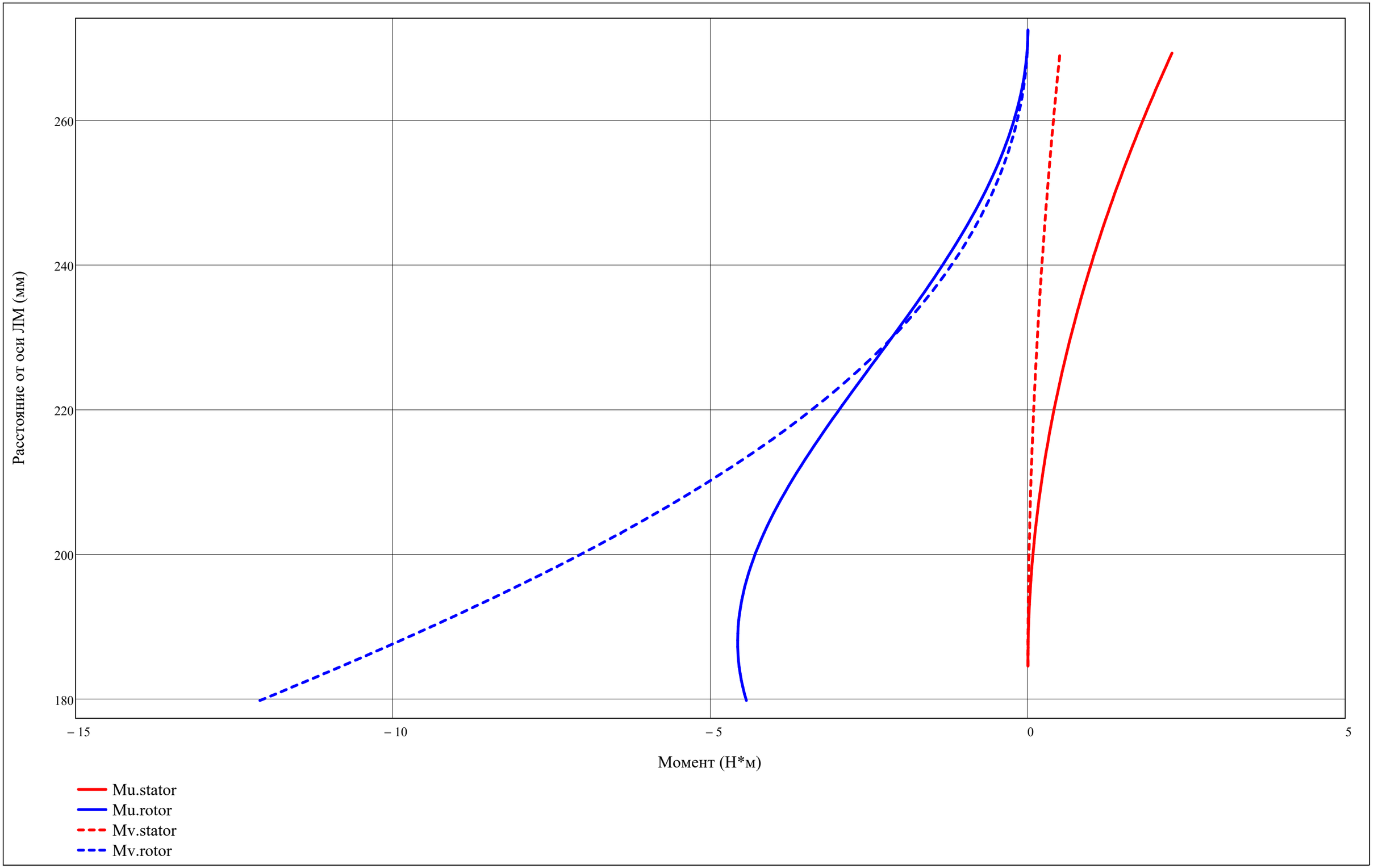

Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
260
240
220
200
180
0
100
200
Растягивающее напряжение (МПа)
c.a1
c.a2
c.a3
c.u1
c.u2
c.u3

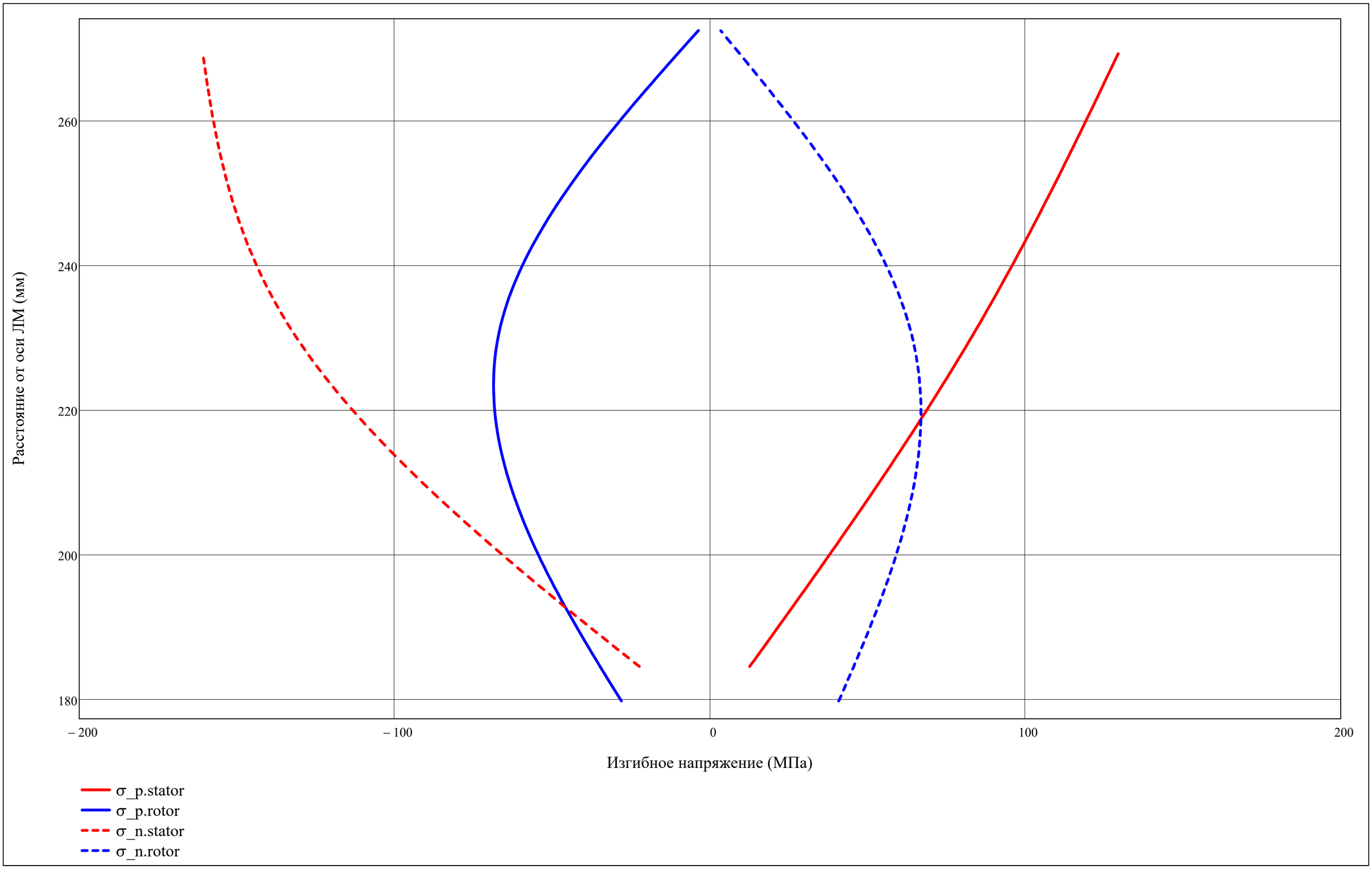

Расстояние от оси ЛМ (мм)
260
240
220
200
180
– 4
– 3
– 2
– 1
0
1
Распределенная нагрузка (кН/м)
qx.stator
qx.rotor
qy.stator
qy.rotor

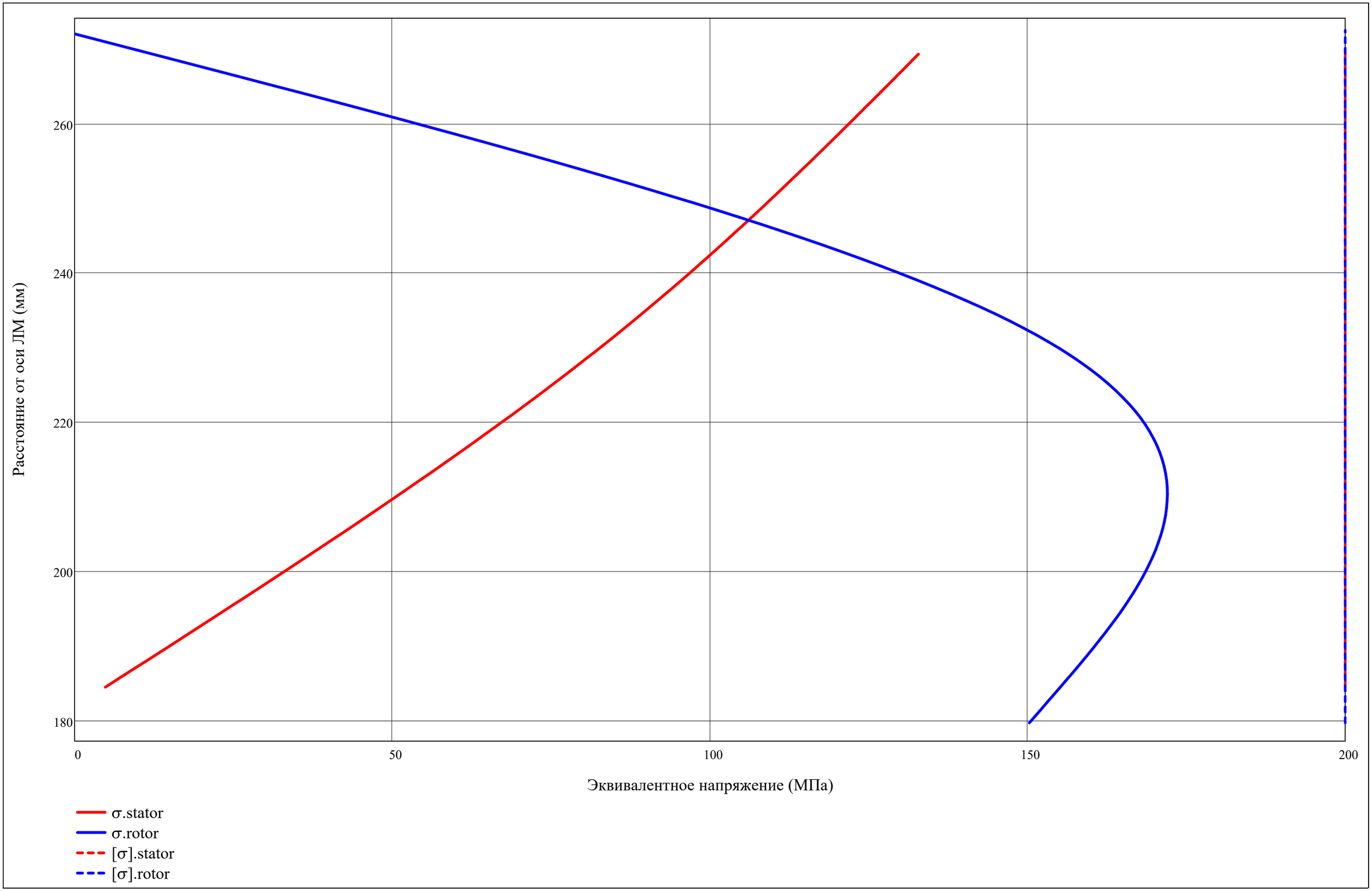

Расстояние от оси ЛМ (мм)
260
240
220
200
180
– 15
– 10
– 5
0
5
Момент (Н*м)
Mx.stator
Mx.rotor
My.stator
My.rotor
Mz.stator
Mz.rotor


260
240
220
200
180
– 1.5
– 1
– 0.5
0
Расстояние от оси ЛМ (мм)
Выносы Л РК (мм)
x
y


260
240
220
200
180
– 1.5
– 1
– 0.5
0
0.5
Расстояние от оси ЛМ (мм)
Напряжение кручения (МПа)
stator
rotor


260
240
220
200
180
Расстояние от оси ЛМ (мм)
– 15
– 10
– 5
0
5
Момент (Н*м)
Mu.stator
Mu.rotor
Mv.stator
Mv.rotor


260
240
220
200
180
– 200
– 100
0
100
200
Расстояние от оси ЛМ (мм)
Изгибное напряжение (МПа)
σ_p.stator
σ_p.rotor
σ_n.stator
σ_n.rotor


260
240
220
200
180
0
50
100
150
200
Расстояние от оси ЛМ (мм)
Эквивалентное напряжение (МПа)
σ.stator
σ.rotor
[σ].stator
[σ].rotor

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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u\text{rotor}_{j,r} & v\_u\text{rotor}_{j,r} \\ u\_l\text{rotor}_{j,r} & v\_l\text{rotor}_{j,r} \\ u\_u\text{stator}_{j,r} & v\_u\text{stator}_{j,r} \\ u\_l\text{stator}_{j,r} & v\_l\text{stator}_{j,r} \end{pmatrix} = \begin{array}{|c|cc|} \hline & 1 & 2 \\ \hline 1 & -2.55 & 4.01 \\ 2 & 29.51 & -5.04 \\ 3 & 0.21 & 0.77 \\ 4 & 12.34 & -1.74 \\ \hline \end{array} \cdot 10^{-3}$$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p\text{rotor}_{j,r} & \sigma\_p\text{stator}_{j,r} \\ \sigma\_n\text{rotor}_{j,r} & \sigma\_n\text{stator}_{j,r} \end{pmatrix} = \begin{pmatrix} -25 & 1 \\ 38 & -1 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma\text{stator}_{j,r} \\ \sigma\text{rotor}_{j,r} \end{pmatrix} = \begin{pmatrix} 1 \\ 153 \end{pmatrix} \cdot 10^{6}$$

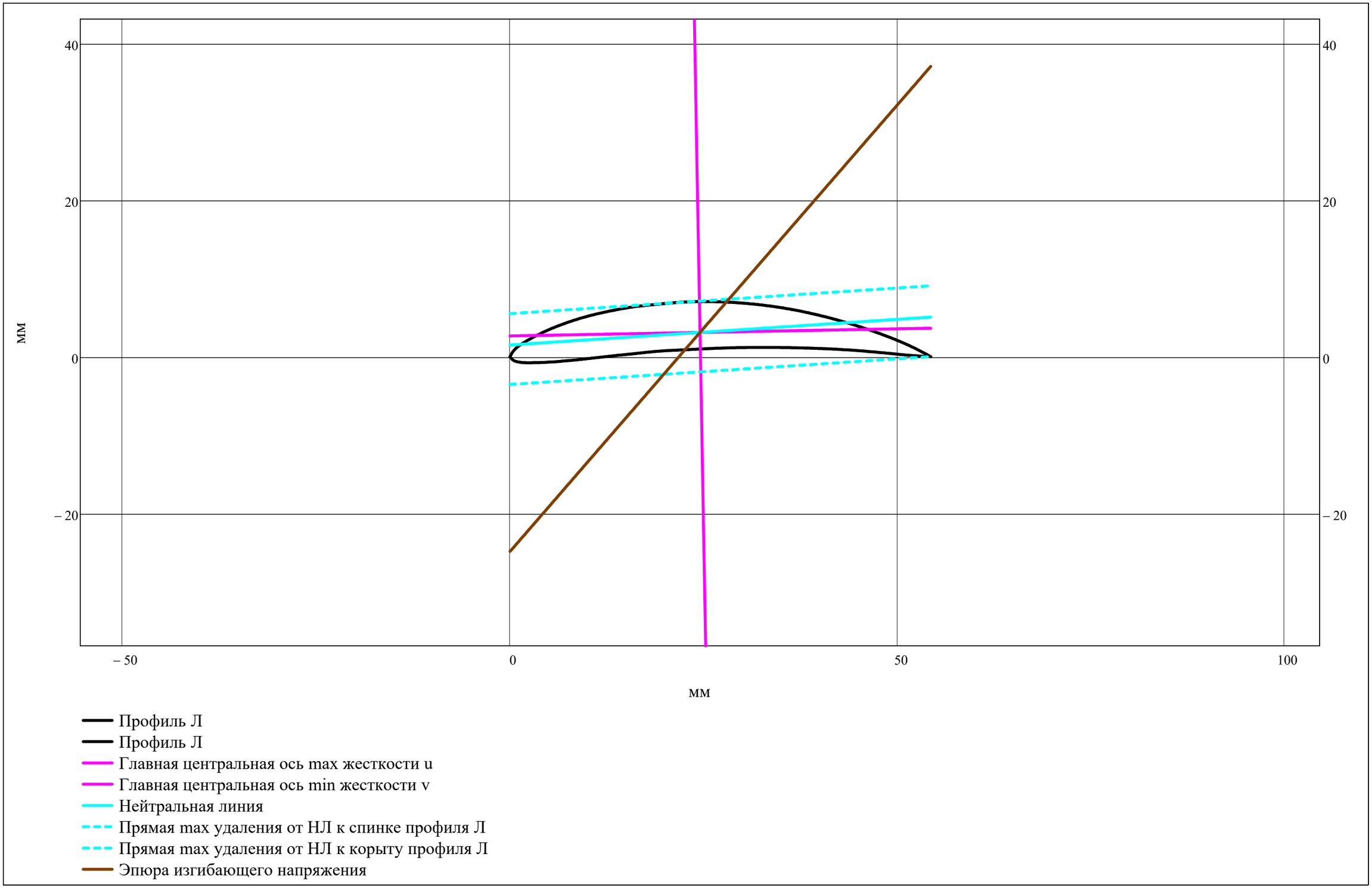
Коэф. запаса:

$$\begin{pmatrix} \text{safety}\text{stator}_{j,r} \\ \text{safety}\text{rotor}_{j,r} \end{pmatrix} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 352.115 \\ 2 & 1.309 \\ \hline \end{array}$$

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \begin{cases} \begin{pmatrix} v\_u\text{rotor}_{j,r} \\ v\_l\text{rotor}_{j,r} \end{pmatrix} & \text{if blade} = \text{"rotor"} \\ \begin{pmatrix} v\_u\text{stator}_{j,r} \\ v\_l\text{stator}_{j,r} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 4.006 \\ 2 & -5.036 \\ \hline \end{array} \cdot 10^{-3}$$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0\text{rotor}_{j,r} \\ y0\text{rotor}_{j,r} \end{pmatrix} & \text{if blade} = \text{"rotor"} \\ \begin{pmatrix} x0\text{stator}_{j,r} \\ y0\text{stator}_{j,r} \end{pmatrix} & \text{otherwise} \end{cases} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 24.522 \\ 2 & 3.097 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{chord} = \begin{cases} \text{chord}\text{rotor}_{j,r} & \text{if blade} = \text{"rotor"} \\ \text{chord}\text{stator}_{j,r} & \text{if blade} = \text{"stator"} \end{cases} = 54 \cdot 10^{-3}$$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Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u\mathrm{rotor}_{j,r} & v\_u\mathrm{rotor}_{j,r} \\ u\_l\mathrm{rotor}_{j,r} & v\_l\mathrm{rotor}_{j,r} \\ u\_u\mathrm{stator}_{j,r} & v\_u\mathrm{stator}_{j,r} \\ u\_l\mathrm{stator}_{j,r} & v\_l\mathrm{stator}_{j,r} \end{pmatrix} =$$

	1	2
1	-0.72	1.46
2	34.67	-1.33
3	-0.01	1.21
4	13.70	-1.88

$\cdot 10^{-3}$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p\mathrm{rotor}_{j,r} & \sigma\_p\mathrm{stator}_{j,r} \\ \sigma\_n\mathrm{rotor}_{j,r} & \sigma\_n\mathrm{stator}_{j,r} \end{pmatrix} = \begin{pmatrix} -67 & 84 \\ 64 & -132 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma\mathrm{stator}_{j,r} \\ \sigma\mathrm{rotor}_{j,r} \end{pmatrix} = \begin{pmatrix} 84 \\ 153 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса:

$$\begin{pmatrix} \mathrm{safety}\_\mathrm{stator}_{j,r} \\ \mathrm{safety}\_\mathrm{rotor}_{j,r} \end{pmatrix} =$$

	1
1	2.382
2	1.306

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \begin{cases} \begin{pmatrix} v\_u\mathrm{rotor}_{j,r} \\ v\_l\mathrm{rotor}_{j,r} \end{pmatrix} & \text{if } blade = "rotor" \\ \begin{pmatrix} v\_u\mathrm{stator}_{j,r} \\ v\_l\mathrm{stator}_{j,r} \end{pmatrix} & \text{otherwise} \end{cases} =$$

	1
1	1.463
2	-1.331

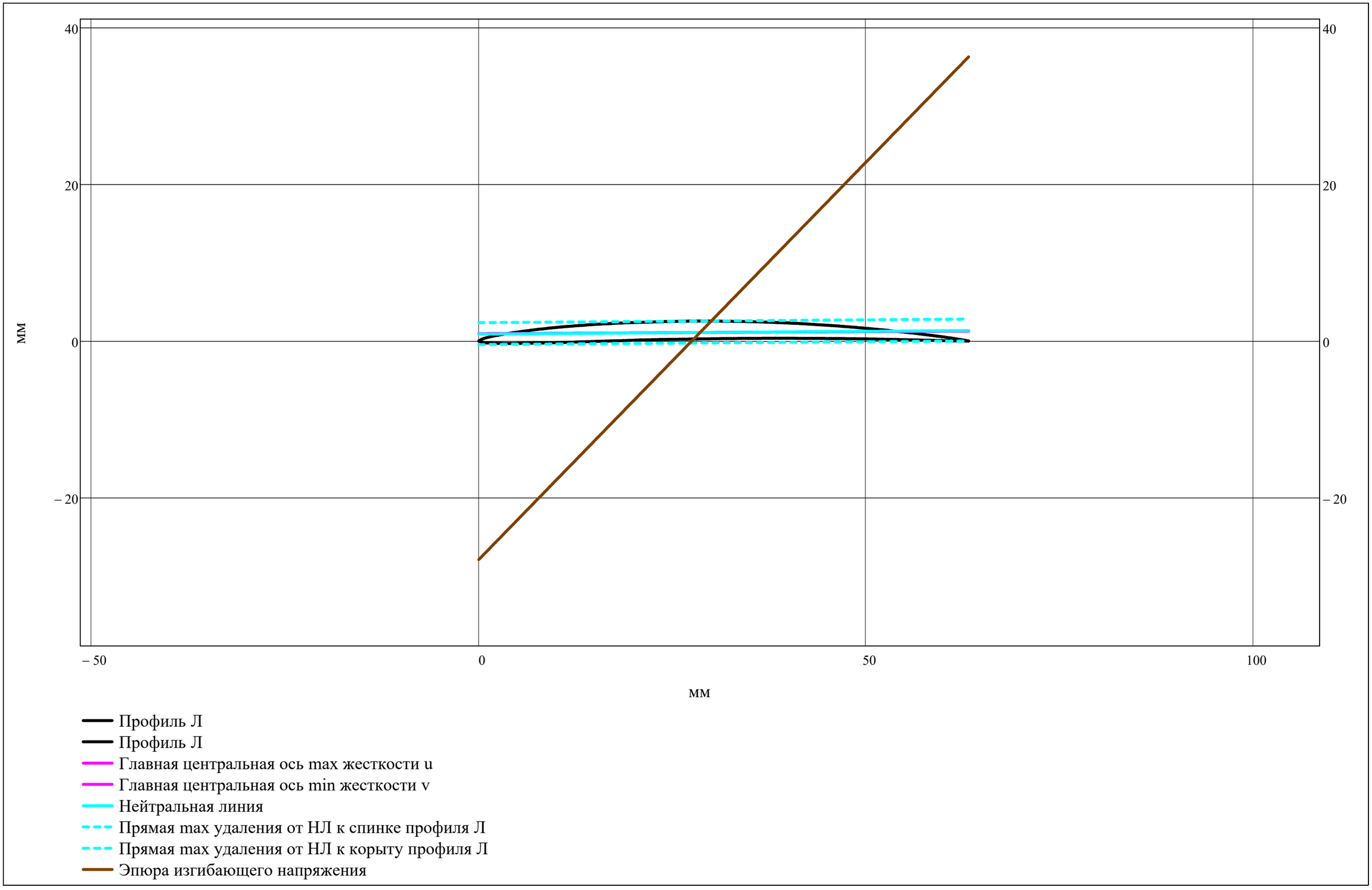
$\cdot 10^{-3}$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0\mathrm{rotor}_{j,r} \\ y0\mathrm{rotor}_{j,r} \end{pmatrix} & \text{if } blade = "rotor" \\ \begin{pmatrix} x0\mathrm{stator}_{j,r} \\ y0\mathrm{stator}_{j,r} \end{pmatrix} & \text{otherwise} \end{cases} =$$

	1
1	28.557
2	1.079

$\cdot 10^{-3}$

$$chord = \begin{cases} \mathrm{chord}\_\mathrm{rotor}_{j,r} & \text{if } blade = "rotor" \\ \mathrm{chord}\_\mathrm{stator}_{j,r} & \text{if } blade = "stator" \end{cases} = 63 \cdot 10^{-3}$$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Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} =$$

	1	2
1	-0.72	1.46
2	34.67	-1.33
3	-0.01	1.21
4	13.70	-1.88

$\cdot 10^{-3}$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -67 & 84 \\ 64 & -132 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 84 \\ 153 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса:

$$\begin{pmatrix} safety_{stator_{j,r}} \\ safety_{rotor_{j,r}} \end{pmatrix} =$$

	1
1	2.382
2	1.306

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \begin{cases} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} =$$

	1
1	1.210
2	-1.876

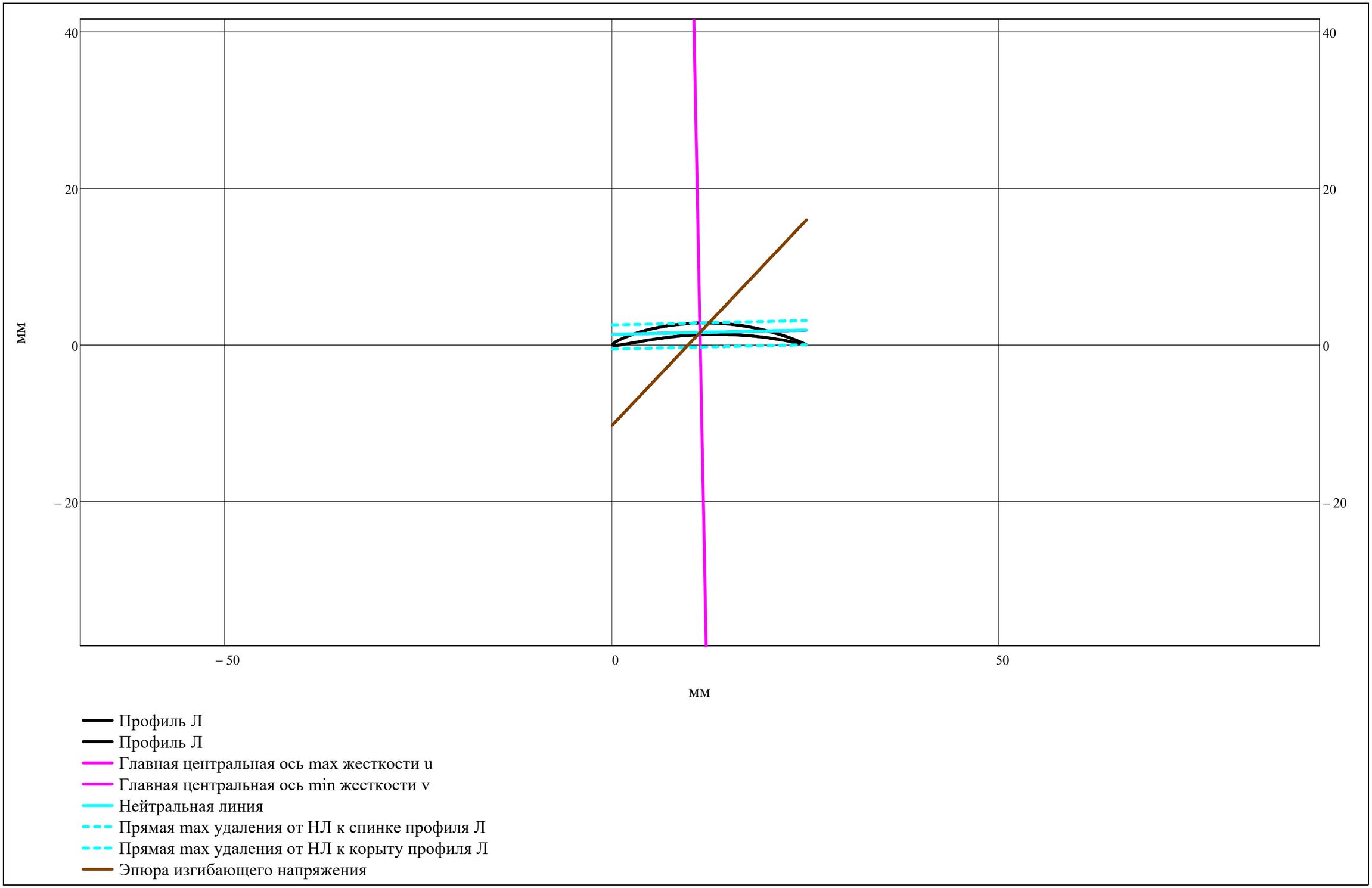
$\cdot 10^{-3}$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0_{rotor_{j,r}} \\ y0_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{stator_{j,r}} \\ y0_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} =$$

	1
1	11.312
2	1.573

$\cdot 10^{-3}$

$$chord = \begin{cases} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{cases} = 25 \cdot 10^{-3}$$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Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} =$$

	1	2
1	0.00	0.85
2	23.29	-0.58
3	-0.28	1.70
4	14.81	-2.00

$\cdot 10^{-3}$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -0 & 135 \\ 0 & -162 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 135 \\ 5 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса:

$$\begin{pmatrix} safety_{stator_{j,r}} \\ safety_{rotor_{j,r}} \end{pmatrix} =$$

	1
1	1.485
2	38.900

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \begin{cases} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} =$$

	1
1	1.703
2	-2.005

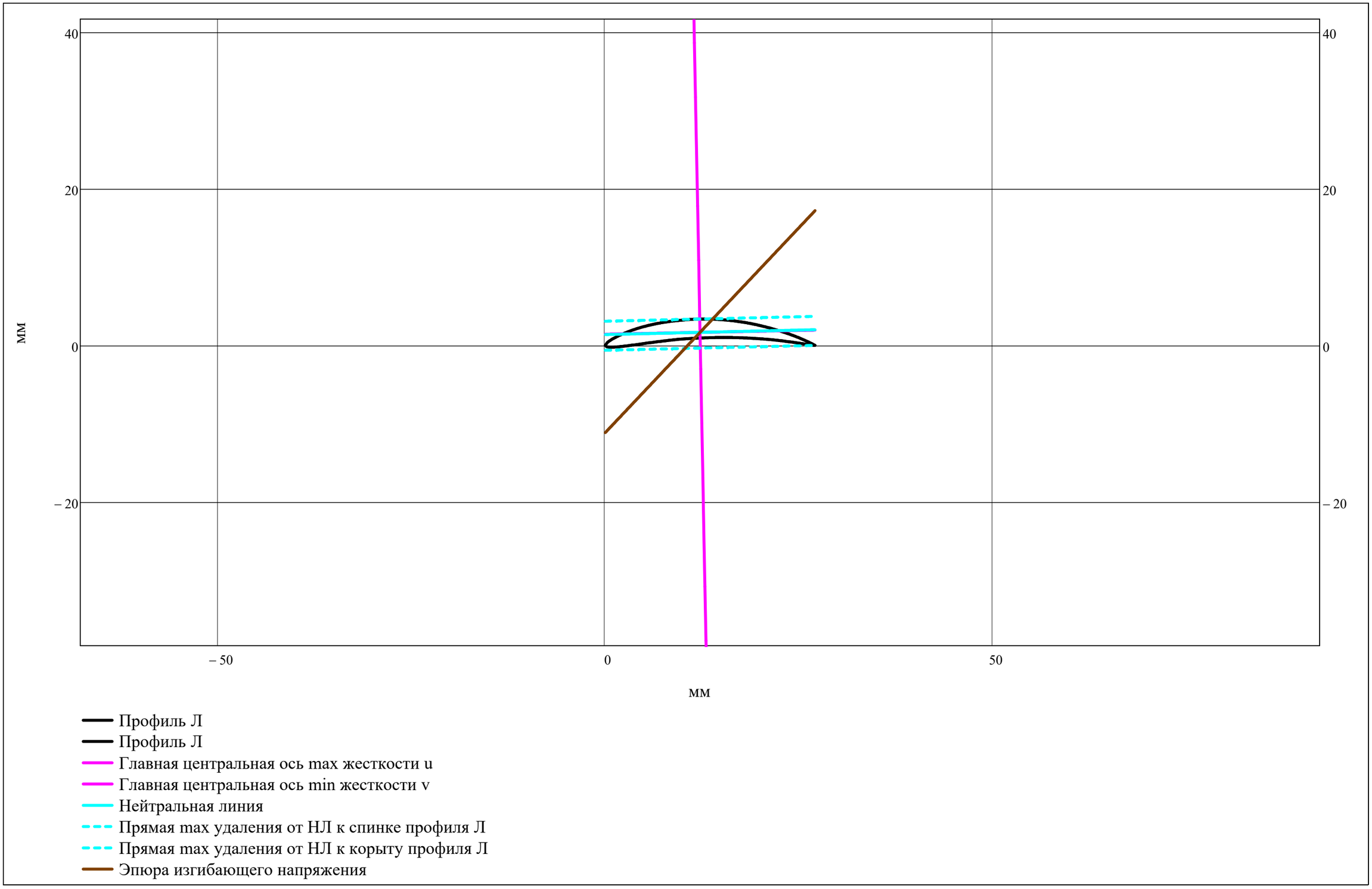
$\cdot 10^{-3}$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \begin{cases} \begin{pmatrix} x0_{rotor_{j,r}} \\ y0_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{stator_{j,r}} \\ y0_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{cases} =$$

	1
1	12.233
2	1.667

$\cdot 10^{-3}$

$$chord = \begin{cases} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{cases} = 27 \cdot 10^{-3}$$



Результаты расчета на прочность Л

Вывод результатов расчета Л на прочность

Выбор материала Д

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

Выбранный материал Д:

$$material\_disk_i = \begin{cases} "ВТ23" & \text{if } compressor = "Вл" \\ "ВТ6" & \text{if } compressor = "КНД" \\ "ВТ9" & \text{if } compressor = "КВД" \end{cases}$$

Плотность материала Д (кг/м^3):

$$\rho\_disk_i = \begin{cases} 8266 & \text{if } material\_disk_i = "ВЖ175" \\ 8320 & \text{if } material\_disk_i = "ЭП742" \\ 8393 & \text{if } material\_disk_i = "ЖС-6К" \\ 7900 & \text{if } material\_disk_i = "ВТ41" \\ 4500 & \text{if } material\_disk_i = "ВТ25" \\ 4570 & \text{if } material\_disk_i = "ВТ23" \\ 4510 & \text{if } material\_disk_i = "ВТ9" \\ 4430 & \text{if } material\_disk_i = "ВТ6" \\ NaN & otherwise \end{cases}$$

Предел длительной прочности Д (Па):

$$\sigma\_disk\_long_i = 10^6 \cdot \begin{cases} 620 & \text{if } material\_disk_i = "ВЖ175" \\ 680 & \text{if } material\_disk_i = "ЭП742" \\ 125 & \text{if } material\_disk_i = "ЖС-6К" \\ 123 & \text{if } material\_disk_i = "ВТ41" \\ 150 & \text{if } material\_disk_i = "ВТ25" \\ 230 & \text{if } material\_disk_i = "ВТ23" \\ 200 & \text{if } material\_disk_i = "ВТ9" \\ 210 & \text{if } material\_disk_i = "ВТ6" \\ NaN & otherwise \end{cases}$$

$material\_disk^T =$

	1	2	3	4	5	6	7	8	9
1	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"	"ВТ9"

$\rho\_disk^T =$

	1	2	3	4	5	6	7	8	9
1	4510	4510	4510	4510	4510	4510	4510	4510	4510

$\sigma\_disk\_long^T =$

	1	2	3	4	5	6	7	8	9
1	200	200	200	200	200	200	200	200	200

$\cdot 10^6$

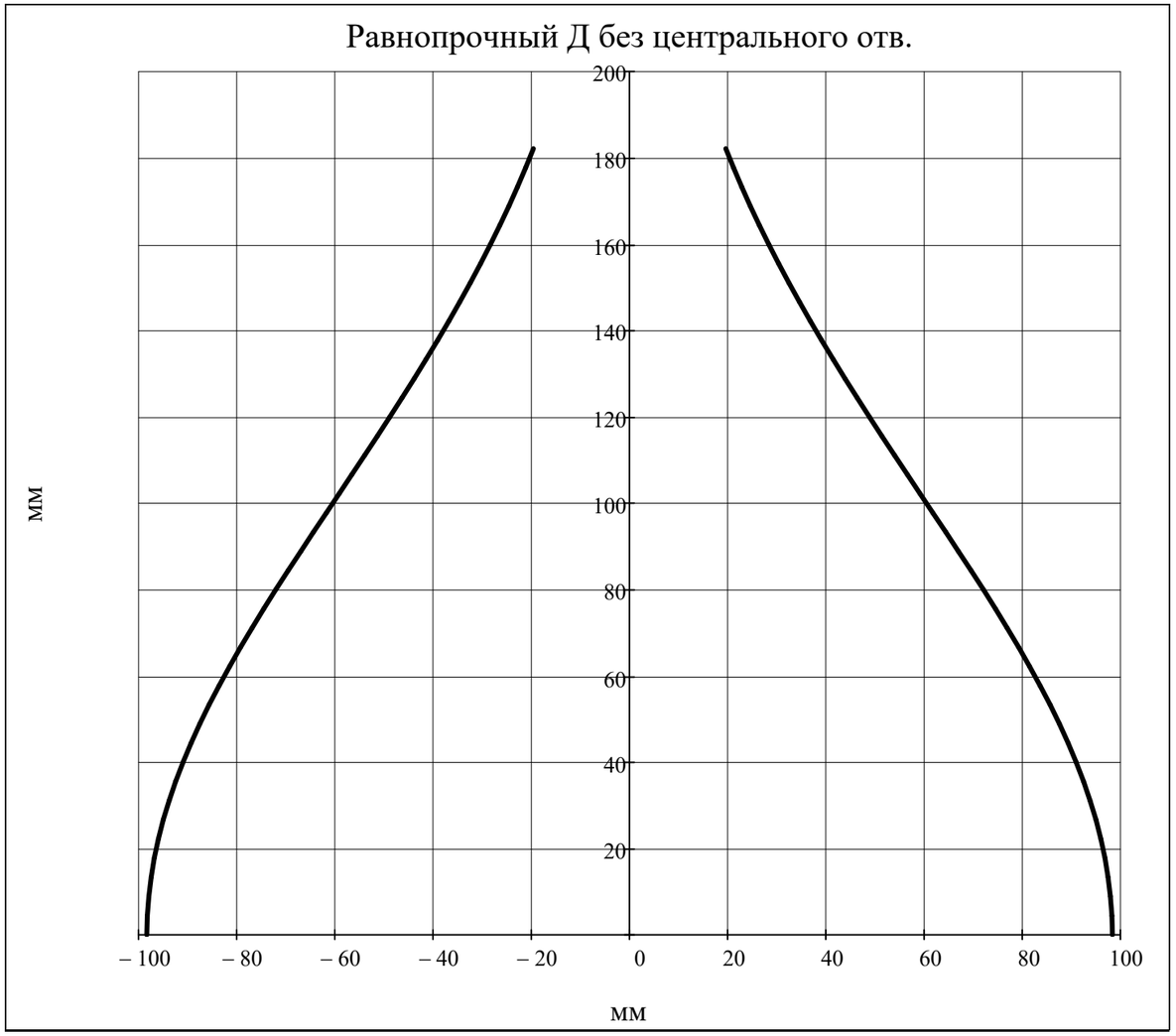
Выбор материала Д

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

Профилирование равнопрочного Д без центрального отв.

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

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



Профилирование равнопрочного Д без центрального отв.

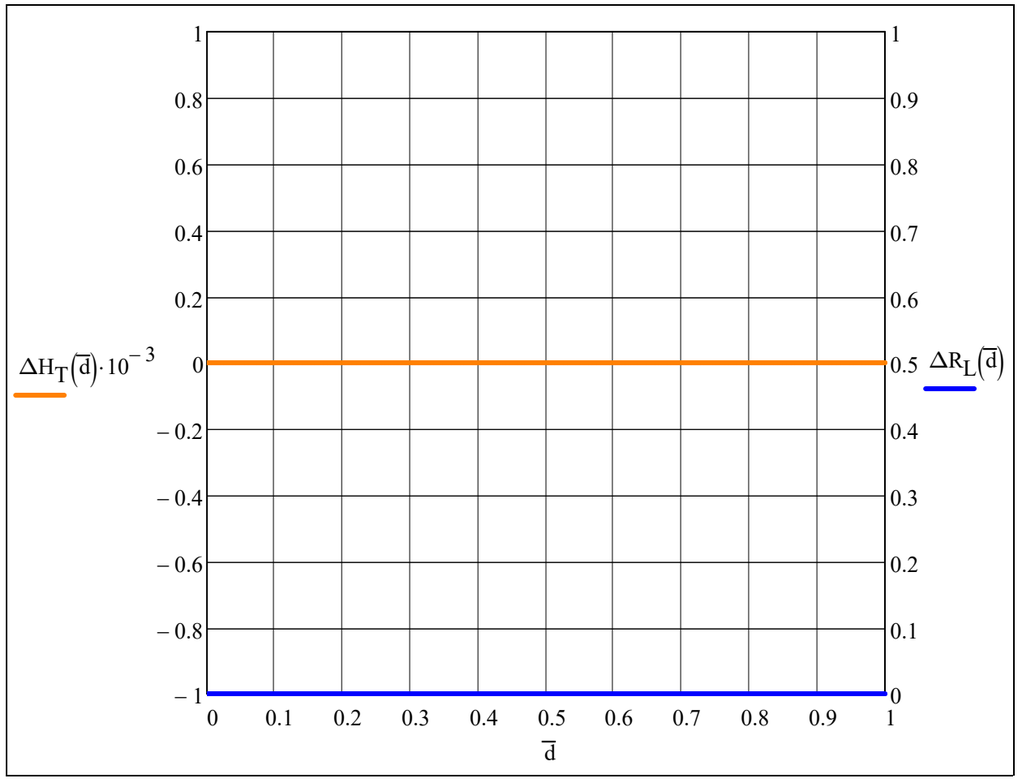
Max разница теор. напора ступени и реактивности от периферии к корню по высоте Л (Дж/кг) [16, с.118-119]:

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

$\Delta R_{Lmax} = 0.0$

$\Delta H_T(\overline{d}) = -\Delta H_{Tmax} \cdot \overline{d} + \Delta H_{Tmax}$

$\Delta R_L(\overline{d}) = -\Delta R_{Lmax} \cdot \overline{d} + \Delta R_{Lmax}$



$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 112.65 \\ 242.98 \\ 104.19 \end{pmatrix}$$

$$\begin{pmatrix} ca_{st(j,1),r} \\ ca_{st(j,2),r} \\ ca_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 103.47 \\ 111.3 \\ 94.4 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 255.76 \\ 131.57 \\ 266.58 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 66.71 \\ 27.26 \\ 64.95 \end{pmatrix} \cdot ^\circ$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 278.42 \\ 286.15 \\ 293.41 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 23.86 \\ 57.77 \\ 20.74 \end{pmatrix} \cdot ^\circ$$

$$\varepsilon_{stator_{j,r}} = 38.38 \cdot ^\circ$$

$$\varepsilon_{rotor_{j,r}} = 33.91 \cdot ^\circ$$

$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 108.2 \\ 201.04 \\ 100.9 \end{pmatrix}$$

$$\begin{pmatrix} ca_{st(j,1),r} \\ ca_{st(j,2),r} \\ ca_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 99.89 \\ 97.28 \\ 94.28 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 336.14 \\ 210.45 \\ 339.94 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 67.39 \\ 28.94 \\ 69.13 \end{pmatrix} \cdot °$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 362.55 \\ 362.55 \\ 362.55 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 17.29 \\ 27.53 \\ 16.1 \end{pmatrix} \cdot °$$

$$\varepsilon_{stator_{j,r}} = 37.26 \cdot °$$

$$\varepsilon_{rotor_{j,r}} = 10.25 \cdot °$$

$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 105.56 \\ 177.58 \\ 99.23 \end{pmatrix}$$

$$\begin{pmatrix} ca_{st(j,1),r} \\ ca_{st(j,2),r} \\ ca_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 97.97 \\ 89.56 \\ 94.22 \end{pmatrix}$$

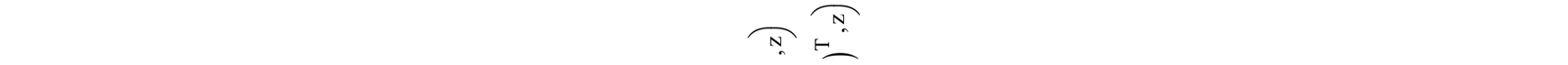
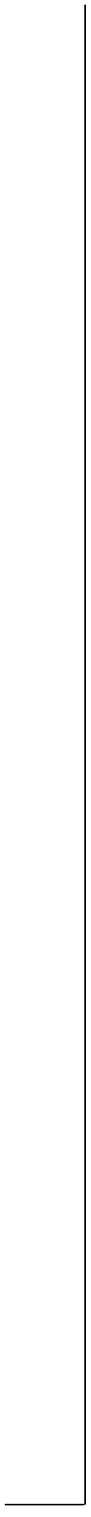
$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 403.30 \\ 286.46 \\ 400.56 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 68.13 \\ 30.29 \\ 71.71 \end{pmatrix} \cdot °$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 430.54 \\ 425.44 \\ 420.47 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 14.06 \\ 18.22 \\ 13.6 \end{pmatrix} \cdot °$$

$$\varepsilon_{stator_{j,r}} = 36.52 \cdot °$$

$$\varepsilon_{rotor_{j,r}} = 4.16 \cdot °$$

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