Исходные данные

Коэф. запаса: safety = 1.3

Степень двухконтурности: m2 = 6

РТ: Воздух

compressor = "КВД"

Число Маха: M = 0

Геометрическая высота работы (м): H = 0

Массовый расход (кг/с):

$$G = \begin{cases} 35.65 + 213.93 & \text{if compressor = "Вл"} \\ 35.65 & \text{if compressor = "КНД"} \\ 34.81 & \text{if compressor = "КВД"} \end{cases} = 34.81$$

Полная температура на входе в К (К):

$$T^*_{K1} = \begin{cases} 418.2 & \text{if compressor = "КВД"} \\ 288.2 & \text{otherwise} \end{cases} = 418.2$$

Полное давление на входе в К (Па):

$$P^*_{K1} = \begin{cases} 316.2 \cdot 10^3 & \text{if compressor = "КВД"} \\ 101325 & \text{otherwise} \end{cases} = 316.2 \cdot 10^3$$

Степень повышения давления КВД:

$$\pi^*_{K} = \begin{cases} 1.6 & \text{if compressor = "Вл"} \\ \dfrac{3.2}{1.6} & \text{if compressor = "КНД"} \\ 9 & \text{if compressor = "КВД"} \end{cases} = 9.000$$

Ожидаемый адиабатический КПД ОК:

$$\eta^*_K = \left| \begin{array}{l} 0.86 \ \text{ if } \ compressor = \text{"Вл"} \\ 0.87 \ \text{ if } \ compressor = \text{"КНД"} \\ 0.88 \ \text{ if } \ compressor = \text{"КВД"} \end{array} \right. = 88.00 \cdot \%$$

Частота вращения ротора (c^{-1}):

$$\omega = \left| \begin{array}{l} 1570.8 \ \text{ if } \ compressor = \text{"КВД"} \\ 555 \ \ otherwise \end{array} \right. = 1570.8$$

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

$$\bar{d}_1 = \left| \begin{array}{l} 0.40 \ \text{ if } \ compressor = \text{"Вл"} \\ 0.75 \ \text{ if } \ compressor = \text{"КНД"} \\ 0.65 \ \text{ if } \ compressor = \text{"КВД"} \end{array} \right. = 0.65$$

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

Частота вращения ротора (об/мин):

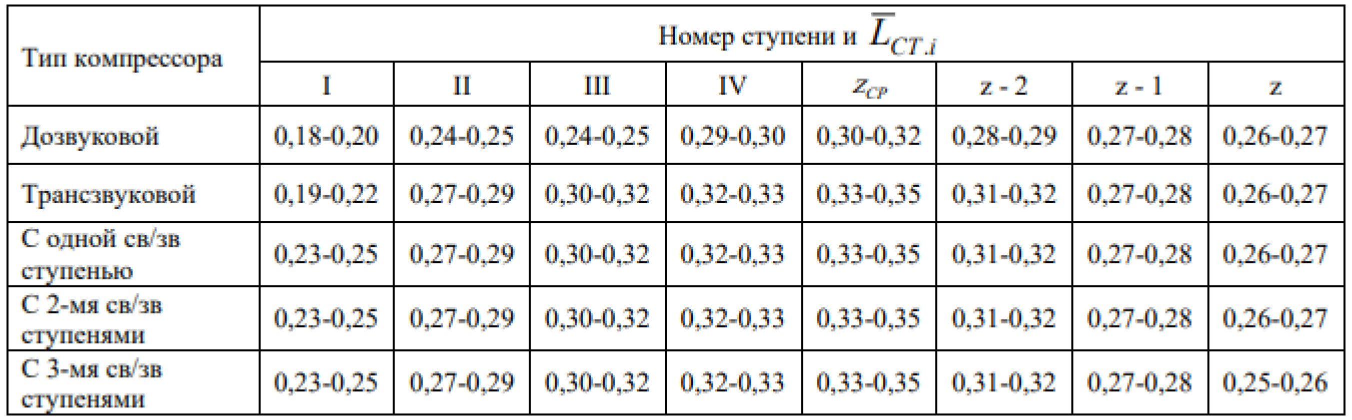
$$n = \frac{60 \cdot \omega}{2 \cdot \pi} = 15000$$

Закон профилирования проточной части (ЗППЧ):

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

Относ. параметры по относительным ступеням:

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



Тип компрессора	Номер ступени и $\bar{L}_{CT.i}$							
	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:

$$R_{L\sim cp} = R_{L\sim cp} + \left|\begin{array}{l} 0.0 \ \text{ if } \ compressor = \text{"Вл"} \\ 0.1 \ \text{ if } \ compressor = \text{"КНД"} \\ 0.2 \ \text{ if } \ compressor = \text{"КВД"} \end{array}\right.$$

$$\bar{c}_{\sim a1} = \bar{c}_{\sim a1} - \left|\begin{array}{l} 0.100 \ \text{ if } \ compressor = \text{"Вл"} \\ 0.141 \ \text{ if } \ compressor = \text{"КНД"} \\ 0.203 \ \text{ if } \ compressor = \text{"КВД"} \end{array}\right.$$

увеличение несущественно увеличивает π

понижение существенно увеличивает π

$$\eta^*_{\sim} = \eta^*_{\sim} + \left|\begin{array}{l} -0.020 \ \text{ if } \ compressor = \text{"Вл"} \\ -0.028 \ \text{ if } \ compressor = \text{"КНД"} \\ -0.017 \ \text{ if } \ compressor = \text{"КВД"} \end{array}\right.$$

$$\bar{H}_{\sim T} = \bar{H}_{\sim T} + \left|\begin{array}{l} 0.0145 \ \text{ if } \ compressor = \text{"Вл"} \\ 0.0164 \ \text{ if } \ compressor = \text{"КНД"} \\ 0.0173 \ \text{ if } \ compressor = \text{"КВД"} \end{array}\right.$$

[16, c. 234]

увеличение несущественно увеличивает π

увеличение существенно увеличивает π

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

	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

$$0.15 \le \bar{c}_{\sim a1}^{\,T} = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

$$\bar{c}_{\sim a1}^{\,T} \le 0.65 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

$$0.18 \le \bar{H}_{\sim T}^{\,T} = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

$$\bar{H}_{\sim T}^{\,T} \le 0.35 = \begin{pmatrix} 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \end{pmatrix}$$

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

$$\bar{H}_{Tcp} = \frac{\displaystyle\sum_{i=1}^{rows(z_{\sim})} \bar{H}_{\sim T_i}}{rows(z_{\sim})} = 0.3198$$

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

Исходные данные

Распределение основных параметров ОК по ступеням

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

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

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

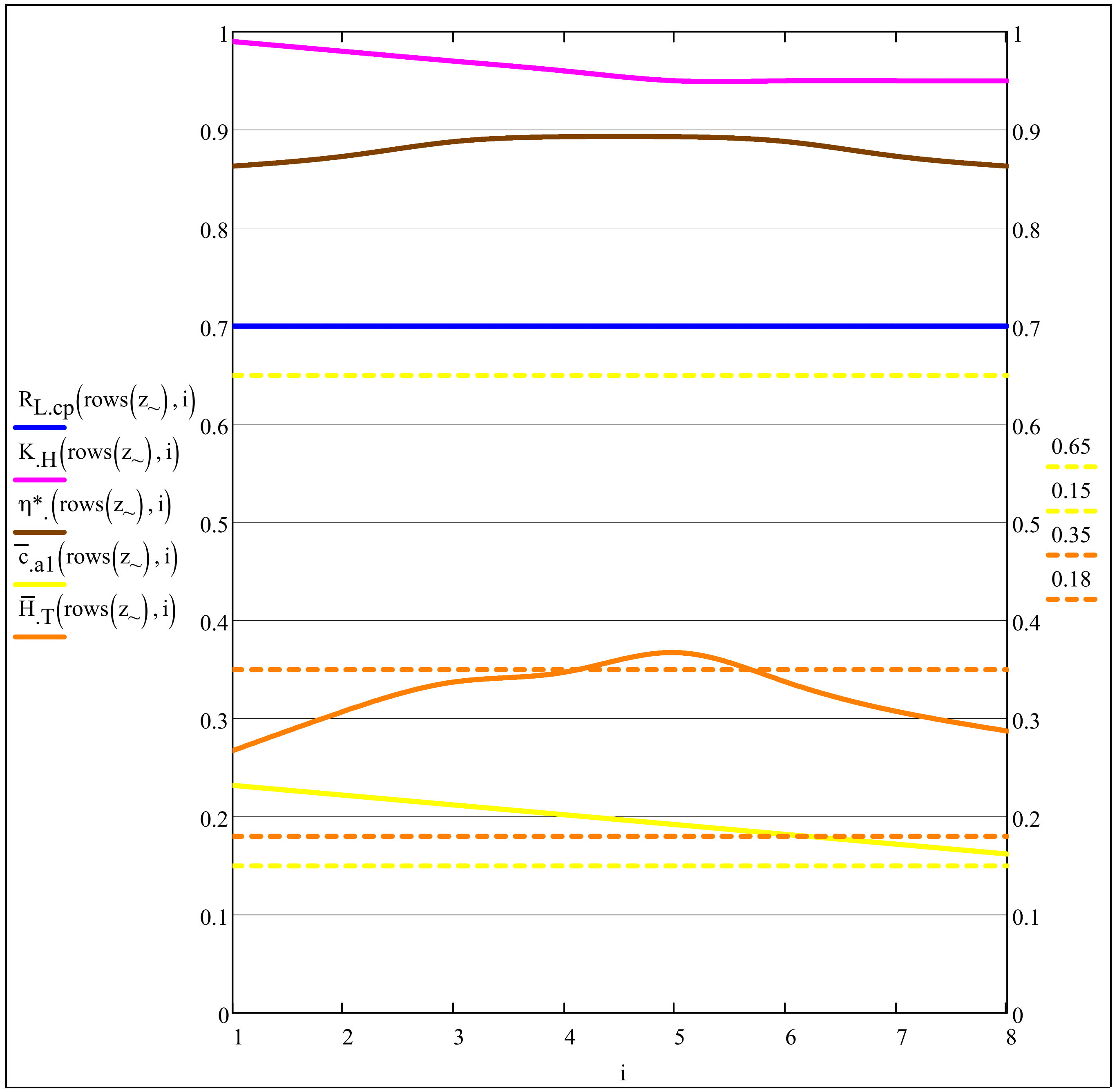
Коэф. расхода: $\bar{c}_{\sim a1}(i) = \mathrm{interp}\left(\mathrm{lspline}\left(\frac{z_{\sim}}{\mathrm{rows}(z_{\sim})}, \bar{c}_{\sim a1}\right), \frac{z_{\sim}}{\mathrm{rows}(z_{\sim})}, \bar{c}_{\sim a1}, i\right)$

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

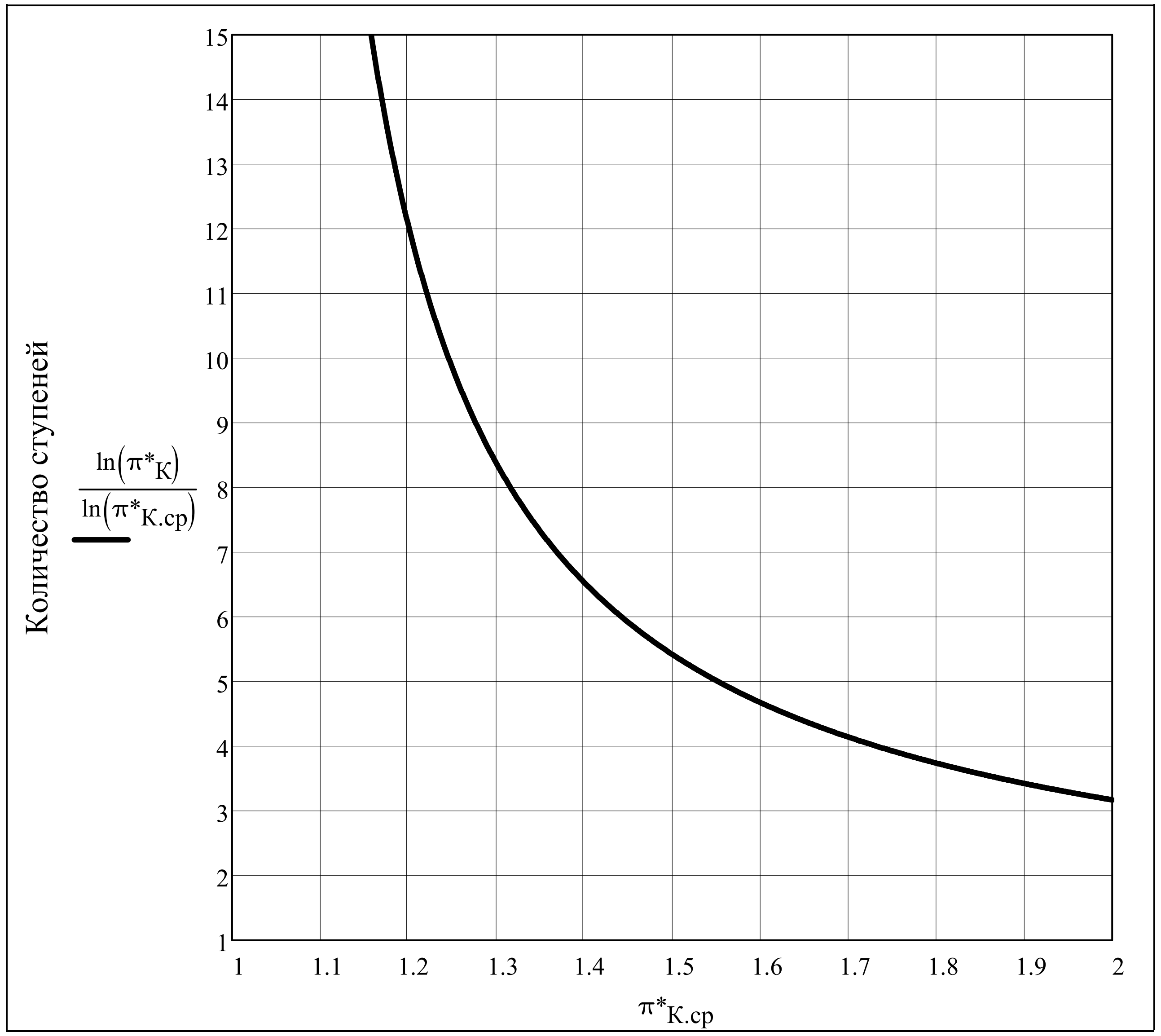
$$\begin{pmatrix} R_{L.cp} \\ K_{.H} \\ \eta^*_{.} \\ \bar{c}_{.a1} \\ \bar{H}_{.T} \end{pmatrix} = \left| \begin{array}{l}
R_{L.cp}(Z,i) = \left| \begin{array}{ll} R_{L\sim cp}\left(\dfrac{1}{rows(z_\sim)}\right) & \text{if } i < 1 \\ R_{L\sim cp}(1) & \text{if } i > Z \\ R_{L\sim cp}\left(\dfrac{i}{Z}\right) & \text{otherwise} \end{array}\right. \\
K_{.H}(Z,i) = \left| \begin{array}{ll} K_{\sim H}\left(\dfrac{1}{rows(z_\sim)}\right) & \text{if } i < 1 \\ K_{\sim H}(1) & \text{if } i > Z \\ K_{\sim H}\left(\dfrac{i}{Z}\right) & \text{otherwise} \end{array}\right. \\
\eta^*_{.}(Z,i) = \left| \begin{array}{ll} \eta^*_{\sim}\left(\dfrac{1}{rows(z_\sim)}\right) & \text{if } i < 1 \\ \eta^*_{\sim}(1) & \text{if } i > Z \\ \eta^*_{\sim}\left(\dfrac{i}{Z}\right) & \text{otherwise} \end{array}\right. \\
\bar{c}_{.a1}(Z,i) = \left| \begin{array}{ll} \bar{c}_{\sim a1}\left(\dfrac{1}{rows(z_\sim)}\right) & \text{if } i < 1 \\ \bar{c}_{\sim a1}(1) & \text{if } i > Z \\ \bar{c}_{\sim a1}\left(\dfrac{i}{Z}\right) & \text{otherwise} \end{array}\right. \\
\bar{H}_{.T}(Z,i) = \left| \begin{array}{ll} \bar{H}_{\sim T}\left(\dfrac{1}{rows(z_\sim)}\right) & \text{if } i < 1 \\ \bar{H}_{\sim T}(1) & \text{if } i > Z \\ \bar{H}_{\sim T}\left(\dfrac{i}{Z}\right) & \text{otherwise} \end{array}\right. \\
\left(R_{L.cp}\ \ K_{.H}\ \ \eta^*_{.}\ \ \bar{c}_{.a1}\ \ \bar{H}_{.T}\right)^T
\end{array}\right.$$

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

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



▲ Распределение основных параметров ОК по ступеням


Количество ступеней
$\frac{\ln(\pi^*_К)}{\ln(\pi^*_{К.ср})}$
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
$\pi^*_{К.ср}$

Нулевые приближения

Показатель адиаьаты перед К []: $k_{К1} = k_{ад}\left(Cp_{воздух}\left(P^*_{К1}, T^*_{К1}\right), R_в\right) = 1.394$

Полное давление после К [Па]: $P^*_{К3} = \pi^*_К \cdot P^*_{К1} = 2846\cdot 10^3$

$$\begin{pmatrix} iteration_3 \\ T^*_{К3} \\ k_{К3} \end{pmatrix} =$$

```
$iteration_3 = 0$
$k_{К3} = k_{К1}$
while $0 < 1$
    $iteration_3 = iteration_3 + 1$
    trace("iteration.3 = ", num2str($iteration_3$))
    $k_{cp} = mean(k_{К1}, k_{К3})$
    $T^*_{К3} = T^*_{К1} \cdot \left(1 + \frac{{\pi^*_К}^{\frac{k_{cp}-1}{k_{cp}}} - 1}{\eta^*_К}\right)$
    $Cp_{К3} = Cp_{воздух}(P^*_{К3}, T^*_{К3})$
    $k'_{К3} = k_{ад}(Cp_{К3}, R_в)$
    if $\left|eps("rel", k_{К3}, k'_{К3})\right| \le epsilon$
        $k_{К3} = k'_{К3}$
        break
    $k_{К3} = k'_{К3}$
$\begin{pmatrix} iteration_3 \\ T^*_{К3} \\ k_{К3} \end{pmatrix}$
```

Количество итераций []: $iteration_3 = 2$

Полная температура после К [К]: $T^*_{К3} = 805.9$

Показатель адиаьаты после К []: $k_{К3} = 1.354$

Полная плотность перед и после К [кг/м^3]: $\begin{pmatrix} \rho^*_{К1} \\ \rho^*_{К3} \end{pmatrix} = \frac{1}{R_в} \cdot \begin{pmatrix} \frac{P^*_{К1}}{T^*_{К1}} \\ \frac{P^*_{К3}}{T^*_{К3}} \end{pmatrix} = \begin{pmatrix} 2.633 \\ 12.297 \end{pmatrix}$

Критические скорости перед и после К [м/с]: $\begin{pmatrix} a^*_{с.вх} \\ a^*_{с.вых} \end{pmatrix} = \begin{pmatrix} a_{кр}\left(k_{К1}, R_в, T^*_{К1}\right) \\ a_{кр}\left(k_{К3}, R_в, T^*_{К3}\right) \end{pmatrix} = \begin{pmatrix} 373.9 \\ 515.9 \end{pmatrix}$

Ср. показатель адиабаты К []: $k_{cp} = k_{ад}\left(Cp_{воздух.ср}\left(P^*_{К1}, P^*_{К3}, T^*_{К1}, T^*_{К3}\right), R_в\right) = 1.374$

Теоретический напор [Дж/кг]: $H_{ТК} = \frac{Cp_{воздух.ср}\left(P^*_{К1}, P^*_{К3}, T^*_{К1}, T^*_{К3}\right) \cdot T^*_{К1} \cdot \left({\pi^*_К}^{\frac{k_{cp}-1}{k_{cp}}} - 1\right)}{\eta^*_К} = 410.3\cdot 10^3$

```
$\begin{pmatrix} \text{iteration}_u \\ u_{1\text{пер}} \\ Z_{\text{recomend}} \\ c_{\text{вх}} \\ \lambda_{\text{вх}} \\ \rho_{\text{К1}} \end{pmatrix}$ =
    $\text{iteration}_u = 0$
    $\rho_{\text{К1}} = \rho^*_{\text{К1}}$
    while $0 < 1$
        $\text{iteration}_u = \text{iteration}_u + 1$
        trace(concat("iteration.u = ", num2str($\text{iteration}_u$)))
        $u_{1\text{пер}} = \sqrt[3]{\dfrac{\pi \cdot G \cdot n^2}{900 \cdot \overline{c}_{.a1}(1,0) \cdot \rho_{\text{К1}} \cdot \left[1 - (\overline{d}_1)^2\right]}}$
        $Z_{\text{recomend}} = \max\left(\text{round}\left(\dfrac{H_{\text{ТК}}}{\overline{H}_{\text{Тср}} \cdot u_{1\text{пер}}^2}\right), 1\right)$
        $c_{\text{вх}} = \overline{c}_{.a1}(Z_{\text{recomend}}, 0) \cdot u_{1\text{пер}}$
        $\lambda_{\text{вх}} = \dfrac{c_{\text{вх}}}{a^*_{\text{с.вх}}}$
        $\rho'_{\text{К1}} = \rho^*_{\text{К1}} \cdot \text{ГДФ}(\text{"}\rho\text{"}, \lambda_{\text{вх}}, k_{\text{К1}})$
        if $\left|\text{eps}(\text{"rel"}, \rho'_{\text{К1}}, \rho_{\text{К1}})\right| \le \text{epsilon}$
            $\rho_{\text{К1}} = \rho'_{\text{К1}}$
            break
        $\rho_{\text{К1}} = \rho'_{\text{К1}}$
    $\begin{pmatrix} \text{iteration}_u \\ u_{1\text{пер}} \\ Z_{\text{recomend}} \\ c_{\text{вх}} \\ \lambda_{\text{вх}} \\ \rho_{\text{К1}} \end{pmatrix}$
```

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

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

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

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

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

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

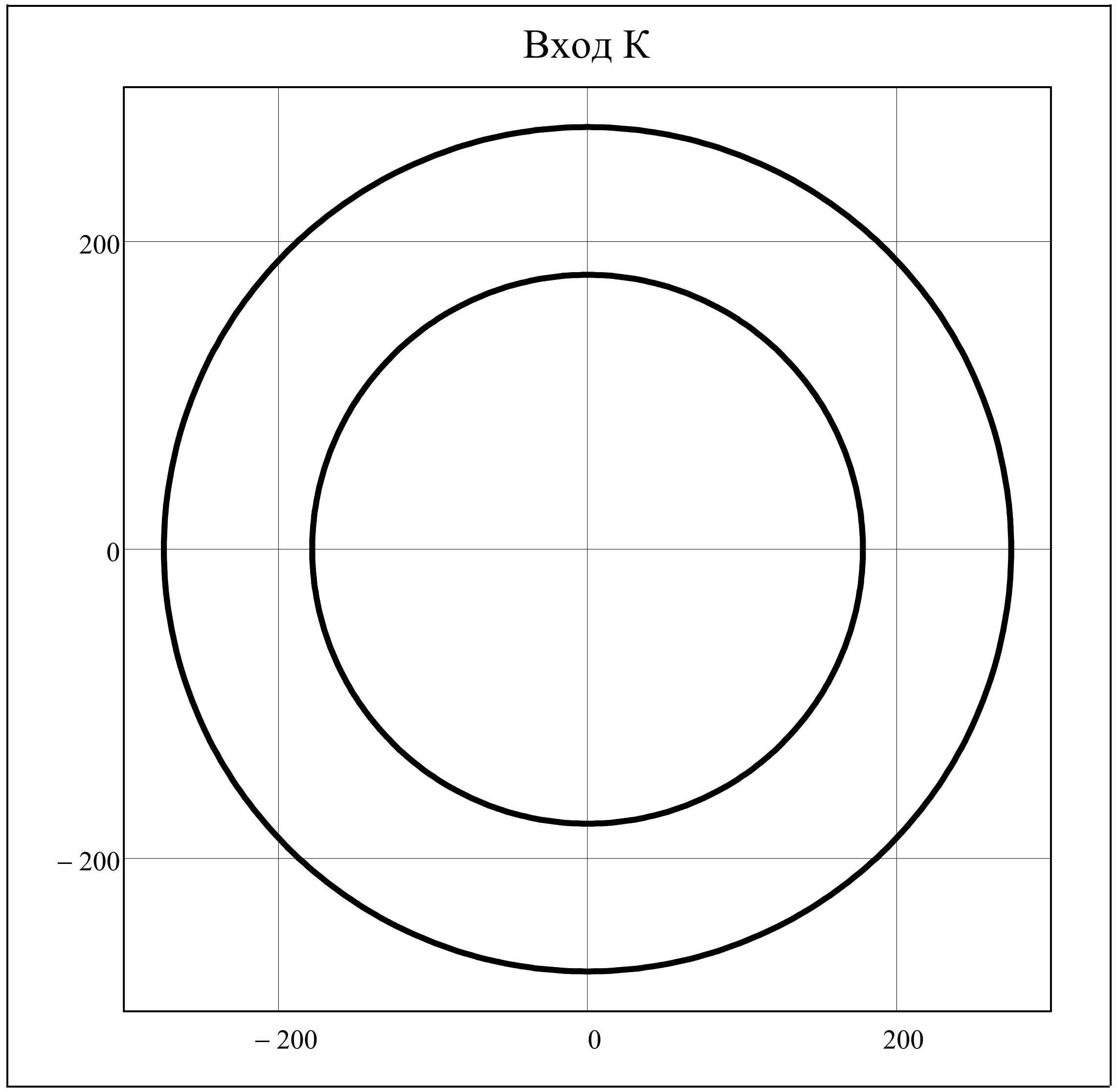
Кольцевая площадь перед К [м^2]: $F_{\text{вх}} = \dfrac{G \cdot \sqrt{R_{\text{в}} \cdot T^*_{\text{К1}}}}{m_q(k_{\text{К1}}) \cdot P^*_{\text{К1}} \cdot \text{ГДФ}(\text{"G"}, \lambda_{\text{вх}}, k_{\text{К1}})} = 0.1364$

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

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

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

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



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

Количество ступеней []: $Z = \left| \begin{array}{l} 1 \;\text{ if }\; compressor = \text{"Вл"} \\ 3 \;\text{ if }\; compressor = \text{"КНД"} \\ 9 \;\text{ if }\; compressor = \text{"КВД"} \end{array} \right. = 9$

Нулевые приближения

$$BHA = \left|\begin{array}{l} 1 \ \text{ if } compressor = \text{"КВД"} \\ 0 \ \text{ otherwise} \end{array}\right. = 1$$

Расчет BHA:

$$\begin{pmatrix} \alpha_{1BHA} & \alpha_{3BHA} \\ \sigma_{BHA} & \sigma_{BHA} \\ \bar{d}_{1BHA} & \bar{d}_{3BHA} \\ T^*_{1BHA} & T^*_{3BHA} \\ P^*_{1BHA} & P^*_{3BHA} \\ \rho^*_{1BHA} & \rho^*_{3BHA} \\ k_{1BHA} & k_{3BHA} \\ a_{кр1BHA} & a_{кр3BHA} \\ \bar{c}_{a1BHA} & \bar{c}_{a3BHA} \\ \bar{c}_{u1BHA} & \bar{c}_{u3BHA} \\ c_{a1BHA} & c_{a3BHA} \\ c_{u1BHA} & c_{u3BHA} \\ c_{1BHA} & c_{3BHA} \\ \lambda_{c1BHA} & \lambda_{c3BHA} \\ F_{1BHA} & F_{3BHA} \\ \varepsilon_{BHA} & \varepsilon_{BHA} \end{pmatrix} = \left| \begin{array}{l} \text{for } r \in av(N_r) \\ \quad \left| \begin{array}{l} \alpha_{1BHA_r} = 90° \\ \bar{d}_{1BHA} = \bar{d}_1 \\ \bar{d}_{3BHA} = \bar{d}_{1BHA} \\ T^*_{1BHA_r} = T^*_{K1} \\ T^*_{3BHA_r} = T^*_{1BHA_r} \\ P^*_{1BHA_r} = P^*_{K1} \\ \rho^*_{1BHA_r} = \dfrac{P^*_{1BHA_r}}{R_в \cdot T^*_{1BHA_r}} \\ k_{1BHA_r} = k_{ад}\left(Cp_{воздух}\left(P^*_{1BHA_r}, T^*_{1BHA_r}\right), R_в\right) \\ a_{кр1BHA_r} = a_{кр}\left(k_{1BHA_r}, R_в, T^*_{1BHA_r}\right) \\ \bar{c}_{a1BHA_r} = \bar{c}_{.a1}(Z,0) \\ \bar{c}_{u1BHA_r} = \left| \begin{array}{l} \bar{r}_{cp}\left(\bar{d}_{1BHA}\right) \cdot \left(1 - R_{L.cp}(Z,0)\right) - \dfrac{\bar{H}_{.T}(Z,0)}{2 \cdot \bar{r}_{cp}\left(\bar{d}_{1BHA}\right)} \ \text{ if } BHA = 1 \\ 0 \ \text{ otherwise} \end{array}\right. \\ c_{a1BHA_r} = \bar{c}_{a1BHA_r} \cdot u_{1пер} \end{array}\right. \end{array}\right.$$

$$\sigma_{BHA} = 0.9982$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

кр3ВНА_r

$$\begin{pmatrix} F_{\text{1ВНА}} \\ F_{\text{3ВНА}} \end{pmatrix} = G\cdot\sqrt{R_{\text{в}}}\cdot\begin{pmatrix} \dfrac{\sqrt{T^*_{\text{1ВНА}_r}}}{m_q\left(k_{\text{1ВНА}_r}\right)\cdot P^*_{\text{1ВНА}_r}\cdot \text{ГДФ}\left(\text{"G"},\lambda_{\text{c1ВНА}_r},k_{\text{1ВНА}_r}\right)\cdot\sin\left(\alpha_{\text{1ВНА}_r}\right)} \\ \dfrac{\sqrt{T^*_{\text{3ВНА}_r}}}{m_q\left(k_{\text{3ВНА}_r}\right)\cdot P^*_{\text{3ВНА}_r}\cdot \text{ГДФ}\left(\text{"G"},\lambda_{\text{c3ВНА}_r},k_{\text{3ВНА}_r}\right)\cdot\sin\left(\alpha_{\text{3ВНА}_r}\right)} \end{pmatrix}$$

$$\varepsilon_{\text{ВНА}_r} = -1\cdot\left(\alpha_{\text{3ВНА}_r} - \alpha_{\text{1ВНА}_r}\right)$$

$$\begin{pmatrix}
\alpha_{\text{1ВНА}} & \alpha_{\text{3ВНА}} \\
\sigma_{\text{ВНА}} & \sigma_{\text{ВНА}} \\
\bar{d}_{\text{1ВНА}} & \bar{d}_{\text{3ВНА}} \\
T^*_{\text{1ВНА}} & T^*_{\text{3ВНА}} \\
P^*_{\text{1ВНА}} & P^*_{\text{3ВНА}} \\
\rho^*_{\text{1ВНА}} & \rho^*_{\text{3ВНА}} \\
k_{\text{1ВНА}} & k_{\text{3ВНА}} \\
a_{\text{кр1ВНА}} & a_{\text{кр3ВНА}} \\
\bar{c}_{\text{a1ВНА}} & \bar{c}_{\text{a3ВНА}} \\
\bar{c}_{\text{u1ВНА}} & \bar{c}_{\text{u3ВНА}} \\
c_{\text{a1ВНА}} & c_{\text{a3ВНА}} \\
c_{\text{u1ВНА}} & c_{\text{u3ВНА}} \\
c_{\text{1ВНА}} & c_{\text{3ВНА}} \\
\lambda_{\text{c1ВНА}} & \lambda_{\text{c3ВНА}} \\
F_{\text{1ВНА}} & F_{\text{3ВНА}} \\
\varepsilon_{\text{ВНА}} & \varepsilon_{\text{ВНА}}
\end{pmatrix}$$

▲ Расчет ВНА:

Поступенчатый расчет ОК по ср. ЛТ

$$\begin{pmatrix} R_L & \pi^* \\ K_H & \eta^* \\ Cp & k \\ \overline{H}_T & H_T \\ L^* & L \\ T^* & T \\ P^* & P \\ \rho^* & \rho \\ a^*_c & a_{\text{зв}} \\ \lambda_c & \lambda_c \\ F & F \\ D & R \\ \overline{d} & h \\ \overline{c}_a & \overline{c}_u \\ c_a & c_u \\ u & w_u \\ c & w \\ M_c & M_w \\ \alpha & \beta \\ \varepsilon_{rotor} & \varepsilon_{stator} \end{pmatrix} = \left| \begin{array}{l} r = av(N_r) \\ T^*_{st(1,1),r} = T^*_{\text{3ВНА}_r} \\ P^*_{st(1,1),r} = P^*_{\text{3ВНА}_r} \\ \rho^*_{st(1,1),r} = \rho^*_{\text{3ВНА}_r} \\ Cp_{st(1,1),r} = Cp_{\text{воздух}}\left(P^*_{st(1,1),r}, T^*_{st(1,1),r}\right) \\ k_{st(1,1),r} = k_{\text{ад}}\left(Cp_{st(1,1),r}, R_{\text{в}}\right) \\ a^*_{c_{st(1,1),r}} = a_{\text{кр}}\left(k_{st(1,1),r}, R_{\text{в}}, T^*_{st(1,1),r}\right) \\ \overline{c}_{a_{st(1,1),r}} = \overline{c}_{\text{a3ВНА}_r} \\ \overline{c}_{u_{st(1,1),r}} = \overline{c}_{\text{u3ВНА}_r} \\ c_{a_{st(1,1),r}} = c_{\text{a3ВНА}_r} \\ u_{st(1,1),N_r} = u_{\text{1пер}} \\ \alpha_{st(1,1),r} = \alpha_{\text{3ВНА}_r} \\ c_{st(1,1),r} = \dfrac{c_{a_{st(1,1),r}}}{\sin\left(\alpha_{st(1,1),r}\right)} \\ \lambda_{c_{st(1,1),r}} = \dfrac{c_{st(1,1),r}}{a^*_{c_{st(1,1),r}}} \\ F_{st(1,1)} = \dfrac{G\cdot\sqrt{R_{\text{в}}\cdot T^*_{st(1,1),r}}}{m_q\left(k_{st(1,1),r}\right)\cdot \text{ГДФ}\left(\text{"G"}, \lambda_{c_{st(1,1),r}}, k_{st(1,1),r}\right)\cdot\sin\left(\alpha_{st(1,1),r}\right)\cdot P^*_{st(1,1),r}} \end{array} \right.$$

```
$D_{st(1,1),N_r} = \frac{2 \cdot u_{st(1,1),N_r}}{\omega}$
$D_{st(1,1),1} = \sqrt{\left(D_{st(1,1),N_r}\right)^2 - \frac{4 \cdot F_{st(1,1)}}{\pi}}$
$D_{st(1,1),r} = \overline{r}_{cp}\left(\frac{D_{st(1,1),1}}{D_{st(1,1),N_r}}\right) \cdot D_{st(1,1),N_r}$
$\overline{d}_{st(1,1)} = \frac{D_{st(1,1),1}}{D_{st(1,1),N_r}}$
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})))
        $k_{12} = mean\left(k_{st(i,1),r}, k_{st(i,2),r}\right)$
        $Cp_{12} = \frac{k_{12}}{k_{12} - 1} \cdot R_{в}$
        $T^*_{st(i,2),r} = T^*_{st(i,1),r} + \frac{L_i}{Cp_{12}}$
        $\pi^*_i = \left(1 + \frac{L^*_i}{Cp_{12} \cdot T^*_{st(i,1),r}}\right)^{\frac{k_{12}}{k_{12}-1}}$
        $P^*_{st(i,2),r} = P^*_{st(i,1),r} \cdot \pi^*_i$
        $Cp_{st(i,2),r} = Cp_{воздух}\left(P^*_{st(i,2),r}, T^*_{st(i,2),r}\right)$
```

```
        $Cp_{st(i,2),r} = Cp_{воздух}(P*_{st(i,2),r}, T*_{st(i,2),r})$
        $k'_2 = k_{ад}(Cp_{st(i,2),r}, R_в)$
        if $|eps("rel", k_{st(i,2),r}, k'_2)| < epsilon$
            $k_{st(i,2),r} = k'_2$
            break
        $k_{st(i,2),r} = k'_2$
    $a*_{c_{st(i,2),r}} = a_{кр}(k_{st(i,2),r}, R_в, T*_{st(i,2),r})$
    $T*_{st(i,3),r} = T*_{st(i,2),r}$
    $P*_{st(i,3),r} = P*_{st(i,2),r}$
    $Cp_{st(i,3),r} = Cp_{воздух}(P*_{st(i,3),r}, T*_{st(i,3),r})$
    $k_{st(i,3),r} = k_{ад}(Cp_{st(i,3),r}, R_в)$
    $a*_{c_{st(i,3),r}} = a_{кр}(k_{st(i,3),r}, R_в, T*_{st(i,3),r})$
    $\overline{c}_{a_{st(i,3),r}} = \overline{c}.a1(Z, i+1)$
    $iteration_3 = 0$
    $\begin{pmatrix} \alpha_{st(i,3),r} \\ u_{st(i,3),N_r} \end{pmatrix} = \begin{pmatrix} \alpha_{st(i,1),r} \\ u_{st(i,1),N_r} \end{pmatrix}$
    $c_{a_{st(i,3),r}} = \overline{c}_{a_{st(i,3),r}} \cdot u_{st(i,3),N_r}$
    $c_{st(i,3),r} = \frac{c_{a_{st(i,3),r}}}{\sin(\alpha_{st(i,3),r})}$
    $\lambda_{c_{st(i,3),r}} = \frac{c_{st(i,3),r}}{a*_{c_{st(i,3),r}}}$
    $F_{st(i,3)} = \frac{F_{st(i,1)} \cdot m_q(k_{st(i,1),r}) \cdot ГДФ("G", \lambda_{c_{st(i,1),r}}, k_{st(i,1),r}) \cdot \sin(\alpha_{st(i,1),r}) \cdot P*_{st(i,1),r} \cdot \sqrt{T*_{st(i,3),r}}}{m_q(k_{st(i,3),r}) \cdot ГДФ("G", \lambda_{c_{st(i,3),r}}, k_{st(i,3),r}) \cdot \sin(\alpha_{st(i,3),r}) \cdot P*_{st(i,3),r} \sqrt{T*_{st(i,1),r}}}$
    while $0 < 1$
        $iteration_3 = iteration_3 + 1$
        trace(concat("    iteration.3 = ", num2str($iteration_3$)))
        if $(ЗППЧ_i \neq "пер") \wedge (ЗППЧ_i \neq "кор") \wedge (ЗППЧ_i \neq "ср")$
            $D_{st(i,3),N_r} = D_{st(i,1),N_r} \cdot str2num(ЗППЧ_i)$
            $D_{st(i,3),1} = \sqrt{(D_{st(i,3),N_r})^2 - \frac{4 F_{st(i,3)}}{\pi}}$
        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"

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

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

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

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

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

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

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

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

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

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

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

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

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

```
        $F_{st(i,3)} = F'_3$
    $\bar{c}_{a_{st(i,2),r}} = mean\left(\bar{c}_{a_{st(i,1),r}}, \bar{c}_{a_{st(i,3),r}}\right)$
    $iteration_2 = 0$
    $F_{st(i,2)} = mean\left(F_{st(i,1)}, F_{st(i,3)}\right)$
    while $0 < 1$
        $iteration_2 = iteration_2 + 1$
        trace(concat("    iteration.2 = ", num2str($iteration_2$)))
        if $(ЗППЧ_i \ne "пер") \wedge (ЗППЧ_i \ne "кор") \wedge (ЗППЧ_i \ne "ср")$
            $D_{st(i,2),N_r} = mean\left(D_{st(i,1),N_r}, D_{st(i,3),N_r}\right)$
            $\bar{d}_{st(i,2)} = \sqrt{2 \cdot mean\left(\bar{r}_{cp}(\bar{d}_{st(i,1)}), \bar{r}_{cp}(\bar{d}_{st(i,3)})\right)^2 - 1}$
            $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \bar{r}_{cp}(\bar{d}_{st(i,2)})$
            $D_{st(i,2),1} = \bar{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$
        if $ЗППЧ_i = "пер"$
            $D_{st(i,2),N_r} = D_{st(i,1),N_r}$
            $\bar{d}_{st(i,2)} = \sqrt{2 \cdot mean\left(\bar{r}_{cp}(\bar{d}_{st(i,1)}), \bar{r}_{cp}(\bar{d}_{st(i,3)})\right)^2 - 1}$
            $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \bar{r}_{cp}(\bar{d}_{st(i,2)})$
            $D_{st(i,2),1} = \bar{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$
        if $ЗППЧ_i = "кор"$
            $D_{st(i,2),1} = D_{st(i,1),1}$
            $\bar{d}_{st(i,2)} = \sqrt{2 \cdot mean\left(\bar{r}_{cp}(\bar{d}_{st(i,1)}), \bar{r}_{cp}(\bar{d}_{st(i,3)})\right)^2 - 1}$
            $D_{st(i,2),N_r} = \frac{D_{st(i,2),1}}{\bar{d}_{st(i,2)}}$
            $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \bar{r}_{cp}(\bar{d}_{st(i,2)})$
        if $ЗППЧ_i = "ср"$
            $D_{st(i,2),r} = D_{st(i,1),r}$
            $\bar{d}_{st(i,2)} = \sqrt{2 \cdot mean\left(\bar{r}_{cp}(\bar{d}_{st(i,1)}), \bar{r}_{cp}(\bar{d}_{st(i,3)})\right)^2 - 1}$
            $D_{st(i,2),N_r} = \frac{D_{st(i,2),r}}{\bar{r}_{cp}(\bar{d}_{st(i,2)})}$
            $D_{st(i,2),1} = \bar{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$
```

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

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

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

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

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

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

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

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

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

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

for $a \in 1..3$

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

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

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

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

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

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

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

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

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

$$M_{w_{st(i,a),r}} = \frac{w_{st(i,a),r}}{a_{\text{зв}_{st(i,a),r}}}$$

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

```
      $M_{c_{st(i,a),r}} = \frac{}{a_{\text{зв}_{st(i,a),r}}}$
      $h_{st(i,a)} = 0.5\cdot\left(D_{st(i,a),N_r} - D_{st(i,a),1}\right)$
      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 $r \in 1 .. N_r$
        $R_{st(i,a),r} = 0.5\cdot D_{st(i,a),r}$
  $\begin{pmatrix}R_L & K_H & Cp & \overline{H}_T & L* & T* & P* & \rho* & a*_c & \lambda_c & F & D & \overline{d} & \overline{c}_a & c_a & u & c & M_c & \alpha & \varepsilon_{rotor} \\ \pi* & \eta* & k & H_T & L & T & P & \rho & a_{\text{зв}} & \lambda_c & F & R & h & \overline{c}_u & c_u & w_u & w & M_w & \beta & \varepsilon_{stator}\end{pmatrix}^T$
```

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

▲ Поступенчатый расчет ОК по ср. ЛТ

```
CA = | 1  if compressor = "КВД"    = 1
     | 0  otherwise
```

Расчет CA:

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

```
for $r \in av(N_r)$
    $\alpha_{1CA_r} = \alpha_{st(Z,3),r}$
    $\alpha_{3CA_r} = $ | $90\cdot°$  if $CA = 1$
                        | $\alpha_{1CA_r}$  otherwise
    $\overline{d}_{1CA} = \overline{d}_{st(Z,3)}$
    $\overline{d}_{3CA} = \overline{d}_{1CA}$
    $T^*_{1CA_r} = T^*_{st(Z,3),r}$
    $T^*_{3CA_r} = T^*_{1CA_r}$
    $P^*_{1CA_r} = P^*_{st(Z,3),r}$
    $iterarion_{CA} = 0$
    $\sigma_{CA} = 1$
    while $0 < 1$
        $iterarion_{CA} = iterarion_{CA} + 1$
        trace(concat("iterarion.CA = ", num2str($iterarion_{CA}$)))
        $P^*_{3CA_r} = P^*_{1CA_r}\cdot\sigma_{CA}$
        $\begin{pmatrix}\rho^*_{1CA_r}\end{pmatrix}$    1    $\begin{pmatrix}\frac{P^*_{1CA_r}}{T^*_{1CA_r}}\end{pmatrix}$
```

$\sigma_{CA} = 0.9981$

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

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

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

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

$$\begin{pmatrix} \rho^*_{3CA_r} \end{pmatrix} = \frac{1}{R_в}\cdot\begin{pmatrix} \dfrac{P^*_{3CA_r}}{T^*_{3CA_r}} \end{pmatrix}$$

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

$$\begin{pmatrix} a_{кр1CA_r} \\ a_{кр3CA_r} \end{pmatrix} = \begin{pmatrix} a_{кр}\left(k_{1CA_r}, R_в, T^*_{1CA_r}\right) \\ a_{кр}\left(k_{3CA_r}, R_в, T^*_{3CA_r}\right) \end{pmatrix}$$

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

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

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

$$\overline{c}_{u3CA_r} = \left| \begin{array}{ll} 0 & \text{if } CA = 1 \\ \overline{c}_{u1CA_r} & \text{otherwise} \end{array} \right.$$

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

$$c_{a3CA_r} = c_{a1CA_r} - \left| \begin{array}{ll} 10 & \text{if } CA = 1 \\ 0 & \text{otherwise} \end{array} \right.$$

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

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

$$\begin{pmatrix} \lambda_{1CA_r} \\ \lambda_{3CA_r} \end{pmatrix} = \begin{pmatrix} \dfrac{c_{1CA_r}}{a_{кр1CA_r}} \\ \dfrac{c_{3CA_r}}{a_{кр3CA_r}} \end{pmatrix}$$

$$\sigma'_{CA} = \left| 1 - \text{mean}(0.25, 0.5)\cdot ГДФ\left(\text{"}\rho\text{"}, \lambda_{3CA_r}, k_{3CA_r}\right)\cdot\frac{k_{3CA_r}}{k_{3CA_r}+1}\cdot\left(\lambda_{3CA_r}\right)^2 \;\; \text{if } CA = 1 \right.$$

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

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

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

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

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

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

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

$$\text{submatrix}\left(k_{3CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (1.352)$$

$$\text{submatrix}\left(a_{кр1CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (522.4)$$

$$\text{submatrix}\left(a_{кр3CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (522.4)$$

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

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

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

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

$$\text{submatrix}\left(c_{a1CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (58.9)$$

$$\text{submatrix}\left(c_{a3CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (48.9)$$

$$\text{submatrix}\left(c_{u1CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (44.1)$$

$$\text{submatrix}\left(c_{u3CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.0)$$

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

$$\text{submatrix}\left(c_{3CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (48.9)$$

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

$$\text{submatrix}\left(\lambda_{3CA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.094)$$

```
            1  otherwise
        break if $\left(\left|eps\left("rel", \sigma'_{CA}, \sigma_{CA}\right)\right| < epsilon\right) \wedge \left(iterarion_{CA} = 0\right)$
        $iterarion_{CA} = -1$ if $\left(\left|eps\left("rel", \sigma'_{CA}, \sigma_{CA}\right)\right| < epsilon\right)$
        $\sigma_{CA} = \sigma'_{CA}$
    $\begin{pmatrix} F_{1CA} \\ F_{3CA} \end{pmatrix} = \left( \dfrac{F_{st(Z,3)}}{\dfrac{G \cdot \sqrt{R_{В} \cdot T^*_{3CA_r}}}{m_q\left(k_{3CA_r}\right) \cdot P^*_{3CA_r} \cdot ГДФ\left("G", \lambda_{3CA_r}, k_{3CA_r}\right) \cdot \sin\left(\alpha_{3CA_r}\right)}} \right)$
    $\varepsilon_{CA_r} = \alpha_{3CA_r} - \alpha_{1CA_r}$
$\begin{pmatrix} \alpha_{1CA} & \alpha_{3CA} \\ \sigma_{CA} & \sigma_{CA} \\ \bar{d}_{1CA} & \bar{d}_{3CA} \\ T^*_{1CA} & T^*_{3CA} \\ P^*_{1CA} & P^*_{3CA} \\ \rho^*_{1CA} & \rho^*_{3CA} \\ k_{1CA} & k_{3CA} \\ a_{кр1CA} & a_{кр3CA} \\ \bar{c}_{a1CA} & \bar{c}_{a3CA} \\ \bar{c}_{u1CA} & \bar{c}_{u3CA} \\ c_{a1CA} & c_{a3CA} \\ c_{u1CA} & c_{u3CA} \\ c_{1CA} & c_{3CA} \\ \lambda_{1CA} & \lambda_{3CA} \\ F_{1CA} & F_{3CA} \\ \varepsilon_{CA} & \varepsilon_{CA} \end{pmatrix}$
```

Расчет CA:

Результаты поступенчатого расчета по ср. ЛТ

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

```
$\bar{\Delta}G$ = | for $i \in 1..Z$
                  |   for $a \in 1..3$
                  |     $\bar{\Delta}G_{st(i,a)} = \left|eps\left("rel", G, \rho_{st(i,a),av(N_r)} \cdot c_{a_{st(i,a),av(N_r)}} \cdot F_{st(i,a)}\right)\right|$
                  | $\bar{\Delta}G$
```

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

	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

$\cdot \%$

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

	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: $\pi^*_{ЛА} := \dfrac{P^*_{3CA_{av(N_r)}}}{P^*_{1ВНА_{av(N_r)}}} = 8.970$ $\quad \pi^*_{ЛА} \ge \pi^*_К = 0$

$H_T^{\,T} =$

	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 []: $\eta^*_K = \dfrac{L^*_K}{L_K} = 88.00\cdot\%$

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

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

	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						

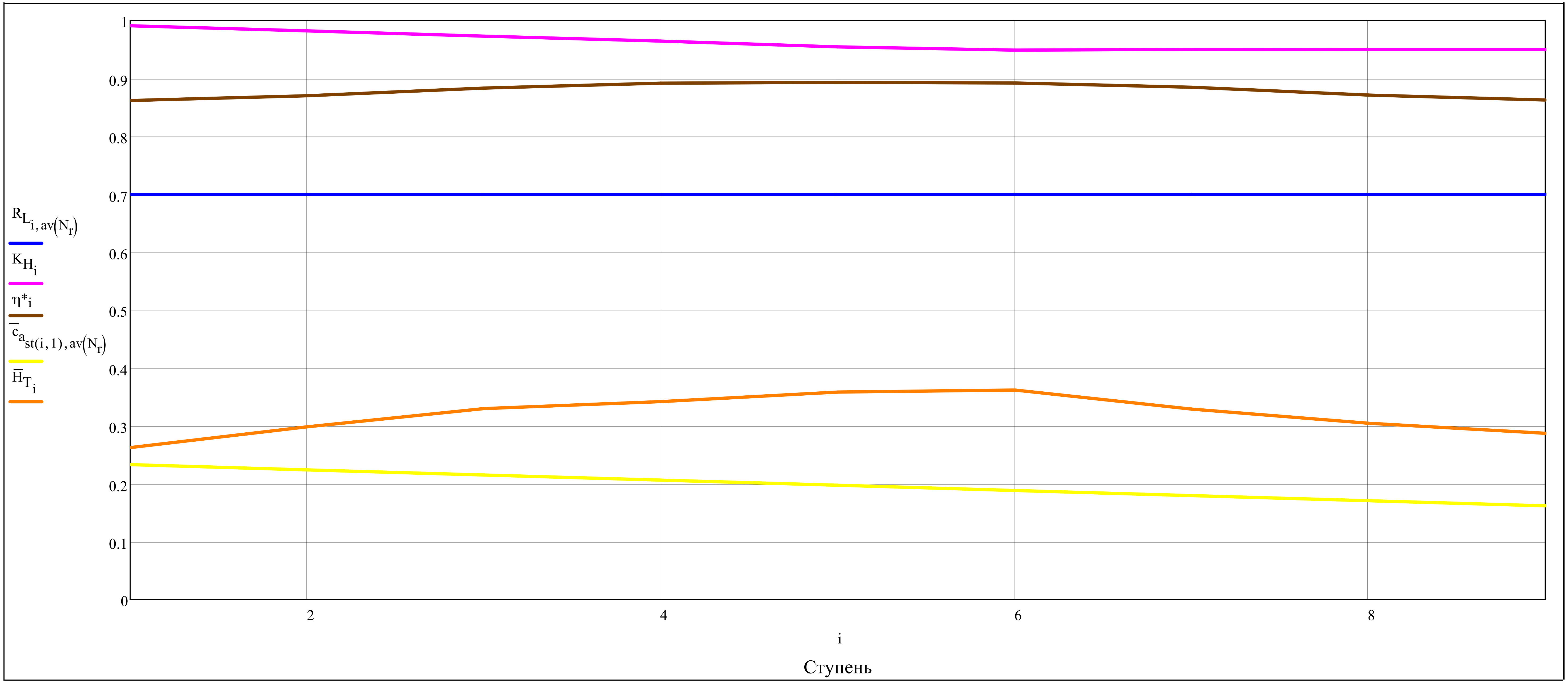
$\cdot\%$

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

	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						



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

	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

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

	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		

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

	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		

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

	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		

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

	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	...

$\cdot 10^3$

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

	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	...

$\cdot 10^3$

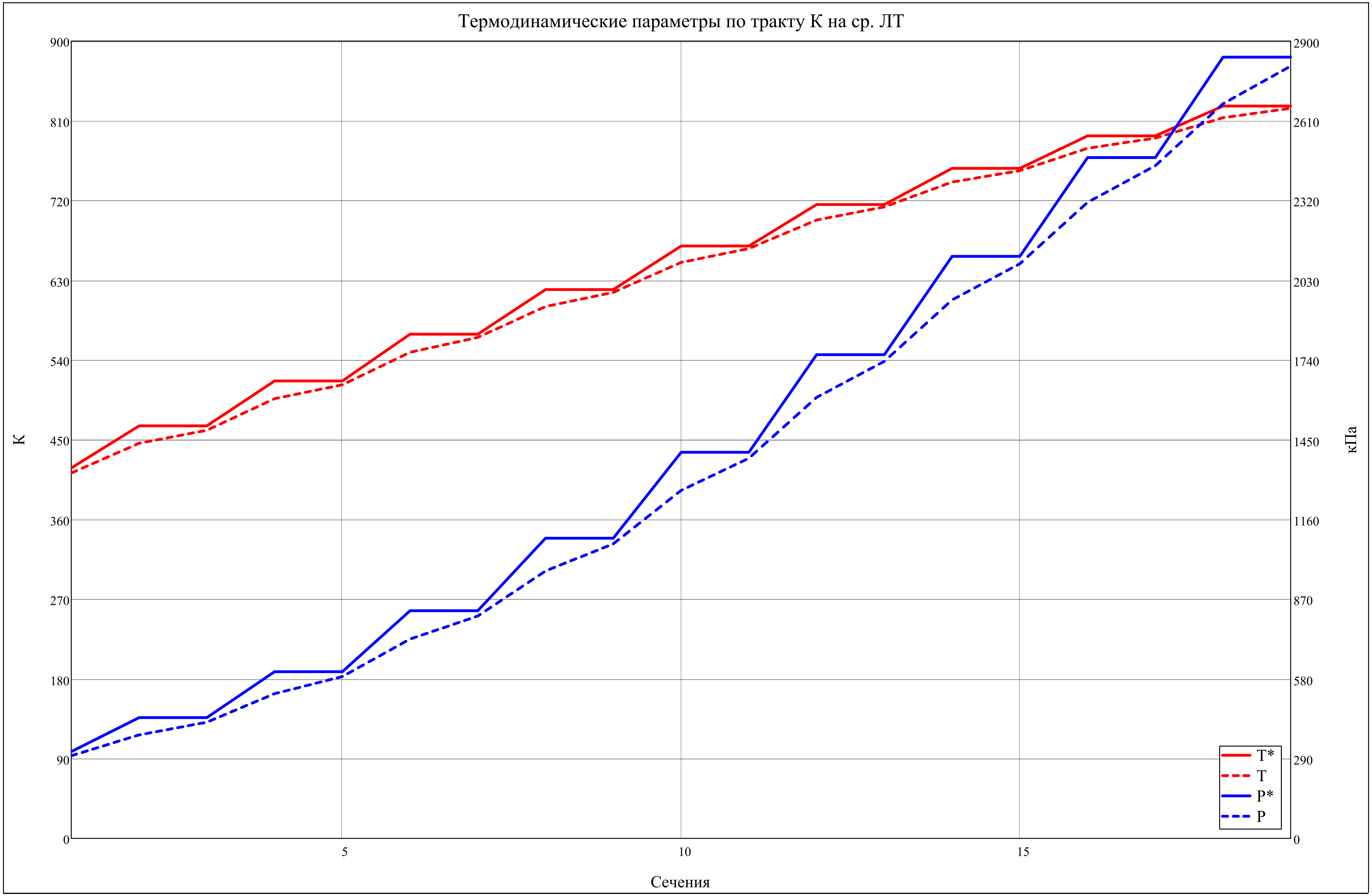
$\text{submatrix}\left(\rho*, 1, 2Z+1, av\left(N_r\right), av\left(N_r\right)\right)^T =$

	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

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

	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

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


Термодинамические параметры по тракту К на ср. ЛТ
900
810
720
630
540
450
360
270
180
90
0
К
2900
2610
2320
2030
1740
1450
1160
870
580
290
0
кПа
5
10
15
Сечения
T*
T
P*
P

$F^T =$

	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				

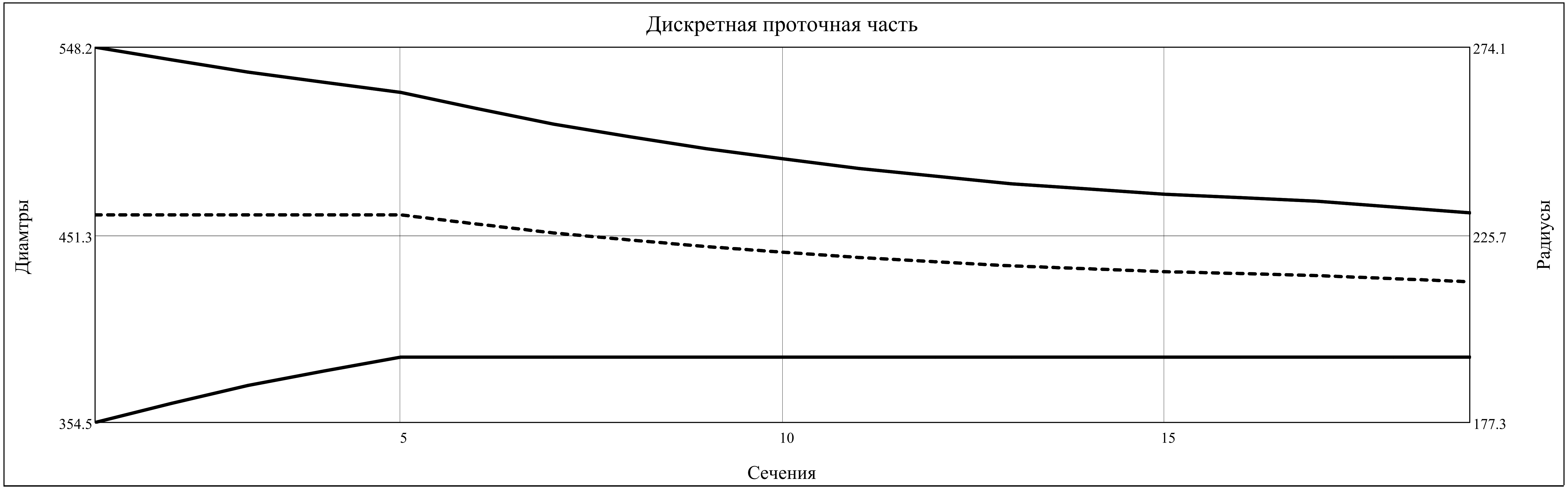
$\overline{d}_{st(Z,3)} = 0.839$ $\overline{d}_{st(Z,3)} \le 0.9 = 1$

$D^T =$ $\cdot 10^{-3}$

	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		

$R^T =$ $\cdot 10^{-3}$

	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						



$h^T =$ $\cdot 10^{-3}$

	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						

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

	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		

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

	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		

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

	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		

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

	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						

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

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

Для КС

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

	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		

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

	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		

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

	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		

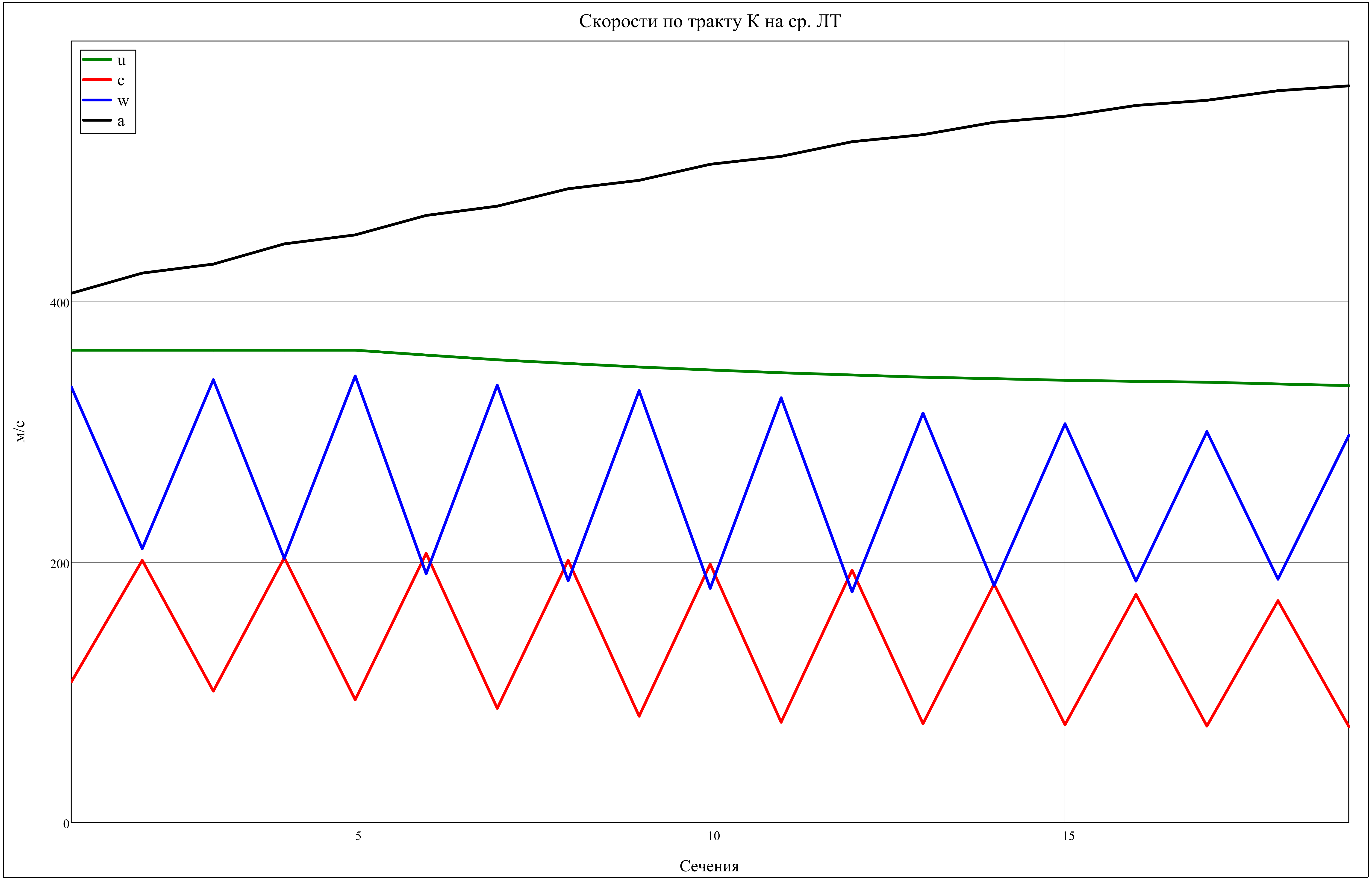
$$\Delta c_{a_{i,\mathrm{av}(N_r)}} = \left(c_{a_{st(i,2),\mathrm{av}(N_r)}} - c_{a_{st(i,1),\mathrm{av}(N_r)}}\right)$$

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

	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			

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

	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
u
c
w
a
м/с
400
200
0
5
10
15
Сечения

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

	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		

$\cdot^\circ$

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

	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		

$\cdot^\circ$

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

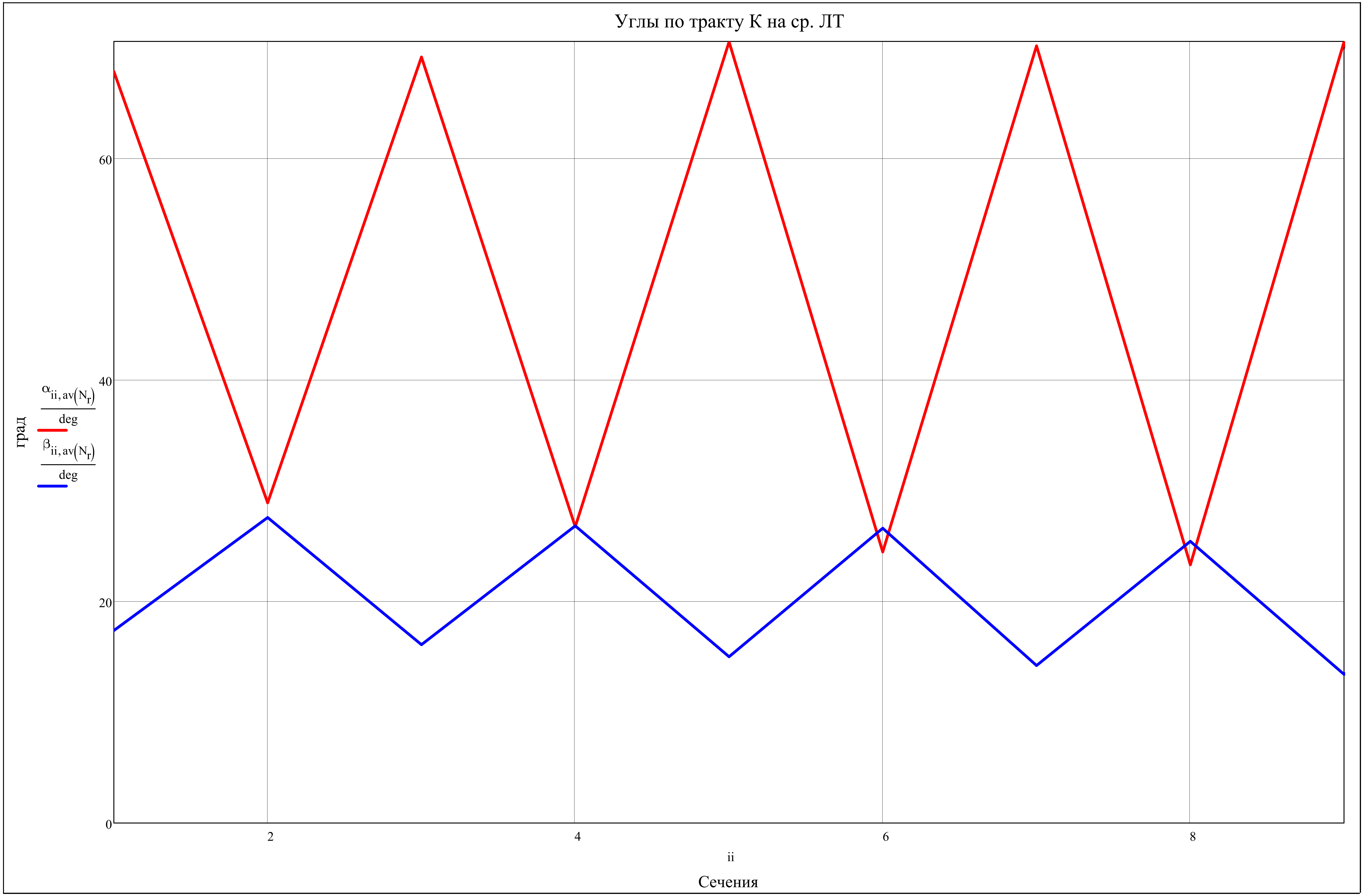
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	10.19	10.72	11.6	11.21	11.04	10.42	8.68	7.44	7.04												

$\cdot^\circ$

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

	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												

$\cdot^\circ$


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

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

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

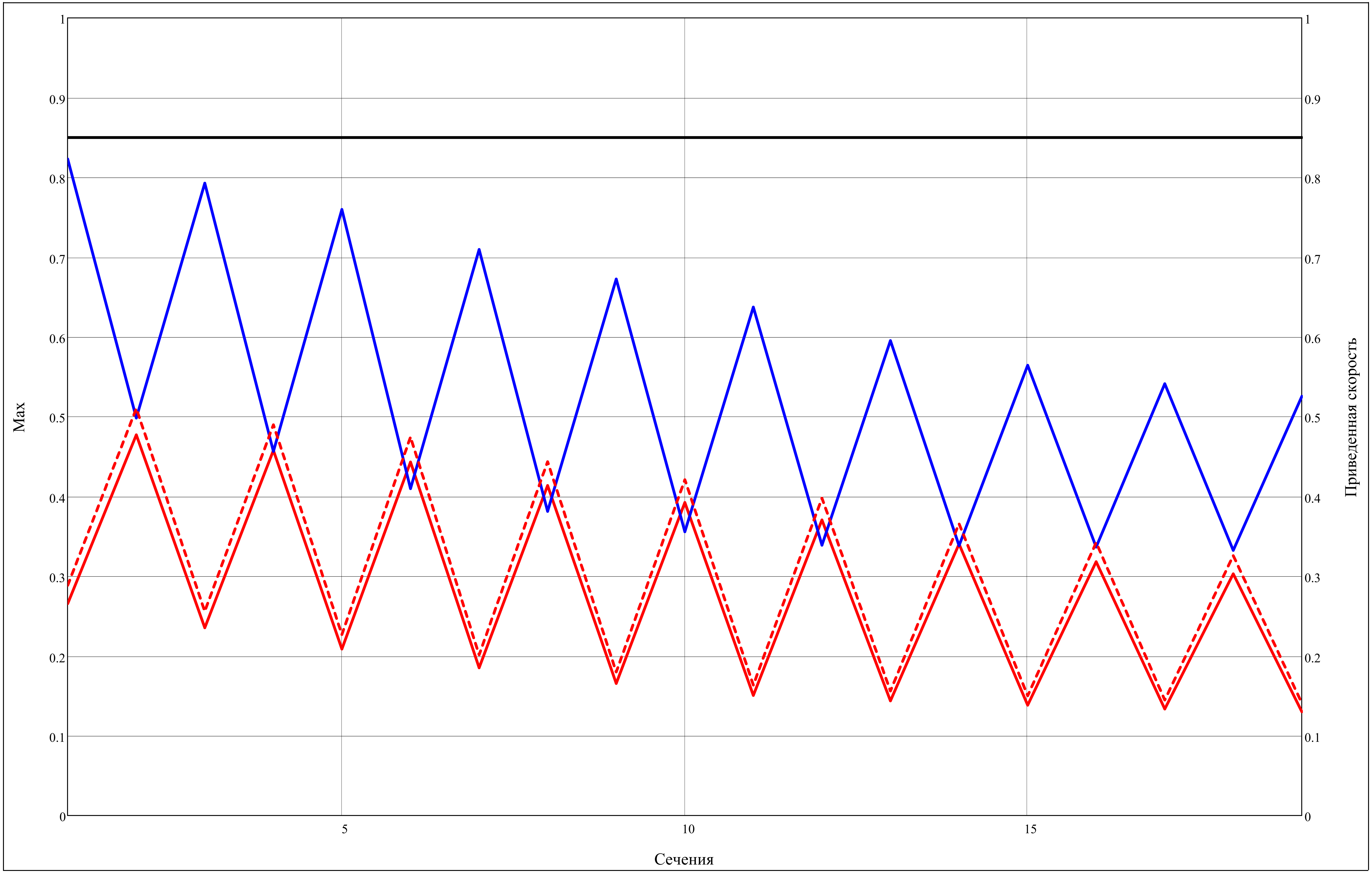
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	...

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

	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	

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

	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

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 = | for i ∈ 1 .. Z
    |   m_i = | −1  if  $\bar{d}_{st(i,1)} \le \bar{d}_{R2m}$
    |         | 1  if  $\bar{d}_{st(i,1)} \ge \bar{d}_{m2Ц}$
    |         | $-1 + \frac{1-(-1)}{\bar{d}_{m2Ц} - \bar{d}_{R2m}} \cdot \left(\bar{d}_{st(i,1)} - \bar{d}_{R2m}\right)$  otherwise
    | m
```

```
m_i = | 0.73  if  compressor = "Вл"
      | m_i  otherwise
```

$m^T =$

	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 $r \in 1..N_r$
    $\begin{pmatrix} T^*{}_{1BHA_r} \\ T^*{}_{3BHA_r} \end{pmatrix} = \begin{pmatrix} T^*{}_{1BHA_{av(N_r)}} \\ T^*{}_{3BHA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} P^*{}_{1BHA_r} \\ P^*{}_{3BHA_r} \end{pmatrix} = \begin{pmatrix} P^*{}_{1BHA_{av(N_r)}} \\ P^*{}_{3BHA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} \rho^*{}_{1BHA_r} \\ \rho^*{}_{3BHA_r} \end{pmatrix} = \begin{pmatrix} \rho^*{}_{1BHA_{av(N_r)}} \\ \rho^*{}_{3BHA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} Cp_{1BHA_r} \\ Cp_{3BHA_r} \end{pmatrix} = \begin{pmatrix} Cp_{воздух}\left(P^*{}_{1BHA_r}, T^*{}_{1BHA_r}\right) \\ Cp_{воздух}\left(P^*{}_{3BHA_r}, T^*{}_{3BHA_r}\right) \end{pmatrix}$
    $\begin{pmatrix} k_{1BHA_r} \\ k_{3BHA_r} \end{pmatrix} = \begin{pmatrix} k_{ад}\left(Cp_{1BHA_r}, R_в\right) \\ k_{ад}\left(Cp_{3BHA_r}, R_в\right) \end{pmatrix}$
    $\begin{pmatrix} a^*{}_{c1BHA_r} \\ a^*{}_{c3BHA_r} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{2 \cdot k_{1BHA_r}}{k_{1BHA_r} + 1} \cdot R_в \cdot T^*{}_{1BHA_r}} \\ \sqrt{\frac{2 \cdot k_{3BHA_r}}{k_{3BHA_r} + 1} \cdot R_в \cdot T^*{}_{3BHA_r}} \end{pmatrix}$
    $A = \left(1 - R_{L_{i,av(N_r)}}\right) \cdot \omega \cdot \left(R_{st(i,1),av(N_r)}\right)^{m_i + 1}$
    $B = \frac{H_{T_{i,av(N_r)}}}{2 \cdot \omega}$
    $\begin{pmatrix} c_{u1BHA_r} \\ \end{pmatrix} = \left[ c_{u1BHA_{av(N_r)}} \quad A \quad B \right.$
```

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

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

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

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

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

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

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

```
$\begin{pmatrix} T^* & T \\ P^* & P \\ \rho^* & \rho \\ Cp & k \\ a^*_c & a_{зв} \\ c_u & c_a \\ \alpha & \beta \\ c & w \\ \lambda_c & w_u \\ M_w & M_c \\ R_L & R_L \\ \varepsilon_{rotor} & \varepsilon_{stator} \end{pmatrix} =$
  for $i \in 1..Z$
    for $a \in 1..3$
      for $r \in 1..N_r$
        $T^*_{st(i,a),r} = T^*_{st(i,a),av(N_r)}$
        $P^*_{st(i,a),r} = P^*_{st(i,a),av(N_r)}$
        $\rho^*_{st(i,a),r} = \rho^*_{st(i,a),av(N_r)}$
        $Cp_{st(i,a),r} = Cp_{воздух}\left(P^*_{st(i,a),r}, T^*_{st(i,a),r}\right)$
        $k_{st(i,a),r} = k_{ад}\left(Cp_{st(i,a),r}, R_в\right)$
        $a^*_{c_{st(i,a),r}} = \sqrt{\frac{2\cdot k_{st(i,a),r}}{k_{st(i,a),r}+1}\cdot R_в\cdot T^*_{st(i,a),r}}$
        if $\Delta H_{Tmax} = 0$
          $A_{st(i,a)} = \left(1 - R_{L_{i,av(N_r)}}\right)\cdot\omega\cdot\left(R_{st(i,a),av(N_r)}\right)^{m_i+1}$
          $B_{st(i,a)} = \frac{H_{T_{i,av(N_r)}}}{2\cdot\omega}$
          $c_{u_{st(i,a),r}} =$
            $c_{u_{st(i,a-1),r}}\cdot\frac{R_{st(i,a),r}}{R_{st(i,a-1),r}} + \frac{H_{T_{i,av(N_r)}}}{\omega\cdot R_{st(i,a),r}}$ if $a = 2$
            otherwise
              $0$ if $(a = 1)\wedge(i = 1)\wedge(BHA = 0)$
              $\frac{A_{st(i,a)}}{\left(R_{st(i,a),r}\right)^{m_i}} - \frac{B_{st(i,a)}}{\left(R_{st(i,a),r}\right)}$ otherwise
          $c_{a_{st(i,a),r}} =$
            $c_{a3BHA_r}$ if $(a = 1)\wedge(i = 1)\wedge(BHA = 1)$
            $\sqrt{\left(c_{a_{st(i,a),av(N_r)}}\right)^2 - 2\cdot\left(A_{st(i,a)}\right)^2\cdot\left[\left(R_{st(i,a),r}\right)^2 - \left(R_{st(i,a),av(N_r)}\right)^2\right] + 4\cdot A_{st(i,a)}\cdot B_{st(i,a)}\cdot\ln\left(\frac{R_{st(i,a),r}}{R_{st(i,a),av(N_r)}}\right)\cdot\begin{cases}-1 & \text{if } a = 2\\ 1 & \text{otherwise}\end{cases}}$ if $m_i = -1$
            $\sqrt{\left(c_{a_{st(i,a),av(N_r)}}\right)^2 - 2\cdot\left(A_{st(i,a)}\right)^2\cdot\ln\left(\frac{R_{st(i,a),r}}{R}\right) - 2\cdot A_{st(i,a)}\cdot B_{st(i,a)}\cdot\left(\frac{1}{R} - \frac{1}{R}\right)\cdot\begin{cases}-1 & \text{if } a = 2\end{cases}}$ if $m_i = 0$
```

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

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

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

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

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

$$c_{u_{st(i,a),r}} = \left|\begin{array}{l}A_{st(i,a)}\cdot R_{st(i,a),r} + \dfrac{B_{st(i,a)}}{R_{st(i,a),r}} + \dfrac{H_{T_{i,r}}}{\omega\cdot R_{st(i,a),r}} \quad \text{if } a = 2\\ \text{otherwise}\\ \quad\left|\begin{array}{l}0 \quad \text{if } (a = 1)\wedge(i = 1)\wedge(BHA = 0)\\ A_{st(i,a)}\cdot R_{st(i,a),r} + \dfrac{B_{st(i,a)}}{R_{st(i,a),r}} \quad \text{otherwise}\end{array}\right.\end{array}\right.$$

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

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

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

$$= \text{triangle}\left(c \qquad c \qquad\right)$$

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        $\alpha_{st(i,a),r} = \text{triangle}\left(c_{a_{st(i,a),r}}, c_{u_{st(i,a),r}}\right)$
        $c_{st(i,a),r} = \dfrac{c_{a_{st(i,a),r}}}{\sin\left(\alpha_{st(i,a),r}\right)}$
        $\lambda_{c_{st(i,a),r}} = \dfrac{c_{st(i,a),r}}{a*_{c_{st(i,a),r}}}$
        $\begin{pmatrix} T_{st(i,a),r} \\ P_{st(i,a),r} \\ \rho_{st(i,a),r} \end{pmatrix} = \begin{pmatrix} T*_{st(i,a),r} \cdot ГДФ\left(\text{"T"}, \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right) \\ P*_{st(i,a),r} \cdot ГДФ\left(\text{"P"}, \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right) \\ \rho*_{st(i,a),r} \cdot ГДФ\left(\text{"}\rho\text{"}, \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right) \end{pmatrix}$
        $a_{зв_{st(i,a),r}} = \sqrt{k_{st(i,a),r} \cdot R_в \cdot T_{st(i,a),r}}$
        $\beta_{st(i,a),r} = \text{triangle}\left(c_{a_{st(i,a),r}}, u_{st(i,a),r} - c_{u_{st(i,a),r}}\right)$
        $w_{st(i,a),r} = \dfrac{c_{a_{st(i,a),r}}}{\sin\left(\beta_{st(i,a),r}\right)}$
        $w_{u_{st(i,a),r}} = w_{st(i,a),r} \cdot \cos\left(\beta_{st(i,a),r}\right)$
        $\begin{pmatrix} M_{w_{st(i,a),r}} \\ M_{c_{st(i,a),r}} \end{pmatrix} = \dfrac{1}{a_{зв_{st(i,a),r}}} \cdot \begin{pmatrix} w_{st(i,a),r} \\ c_{st(i,a),r} \end{pmatrix}$
    for $r \in 1 .. N_r$
        $R_{L_{i,r}} = 1 - \dfrac{c_{u_{st(i,1),r}} + c_{u_{st(i,2),r}}}{u_{st(i,1),r} + u_{st(i,2),r}}$
        $\begin{pmatrix} \varepsilon_{rotor_{i,r}} \\ \varepsilon_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \beta_{st(i,2),r} - \beta_{st(i,1),r} \\ \alpha_{st(i,3),r} - \alpha_{st(i,2),r} \end{pmatrix}$
$\begin{pmatrix} T* & P* & \rho* & Cp & a*_c & c_u & \alpha & c & \lambda_c & M_w & R_L & \varepsilon_{rotor} \\ T & P & \rho & k & a_{зв} & c_a & \beta & w & w_u & M_c & R_L & \varepsilon_{stator} \end{pmatrix}^T$
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$\begin{pmatrix} T^*_{1CA} & T^*_{3CA} \\ P^*_{1CA} & P^*_{3CA} \\ \rho^*_{1CA} & \rho^*_{3CA} \\ Cp_{1CA} & Cp_{3CA} \\ k_{1CA} & k_{3CA} \\ a^*_{c1CA} & a^*_{c3CA} \\ c_{u1CA} & c_{u3CA} \\ c_{a1CA} & c_{a3CA} \\ \alpha_{1CA} & \alpha_{3CA} \\ c_{1CA} & c_{3CA} \\ \lambda_{c1CA} & \lambda_{c3CA} \\ \varepsilon_{CA} & \varepsilon_{CA} \end{pmatrix} =$
for $i \in Z$
  for $r \in 1 .. N_r$
    $\begin{pmatrix} T^*_{1CA_r} \\ T^*_{3CA_r} \end{pmatrix} \leftarrow \begin{pmatrix} T^*_{st(i,3),r} \\ T^*_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} P^*_{1CA_r} \\ P^*_{3CA_r} \end{pmatrix} \leftarrow \begin{pmatrix} P^*_{st(i,3),r} \\ P^*_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} \rho^*_{1CA_r} \\ \rho^*_{3CA_r} \end{pmatrix} \leftarrow \begin{pmatrix} \rho^*_{st(i,3),r} \\ \rho^*_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} Cp_{1CA_r} \\ Cp_{3CA_r} \end{pmatrix} \leftarrow \begin{pmatrix} Cp_{воздух}\left(P^*_{1CA_r}, T^*_{1CA_r}\right) \\ Cp_{воздух}\left(P^*_{3CA_r}, T^*_{3CA_r}\right) \end{pmatrix}$
    $\begin{pmatrix} k_{1CA_r} \\ k_{3CA_r} \end{pmatrix} \leftarrow \begin{pmatrix} k_{ад}\left(Cp_{1CA_r}, R_в\right) \\ k_{ад}\left(Cp_{3CA_r}, R_в\right) \end{pmatrix}$
    $\begin{pmatrix} a^*_{c1CA_r} \\ a^*_{c3CA_r} \end{pmatrix} \leftarrow \begin{pmatrix} \sqrt{\frac{2 \cdot k_{1CA_r}}{k_{1CA_r} + 1} \cdot R_в \cdot T^*_{1CA_r}} \\ \sqrt{\frac{2 \cdot k_{3CA_r}}{k_{3CA_r} + 1} \cdot R_в \cdot T^*_{3CA_r}} \end{pmatrix}$
    $A \leftarrow \left(1 - R_{L_{i,av(N_r)}}\right) \cdot \omega \cdot \left(R_{st(i,3),av(N_r)}\right)^{m_i+1}$
    $B \leftarrow \frac{H_{T_{i,av(N_r)}}}{2 \cdot \omega}$
    $\begin{pmatrix} c_{u1CA_r} \\ c_{u3CA} \end{pmatrix} \leftarrow \begin{pmatrix} c_{u_{st(i,3),r}} \\ \quad c_{u3CA_{av(N_r)}} \text{ if } CA = 1 \end{pmatrix}$
```

$$c_{u_{st(i,3),r}} \quad \text{otherwise}$$

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

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

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

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

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

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

▲ Расчет параметров потока по высоте Л

▼ Результаты расчета параметров потока по высоте Л

$$T^*_{1\text{ВНА}} = \begin{pmatrix} 418.2 \\ 418.2 \\ 418.2 \end{pmatrix} \quad T^*_{3\text{ВНА}} = \begin{pmatrix} 418.2 \\ 418.2 \\ 418.2 \end{pmatrix} \quad a^*_{c1\text{ВНА}} = \begin{pmatrix} 373.95 \\ 373.95 \\ 373.95 \end{pmatrix} \quad a^*_{c3\text{ВНА}} = \begin{pmatrix} 373.95 \\ 373.95 \\ 373.95 \end{pmatrix} \quad \alpha_{1\text{ВНА}} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ^\circ \quad \alpha_{3\text{ВНА}} = \begin{pmatrix} 66.71 \\ 67.39 \\ 68.13 \end{pmatrix} \cdot ^\circ$$

$$P^*_{1\text{ВНА}} = \begin{pmatrix} 316.2 \\ 316.2 \\ 316.2 \end{pmatrix} \cdot 10^3 \quad P^*_{3\text{ВНА}} = \begin{pmatrix} 315.6 \\ 315.6 \\ 315.6 \end{pmatrix} \cdot 10^3 \quad c_{1\text{ВНА}} = \begin{pmatrix} 99.9 \\ 99.9 \\ 99.9 \end{pmatrix} \quad c_{3\text{ВНА}} = \begin{pmatrix} 112.6 \\ 108.2 \\ 105.6 \end{pmatrix} \quad \varepsilon_{\text{ВНА}} = \begin{pmatrix} 23.29 \\ 22.61 \\ 21.87 \end{pmatrix} \cdot ^\circ$$

$$\rho^*_{1\text{ВНА}} = \begin{pmatrix} 2.633 \\ 2.633 \\ 2.633 \end{pmatrix} \quad \rho^*_{3\text{ВНА}} = \begin{pmatrix} 2.628 \\ 2.628 \\ 2.628 \end{pmatrix} \quad c_{u1\text{ВНА}} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \quad c_{u3\text{ВНА}} = \begin{pmatrix} 44.5 \\ 41.6 \\ 39.3 \end{pmatrix}$$

$$Cp_{1\text{ВНА}} = \begin{pmatrix} 1016.2 \\ 1016.2 \\ 1016.2 \end{pmatrix} \quad Cp_{3\text{ВНА}} = \begin{pmatrix} 1016.2 \\ 1016.2 \\ 1016.2 \end{pmatrix} \quad c_{a1\text{ВНА}} = \begin{pmatrix} 99.9 \\ 99.9 \\ 99.9 \end{pmatrix} \quad c_{a3\text{ВНА}} = \begin{pmatrix} 103.5 \\ 99.9 \\ 98.0 \end{pmatrix} \quad \lambda_{c1\text{ВНА}} = \begin{pmatrix} 0.267 \\ 0.267 \\ 0.267 \end{pmatrix} \quad \lambda_{c3\text{ВНА}} = \begin{pmatrix} 0.301 \\ 0.289 \\ 0.282 \end{pmatrix}$$

$$k_{1\text{ВНА}} = \begin{pmatrix} 1.394 \\ 1.394 \\ 1.394 \end{pmatrix} \quad k_{3\text{ВНА}} = \begin{pmatrix} 1.394 \\ 1.394 \\ 1.394 \end{pmatrix}$$

$T^{*T} =$

	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		

$\rho^{T} =$

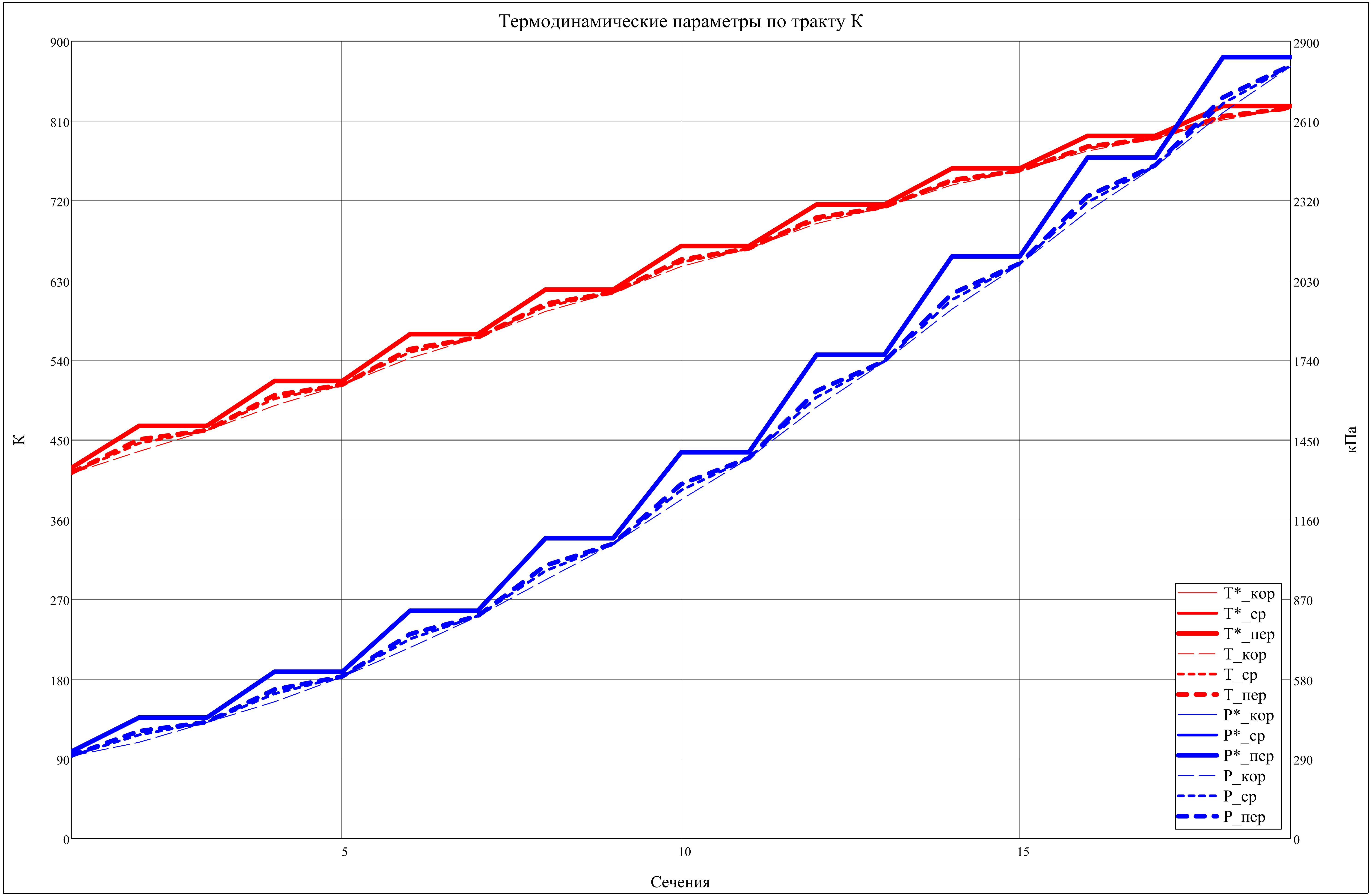
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	2.530	2.788	3.190	3.542	3.999	4.458	4.977	5.506	6.052	6.648	7.230	7.875	8.472	9.091	9.651	10.236	10.772	11.338	11.866		
2	2.537	2.940	3.196	3.691	4.003	4.604	4.981	5.644	6.055	6.782	7.233	8.004	8.477	9.207	9.657	10.345	10.780	11.441	11.873		
3	2.542	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
900
810
720
630
540
450
360
270
180
90
0
К
2900
2610
2320
2030
1740
1450
1160
870
580
290
0
кПа
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

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

	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	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					

```
$\Delta c_a$ = | for $i \in 1..Z$
                 for $a \in 2..3$
                   for $r \in 1..N_r$
                     $\Delta c_{a_{st(i,a),r}} = c_{a_{st(i,a),r}} - c_{a_{st(i,a-1),r}}$
               $\Delta c_a$
```

$\Delta c_a{}^T =$

	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] $\Delta c_a{}^T \geq -25 =$

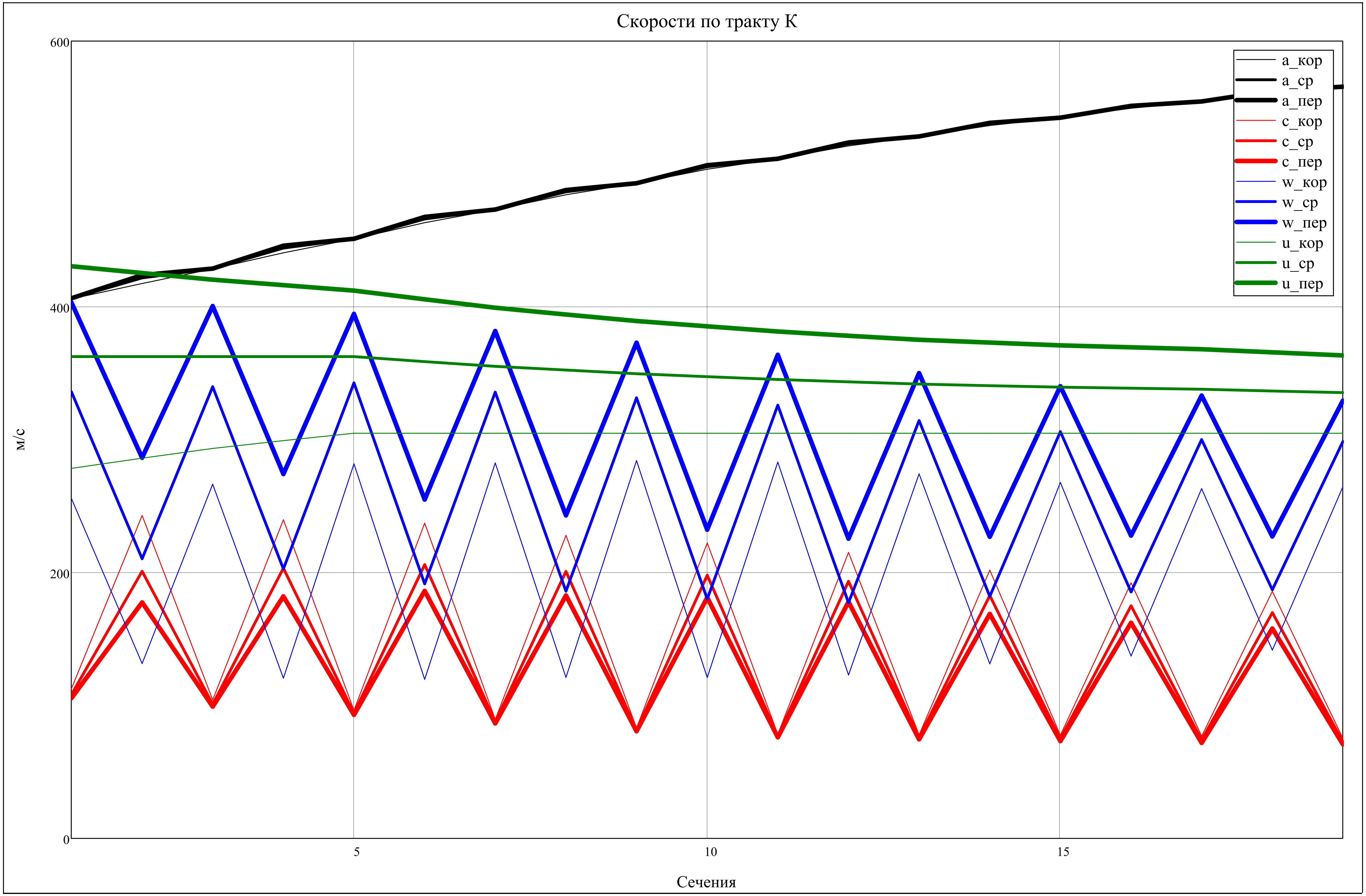
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						

$R_L{}^T =$

	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						

$\cdot°$

$\beta^T =$

	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		

$\cdot°$

$\beta^T \le 91\cdot° =$

	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		

β.2 > 91 => поменять з-н профилирования

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

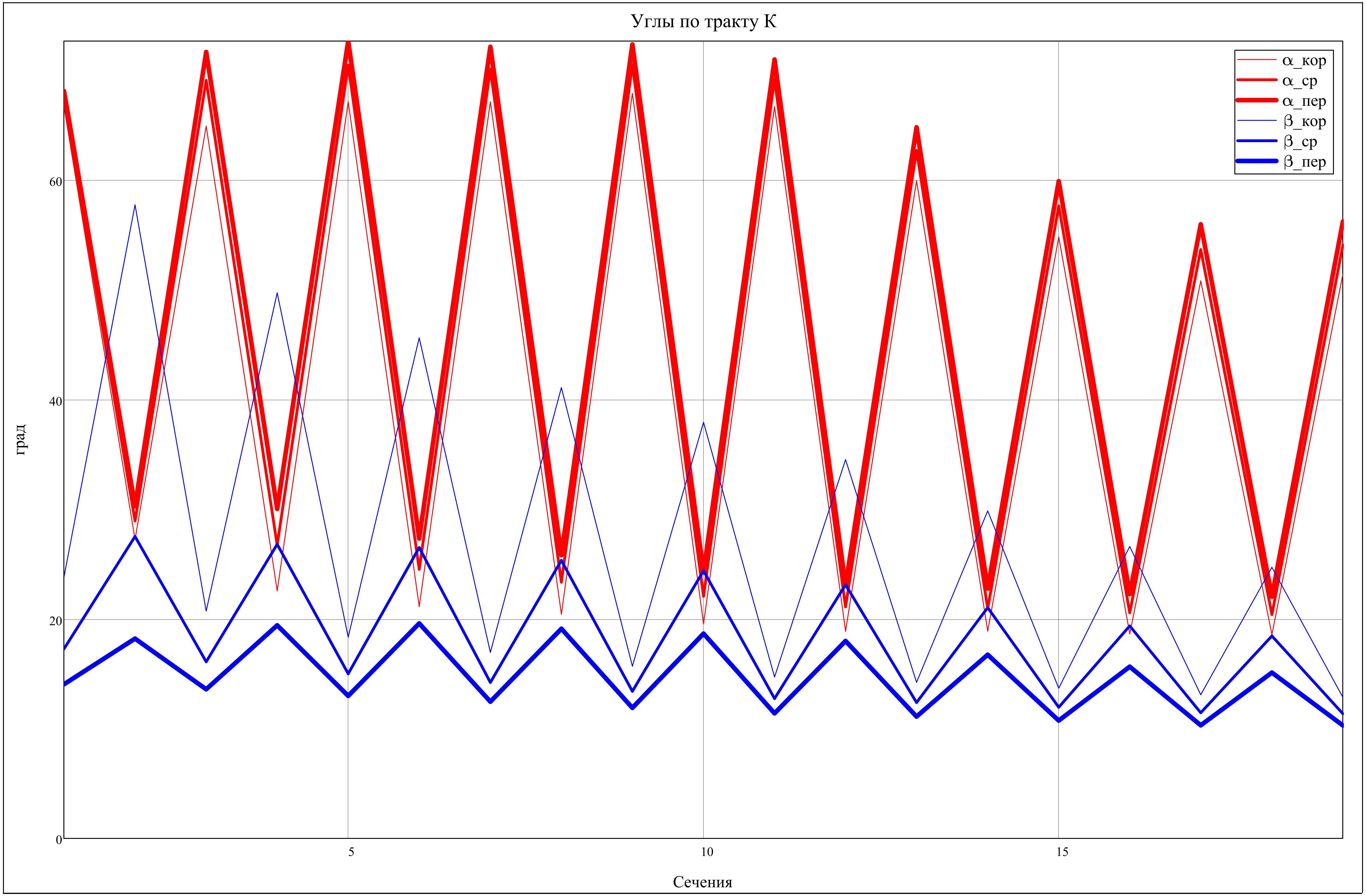
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	33.91	29.01	27.29	24.14	22.24	19.81	15.63	12.93	11.63						
2	10.25	10.72	11.51	11.14	10.99	10.38	8.66	7.42	7.01						
3	4.16	5.82	6.61	6.65	6.78	6.59	5.64	4.92	4.81						

$\cdot°$

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

	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						

$\cdot°$


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]

$\lambda_c^T \le 0.85 =$

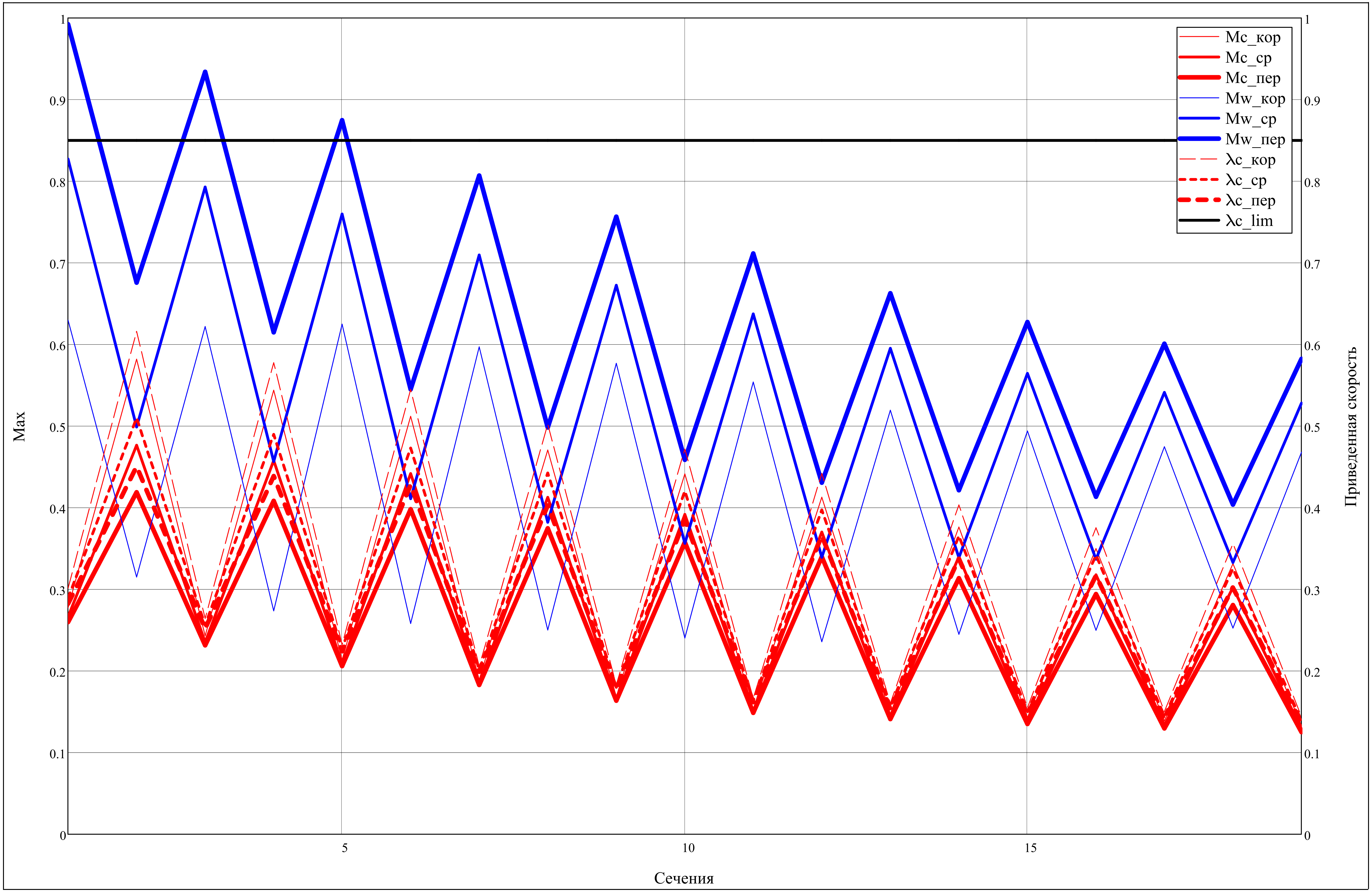
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

$M_c^T =$

	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				


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
Mc_кор
Mc_ср
Mc_пер
Mw_кор
Mw_ср
Mw_пер
λc_кор
λc_ср
λc_пер
λc_lim

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

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

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

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

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

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

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

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

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

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

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

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

▲ Результаты расчета параметров потока по высоте Л

Рассматриваемая ступень: $j = \left| \begin{array}{l} j = 1 \\ j = \left| \begin{array}{ll} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{array} \right. \end{array} \right. = 1$

Построение треугольников скоростей в 3х сечениях

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

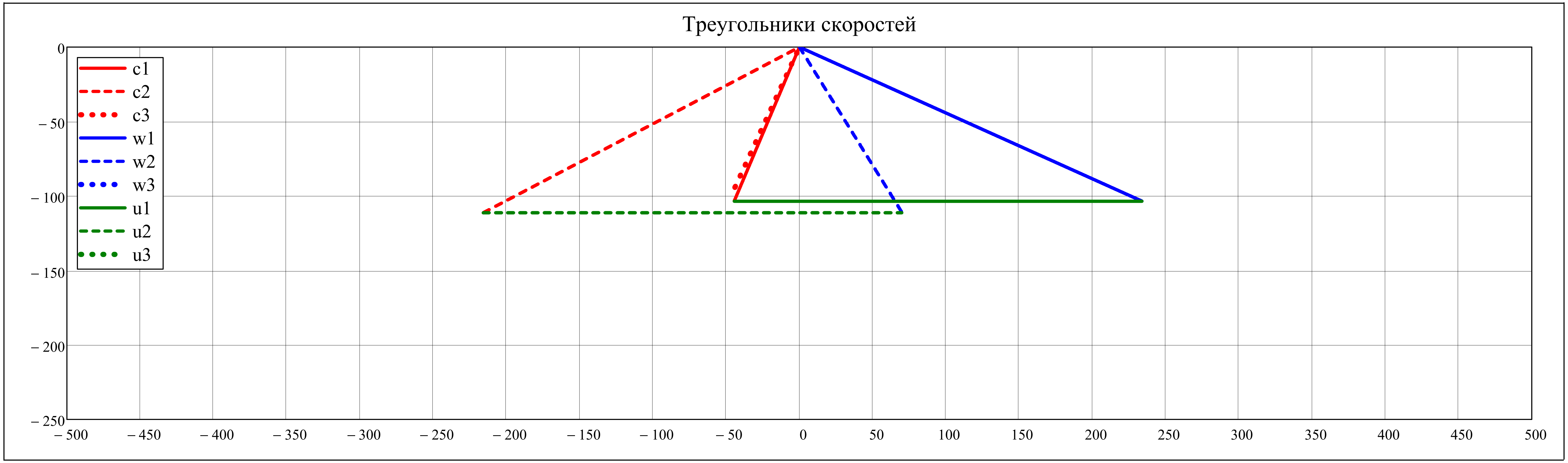
$$\Delta_w(v,i,j,r) = \left| \begin{array}{l} -\tan\left(\beta_{st(i,j),r}\right)\cdot v \ \ \text{if } \left(-\tan\left(\beta_{st(i,j),r}\right) \geq 0\right) \wedge \left(-\left|w_{st(i,j),r}\cdot\cos\left(\beta_{st(i,j),r}\right)\right| \leq v \leq 0\right) \wedge (j \neq 3) \\ -\tan\left(\beta_{st(i,j),r}\right)\cdot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

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

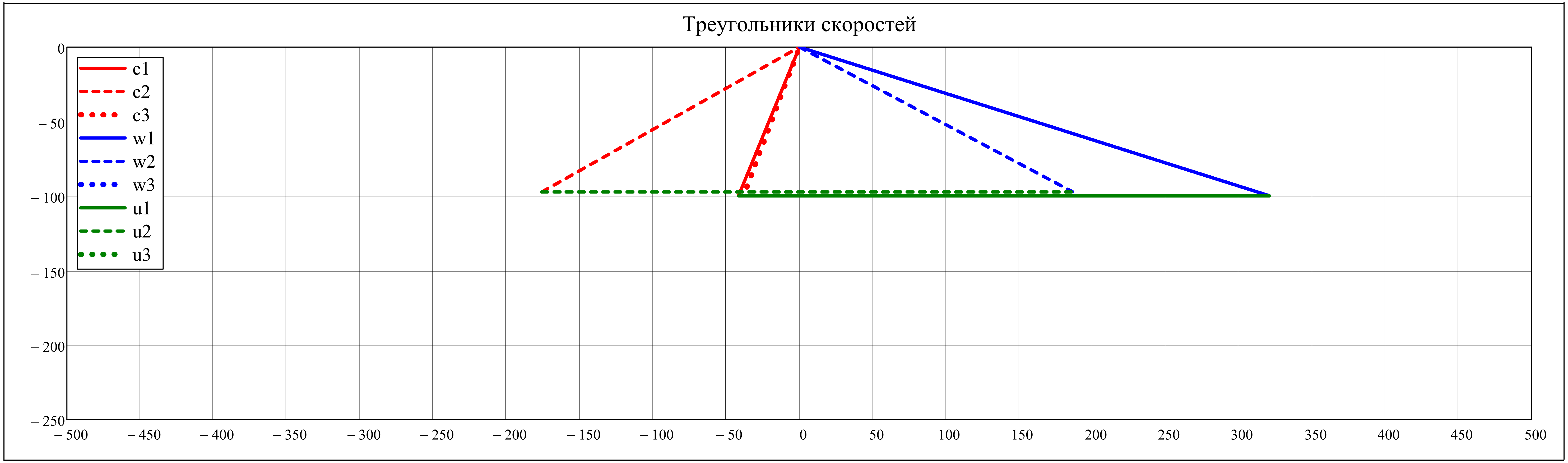
$$v_{lim} = \text{ceil}\left(\frac{\max(c,w,u)}{10^2}\right)\cdot 10^2 = 500$$

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

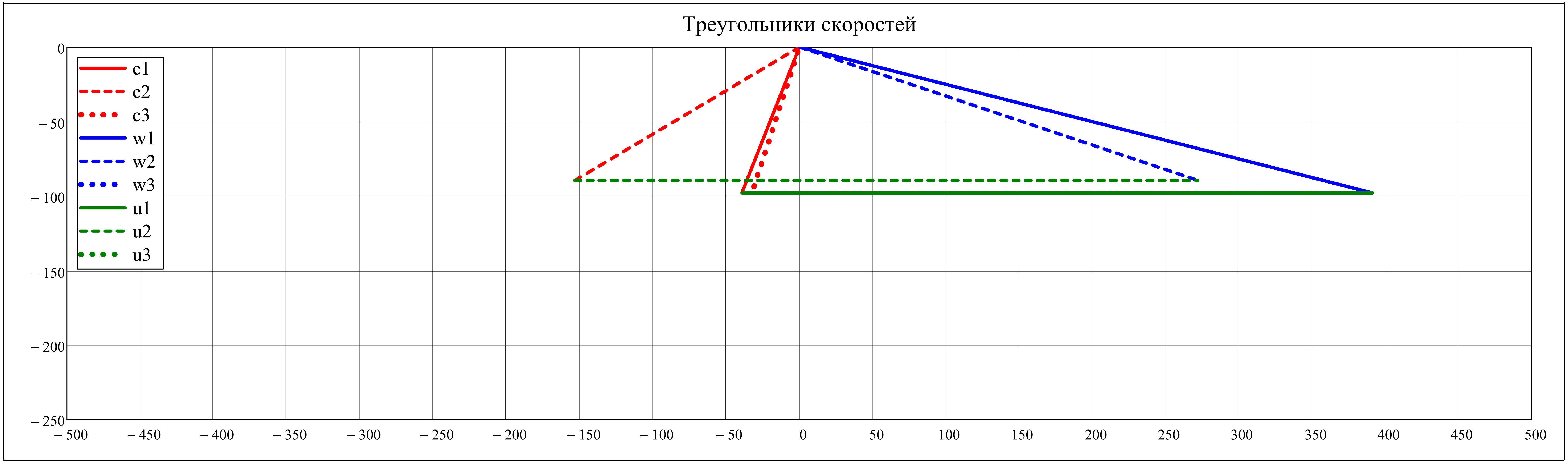
r = 1


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

$r = av(N_r)$


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

$r = N_r$



▲ Построение треугольников скоростей в 3х сечениях

Определение степени повышения полного давлеия по 2ум контурам

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

Кольцевые площади (м^2):

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

	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):

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

	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

$\cdot 10^{-3}$

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

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

	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

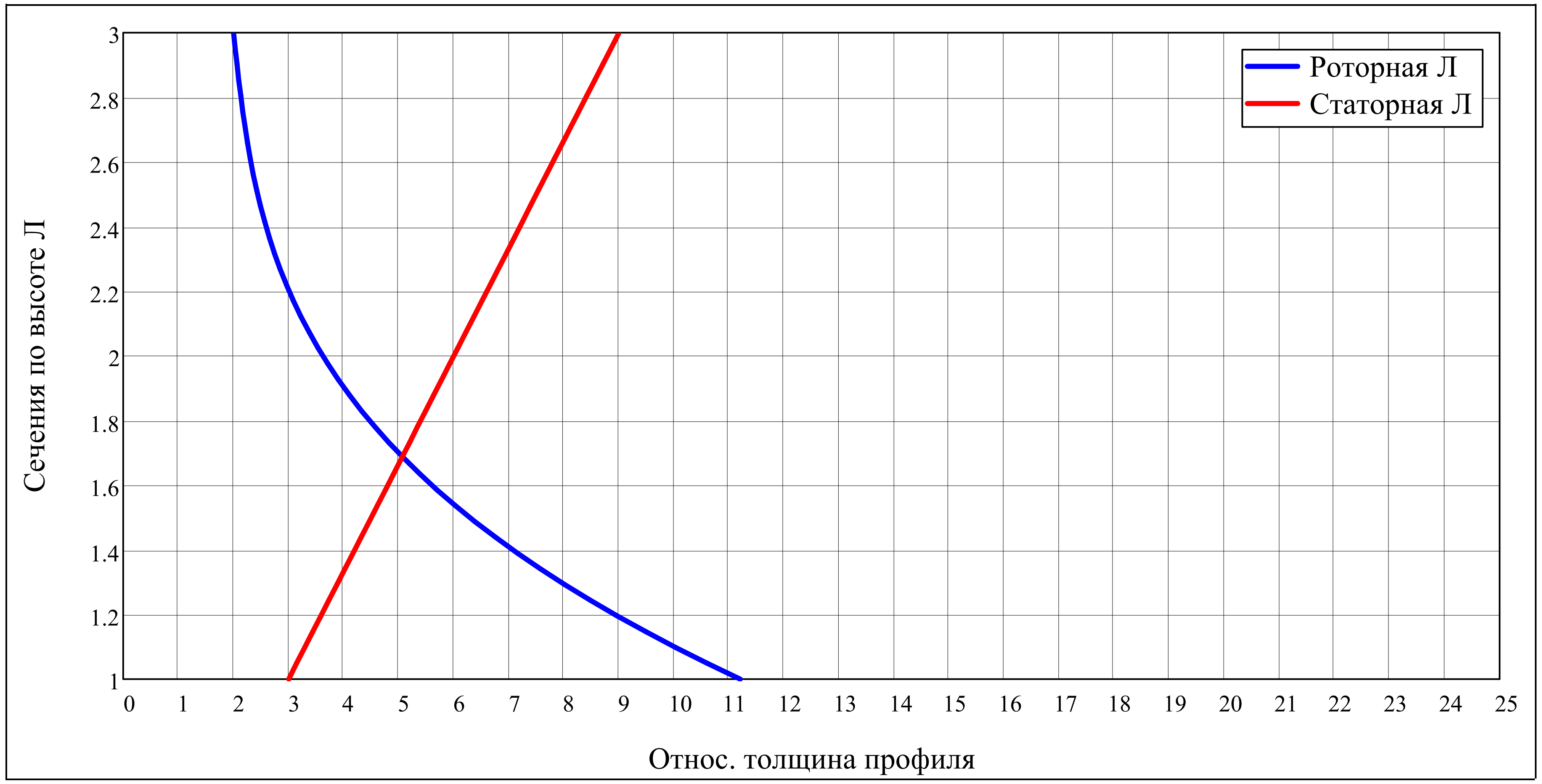
Относ. толщины и радиусы профилей

Относ. толщины Л РК и СА:

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

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

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



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

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

	1
1	3.00
2	6.00
3	9.00

$\cdot\%$

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

$\bar{c}_{stator}^{\,T} =$

	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

$\cdot\%$

$\bar{c}_{rotor}^{\,T} =$

	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

$\cdot\%$

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

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

	1
1	3.00
2	6.00
3	9.00

$\cdot\%$

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

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

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

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

	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

$\cdot\%$

Относ. толщины и радиусы профилей

▼ Распределение параметров по высоте Л

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

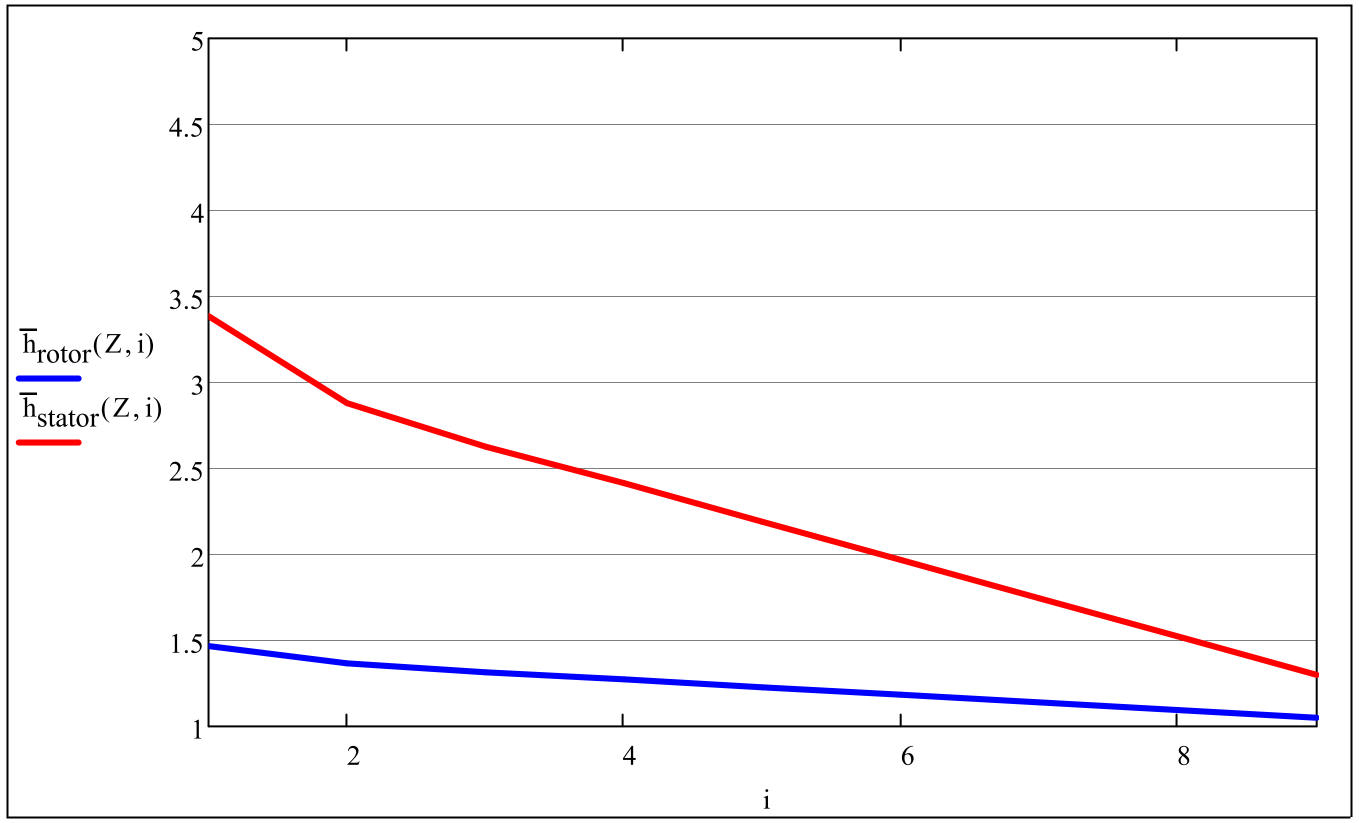
$$\overline{h}_{\sim rotor} = (2\ \ 1.9\ \ 1.85\ \ 1.8\ \ 1.75\ \ 1.7\ \ 1.65\ \ 1.6)^{T} + \left|\begin{array}{l} 1.1 \ \text{ if } compressor = \text{"Вл"} \\ -0.1 \ \text{ if } compressor = \text{"КНД"} \\ -0.55 \ \text{ if } compressor = \text{"КВД"} \end{array}\right.$$

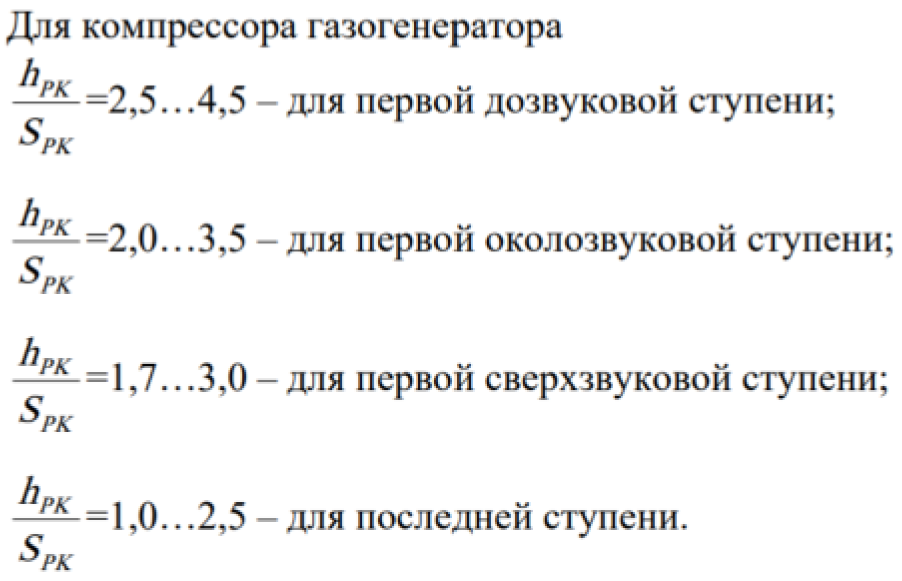
$$\overline{h}_{\sim stator} = (4\ \ 3.5\ \ 3.25\ \ 3\ \ 2.75\ \ 2.5\ \ 2.25\ \ 2)^{T} + \left|\begin{array}{l} 1.1 \ \text{ if } compressor = \text{"Вл"} \\ -0.1 \ \text{ if } compressor = \text{"КНД"} \\ -0.7 \ \text{ if } compressor = \text{"КВД"} \end{array}\right.$$

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

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

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




Для компрессора газогенератора

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

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

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

$\frac{h_{\text{РК}}}{S_{\text{РК}}}$=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 $BHA = 1$
        $chord_{BHA_{av(N_r)}} = \frac{h_{st(i,1)}}{\overline{h}_{stator}(Z,0)}$
        $sail = \frac{R_{st(1,1),N_r} - R_{st(1,1),1}}{R_{st(1,1),av(N_r)} - R_{st(1,1),1}}$
        for $r \in 1..N_r$
            $b_{BHAкор} = \frac{chord_{BHA_{av(N_r)}} \cdot sail}{sail_{stator} - 1 + sail}$
            $b_{BHAпер} = b_{BHAкор} \cdot sail_{stator}$
            $b_{BHA.}(z) = interp\left[cspline\left[\begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{BHAкор} \\ chord_{BHA_{av(N_r)}} \\ b_{BHAпер} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{BHAкор} \\ chord_{BHA_{av(N_r)}} \\ b_{BHAпер} \end{pmatrix}, z\right]$
            $chord_{BHA_r} = b_{BHA.}(R_{st(i,1),r})$
    $chord_{BHA}$
```

```
$\left(\mathrm{chord}_{\mathrm{rotor}}\ \ \mathrm{chord}_{\mathrm{stator}}\right) =$
    for  $i \in 1 .. Z$
        $\begin{pmatrix} \mathrm{chord}_{\mathrm{rotor}_{i,\,av\left(N_r\right)}} \\ \mathrm{chord}_{\mathrm{stator}_{i,\,av\left(N_r\right)}} \end{pmatrix} \leftarrow \begin{pmatrix} \dfrac{\mathrm{mean}\left(h_{st(i,1)}, h_{st(i,2)}\right)}{\overline{h}_{\mathrm{rotor}}(Z,i)} \\ \dfrac{\mathrm{mean}\left(h_{st(i,2)}, h_{st(i,3)}\right)}{\overline{h}_{\mathrm{stator}}(Z,i)} \end{pmatrix}$
        $\mathrm{sail} \leftarrow \dfrac{R_{st(i,2),\,N_r} - R_{st(i,2),\,1}}{R_{st(i,2),\,av\left(N_r\right)} - R_{st(i,2),\,1}}$
        for  $r \in 1 .. N_r$
            $b_{\text{РКкор}} \leftarrow \dfrac{\mathrm{chord}_{\mathrm{rotor}_{i,\,av\left(N_r\right)}} \cdot \mathrm{sail}}{\mathrm{sail}_{\mathrm{rotor}} - 1 + \mathrm{sail}}$
            $b_{\text{НАкор}} \leftarrow \dfrac{\mathrm{chord}_{\mathrm{stator}_{i,\,av\left(N_r\right)}} \cdot \mathrm{sail}}{\mathrm{sail}_{\mathrm{stator}} - 1 + \mathrm{sail}}$
            $\begin{pmatrix} b_{\text{РКпер}} \\ b_{\text{НАпер}} \end{pmatrix} \leftarrow \begin{pmatrix} b_{\text{РКкор}} \cdot \mathrm{sail}_{\mathrm{rotor}} \\ b_{\text{НАкор}} \cdot \mathrm{sail}_{\mathrm{stator}} \end{pmatrix}$
            $\mathrm{chord}_{\mathrm{rotor.}}(z) \leftarrow \mathrm{interp}\left[\mathrm{cspline}\left[\begin{pmatrix} R_{st(i,2),\,1} \\ R_{st(i,2),\,av\left(N_r\right)} \\ R_{st(i,2),\,N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{РКкор}} \\ \mathrm{chord}_{\mathrm{rotor}_{i,\,av\left(N_r\right)}} \\ b_{\text{РКпер}} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,2),\,1} \\ R_{st(i,2),\,av\left(N_r\right)} \\ R_{st(i,2),\,N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{РКкор}} \\ \mathrm{chord}_{\mathrm{rotor}_{i,\,av\left(N_r\right)}} \\ b_{\text{РКпер}} \end{pmatrix}, z\right]$
            $\mathrm{chord}_{\mathrm{stator.}}(z) \leftarrow \mathrm{interp}\left[\mathrm{cspline}\left[\begin{pmatrix} R_{st(i,2),\,1} \\ R_{st(i,2),\,av\left(N_r\right)} \\ R_{st(i,2),\,N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{НАкор}} \\ \mathrm{chord}_{\mathrm{stator}_{i,\,av\left(N_r\right)}} \\ b_{\text{НАпер}} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,2),\,1} \\ R_{st(i,2),\,av\left(N_r\right)} \\ R_{st(i,2),\,N_r} \end{pmatrix}, \begin{pmatrix} b_{\text{НАкор}} \\ \mathrm{chord}_{\mathrm{stator}_{i,\,av\left(N_r\right)}} \\ b_{\text{НАпер}} \end{pmatrix}, z\right]$
            $\mathrm{chord}_{\mathrm{rotor}_{i,\,r}} \leftarrow \mathrm{chord}_{\mathrm{rotor.}}\left(R_{st(i,2),\,r}\right)$
            $\mathrm{chord}_{\mathrm{stator}_{i,\,r}} \leftarrow \mathrm{chord}_{\mathrm{stator.}}\left(R_{st(i,2),\,r}\right)$
    $\left(\mathrm{chord}_{\mathrm{rotor}}\ \ \mathrm{chord}_{\mathrm{stator}}\right)$
```

```
$chord_{CA} :=$                                                                 if $CA = 1$
    for $i \in Z$
        $chord_{CA_{av(N_r)}} \leftarrow \dfrac{h_{st(i,3)}}{\overline{h}_{stator}(Z, Z+1)}$
        $sail \leftarrow \dfrac{R_{st(1,1),N_r} - R_{st(1,1),1}}{R_{st(1,1),av(N_r)} - R_{st(1,1),1}}$
        for $r \in 1..N_r$
            $b_{CAкор} \leftarrow \dfrac{chord_{CA_{av(N_r)}} \cdot sail}{sail_{stator} - 1 + sail}$
            $b_{CAпер} \leftarrow b_{CAкор} \cdot sail_{stator}$
            $b_{CA.}(z) \leftarrow interp\left[cspline\left[\begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CAкор} \\ chord_{CA_{av(N_r)}} \\ b_{CAпер} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CAкор} \\ chord_{CA_{av(N_r)}} \\ b_{CAпер} \end{pmatrix}, z\right]$
            $chord_{CA_r} \leftarrow b_{CA.}(R_{st(i,1),r})$
    $chord_{CA}$
```

▲ Расчет длин хорд по высоте Л

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

$\overline{x}_f = 0.5$

Определение количества Л РК и НА

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

```
if BHA = 1
    for r ∈ av(N_r)
        $\varepsilon_{BHA(b/t)=1_r} = \varepsilon_{(b/t)=1}\left(\alpha_{3BHA_r}\right)$
        $b/t_{BHA_r} = b/t{=}1\left(\frac{\varepsilon_{BHA_r}}{\varepsilon_{BHA(b/t)=1_r}}\right)$
        $t_{BHA_r} = \frac{chord_{BHA_r}}{b/t_{BHA_r}}$
        $Z_{BHA} = $
            $round\left(\frac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right)$  if  $mod\left(round\left(\frac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right), 2\right) = 0$
            $round\left(\frac{\pi \cdot D_{st(1,1),r}}{t_{BHA_r}}\right) + 1$  otherwise
    for r ∈ 1 .. N_r
        $\left(r\_inlet_{BHA_r} \;\; r\_outlet_{BHA_r}\right) = chord_{BHA_r} \cdot \left(\overline{r\_inlet}_{BHA_r} \;\; \overline{r\_outlet}_{BHA_r}\right)$
        $t_{BHA_r} = \frac{D_{st(1,1),r}}{Z_{BHA}}$
        $i_{BHA_r} = 2.5 \cdot \left(\frac{chord_{BHA_r}}{t_{BHA_r}} - 2\right) \cdot °$
        $m_{BHA_r} = 0.23 \cdot \left(2 \cdot \overline{x}_f\right)^2 + 0.18 - \frac{0.002}{deg} \cdot \left(\alpha_{3BHA_r}\right)$
```

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

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

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

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

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

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

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

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

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

for $r \in 1 .. N_r$

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

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

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

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

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

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

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

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

$chord_{rotor}$

$$\begin{pmatrix} R_{\text{СЛ.rotor}_{i,r}} \\ R_{\text{СЛ.stator}_{i,r}} \end{pmatrix} = \frac{1}{2}\cdot\begin{pmatrix} \dfrac{{}_{i,r}}{\sin\left(0.5\cdot\theta_{\text{rotor}_{i,r}}\right)} \\ \dfrac{\text{chord}_{\text{stator}_{i,r}}}{\sin\left(0.5\cdot\theta_{\text{stator}_{i,r}}\right)} \end{pmatrix}$$

$$\begin{pmatrix} K_{\text{rotor}_{i,r}} \\ K_{\text{stator}_{i,r}} \end{pmatrix} = \begin{pmatrix} \dfrac{c_{a_{st(i,2),r}}}{c_{a_{st(i,1),r}}} \\ \dfrac{c_{a_{st(i,3),r}}}{c_{a_{st(i,2),r}}} \end{pmatrix}$$

$$\begin{pmatrix} D_{\text{rotor}_{i,r}} \\ D_{\text{stator}_{i,r}} \end{pmatrix} = \begin{bmatrix} \left(1 - K_{\text{rotor}_{i,r}}\cdot\dfrac{\sin\left(\beta_{st(i,1),r}\right)}{\sin\left(\left|\beta_{st(i,2),r}\right|\right)}\right) + \left(\dfrac{1}{\tan\left(\beta_{st(i,1),r}\right)} - K_{\text{rotor}_{i,r}}\cdot\dfrac{1}{\tan\left(\beta_{st(i,2),r}\right)}\right)\cdot\dfrac{\sin\left(\beta_{st(i,1),r}\right)}{2\cdot\dfrac{\text{chord}_{\text{rotor}_{i,r}}}{t_{\text{rotor}_{i,r}}}} \\ \left(1 - K_{\text{stator}_{i,r}}\cdot\dfrac{\sin\left(\alpha_{st(i,2),r}\right)}{\sin\left(\alpha_{st(i,3),r}\right)}\right) + \left(\dfrac{1}{\tan\left(\alpha_{st(i,2),r}\right)} - K_{\text{stator}_{i,r}}\cdot\dfrac{1}{\tan\left(\alpha_{st(i,3),r}\right)}\right)\cdot\dfrac{\sin\left(\alpha_{st(i,2),r}\right)}{2\cdot\dfrac{\text{chord}_{\text{stator}_{i,r}}}{t_{\text{stator}_{i,r}}}} \end{bmatrix}$$

$$\begin{pmatrix} \zeta_{\text{rotor}_{i,r}} \\ \zeta_{\text{stator}_{i,r}} \end{pmatrix} = \begin{pmatrix} \dfrac{\zeta\text{•}\sin(\beta3)/(2b/t)\ \left(D_{\text{rotor}_{i,r}}\right)\cdot 2\cdot\dfrac{\text{chord}_{\text{rotor}_{i,r}}}{t_{\text{rotor}_{i,r}}}}{\sin\left(\beta_{st(i,2),r}\right)} \\ \dfrac{\zeta\text{•}\sin(\beta3)/(2b/t)\ \left(D_{\text{stator}_{i,r}}\right)\cdot 2\cdot\dfrac{\text{chord}_{\text{stator}_{i,r}}}{t_{\text{stator}_{i,r}}}}{\sin\left(\alpha_{st(i,3),r}\right)} \end{pmatrix}$$

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

$$\begin{pmatrix} \text{quality}_{\text{rotor}_{i,r}} \\ \text{quality}_{\text{stator}_{i,r}} \end{pmatrix} = \begin{bmatrix} \dfrac{2}{\zeta_{\text{rotor}_{i,r}}}\cdot\left(\dfrac{1}{\tan\left(\beta_{st(i,1),r}\right)} - \dfrac{1}{\tan\left(\beta_{st(i,2),r}\right)}\right)\cdot\left(\dfrac{\sin\left(\beta_{st(i,1),r}\right)}{\sin\left(\beta_{cp_{i,r}}\right)}\right)^2 - \dfrac{1}{\tan\left(\beta_{cp_{i,r}}\right)} \\ \dfrac{2}{\zeta_{\text{stator}_{i,r}}}\cdot\left(\dfrac{1}{\tan\left(\alpha_{st(i,2),r}\right)} - \dfrac{1}{\tan\left(\alpha_{st(i,3),r}\right)}\right)\cdot\left(\dfrac{\sin\left(\alpha_{st(i,2),r}\right)}{\sin\left(\alpha_{cp_{i,r}}\right)}\right)^2 - \dfrac{1}{\tan\left(\alpha_{cp_{i,r}}\right)} \end{bmatrix}$$

$$\left[\ \left(\frac{c_{a_{st(i,1),r}}}{u_{st(i,1),r}}\right)^2 + \left(R_{L_{i,r}}\right)^2 \qquad \left(\frac{c_{a_{st(i,2),r}}}{u_{st(i,2),r}}\right)^2 + \left(1 - R_{L_{i,r}}\right)^2\ \right.$$

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

```
if CA = 1
    for r ∈ av(N_r)
        $\varepsilon_{CA(b/t)=1_r} = \varepsilon_{(b/t)=1}\left(\alpha_{3CA_r}\right)$
        $b/t_{CA_r} = b/t{=}1\left(\frac{\varepsilon_{CA_r}}{\varepsilon_{CA(b/t)=1_r}}\right)$
        $t_{CA_r} = \frac{chord_{CA_r}}{b/t_{CA_r}}$
        $Z_{CA} =$ | $round\left(\frac{\pi \cdot D_{st(Z,3),r}}{t_{CA_r}}\right)$  if  $mod\left(round\left(\frac{\pi \cdot D_{st(Z,3),r}}{t_{CA_r}}\right), 2\right) = 0$
                   | $round\left(\frac{\pi \cdot D_{st(Z,3),r}}{t_{CA_r}}\right) + 1$  otherwise
    for r ∈ 1 .. N_r
        $\left(r\_inlet_{CA_r} \;\; r\_outlet_{CA_r}\right) = chord_{CA_r} \cdot \left(\overline{r}\_inlet_{CA_r} \;\; \overline{r}\_outlet_{CA_r}\right)$
        $t_{CA_r} = \frac{D_{st(Z,3),r}}{Z_{CA}}$
        $i_{CA_r} = 2.5 \cdot \left(\frac{chord_{CA_r}}{t_{CA_r}} - 2\right) \cdot {}^\circ$
        $m_{CA_r} = 0.23 \cdot \left(2 \cdot \overline{x}_f\right)^2 + 0.18 - \frac{0.002}{deg} \cdot \left(\alpha_{3CA_r}\right)$
        $\theta_{CA_r} = \frac{\varepsilon_{CA_r} - i_{CA_r}}{1 - m_{CA_r} \cdot \sqrt{\frac{t_{CA_r}}{chord_{CA_r}}}}$
```

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

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

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

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

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

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

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

Определение количества Л РК и НА

Результаты расчета количества Л и параметров решеток РК и НА

Длина хорды Л (м):

$chord_{BHA} =$

	1
1	26.42
2	29.35
3	31.71

$\cdot 10^{-3}$

$chord_{rotor}{}^{T} =$

	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						

$\cdot 10^{-3}$

$chord_{stator}{}^{T} =$

	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						

$\cdot 10^{-3}$

$chord_{CA} =$

	1
1	25.80
2	28.65
3	30.96

$\cdot 10^{-3}$

Радисы входных и выходных кромок профилей Л (мм):

$r\_inlet_{BHA} =$

	1
1	0.16
2	0.35
3	0.57

$\cdot 10^{-3}$

$r\_outlet_{BHA} =$

	1
1	0.08
2	0.18
3	0.29

$\cdot 10^{-3}$

$r\_inlet_{rotor}{}^{T} =$

	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

$\cdot 10^{-3}$

$r\_outlet_{rotor}{}^{T} =$

	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

$\cdot 10^{-3}$

$r\_inlet_{stator}{}^{T} =$

	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

$\cdot 10^{-3}$

$r\_outlet_{stator}{}^{T} =$

	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

$\cdot 10^{-3}$

$r\_inlet_{CA} =$

	1
1	0.15
2	0.34
3	0.56

$\cdot 10^{-3}$

$r\_outlet_{CA} =$

	1
1	0.08
2	0.17
3	0.28

$\cdot 10^{-3}$

Угол поворота потока:

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

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

	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						

$\cdot°$

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

	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						

$\cdot°$

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

Густота решетки:

$\dfrac{\text{chord}_{\text{ВНА}}}{t_{\text{ВНА}}} =$

	1
1	3.429
2	2.924
3	2.661

$\left(\dfrac{\text{chord}_{\text{rotor}}}{t_{\text{rotor}}}\right)^T =$

	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						

$\left(\dfrac{\text{chord}_{\text{stator}}}{t_{\text{stator}}}\right)^T =$

	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

$\dfrac{\text{chord}_{\text{СА}}}{t_{\text{СА}}} =$

	1
1	3.455
2	3.488
3	3.479

Количество Л:

$Z_{\text{ВНА}} = 46$

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

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

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

	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						

$Z_{\text{СА}} = 52$

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

$t_{BHA} =$

	1
1	7.71
2	10.04
3	11.92

$\cdot 10^{-3}$

$t_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	26.26	20.80	15.44	14.02	13.11	13.11	17.68	23.01	24.89						
2	33.73	25.44	18.26	16.27	14.99	14.81	19.78	25.60	27.54						
3	39.81	29.36	20.70	18.24	16.66	16.34	21.69	27.94	29.95						

$\cdot 10^{-3}$

Шаг решетки (м):

$t_{stator}{}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8.16	7.03	4.59	4.48	3.72	2.28	2.85	3.37	5.04						
2	10.21	8.43	5.37	5.16	4.22	2.56	3.18	3.74	5.56						
3	11.91	9.63	6.05	5.76	4.68	2.81	3.48	4.08	6.03						

$\cdot 10^{-3}$

$t_{CA} =$

	1
1	7.47
2	8.21
3	8.90

$\cdot 10^{-3}$

$i_{BHA} =$

	1
1	3.572
2	2.311
3	1.652

$\cdot {}^{\circ}$

$i_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2.669	3.383	4.524	4.567	4.533	4.133	2.227	1.067	0.764						
2	2.187	3.089	4.392	4.561	4.628	4.301	2.388	1.211	0.913						
3	1.932	2.918	4.309	4.560	4.697	4.423	2.508	1.319	1.026						

$\cdot {}^{\circ}$

Угол атаки:

$i_{stator}{}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.913	2.964	6.651	6.549	8.876	18.099	14.440	12.946	8.122						
2	1.132	2.354	6.015	6.098	8.508	17.717	14.258	12.866	8.150						
3	0.684	1.970	5.593	5.785	8.244	17.436	14.121	12.805	8.170						

$\cdot {}^{\circ}$

$i_{CA} =$

	1
1	3.639
2	3.721
3	3.698

$\cdot {}^{\circ}$

Коэф. формы ср. линии профиля по Ховеллу:

$m_{BHA} =$

	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

$\cdot ^\circ$

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

	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						

$\cdot ^\circ$

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

	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						

$\cdot ^\circ$

$\theta_{CA} =$

	1
1	39.82
2	36.69
3	34.27

$\cdot ^\circ$

Угол отставания:

$\delta_{BHA} =$

	1
1	3.462
2	3.893
3	4.076

$\cdot{}^\circ$

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

	1	2	3	4	5	6	7	8	9
1	8.044	6.504	5.345	4.741	4.406	4.150	4.580	5.052	5.008
2	2.820	2.387	1.950	1.789	1.732	1.721	2.238	2.719	2.858
3	0.868	0.979	0.666	0.595	0.586	0.628	1.136	1.589	1.778

$\cdot{}^\circ$

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

	1	2	3	4	5	6	7	8	9
1	7.387	7.106	5.982	6.016	5.347	3.165	3.149	2.889	3.833
2	7.584	7.228	6.031	6.038	5.339	3.171	3.187	2.953	3.871
3	7.696	7.210	5.993	5.995	5.290	3.146	3.188	2.979	3.880

$\cdot{}^\circ$

$\delta_{CA} =$

	1
1	4.926
2	4.519
3	4.226

$\cdot{}^\circ$

Угол установки Л:

$\upsilon_{BHA} =$

	1
1	105.16
2	104.40
3	103.80

$\cdot{}^\circ$

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

	1	2	3	4	5	6	7	8	9
1	46.18	40.19	36.93	33.69	31.29	28.76	25.45	23.22	21.79
2	24.91	24.20	23.93	22.96	22.09	20.95	19.03	17.63	16.85
3	17.54	18.46	18.79	18.37	17.93	17.23	15.75	14.65	14.11

$\cdot{}^\circ$

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

	1	2	3	4	5	6	7	8	9
1	51.10	48.54	51.21	50.58	51.21	53.57	47.96	44.15	41.01
2	51.93	52.14	54.02	53.11	53.43	55.63	50.24	46.49	43.27
3	52.74	54.77	56.15	55.09	55.20	57.30	52.10	48.43	45.17

$\cdot{}^\circ$

$\upsilon_{CA} =$

	1
1	75.02
2	76.17
3	77.09

$\cdot{}^\circ$

Радиус дуги ср. линии (м):

$R_{СЛ.ВНА} =$

	1
1	65.77
2	70.03
3	75.35

$\cdot 10^{-3}$

$R_{СЛ.rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	80.77	88.42	89.30	94.08	96.17	101.05	106.93	111.63	117.69						
2	333.47	325.78	318.31	314.82	302.80	296.09	260.85	244.20	240.89						
3	1306.64	939.04	1090.02	1098.07	1030.28	927.48	583.29	471.73	435.47						

$\cdot 10^{-3}$

$R_{СЛ.stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	30.22	28.63	26.88	25.89	26.66	36.83	43.90	55.64	53.55						
2	33.64	31.68	29.70	28.56	29.39	40.21	47.27	59.20	57.54						
3	36.52	34.73	32.52	31.20	32.07	43.63	50.73	62.91	61.46						

$\cdot 10^{-3}$

$R_{СЛ.СА} =$

	1
1	37.88
2	45.51
3	52.53

$\cdot 10^{-3}$

Фактор диффузорности решетки:

$K_{ВНА} =$

	1
1	1.0359
2	1.0000
3	0.9808

$K_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.0757	0.9750	0.9637	0.9661	0.9673	0.9684	0.9698	0.9702	0.9936						
2	0.9740	0.9704	0.9637	0.9661	0.9673	0.9684	0.9698	0.9702	0.9936						
3	0.9142	0.9680	0.9637	0.9661	0.9673	0.9684	0.9698	0.9702	0.9936						

$K_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.8481	0.9644	0.9637	0.9659	0.9670	0.9680	0.9692	0.9695	0.9937						
2	0.9691	0.9701	0.9637	0.9659	0.9670	0.9680	0.9692	0.9695	0.9937						
3	1.0520	0.9732	0.9637	0.9659	0.9670	0.9680	0.9692	0.9695	0.9937						

$K_{СА} =$

	1
1	0.8302
2	0.8302
3	0.8302

$D_{BHA} =$

	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

[18, с. 71]

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

	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

Подключение симметричного профиля

$\mathrm{EXCEL}_{\mathrm{AIRFOIL.subsonic}} =$ ...\A40.xlsx

$$X/B_{subsonic} = \mathrm{submatrix}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.subsonic}}, 2, \mathrm{rows}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.subsonic}}\right), \mathrm{ORIGIN} + 0, \mathrm{ORIGIN} + 0\right)$$

$$Y/B_{subsonic} = \mathrm{submatrix}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.subsonic}}, 2, \mathrm{rows}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.subsonic}}\right), \mathrm{ORIGIN} + 1, \mathrm{ORIGIN} + 1\right)$$

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

$\mathrm{EXCEL}_{\mathrm{AIRFOIL.supersonic}} =$ ...\Емин сверхзвуковой профиль.xlsx

$$X/B_{supersonic} = \mathrm{submatrix}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.supersonic}}, 2, \mathrm{rows}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.supersonic}}\right), \mathrm{ORIGIN} + 0, \mathrm{ORIGIN} + 0\right)$$

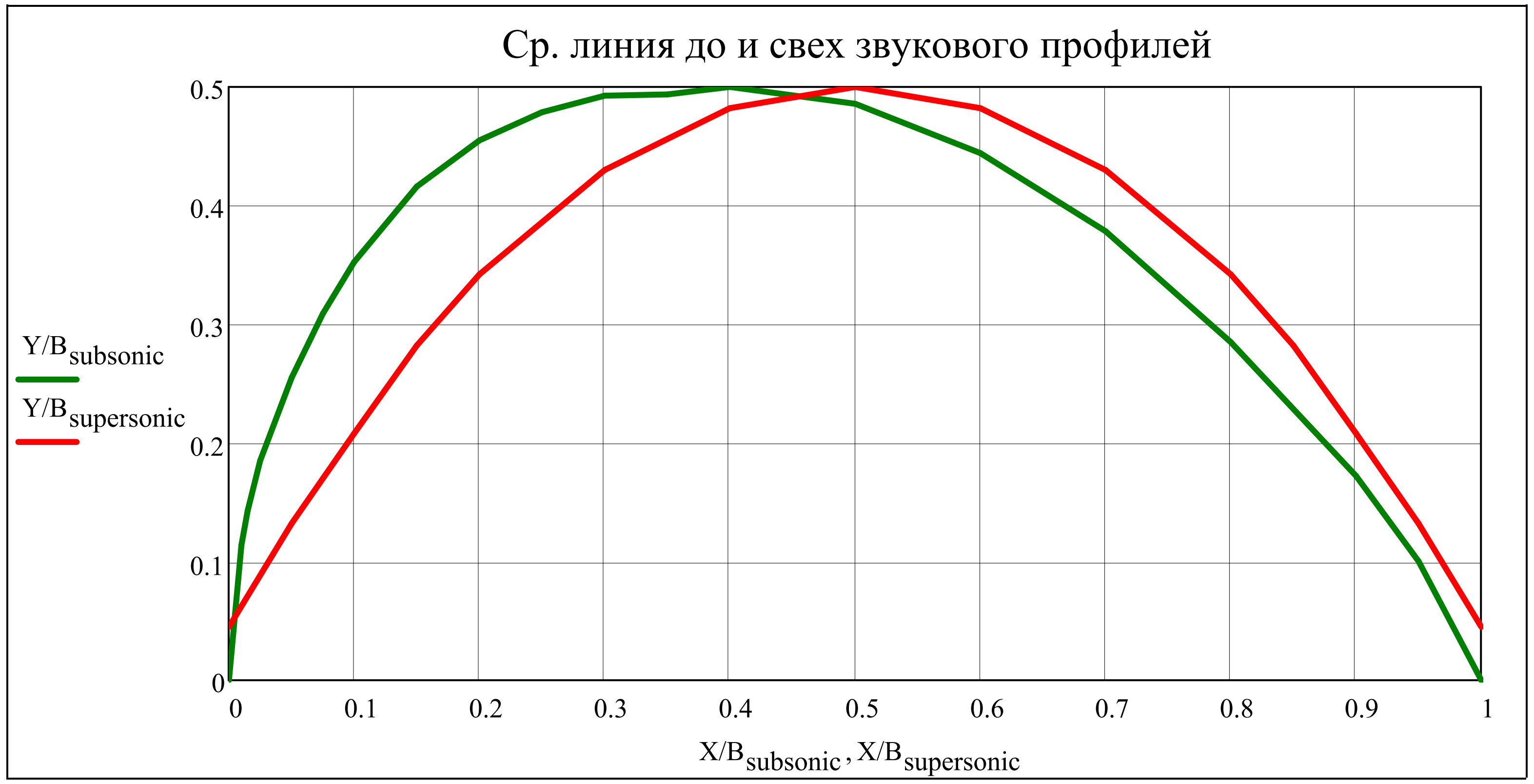
$$Y/B_{supersonic} = \mathrm{submatrix}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.supersonic}}, 2, \mathrm{rows}\left(\mathrm{EXCEL}_{\mathrm{AIRFOIL.supersonic}}\right), \mathrm{ORIGIN} + 1, \mathrm{ORIGIN} + 1\right)$$

$\mathrm{augment}\left(X/B_{subsonic}, Y/B_{subsonic}\right)^{T} =$

	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

$\mathrm{augment}\left(X/B_{supersonic}, Y/B_{supersonic}\right)^{T} =$

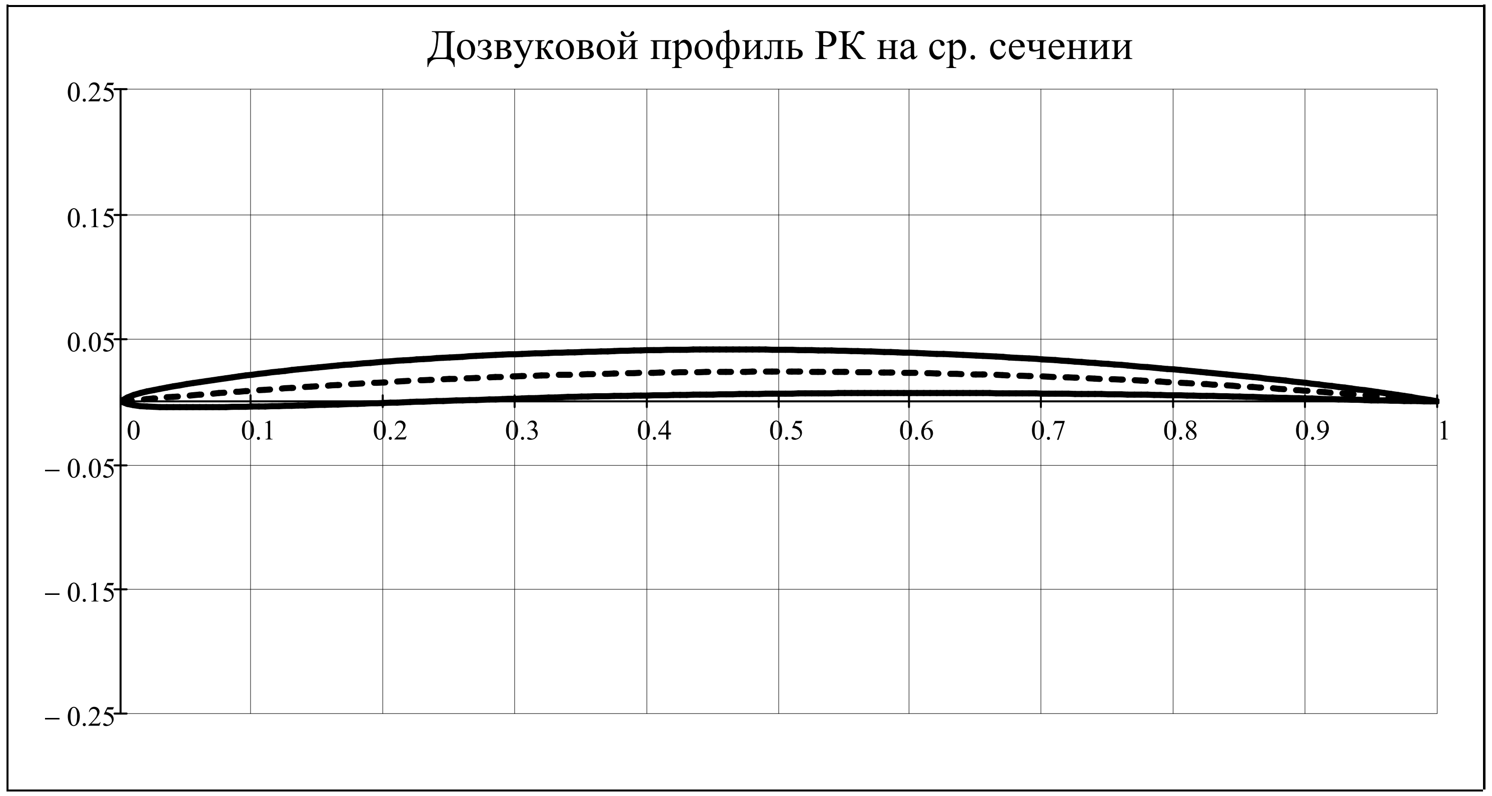
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.000	0.050	0.100	0.150	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.850	0.900	0.950	1.000
2	0.045	0.132	0.208	0.282	0.342	0.430	0.482	0.500	0.482	0.430	0.342	0.282	0.208	0.132	0.045

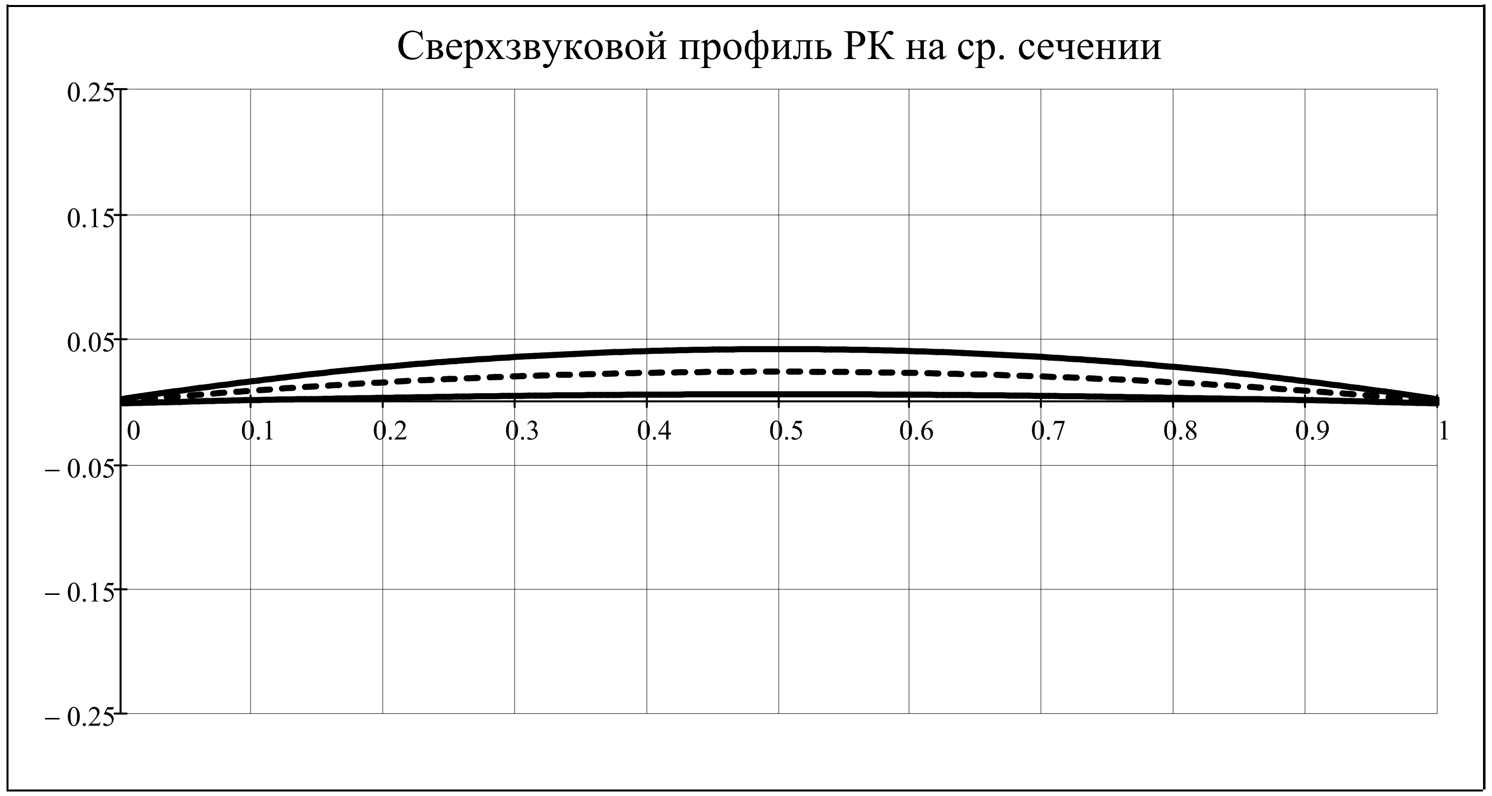


$$\mathrm{AIRFOIL}_{subsonic}(x,line,\overline{c},\theta) = \left|\begin{array}{l} \text{if } 0 \le x \le 1 \\ \quad \left|\begin{array}{l} \mathrm{interp}\left(\mathrm{cspline}\left(X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic},\theta\right)+Y/B_{subsonic}\cdot\overline{c}\right), X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic},\theta\right)+Y/B_{subsonic}\cdot\overline{c}, x\right) \quad \text{if } line = "+" \\ \mathrm{interp}\left(\mathrm{cspline}\left(X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic},\theta\right)\right), X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic},\theta\right), x\right) \quad \text{if } line = "0" \\ \mathrm{interp}\left(\mathrm{cspline}\left(X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic},\theta\right)-Y/B_{subsonic}\cdot\overline{c}\right), X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic},\theta\right)-Y/B_{subsonic}\cdot\overline{c}, x\right) \quad \text{if } line = "-" \end{array}\right. \\ \mathrm{NaN} \quad \text{otherwise} \end{array}\right.$$

$$\mathrm{AIRFOIL}_{supersonic}(x,line,\overline{c},\theta) = \left|\begin{array}{l} \text{if } 0 \le x \le 1 \\ \quad \left|\begin{array}{l} \mathrm{interp}\left(\mathrm{cspline}\left(X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic},\theta\right)+Y/B_{supersonic}\cdot\overline{c}\right), X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic},\theta\right)+Y/B_{supersonic}\cdot\overline{c}, x\right) \quad \text{if } line = "+" \\ \mathrm{interp}\left(\mathrm{cspline}\left(X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic},\theta\right)\right), X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic},\theta\right), x\right) \quad \text{if } line = "0" \\ \mathrm{interp}\left(\mathrm{cspline}\left(X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic},\theta\right)-Y/B_{supersonic}\cdot\overline{c}\right), X/B_{supersonic}, y/b_{ср.л}\left(X/B_{supersonic},\theta\right)-Y/B_{supersonic}\cdot\overline{c}, x\right) \quad \text{if } line = "-" \end{array}\right. \\ \mathrm{NaN} \quad \text{otherwise} \end{array}\right.$$

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


Дозвуковой профиль РК на ср. сечении


Сверхзвуковой профиль РК на ср. сечении

Подключение симметричного профиля

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

$\cdot 10^{-3}$

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

	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

$\cdot 10^{-3}$

$area_{stator}{}^{T} =$

	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

$\cdot 10^{-6}$

$Sx_{stator}{}^{T} =$

	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

$\cdot 10^{-9}$

$Sy_{stator}{}^{T} =$

	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

$\cdot 10^{-9}$

$x0_{stator}{}^{T} =$

	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

$\cdot 10^{-3}$

$y0_{stator}{}^{T} =$

	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

$\cdot 10^{-3}$

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

	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

$\cdot 10^{-3}$

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

	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

$\cdot 10^{-3}$

$area_{rotor}{}^{T} =$

	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

$\cdot 10^{-6}$

$Sx_{rotor}{}^{T} =$

	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

$\cdot 10^{-9}$

$Sy_{rotor}{}^{T} =$

	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	...

$\cdot 10^{-9}$

$x0_{rotor}{}^{T} =$

	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

$\cdot 10^{-3}$

$y0_{rotor}{}^{T} =$

	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

$\cdot 10^{-12}$

$Jy_{stator}^{T} =$

	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	...

$\cdot 10^{-12}$

$Jxy_{stator}^{T} =$

	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

$\cdot 10^{-12}$

$Jx0_{stator}^{T} =$

	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

$\cdot 10^{-12}$

$Jy0_{stator}^{T} =$

	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

$\cdot 10^{-12}$

$Jxy0_{stator}^{T} =$

	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

$\cdot 10^{-12}$

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

	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

$\cdot ^{\circ}$

$Jx_{rotor}^{T} =$

	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

$\cdot 10^{-12}$

$Jy_{rotor}^{T} =$

	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

$\cdot 10^{-12}$

$Jxy_{rotor}^{T} =$

	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

$\cdot 10^{-12}$

$Jx0_{rotor}^{T} =$

	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

$\cdot 10^{-12}$

$Jy0_{rotor}^{T} =$

	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

$\cdot 10^{-12}$

$Jxy0_{rotor}^{T} =$

	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

$\cdot 10^{-12}$

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

	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

$\cdot 10^{-9}$

$stiffness_{stator}{}^{T} =$

	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	...

$\cdot 10^{-12}$

$Ju_{rotor}{}^{T} =$

	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

$\cdot 10^{-9}$

$stiffness_{rotor}{}^{T} =$

	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

$\cdot 1$

$CPx_{stator}^{T} =$

	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

Профилирование решеток

Абс. координаты профиля:

$$\mathrm{Airfoil}(type, x, line, i, r) = \left| \begin{array}{l} \text{if } type = \text{"BHA"} \\ \quad \left| \begin{array}{l} AIRFOIL_{subsonic}\left(x, line, \overline{c}_{BHA_r}, \varepsilon_{BHA_r}\right) \ \text{ if } M_{c_{st(1,1),r}} < M_{lim} \\ AIRFOIL_{supersonic}\left(x, line, \overline{c}_{BHA_r}, \varepsilon_{BHA_r}\right) \ \text{ otherwise} \end{array} \right. \\ \text{if } type = \text{"rotor"} \\ \quad \left| \begin{array}{l} AIRFOIL_{subsonic}\left(x, line, \overline{c}_{rotor_{i,r}}, \varepsilon_{rotor_{i,r}}\right) \ \text{ if } M_{w_{st(i,1),r}} < M_{lim} \\ AIRFOIL_{supersonic}\left(x, line, \overline{c}_{rotor_{i,r}}, \varepsilon_{rotor_{i,r}}\right) \ \text{ otherwise} \end{array} \right. \\ \text{if } type = \text{"stator"} \\ \quad \left| \begin{array}{l} AIRFOIL_{subsonic}\left(x, line, \overline{c}_{stator_{i,r}}, \varepsilon_{stator_{i,r}}\right) \ \text{ if } M_{c_{st(i,2),r}} < M_{lim} \\ AIRFOIL_{supersonic}\left(x, line, \overline{c}_{stator_{i,r}}, \varepsilon_{stator_{i,r}}\right) \ \text{ otherwise} \end{array} \right. \\ \text{if } type = \text{"CA"} \\ \quad \left| \begin{array}{l} AIRFOIL_{subsonic}\left(x, line, \overline{c}_{CA_r}, \varepsilon_{CA_r}\right) \ \text{ if } M_{c_{st(Z,3),r}} < M_{lim} \\ AIRFOIL_{supersonic}\left(x, line, \overline{c}_{CA_r}, \varepsilon_{CA_r}\right) \ \text{ otherwise} \end{array} \right. \end{array} \right.$$

Профилирование решеток

Рассматриваемая ступень: $$j = \left| \begin{array}{l} j = 1 \\ j = \left| \begin{array}{ll} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{array} \right. \end{array} \right. = 1$$

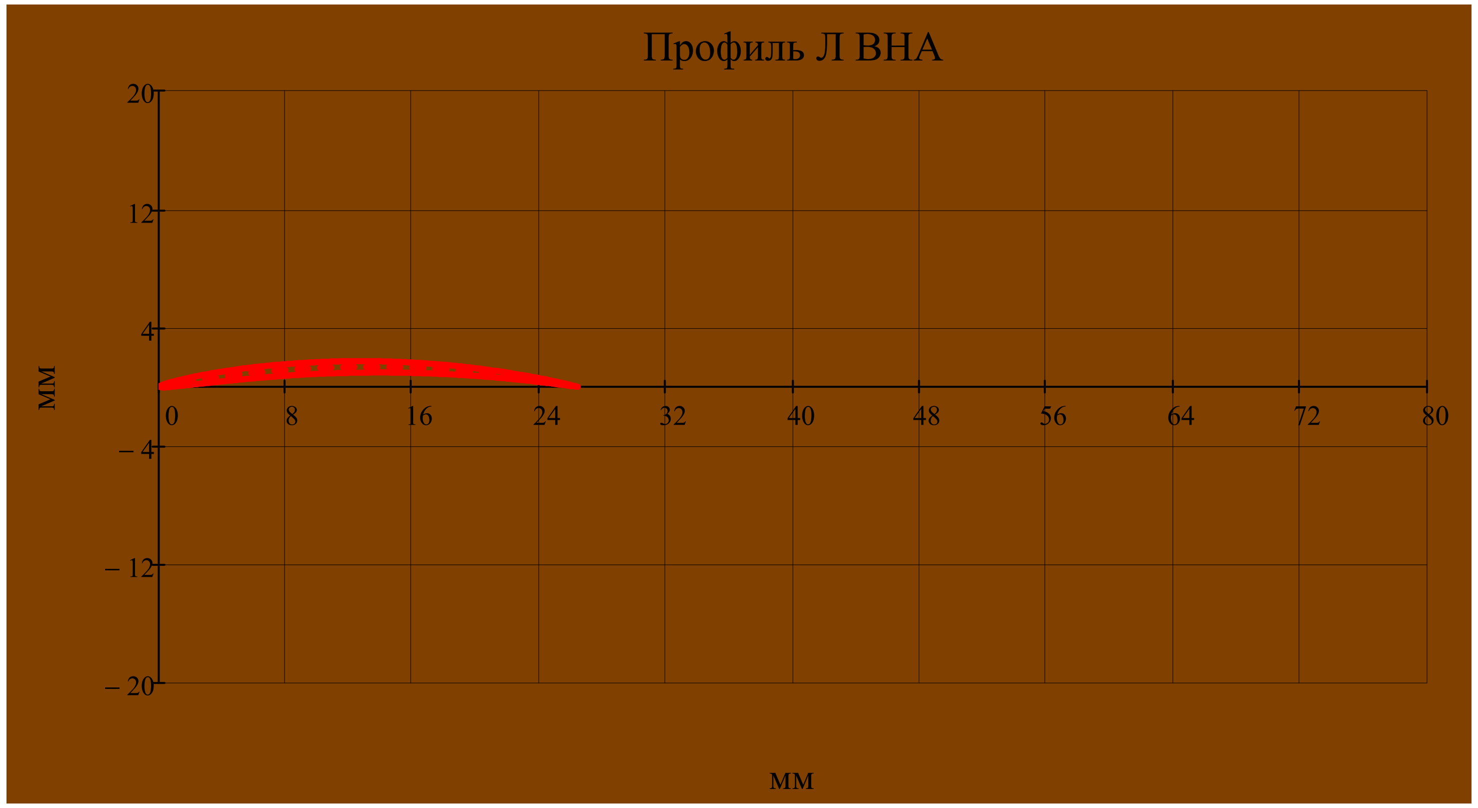
Построение профилей Л РК и НА

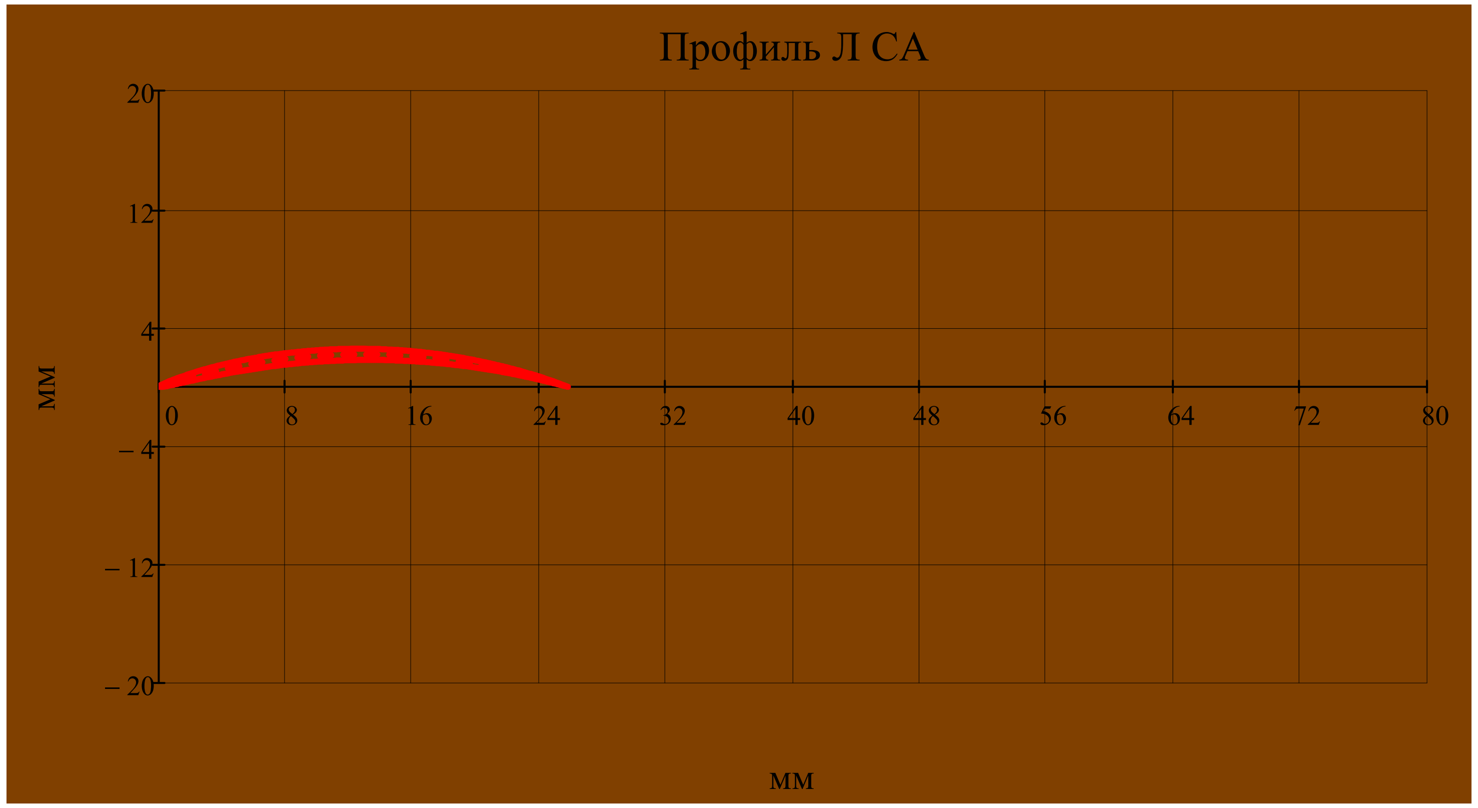
$$\mathrm{AXLE0}(type, x, i, r) = \left| \begin{array}{ll} \dfrac{y0rotor_{i,r}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}}\right) \cdot \left(x - \dfrac{x0rotor_{i,r}}{chord_{rotor_{i,r}}}\right) & \text{if } type = \text{"rotor"} \\ \dfrac{y0stator_{i,r}}{chord_{stator_{i,r}}} + \tan\left(\alpha\_major_{stator_{i,r}}\right) \cdot \left(x - \dfrac{x0stator_{i,r}}{chord_{stator_{i,r}}}\right) & \text{if } type = \text{"stator"} \\ \mathrm{NaN} & \text{otherwise} \end{array} \right.$$

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

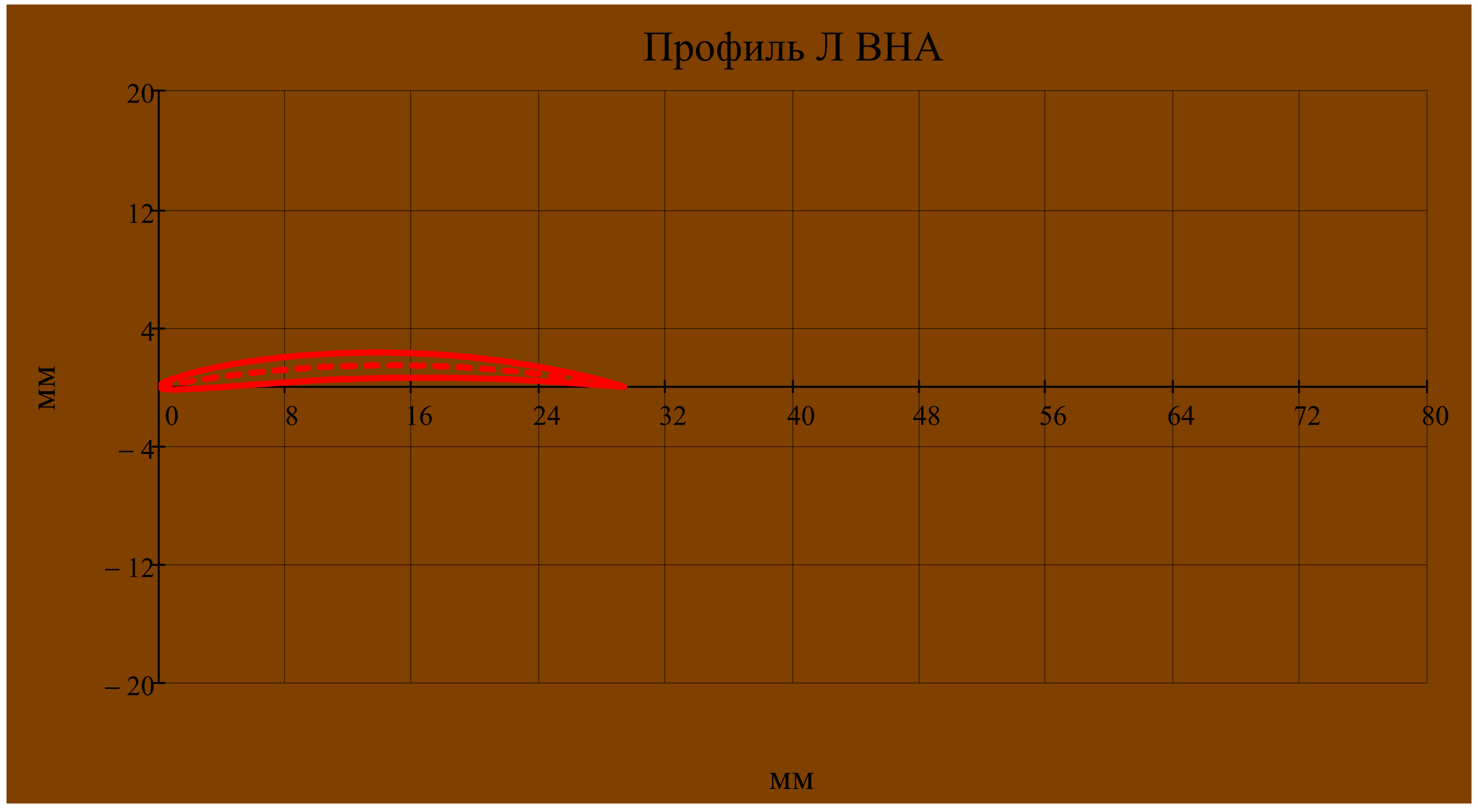
$$\mathrm{AXLE90}(type, x, i, r) = \left| \begin{array}{ll} \dfrac{y0_{rotor_{i,r}}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}} + \dfrac{\pi}{2}\right) \cdot \left(x - \dfrac{x0_{rotor_{i,r}}}{chord_{rotor_{i,r}}}\right) & \text{if } (type = \text{"rotor"}) \wedge \left|\alpha\_major_{rotor_{i,r}}\right|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

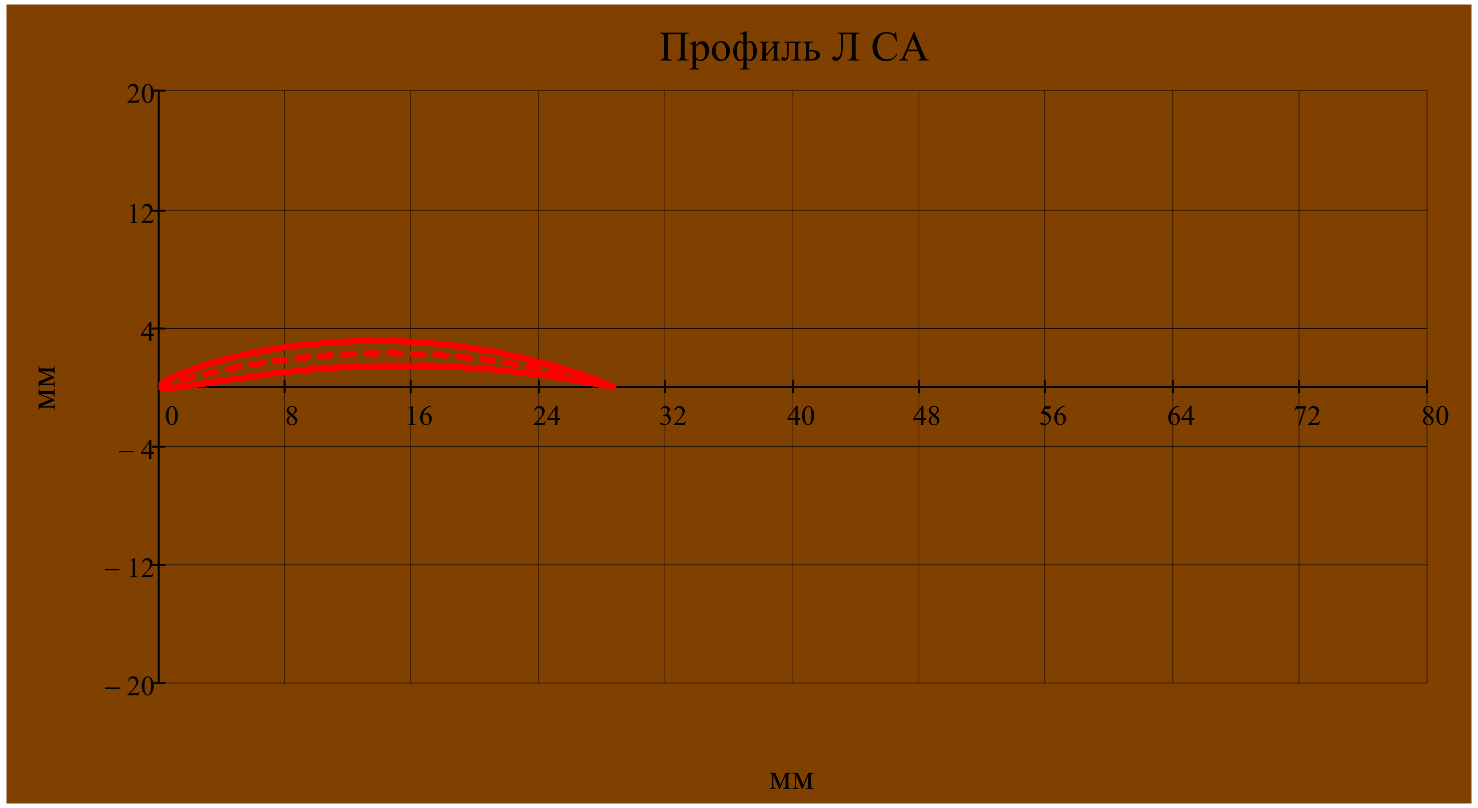
r = 1


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

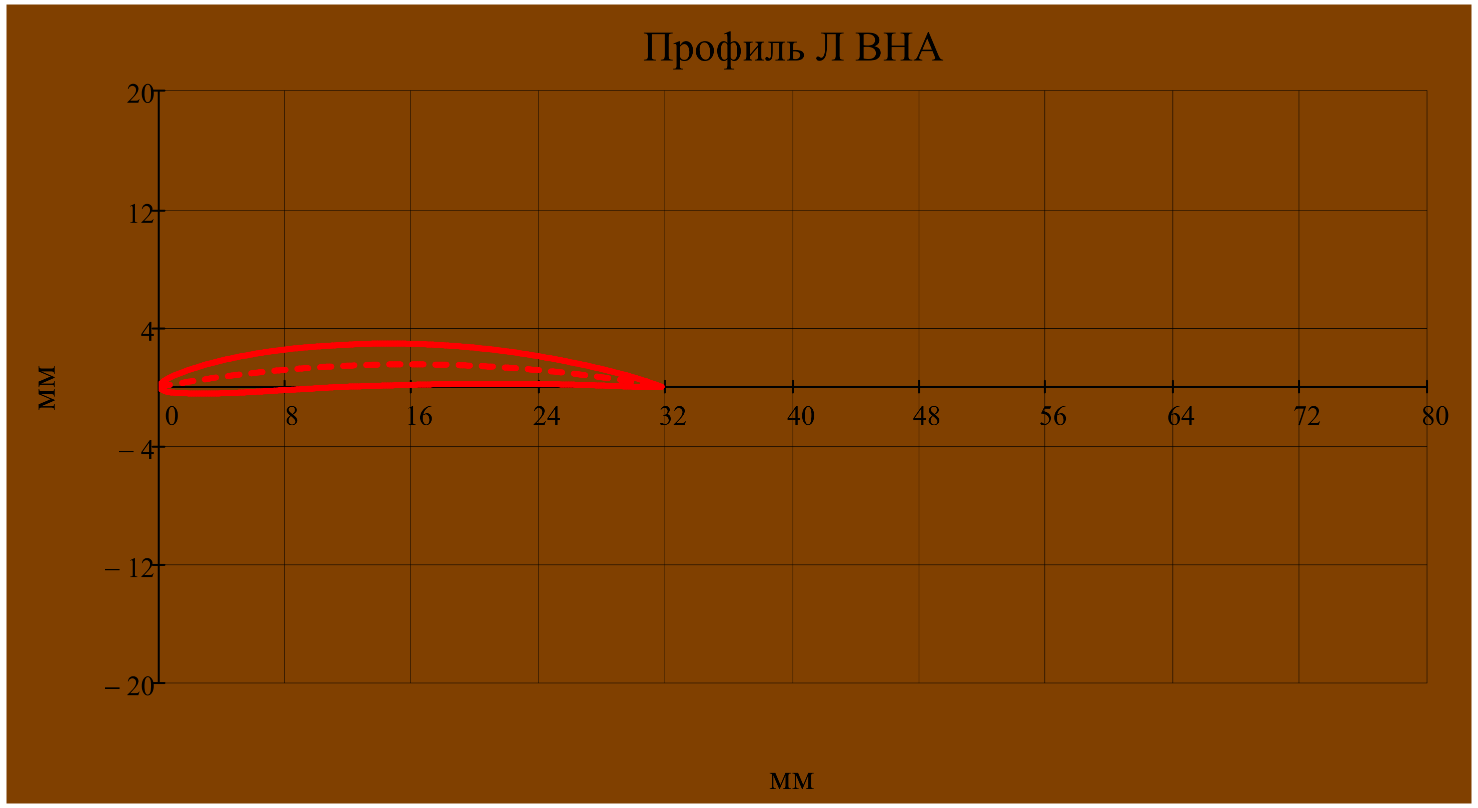

Профиль Л СА
20
12
4
– 4
– 12
– 20
0
8
16
24
32
40
48
56
64
72
80
мм
мм

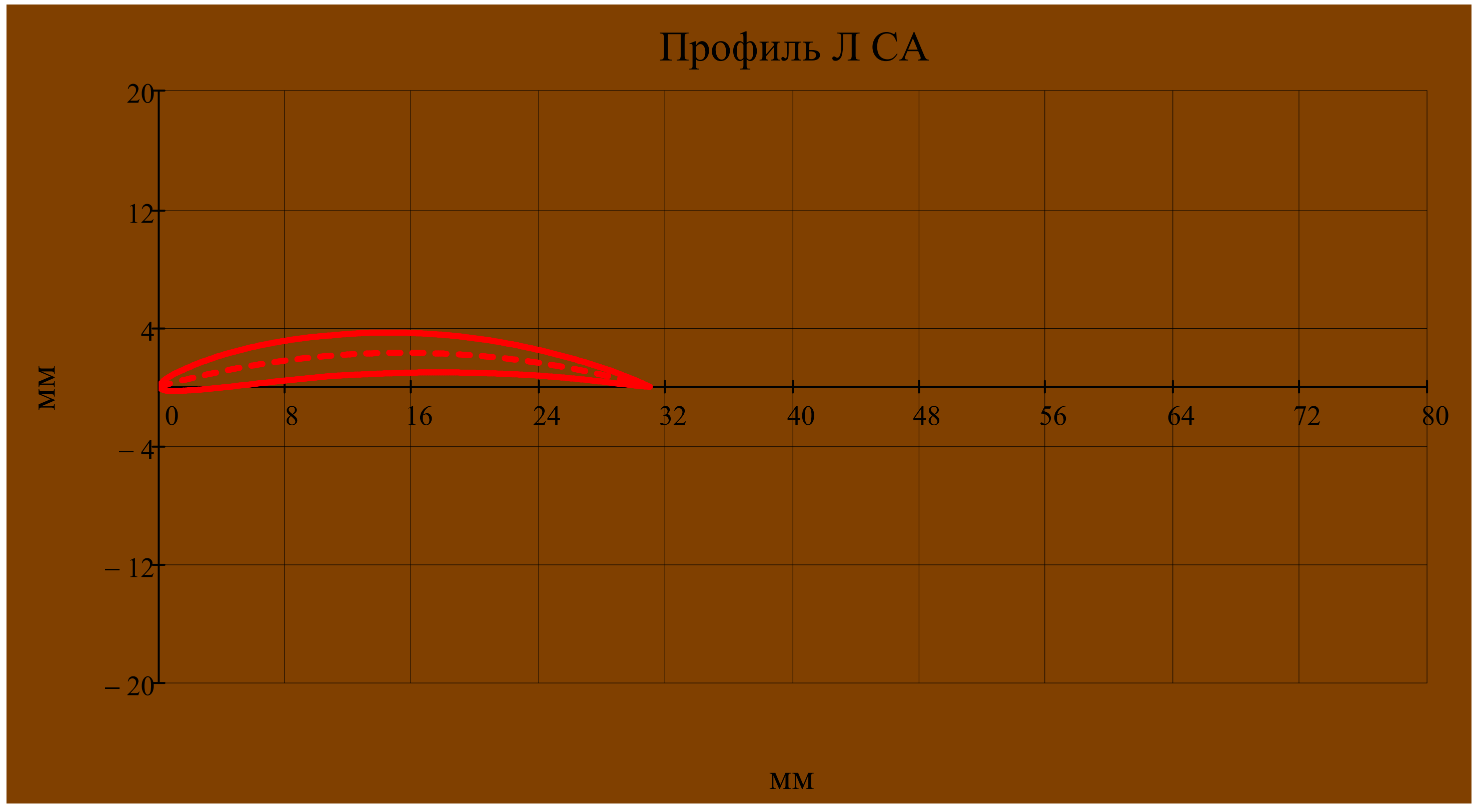
$r = av(N_r)$


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

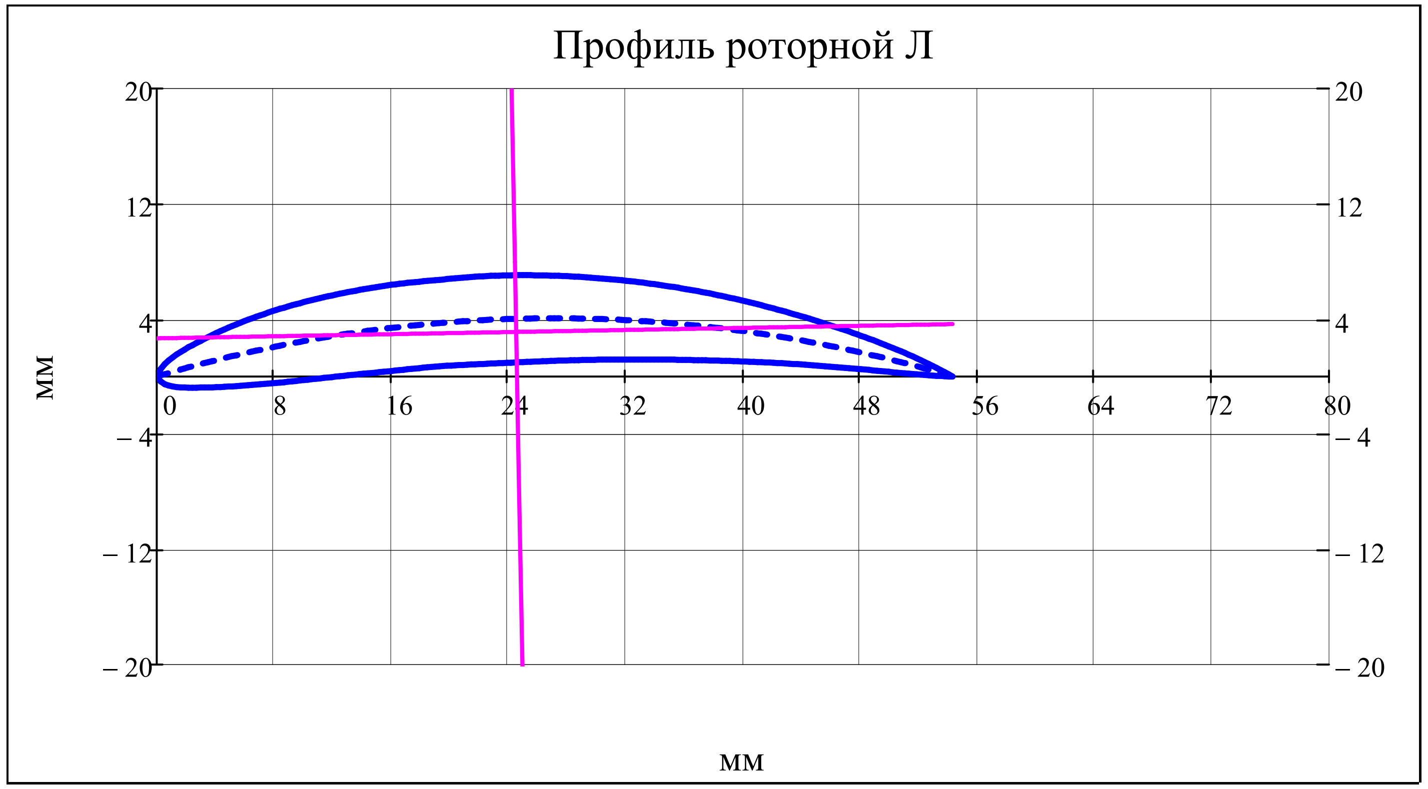

Профиль Л СА
20
12
4
– 4
– 12
– 20
0
8
16
24
32
40
48
56
64
72
80
мм
мм

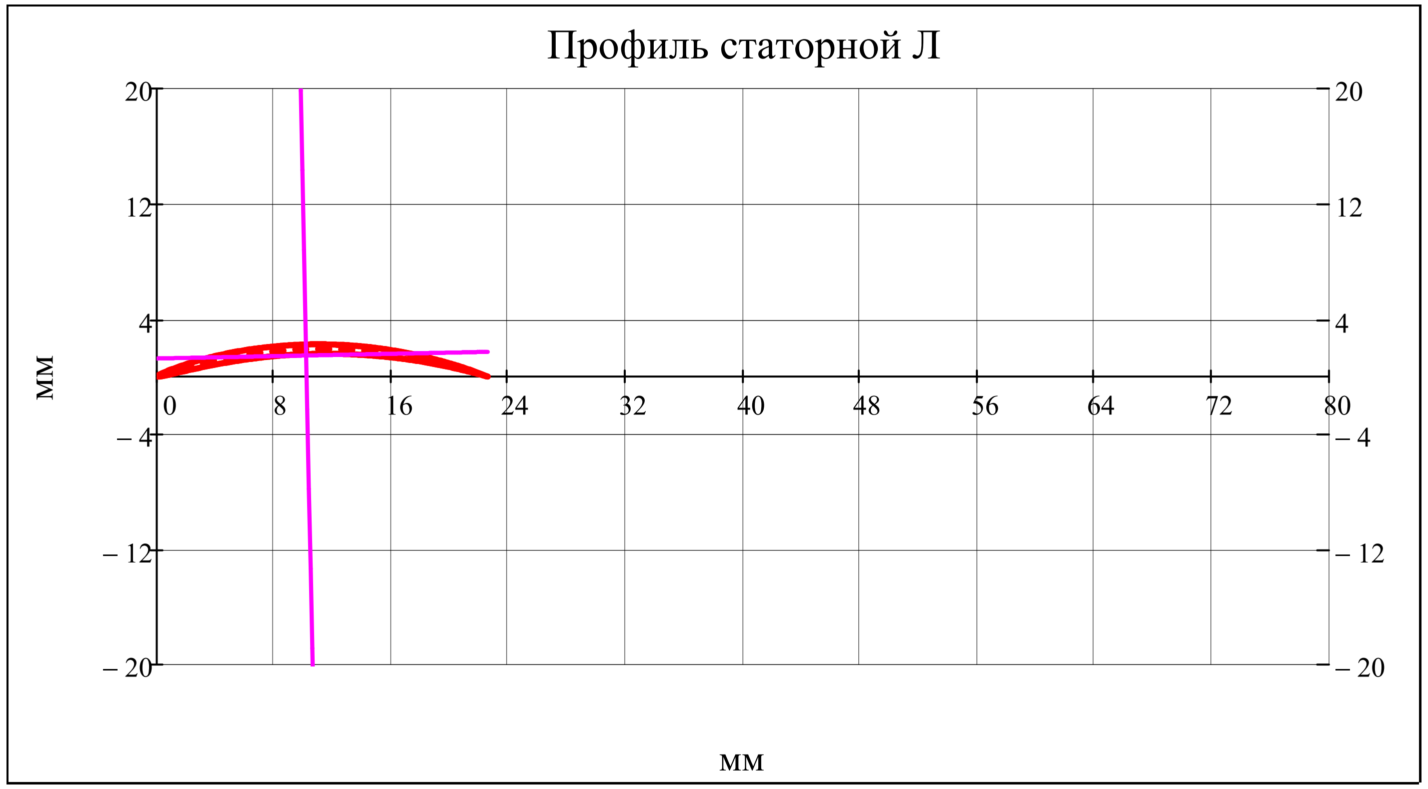
$r = N_r$


Профиль Л ВНА

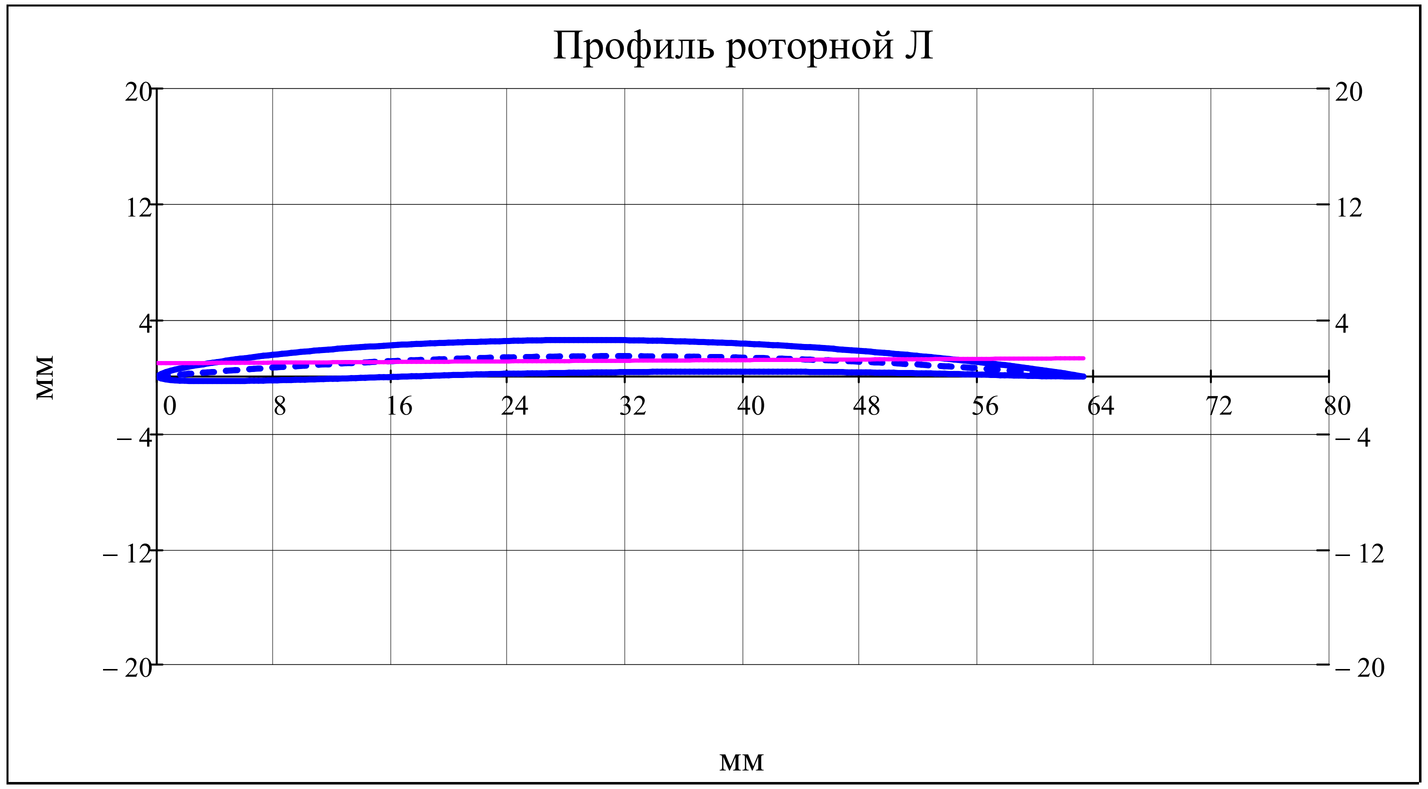

Профиль Л СА

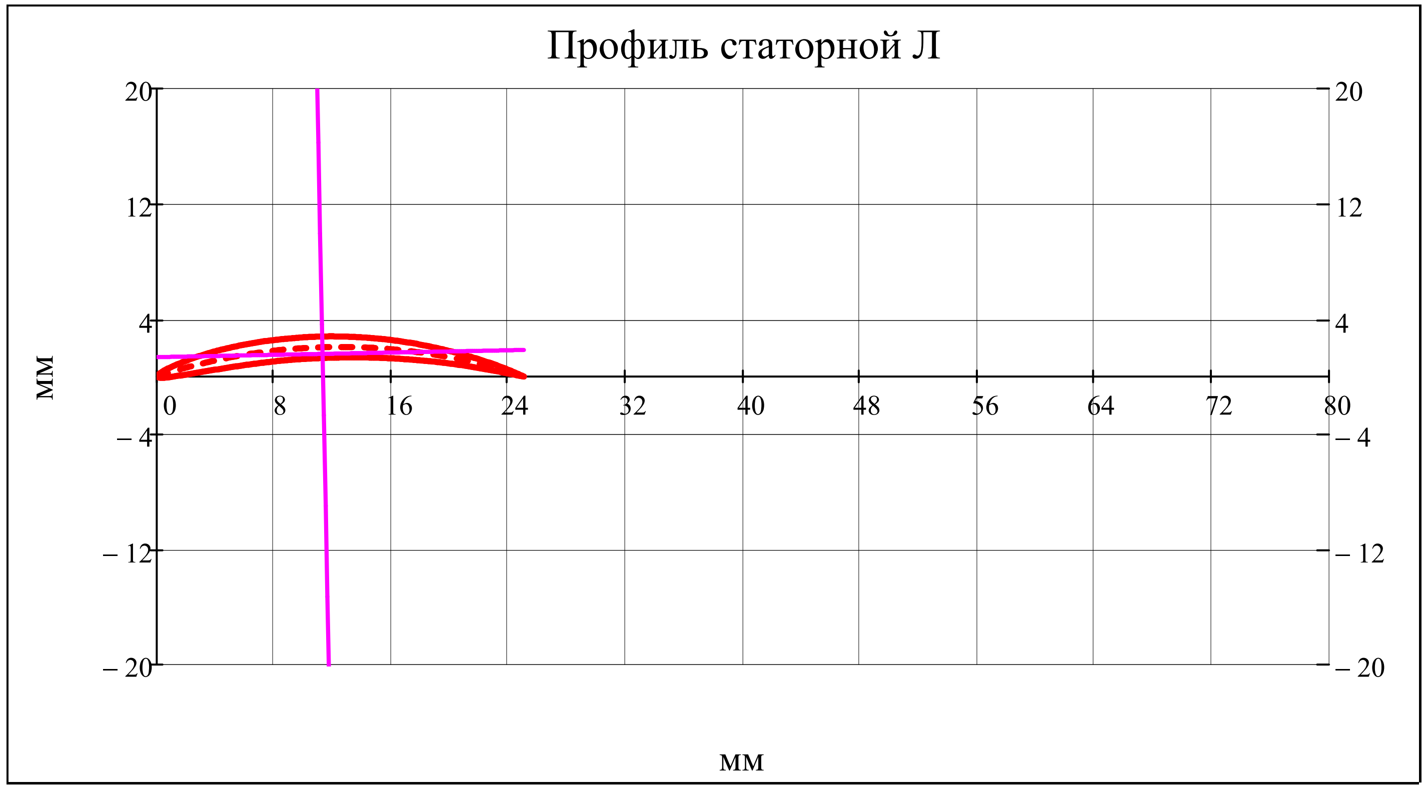
r = 1


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

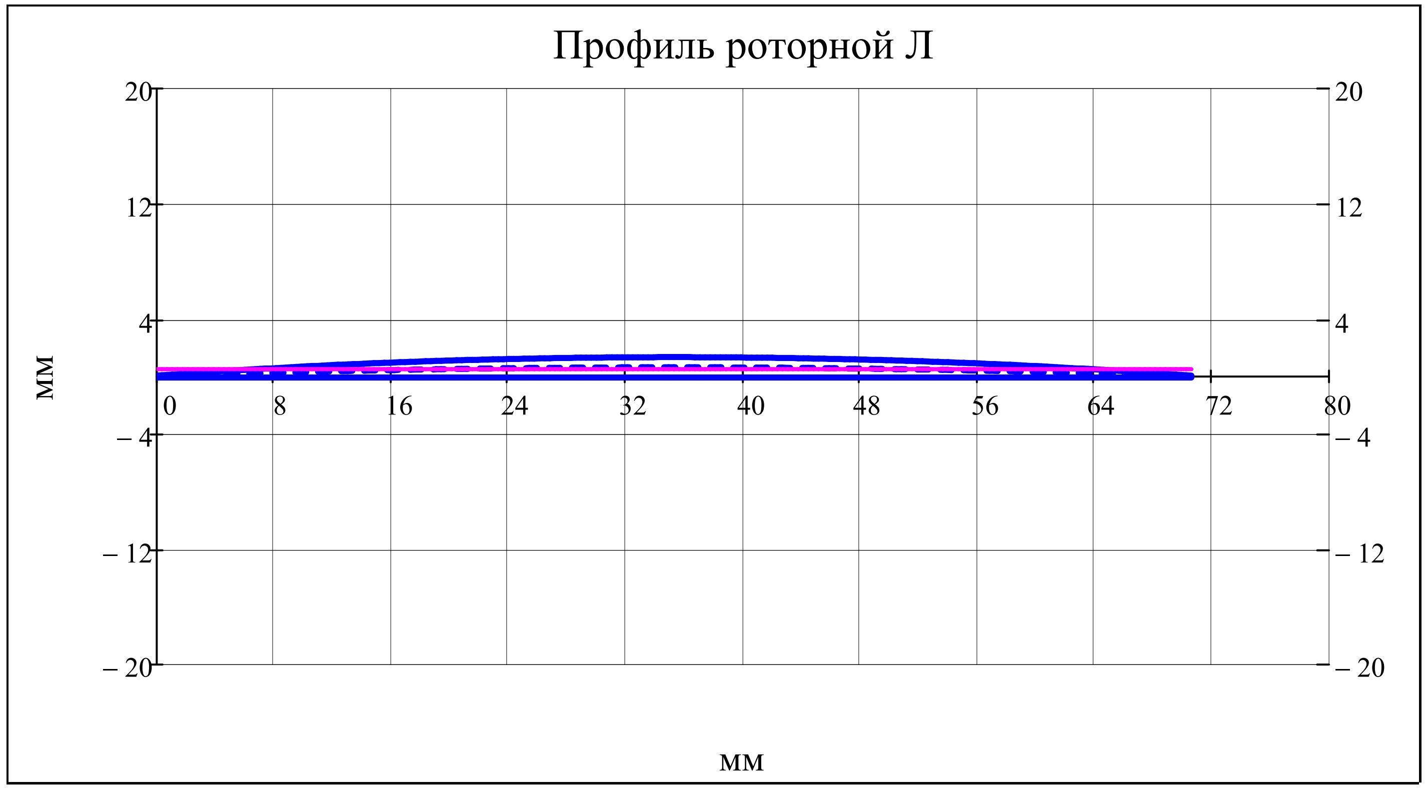

Профиль статорной Л
мм
мм
20
12
4
– 4
– 12
– 20
0
8
16
24
32
40
48
56
64
72
80

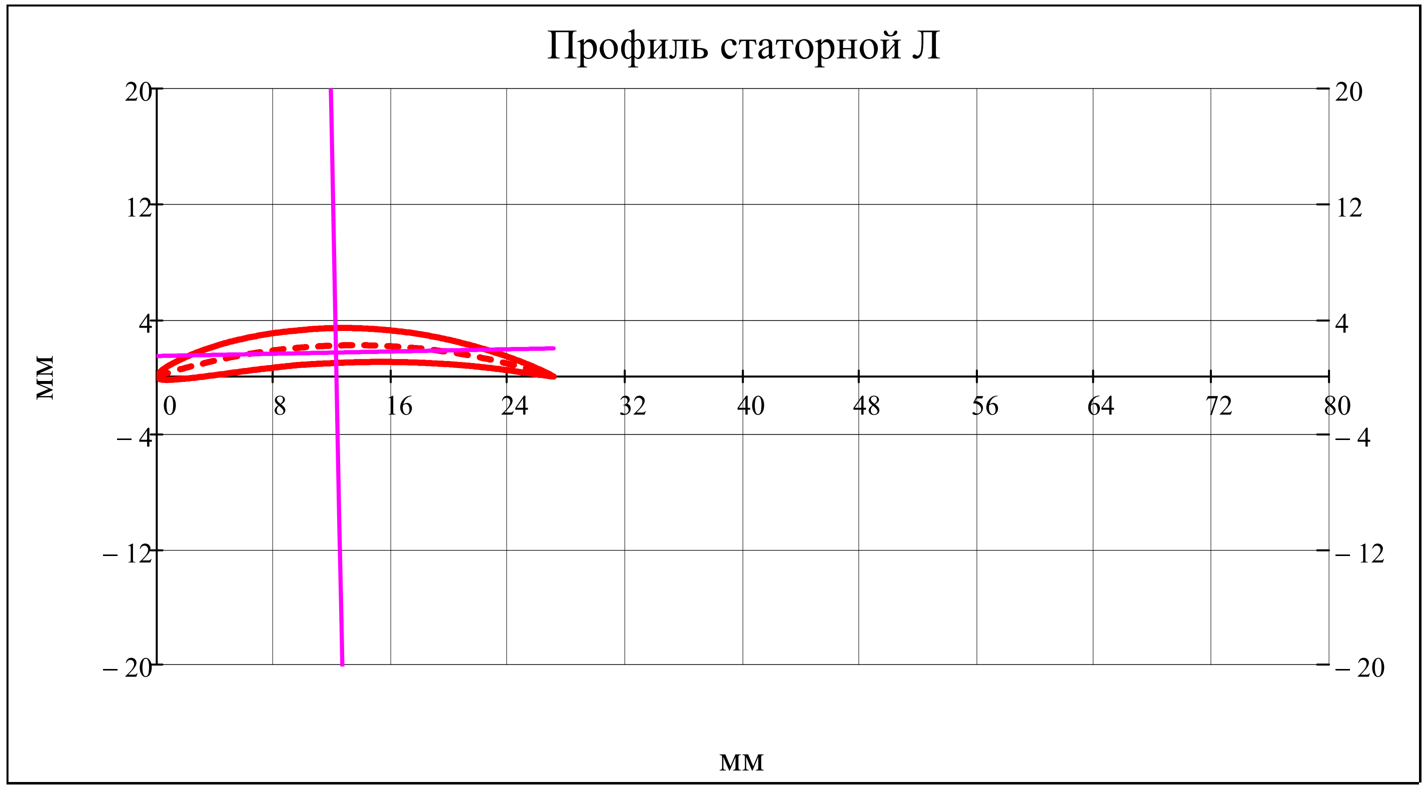
$r = av(N_r)$


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


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

$r = N_r$





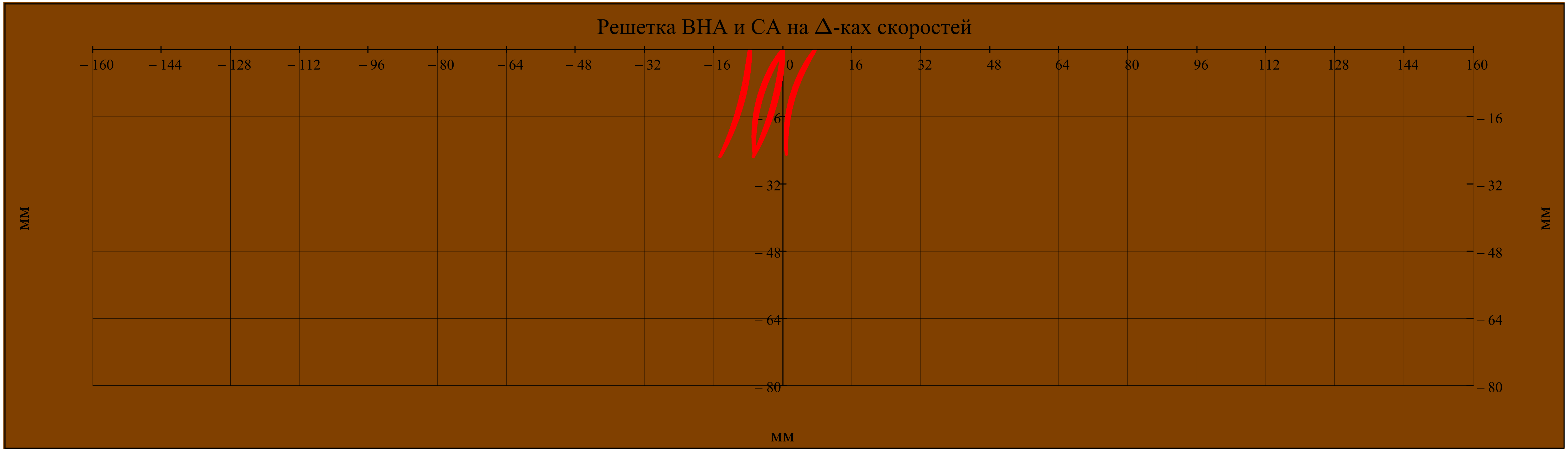
Построение профилей Л РК и НА

Рассматриваемая ступень: $j = \left| \begin{array}{l} j = 1 \\ j = \left| \begin{array}{ll} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{array} \right. \end{array} \right. = 1$

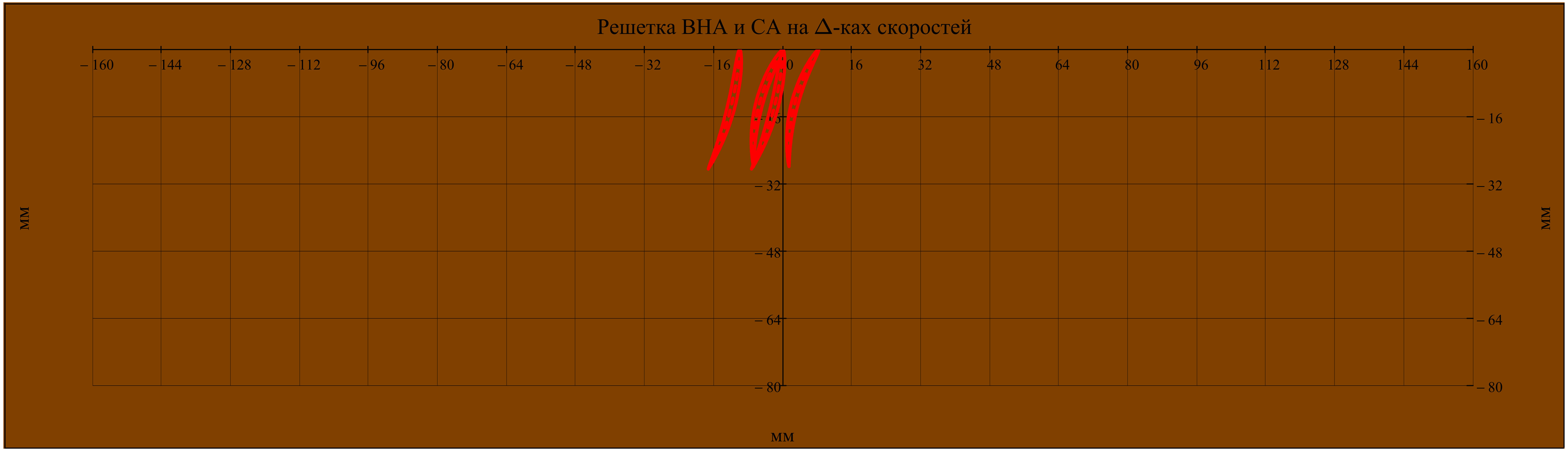
$$b_{lim} = \frac{\mathrm{ceil}\left(\max\left(\mathrm{chord}_{\mathrm{rotor}_{j,N_r}}, \mathrm{chord}_{\mathrm{stator}_{j,N_r}}\right)\cdot 10^2\right)}{10^2} = 80\cdot 10^{-3}$$

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

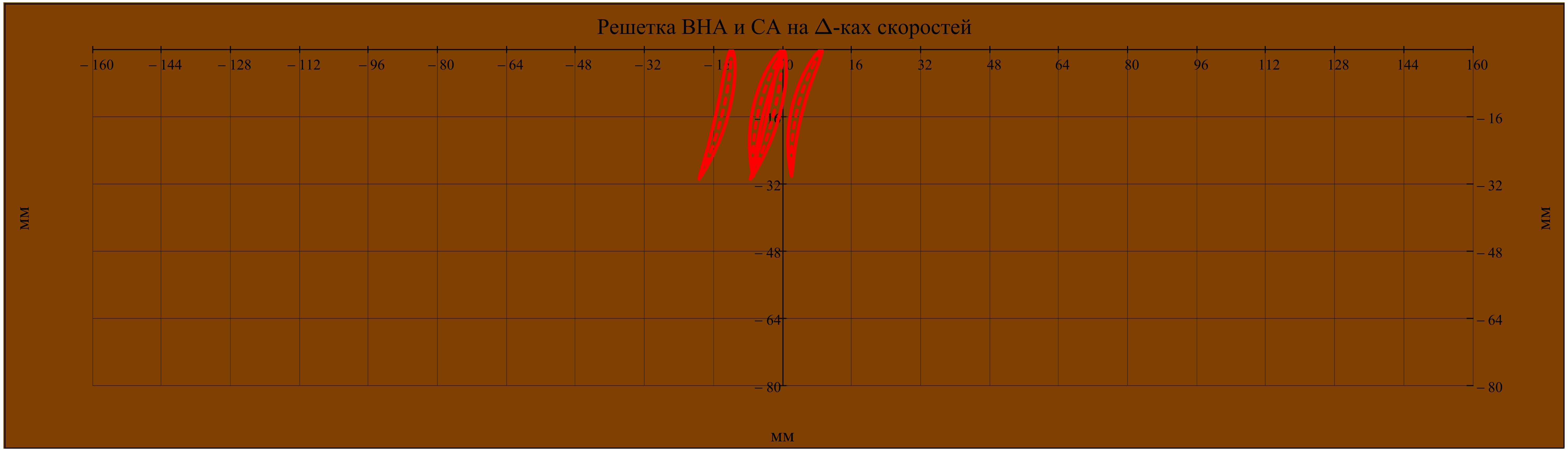
$r = 1$



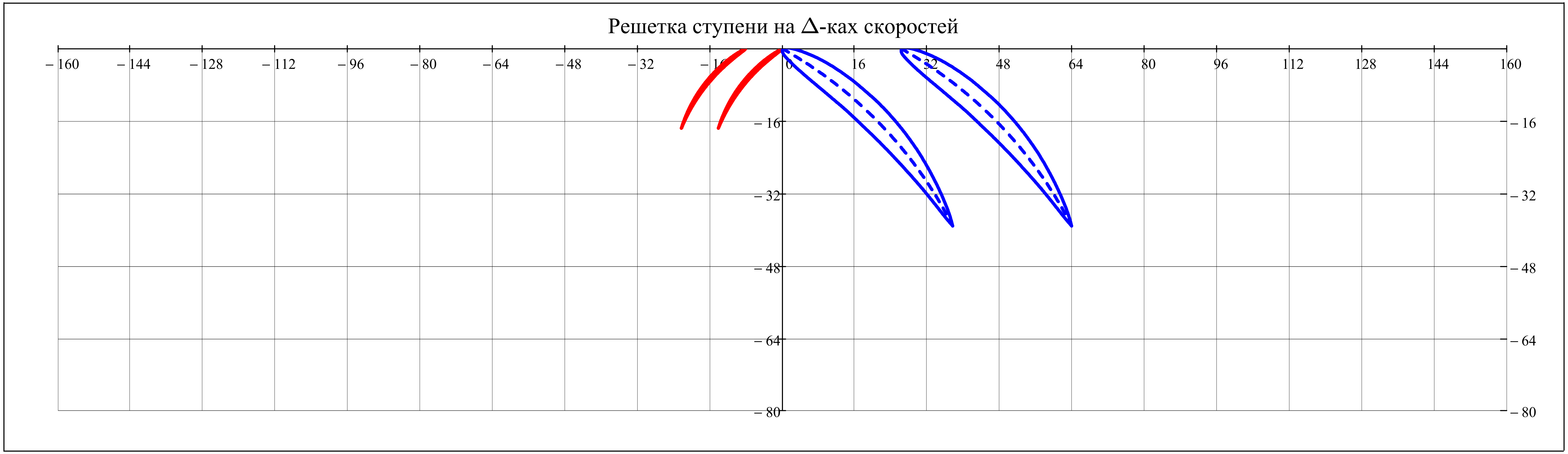
$r = av(N_r)$


Решетка ВНА и СА 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
мм
мм
мм

$r = N_r$

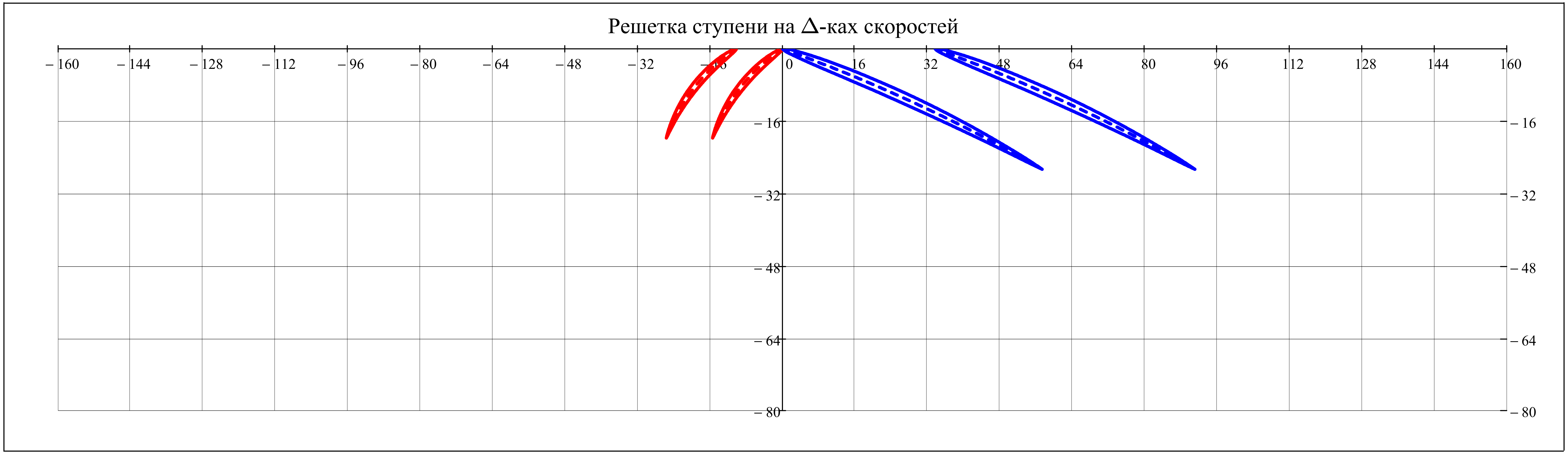

Решетка ВНА и СА на Δ-ках скоростей
– 160
– 144
– 128
– 112
– 96
– 80
– 64
– 48
– 32
– 16
0
16
32
48
64
80
96
112
128
144
160
– 16
– 32
– 48
– 64
– 80
мм
мм
мм

$r = 1$

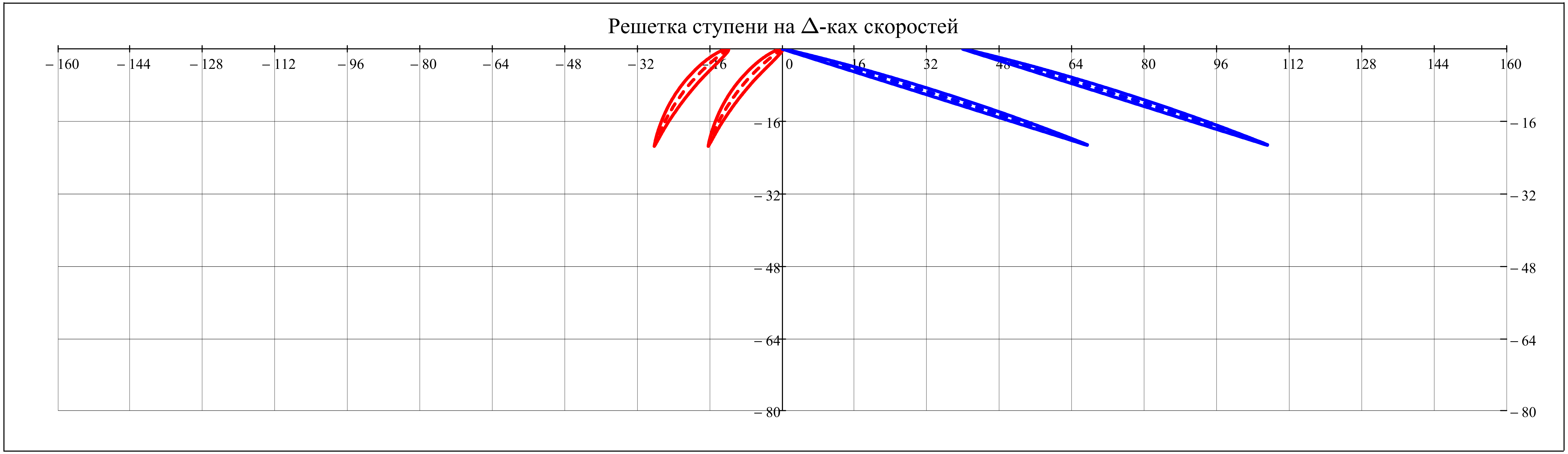


Решетка ступени на Δ-ках скоростей

$r = \mathrm{av}\left(N_r\right)$


Решетка ступени на Δ-ках скоростей

$r = N_r$



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

▼ Радиальные и осевые зазоры и длина К

Радиальный зазор (м)
[с.64 казаджан]:

$\bar{\Delta}r = 0.0025$

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

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

$\Delta_r^{\,T} =$

	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]: $\bar{\Delta}a = 0.17$

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

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

$\Delta a^T =$

	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):

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

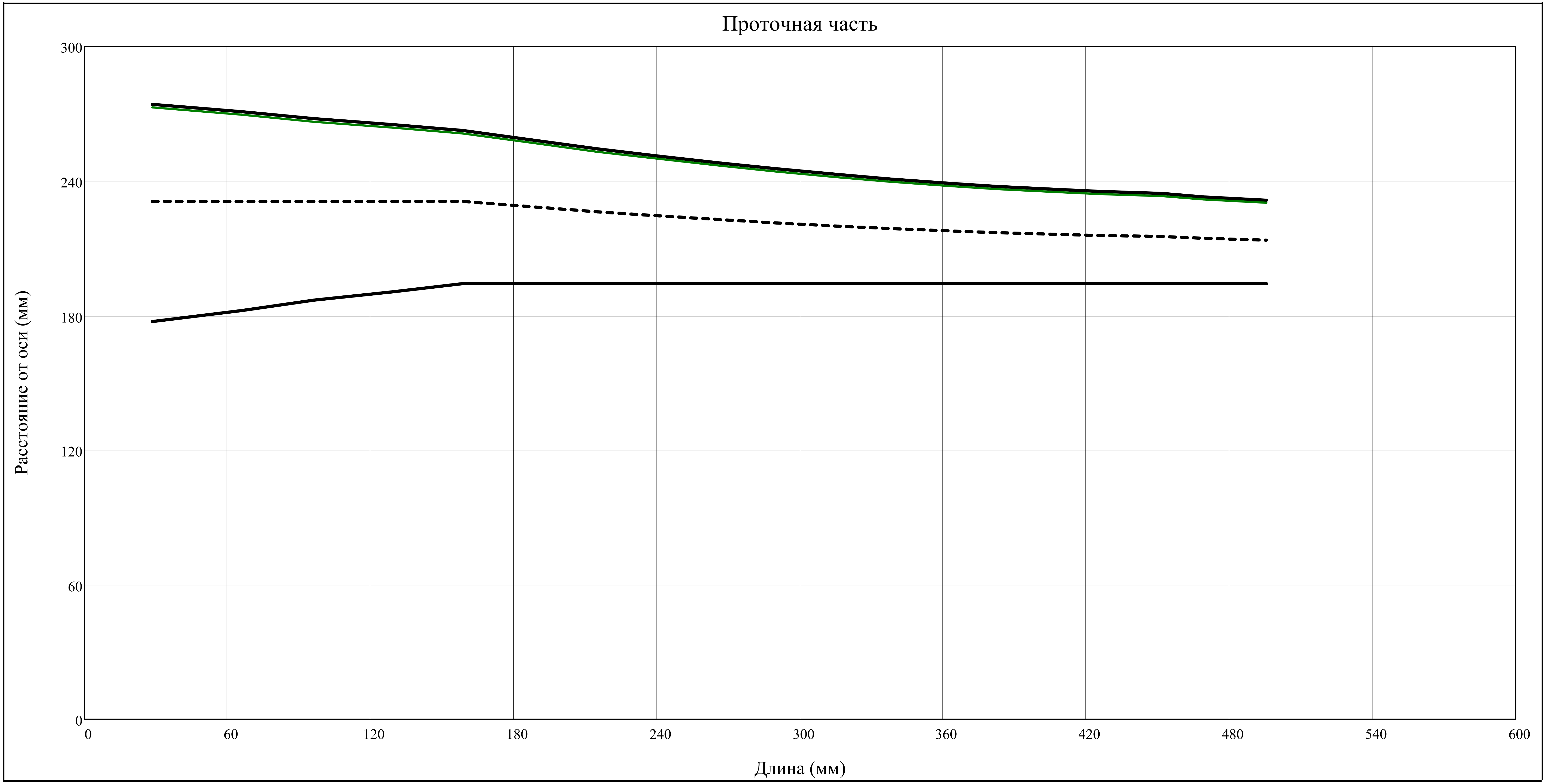
	1	2	3	4	5	6	7	8	9
1	5.37	4.83	4.28	3.91	3.63	3.43	3.29	3.23	3.20

$\cdot 10^{-3}$

Длина ОК (м):

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

▲ Радиальные и осевые зазоры и длина К



▲ Проточная часть

Рассматриваемая ступень: $j = \left| \begin{array}{l} j = 1 \\ j = \left| \begin{array}{ll} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{array} \right. \end{array} \right. = 1$

Поперечная часть ступени

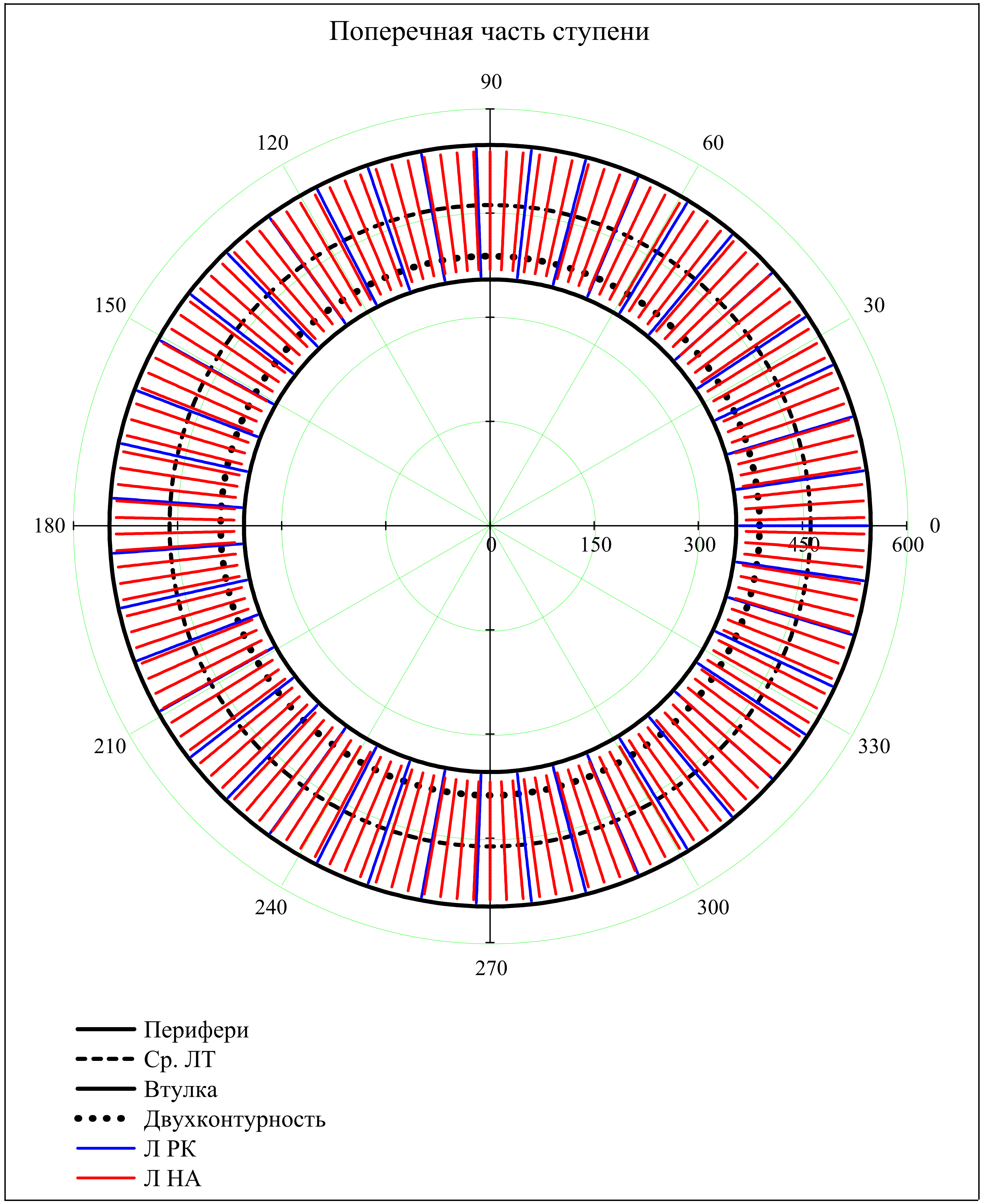
$$r = \min(D), \min(D) + \frac{\max(D) - \min(D)}{N_{dis}} .. \max(D)$$

$$i_{rotor} = 1 .. Z_{rotor_j}$$

$$i_{stator} = 1 .. Z_{stator_j}$$

$$Л_{РК}(r,j) = \left| \begin{array}{ll} \dfrac{2 \cdot \pi}{Z_{rotor_j}} & \text{if } D_{st(j,1),1} < r < D_{st(j,1),N_r} \\ NaN & \text{otherwise} \end{array} \right.$$

$$Л_{НА}(r,j) = \left| \begin{array}{ll} \dfrac{2 \cdot \pi}{Z_{stator_j}} & \text{if } D_{st(j,2),1} < r < D_{st(j,2),N_r} \\ NaN & \text{otherwise} \end{array} \right.$$



Поперечная часть ступени

▼ Выбор материала Л

Запас по температуре (К): $\Delta T_{safety} = 50$

Выбранный материал Л:

$$material\_blade_i = \left|\begin{array}{l} \text{"ЖС-6К"} \;\; \text{if } 1123 \le T^*_{st(i,2),av(N_r)} + \Delta T_{safety} \\ \text{"ВТ41"} \;\; \text{if } 873 \le T^*_{st(i,2),av(N_r)} + \Delta T_{safety} < 1123 \\ \text{"ВТ25"} \;\; \text{if } 753 \le T^*_{st(i,2),av(N_r)} + \Delta T_{safety} < 873 \\ \text{"ВТ9"} \;\; \text{otherwise} \end{array}\right.$$

$$material\_blade_i = \left|\begin{array}{l} \text{"ВТ23"} \;\; \text{if } compressor = \text{"Вл"} \\ \text{"ВТ6"} \;\; \text{if } compressor = \text{"КНД"} \\ material\_blade_i \;\; \text{otherwise} \end{array}\right.$$

Плотность материала Л (кг/м^3):

$$\rho\_blade_i = \left|\begin{array}{l} 8393 \;\; \text{if } material\_blade_i = \text{"ЖС-6К"} \\ 7900 \;\; \text{if } material\_blade_i = \text{"ВТ41"} \\ 4500 \;\; \text{if } material\_blade_i = \text{"ВТ25"} \\ 4570 \;\; \text{if } material\_blade_i = \text{"ВТ23"} \\ 4510 \;\; \text{if } material\_blade_i = \text{"ВТ9"} \\ 4430 \;\; \text{if } material\_blade_i = \text{"ВТ6"} \\ NaN \;\; \text{otherwise} \end{array}\right.$$

Коэф. формы: $k_n = 6.8$

Модуль Юнга I рода материала Л (Па): $E\_blade = 210 \cdot 10^9$

Коэф. Пуассона материала Л (): $\mu\_steel = 0.3$

Предел длительной прочности Л РК (Па):

$$\sigma\_blade\_long_i = 10^6 \cdot \left|\begin{array}{l} 125 \;\; \text{if } material\_blade_i = \text{"ЖС-6К"} \\ 123 \;\; \text{if } material\_blade_i = \text{"ВТ41"} \\ 150 \;\; \text{if } material\_blade_i = \text{"ВТ25"} \\ 230 \;\; \text{if } material\_blade_i = \text{"ВТ23"} \\ 200 \;\; \text{if } material\_blade_i = \text{"ВТ9"} \\ 210 \;\; \text{if } material\_blade_i = \text{"ВТ6"} \\ NaN \;\; \text{otherwise} \end{array}\right.$$

$material\_blade^T =$

	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

```
$\begin{pmatrix} \nu0_{изг.stator} & \nu0_{изг.rotor} \\ \nu0_{угл.stator} & \nu0_{угл.rotor} \\ \nu0_{угл.stator\_bondage} & \nu0_{угл.rotor\_bondage} \end{pmatrix} =$
    for $i \in 1..Z$
        for $r \in av(N_r)$
            for $mode \in 1..6$
                $\nu0_{изг.stator_{i,mode}} = \nu0_{изгиб}\left(mode, mean\left(h_{st(i,2)}, h_{st(i,3)}\right), E\_blade, \rho\_blade_i, area_{stator_{i,r}}, Ju_{stator_{i,r}}\right)$
                $\nu0_{изг.rotor_{i,mode}} = \nu0_{изгиб}\left(mode, mean\left(h_{st(i,1)}, h_{st(i,2)}\right), E\_blade, \rho\_blade_i, area_{rotor_{i,r}}, Ju_{rotor_{i,r}}\right)$
                $\nu0_{угл.stator_{i,mode}} = \nu0_{угл}\left(mode, 0, mean\left(h_{st(i,2)}, h_{st(i,3)}\right), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{stator_{i,r}}, Jp_{stator_{i,r}}\right)$
                $\nu0_{угл.rotor_{i,mode}} = \nu0_{угл}\left(mode, 0, mean\left(h_{st(i,1)}, h_{st(i,2)}\right), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{rotor_{i,r}}, Jp_{rotor_{i,r}}\right)$
                $\nu0_{угл.stator\_bondage_{i,mode}} = \nu0_{угл}\left(mode, 1, mean\left(h_{st(i,2)}, h_{st(i,3)}\right), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{stator_{i,r}}, Jp_{stator_{i,r}}\right)$
                $\nu0_{угл.rotor\_bondage_{i,mode}} = \nu0_{угл}\left(mode, 1, mean\left(h_{st(i,1)}, h_{st(i,2)}\right), Jung(2, \mu\_steel, E\_blade), \rho\_blade_i, stiffness_{rotor_{i,r}}, Jp_{rotor_{i,r}}\right)$
    $\begin{pmatrix} \nu0_{изг.stator} & \nu0_{изг.rotor} \\ \nu0_{угл.stator} & \nu0_{угл.rotor} \\ \nu0_{угл.stator\_bondage} & \nu0_{угл.rotor\_bondage} \end{pmatrix}$
```

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

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

	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:

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

	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

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

	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

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

$$\begin{pmatrix} R0_{rotor} & area0_{rotor} \\ N0_{rotor} & \sigma0\_z_{rotor} \\ area_{rotor.} & area_{stator.} \\ N_{rotor} & \sigma\_z_{rotor} \\ P_1 & \rho_1 \\ P_2 & \rho_2 \\ P_3 & \rho_3 \\ c_{a1} & c_{u1} \\ c_{a2} & c_{u2} \\ c_{a3} & c_{u3} \\ qx_{rotor} & qx_{stator} \\ qy_{rotor} & qy_{stator} \\ Mx_{rotor} & Mx_{stator} \\ My_{rotor} & My_{stator} \\ shift\_x_{rotor} & shift\_y_{rotor} \\ x0_{rotor.} & x0_{stator.} \\ y0_{rotor.} & y0_{stator.} \\ \alpha\_major_{rotor.} & \alpha\_major_{stator.} \\ Ju_{rotor.} & Ju_{stator.} \\ Jv_{rotor.} & Jv_{stator.} \\ CPx_{rotor.} & CPx_{stator.} \\ CPy_{rotor.} & CPy_{stator.} \\ CPx_{rotor.axis} & CPx_{stator.axis} \\ CPy_{rotor.axis} & CPy_{stator.axis} \end{pmatrix} =$$

$$\chi_{rotor}(i,z) = \frac{area_{rotor_{i,N_r}}}{area_{rotor_{i,1}}}$$

$$R0_{rotor}(i,z) = \frac{1}{\sqrt{1 - \ln\left(\chi_{rotor}(i,z)\right)}} \cdot \left| \begin{array}{ll} \sqrt{mean\left(R_{st(i,1),1}, R_{st(i,2),1}\right)^2 - mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)^2 \cdot \ln\left(\chi_{rotor}(i,z)\right)} & \text{if } type = "compressor" \\ \sqrt{mean\left(R_{st(i,2),1}, R_{st(i,3),1}\right)^2 - mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)^2 \cdot \ln\left(\chi_{rotor}(i,z)\right)} & \text{if } type = "turbine" \end{array} \right.$$

$$\sigma0_{rotor.max}(i,z) = \frac{\rho\_blade_i \cdot \omega^2}{2} \cdot \left| \begin{array}{ll} \left[mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)^2 - \left(R0_{rotor}(i,z)\right)^2\right] & \text{if } type = "compressor" \\ \left[mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)^2 - \left(R0_{rotor}(i,z)\right)^2\right] & \text{if } type = "turbine" \end{array} \right.$$

$$\rho\_blade_i \cdot \omega^2 \qquad \int^{R0_{rotor}(i,z)}$$

$$\begin{pmatrix} {}_{rotor.axis} & {}_{stator.axis} \\ Wp_{rotor.} & Wp_{stator.} \\ M\tau_{rotor} & M\tau_{stator} \\ \tau_{rotor} & \tau_{stator} \\ \varphi\_uv_{rotor} & \varphi\_uv_{stator} \\ Mu_{rotor} & Mu_{stator} \\ Mv_{rotor} & Mv_{stator} \\ \varphi\_neutral_{rotor} & \varphi\_neutral_{stator} \end{pmatrix}$$

$$area0_{rotor}(i,z) = area_{rotor_{i,N_r}} \cdot \left| \begin{array}{ll} e^{\left(\frac{}{\sigma 0_{rotor.max}(i,z)} \cdot \int_z z\,dz\right)} & \text{if } z \le R0_{rotor}(i,z) \\ 1 & \text{otherwise} \end{array} \right.$$

$$N0_{rotor}(i,z) = \rho\_blade_i \cdot \omega^2 \cdot \left| \begin{array}{ll} \left(\int_z^{mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)} area0_{rotor}(i,z) \cdot z\,dz + V_{бп} \cdot R_{бп}\right) & \text{if type = "compressor"} \\ \left(\int_z^{mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)} area0_{rotor}(i,z) \cdot z\,dz + V_{бп} \cdot R_{бп}\right) & \text{if type = "turbine"} \end{array} \right.$$

$$\sigma 0\_z_{rotor}(i,z) = \frac{N0_{rotor}(i,z)}{area0_{rotor}(i,z)}$$

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

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

$$N_{rotor}(i,z) = \rho\_blade_i \cdot \omega^2 \cdot \left| \begin{array}{ll} \left(\int_z^{mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)} area_{rotor.}(i,z) \cdot z\,dz + V_{бп} \cdot R_{бп}\right) & \text{if type = "compressor"} \\ \left(\int_z^{mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)} area_{rotor.}(i,z) \cdot z\,dz + V_{бп} \cdot R_{бп}\right) & \text{if type = "turbine"} \end{array} \right.$$

$$\sigma\_z_{rotor}(i,z) = \frac{N_{rotor}(i,z)}{area_{rotor.}(i,z)}$$

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

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

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

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

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

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

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

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

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

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

$$c_{u2}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(c_u,st(i,2),st(i,2),1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(c_u,st(i,2),st(i,2),1,N_r\right)^T,z\right)$$

$$c_{u3}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,3),st(i,3),1,N_r\right)^T,\mathrm{submatrix}\left(c_u,st(i,3),st(i,3),1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,3),st(i,3),1,N_r\right)^T,\mathrm{submatrix}\left(c_u,st(i,3),st(i,3),1,N_r\right)^T,z\right)$$

$$w_{u1}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,1),st(i,1),1,N_r\right)^T,\mathrm{submatrix}\left(w_u,st(i,1),st(i,1),1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,1),st(i,1),1,N_r\right)^T,\mathrm{submatrix}\left(w_u,st(i,1),st(i,1),1,N_r\right)^T,z\right)$$

$$w_{u2}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(w_u,st(i,2),st(i,2),1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(w_u,st(i,2),st(i,2),1,N_r\right)^T,z\right)$$

$$w_{u3}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,3),st(i,3),1,N_r\right)^T,\mathrm{submatrix}\left(w_u,st(i,3),st(i,3),1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,3),st(i,3),1,N_r\right)^T,\mathrm{submatrix}\left(w_u,st(i,3),st(i,3),1,N_r\right)^T,z\right)$$

$$qx_{rotor}(i,z) = -\frac{2\pi z}{Z_{rotor_i}}\cdot \left| \begin{array}{ll} \left[\left(P_2(i,z)-P_1(i,z)\right)+\rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(c_{a2}(i,z)-c_{a1}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\left(P_3(i,z)-P_2(i,z)\right)+\rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(c_{a3}(i,z)-c_{a2}(i,z)\right)\right] & \text{if type = "turbine"} \end{array} \right.$$

$$qx_{stator}(i,z) = -\frac{2\pi z}{Z_{stator_i}}\cdot \left| \begin{array}{ll} \left[\left(P_3(i,z)-P_2(i,z)\right)+\rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(c_{a3}(i,z)-c_{a2}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\left(P_2(i,z)-P_1(i,z)\right)+\rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(c_{a2}(i,z)-c_{a1}(i,z)\right)\right] & \text{if type = "turbine"} \end{array} \right.$$

$$qy_{rotor}(i,z) = \frac{2\pi z}{Z_{rotor_i}}\cdot \left| \begin{array}{ll} \left[\rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(w_{u2}(i,z)-w_{u1}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(w_{u3}(i,z)-w_{u2}(i,z)\right)\right] & \text{if type = "turbine"} \end{array} \right.$$

$$qy_{stator}(i,z) = -\frac{2\pi z}{Z_{stator_i}}\cdot \left| \begin{array}{ll} \left[\rho_2(i,z)\cdot c_{a2}(i,z)\cdot\left(c_{u3}(i,z)-c_{u2}(i,z)\right)\right] & \text{if type = "compressor"} \\ \left[\rho_1(i,z)\cdot c_{a1}(i,z)\cdot\left(c_{u2}(i,z)-c_{u1}(i,z)\right)\right] & \text{if type = "turbine"} \end{array} \right.$$

$$Mx_{rotor}(i,z) = -\int_{z}^{\left| \begin{array}{ll} \mathrm{mean}\left(R_{st(i,1),N_r},R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,2),N_r},R_{st(i,3),N_r}\right) & \text{if type="turbine"} \end{array} \right.} qy_{rotor}(i,z1)\cdot(z1-z)\,dz1$$

$$Mx_{stator}(i,z) = \int_{z}^{\left| \begin{array}{ll} \mathrm{mean}\left(R_{st(i,2),1},R_{st(i,3),1}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,1),1},R_{st(i,2),1}\right) & \text{if type="turbine"} \end{array} \right.} qy_{stator}(i,z1)\cdot(z1-z)\,dz1$$

$$My_{rotor}(i,z) = \int_{z}^{\left| \begin{array}{ll} \mathrm{mean}\left(R_{st(i,1),N_r},R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,2),N_r},R_{st(i,3),N_r}\right) & \text{if type="turbine"} \end{array} \right.} qx_{rotor}(i,z1)\cdot(z1-z)\,dz1$$

$$My_{stator}(i,z) = -\int_{z}^{\left| \begin{array}{ll} \mathrm{mean}\left(R_{st(i,2),1},R_{st(i,3),1}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,1),1},R_{st(i,2),1}\right) & \text{if type="turbine"} \end{array} \right.} qx_{stator}(i,z1)\cdot(z1-z)\,dz1$$

$$\int^{z} \int^{\left| \begin{array}{ll} \mathrm{mean}\left(R_{st(i,1),N_r},R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ \mathrm{mean}\left(R_{st(i,2),N_r},R_{st(i,3),N_r}\right) & \text{if type="turbine"} \end{array} \right.} qx(i,z)\,dz$$

$$\text{shift\_x}_{\text{rotor}}(i,z) = \int_{\begin{cases}\text{mean}\left(R_{st(i,1),1}, R_{st(i,2),1}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{st(i,2),1}, R_{st(i,3),1}\right) & \text{if type="turbine"}\end{cases}} \frac{\int_{z} qx_{\text{rotor}}(i,z)\,dz}{N_{\text{rotor}}(i,z)}\,dz$$

$$\text{shift\_y}_{\text{rotor}}(i,z) = z\cdot\int_{\begin{cases}\text{mean}\left(R_{st(i,1),1}, R_{st(i,2),1}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{st(i,2),1}, R_{st(i,3),1}\right) & \text{if type="turbine"}\end{cases}}^{z} \frac{\int_{z}^{\begin{cases}\text{mean}\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right) & \text{if type="compressor"} \\ \text{mean}\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right) & \text{if type="turbine"}\end{cases}} \left(qy_{\text{rotor}}(i,z)\cdot z\right)dz}{N_{\text{rotor}}(i,z)\cdot z^{2}}\,dz$$

$$x0_{\text{rotor.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(x0_{\text{rotor}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(x0_{\text{rotor}}, i, i, 1, N_r\right)^T, z\right)$$

$$x0_{\text{stator.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(x0_{\text{stator}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(x0_{\text{stator}}, i, i, 1, N_r\right)^T, z\right)$$

$$y0_{\text{rotor.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(y0_{\text{rotor}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(y0_{\text{rotor}}, i, i, 1, N_r\right)^T, z\right)$$

$$y0_{\text{stator.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(y0_{\text{stator}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(y0_{\text{stator}}, i, i, 1, N_r\right)^T, z\right)$$

$$\alpha\text{\_major}_{\text{rotor.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(\alpha\text{\_major}_{\text{rotor}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(\alpha\text{\_major}_{\text{rotor}}, i, i, 1, N_r\right)^T$$

$$\alpha\text{\_major}_{\text{stator.}}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(\alpha\text{\_major}_{\text{stator}}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,2), st(i,2), 1, N_r\right)^T, \text{submatrix}\left(\alpha\text{\_major}_{\text{stator}}, i, i, 1, N\right.$$

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

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

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

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

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

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

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

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

$$CPx_{\text{rotor.axis}}(i,z) = \text{axis}_x\left(CPx_{\text{rotor.}}(i,z), CPy_{\text{rotor.}}(i,z), x0_{\text{rotor.}}(i,z), y0_{\text{rotor.}}(i,z), \alpha\text{\_major}_{\text{rotor.}}(i,z), 1\right)$$

$$CPx_{\text{stator.axis}}(i,z) = \text{axis}_x\left(CPx_{\text{stator.}}(i,z), CPy_{\text{stator.}}(i,z), x0_{\text{stator.}}(i,z), y0_{\text{stator.}}(i,z), \alpha\text{\_major}_{\text{stator.}}(i,z), 1\right)$$

$$CPy_{\text{rotor.axis}}(i,z) = \text{axis}_y\left(CPx_{\text{rotor.}}(i,z), CPy_{\text{rotor.}}(i,z), x0_{\text{rotor.}}(i,z), y0_{\text{rotor.}}(i,z), \alpha\text{\_major}_{\text{rotor.}}(i,z), 1\right)$$

$$CPy_{\text{stator.axis}}(i,z) = \text{axis}_y\left(CPx_{\text{stator.}}(i,z), CPy_{\text{stator.}}(i,z), x0_{\text{stator.}}(i,z), y0_{\text{stator.}}(i,z), \alpha\text{\_major}_{\text{stator.}}(i,z), 1\right)$$

$$Wp_{rotor.}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(Wp_{rotor},i,i,1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(Wp_{rotor},i,i,1,N_r\right)^T,z\right)$$

$$Wp_{stator.}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(Wp_{stator},i,i,1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(Wp_{stator},i,i,1,N_r\right)^T,z\right)$$

$$M\tau_{rotor}(i,z) = \int_z^{\left|\begin{array}{l}\mathrm{mean}\left(R_{st(i,1),N_r},R_{st(i,2),N_r}\right)\ \text{if type="compressor"}\\ \mathrm{mean}\left(R_{st(i,2),N_r},R_{st(i,3),N_r}\right)\ \text{if type="turbine"}\end{array}\right.} \left(qx_{rotor}(i,z1)\cdot CPy_{rotor.axis}(i,z1) - qy_{rotor}(i,z1)\cdot CPx_{rotor.axis}(i,z1)\right)\,dz1$$

$$M\tau_{stator}(i,z) = \int_z^{\left|\begin{array}{l}\mathrm{mean}\left(R_{st(i,2),1},R_{st(i,3),1}\right)\ \text{if type="compressor"}\\ \mathrm{mean}\left(R_{st(i,1),1},R_{st(i,2),1}\right)\ \text{if type="turbine"}\end{array}\right.} \left(qx_{stator}(i,z1)\cdot CPy_{stator.axis}(i,z1) - qy_{stator}(i,z1)\cdot CPx_{stator.axis}(i,z1)\right)\,dz1$$

$$\tau_{rotor}(i,z) = \frac{M\tau_{rotor}(i,z)}{Wp_{rotor.}(i,z)}$$

$$\tau_{stator}(i,z) = \frac{M\tau_{stator}(i,z)}{Wp_{stator.}(i,z)}$$

$$\varphi\_uv_{rotor}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(\frac{\pi}{2}-\upsilon_{rotor},i,i,1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(\frac{\pi}{2}-\upsilon_{rotor},i,i,1,N_r\right)^T,z\right)$$

$$\varphi\_uv_{stator}(i,z) = \mathrm{interp}\left(\mathrm{lspline}\left(\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(\frac{\pi}{2}-\upsilon_{stator},i,i,1,N_r\right)^T\right),\mathrm{submatrix}\left(R,st(i,2),st(i,2),1,N_r\right)^T,\mathrm{submatrix}\left(\frac{\pi}{2}-\upsilon_{stator},i,i,1,N_r\right)^T,z\right)$$

$$Mu_{rotor}(i,z) = \mathrm{axis}_x\left(Mx_{rotor}(i,z),My_{rotor}(i,z),0,0,\varphi\_uv_{rotor}(i,z),1\right)$$

$$Mu_{stator}(i,z) = \mathrm{axis}_x\left(Mx_{stator}(i,z),My_{stator}(i,z),0,0,\varphi\_uv_{stator}(i,z),1\right)$$

$$Mv_{rotor}(i,z) = \mathrm{axis}_y\left(Mx_{rotor}(i,z),My_{rotor}(i,z),0,0,\varphi\_uv_{rotor}(i,z),1\right)$$

$$Mv_{stator}(i,z) = \mathrm{axis}_y\left(Mx_{stator}(i,z),My_{stator}(i,z),0,0,\varphi\_uv_{stator}(i,z),1\right)$$

$$\varphi\_neutral_{rotor}(i,z) = \left|\begin{array}{l}\mathrm{atan}\left(\dfrac{Mv_{rotor}(i,z)\cdot Ju_{rotor.}(i,z)}{Mu_{rotor}(i,z)\cdot Jv_{rotor.}(i,z)}\right)\ \text{if } Mu_{rotor}(i,z)\cdot Jv_{rotor.}(i,z)\neq 0\\ \dfrac{\pi}{2}\ \text{otherwise}\end{array}\right.$$

$$\varphi\_neutral_{stator}(i,z) = \left|\begin{array}{l}\mathrm{atan}\left(\dfrac{Mv_{stator}(i,z)\cdot Ju_{stator.}(i,z)}{Mu_{stator}(i,z)\cdot Jv_{stator.}(i,z)}\right)\ \text{if } Mu_{stator}(i,z)\cdot Jv_{stator.}(i,z)\neq 0\\ \dfrac{\pi}{2}\ \text{otherwise}\end{array}\right.$$

$$\left(\begin{array}{cc} R0_{rotor} & area0_{rotor}\\ N0_{rotor} & \sigma0\_z_{rotor}\\ area_{rotor.} & area_{stator.}\\ N_{rotor} & \sigma\_z_{rotor}\end{array}\right.$$

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

$\cdot 10^{-3}$

$$\begin{pmatrix} \sigma\_p_{rotor} & \sigma\_n_{rotor} \\ \sigma\_p_{stator} & \sigma\_n_{stator} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } r \in 1..N_r \\ \qquad \begin{pmatrix} \sigma\_p_{rotor_{i,r}} & \sigma\_n_{rotor_{i,r}} \\ \sigma\_p_{stator_{i,r}} & \sigma\_n_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \dfrac{Mu_{rotor}\left(i, R_{st(i,2),r}\right)}{Ju_{rotor_{i,r}}} \cdot v\_u_{rotor_{i,r}} - \dfrac{Mv_{rotor}\left(i, R_{st(i,2),r}\right)}{Jv_{rotor_{i,r}}} \cdot u\_u_{rotor_{i,r}} & \dfrac{Mu_{rotor}\left(i, R_{st(i,2),r}\right)}{Ju_{rotor_{i,r}}} \cdot v\_l_{rotor_{i,r}} - \dfrac{Mv_{rotor}\left(i, R_{st(i,2),r}\right)}{Jv_{rotor_{i,r}}} \cdot u\_l_{rotor_{i,r}} \\ \dfrac{Mu_{stator}\left(i, R_{st(i,2),r}\right)}{Ju_{stator_{i,r}}} \cdot v\_u_{stator_{i,r}} - \dfrac{Mv_{stator}\left(i, R_{st(i,2),r}\right)}{Jv_{stator_{i,r}}} \cdot u\_u_{stator_{i,r}} & \dfrac{Mu_{stator}\left(i, R_{st(i,2),r}\right)}{Ju_{stator_{i,r}}} \cdot v\_l_{stator_{i,r}} - \dfrac{Mv_{stator}\left(i, R_{st(i,2),r}\right)}{Jv_{stator_{i,r}}} \cdot u\_l_{stator_{i,r}} \end{pmatrix} \\ \begin{pmatrix} \sigma\_p_{rotor} & \sigma\_n_{rotor} \\ \sigma\_p_{stator} & \sigma\_n_{stator} \end{pmatrix} \end{array} \right.$$

$$\begin{pmatrix} \sigma\_p_{rotor.} & \sigma\_p_{stator.} \\ \sigma\_n_{rotor.} & \sigma\_n_{stator.} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \left| \begin{array}{l} \sigma\_p_{rotor.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{rotor}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{rotor}, i, i, 1, N_r\right)^T, z\right) \\ \sigma\_p_{stator.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{stator}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_p_{stator}, i, i, 1, N_r\right)^T, z\right) \\ \sigma\_n_{rotor.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{rotor}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{rotor}, i, i, 1, N_r\right)^T, z\right) \\ \sigma\_n_{stator.}(i,z) = \text{interp}\left(\text{lspline}\left(\text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{stator}, i, i, 1, N_r\right)^T\right), \text{submatrix}\left(R, st(i,1), st(i,1), 1, N_r\right)^T, \text{submatrix}\left(\sigma\_n_{stator}, i, i, 1, N_r\right)^T, z\right) \end{array} \right. \\ \begin{pmatrix} \sigma\_p_{rotor.} & \sigma\_p_{stator.} \\ \sigma\_n_{rotor.} & \sigma\_n_{stator.} \end{pmatrix} \end{array} \right.$$

$\sigma\_p_{rotor}^{T} =$

	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

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

```
for $i \in 1..Z$
    for $r \in 1..N_r$
        $\sigma_{rotor_{i,r}} = \sqrt{\left(\sigma\_z_{rotor}\left(i, R_{st(i,2),r}\right) + \max\left(\sigma\_p_{rotor_{i,r}}, \sigma\_n_{rotor_{i,r}}\right)\right)^2 + \tau_{rotor}\left(i, R_{st(i,2),r}\right)^2}$
        $\sigma_{stator_{i,r}} = \sqrt{\left(0 + \max\left(\sigma\_p_{stator_{i,r}}, \sigma\_n_{stator_{i,r}}\right)\right)^2 + \tau_{stator}\left(i, R_{st(i,2),r}\right)^2}$
$\begin{pmatrix}\sigma_{rotor}\\ \sigma_{stator}\end{pmatrix}$
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$$\begin{pmatrix}\sigma_{rotor.}\\ \sigma_{stator.}\end{pmatrix} =$$

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

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

	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

$\cdot 10^6$

```
$\begin{pmatrix} safety_{rotor} \\ safety_{stator} \end{pmatrix}$ = for $i \in 1..Z$
    for $r \in 1..N_r$
        $safety_{rotor_{i,r}} = \begin{cases} \dfrac{\sigma\_blade\_long_i}{\sigma_{rotor_{i,r}}} & \text{if } \sigma_{rotor_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{cases}$
        $safety_{stator_{i,r}} = \begin{cases} \dfrac{\sigma\_blade\_long_i}{\sigma_{stator_{i,r}}} & \text{if } \sigma_{stator_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{cases}$
    $\begin{pmatrix} safety_{rotor} \\ safety_{stator} \end{pmatrix}$
```

$safety_{rotor}^{T} =$

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

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

Расстояния от оси ЛМ до рассматриваемой ступени (м):

$$Rj = \mathrm{submatrix}\left(R, 2 \cdot j - 1, 2 \cdot j + 1, 1, N_r\right) = \begin{array}{c|c|c|c} & 1 & 2 & 3 \\ \hline 1 & 177.3 & 230.8 & 274.1 \\ 2 & 182.2 & 230.8 & 270.8 \\ 3 & 186.8 & 230.8 & 267.7 \end{array} \cdot 10^{-3}$$

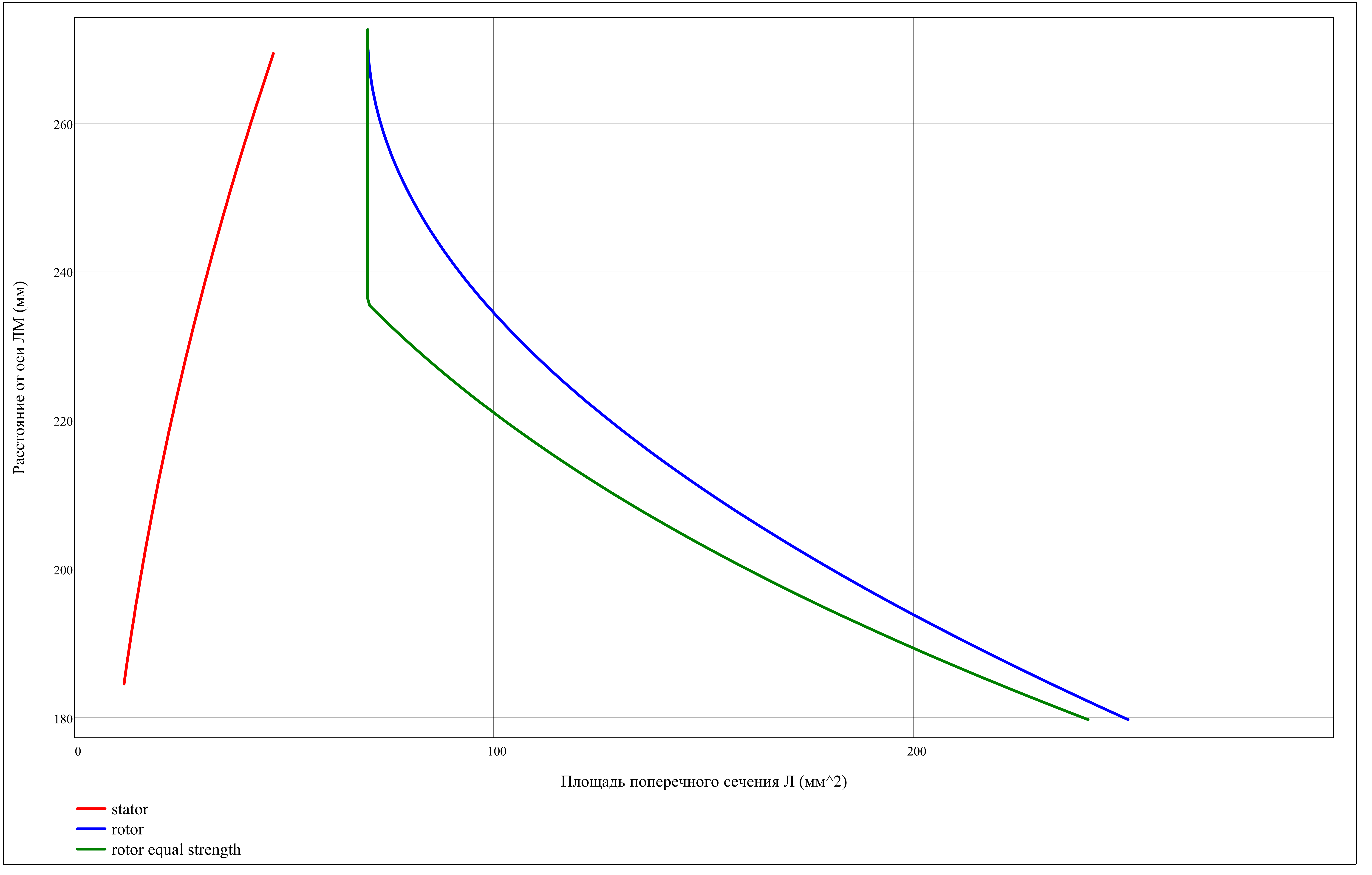
Дискретизация по высоте Л:

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

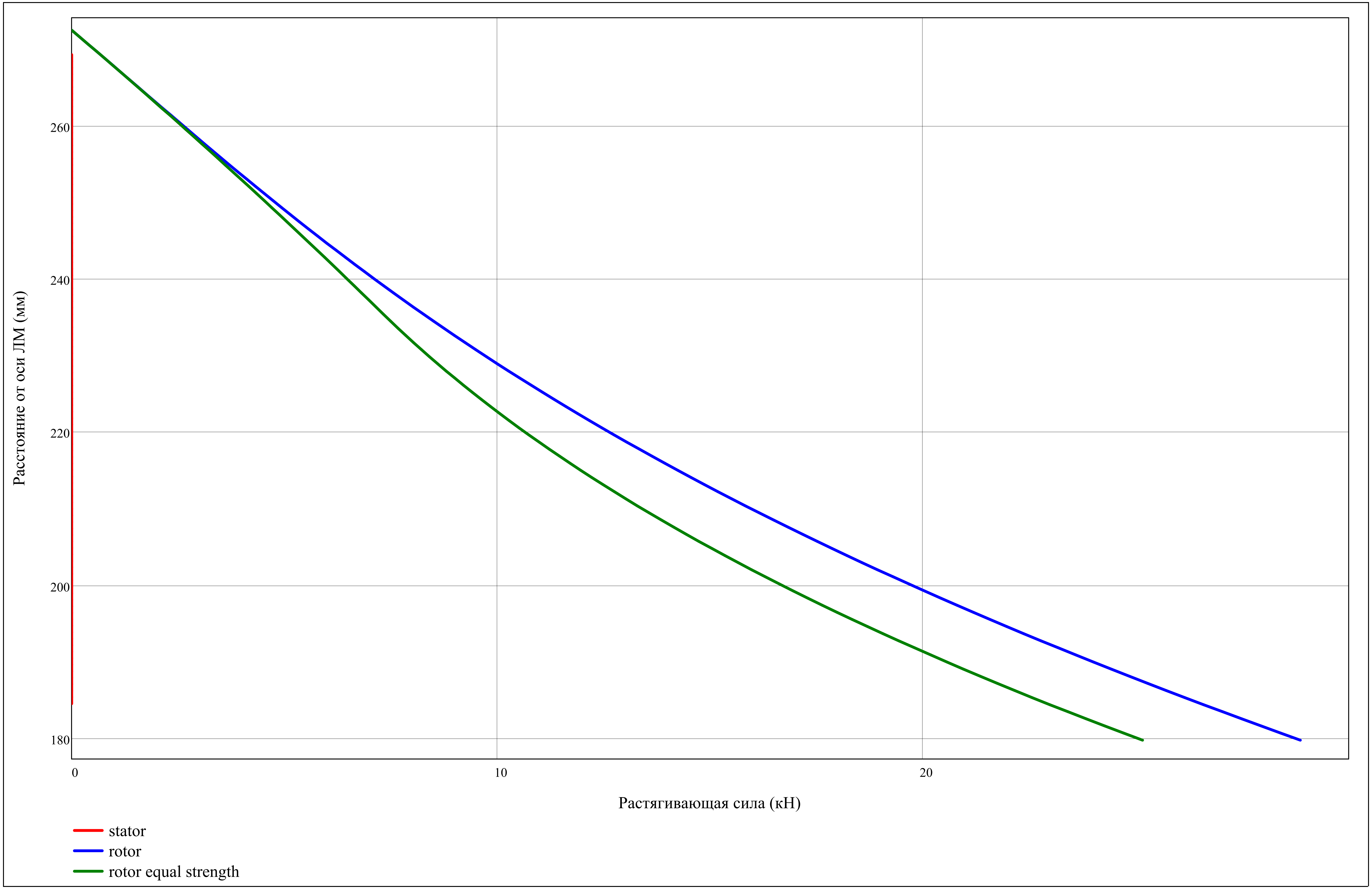
$$z_{rotor} = \left| \begin{array}{l} \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right), \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) - \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right)}{100} .. \mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) \ \text{ if } \ type = \text{"compressor"} \\ \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right), \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) - \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right)}{100} .. \mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) \ \text{ if } \ type = \text{"turbine"} \end{array} \right.$$

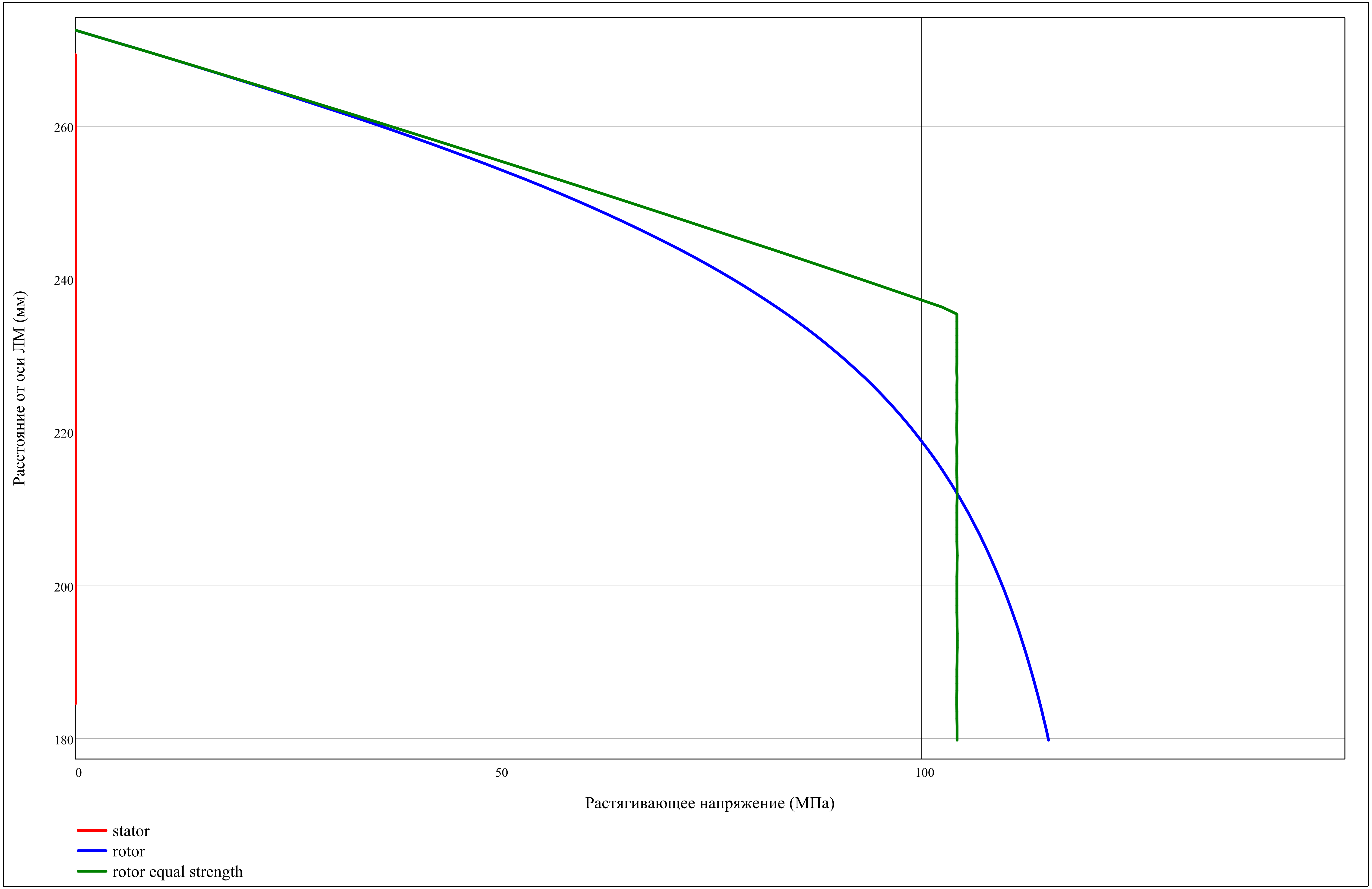
$$z_{stator} = \left| \begin{array}{l} \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right), \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) - \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right)}{100} .. \mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) \ \text{ if } \ type = \text{"compressor"} \\ \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right), \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) - \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right)}{100} .. \mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) \ \text{ if } \ type = \text{"turbine"} \end{array} \right.$$

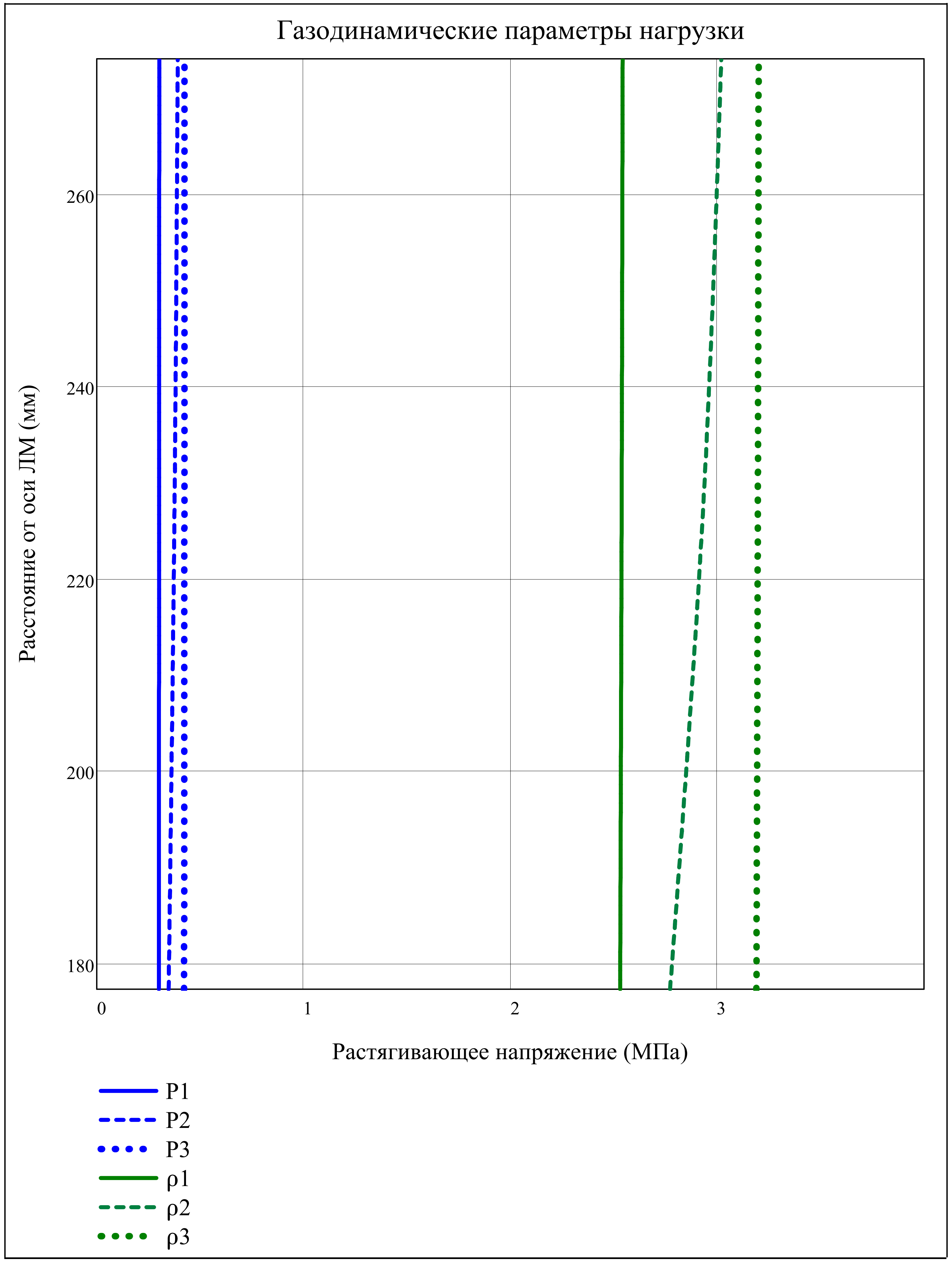
▾ Результаты расчета на прочность Л



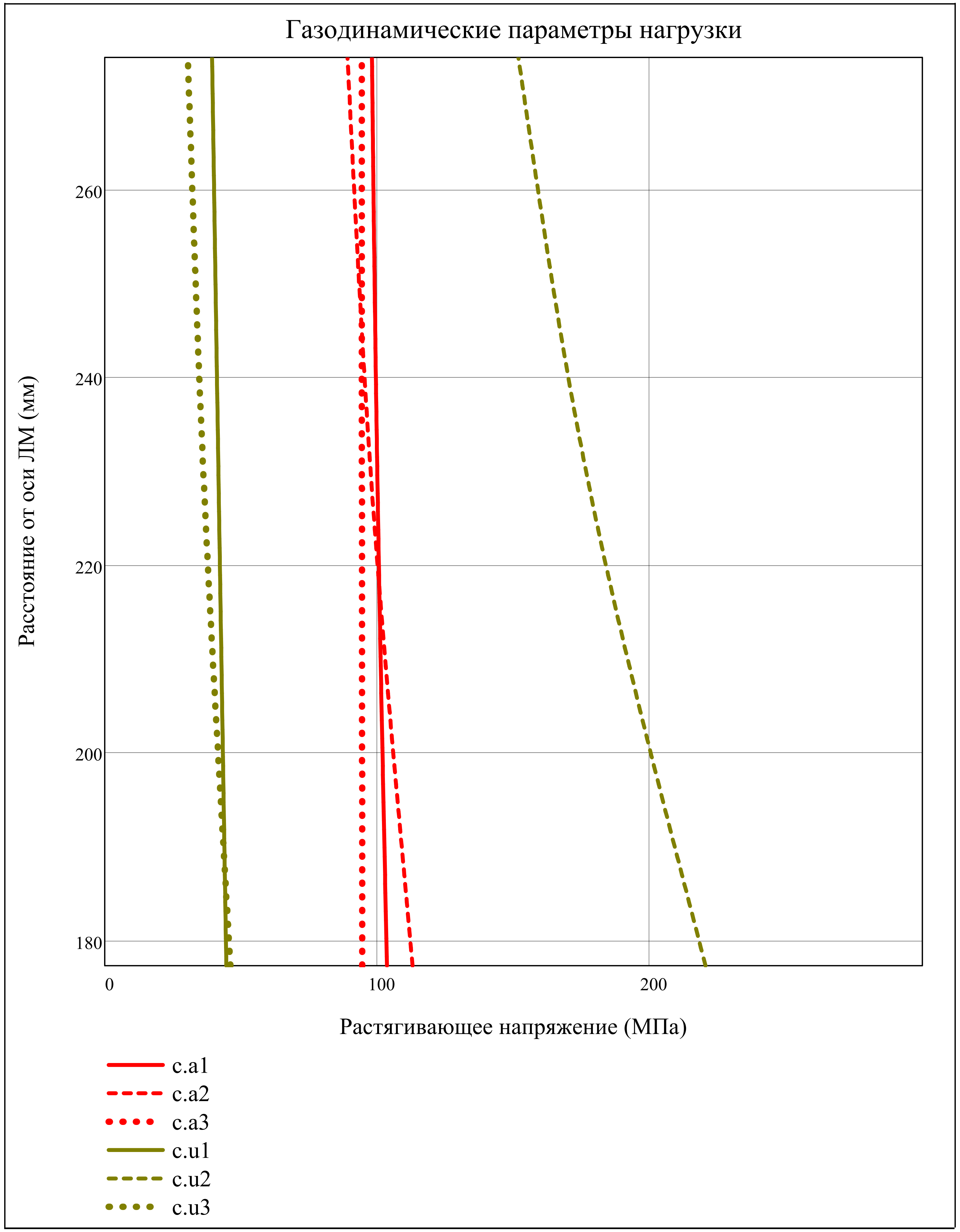
Расстояние от оси ЛМ (мм)
260
240
220
200
180
0
100
200
Площадь поперечного сечения Л (мм^2)
stator
rotor
rotor equal strength


260
240
220
200
180
Расстояние от оси ЛМ (мм)
0
10
20
Растягивающая сила (кН)
stator
rotor
rotor equal strength

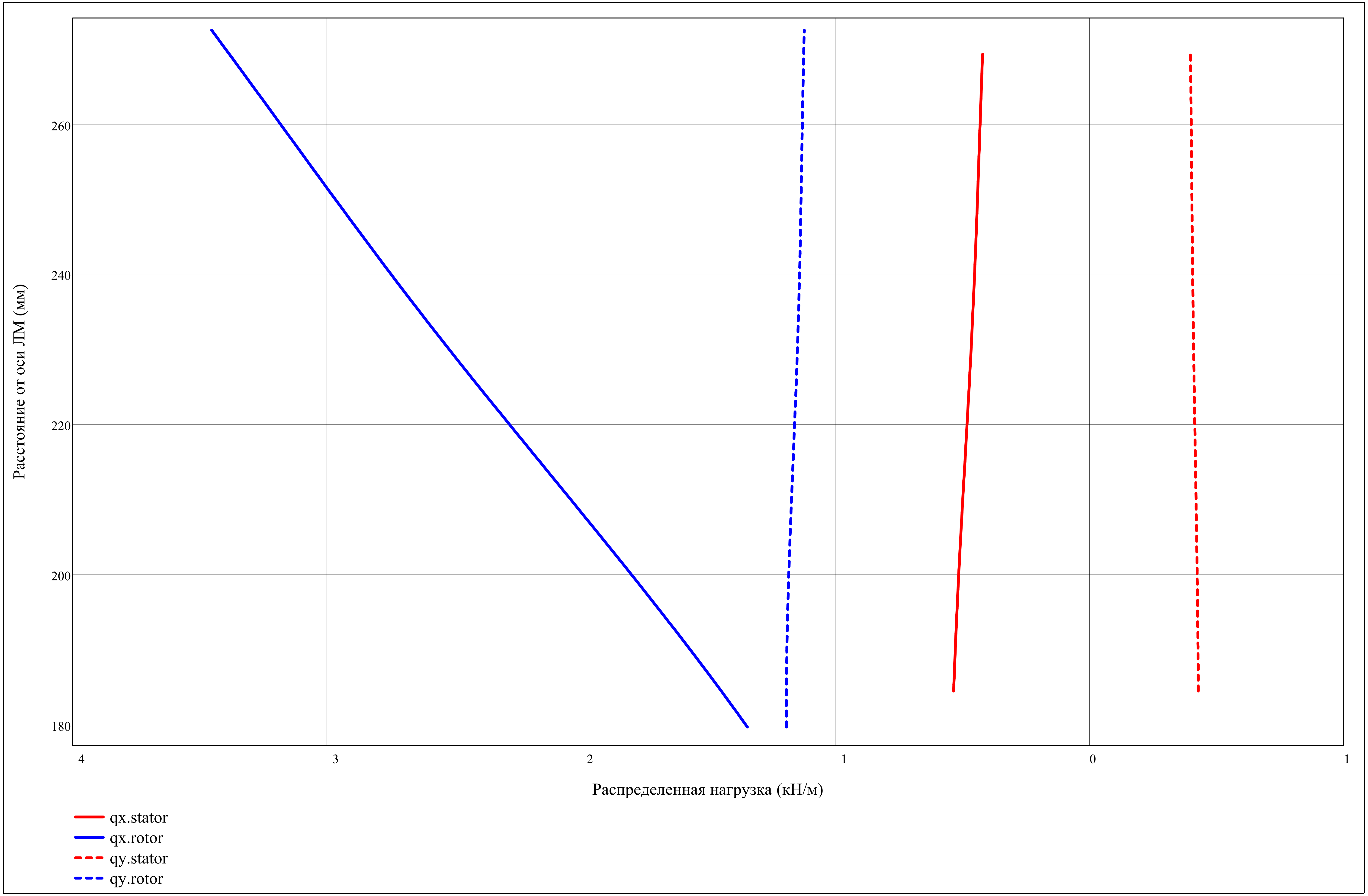

Расстояние от оси ЛМ (мм)
260
240
220
200
180
0
50
100
Растягивающее напряжение (МПа)
stator
rotor
rotor equal strength

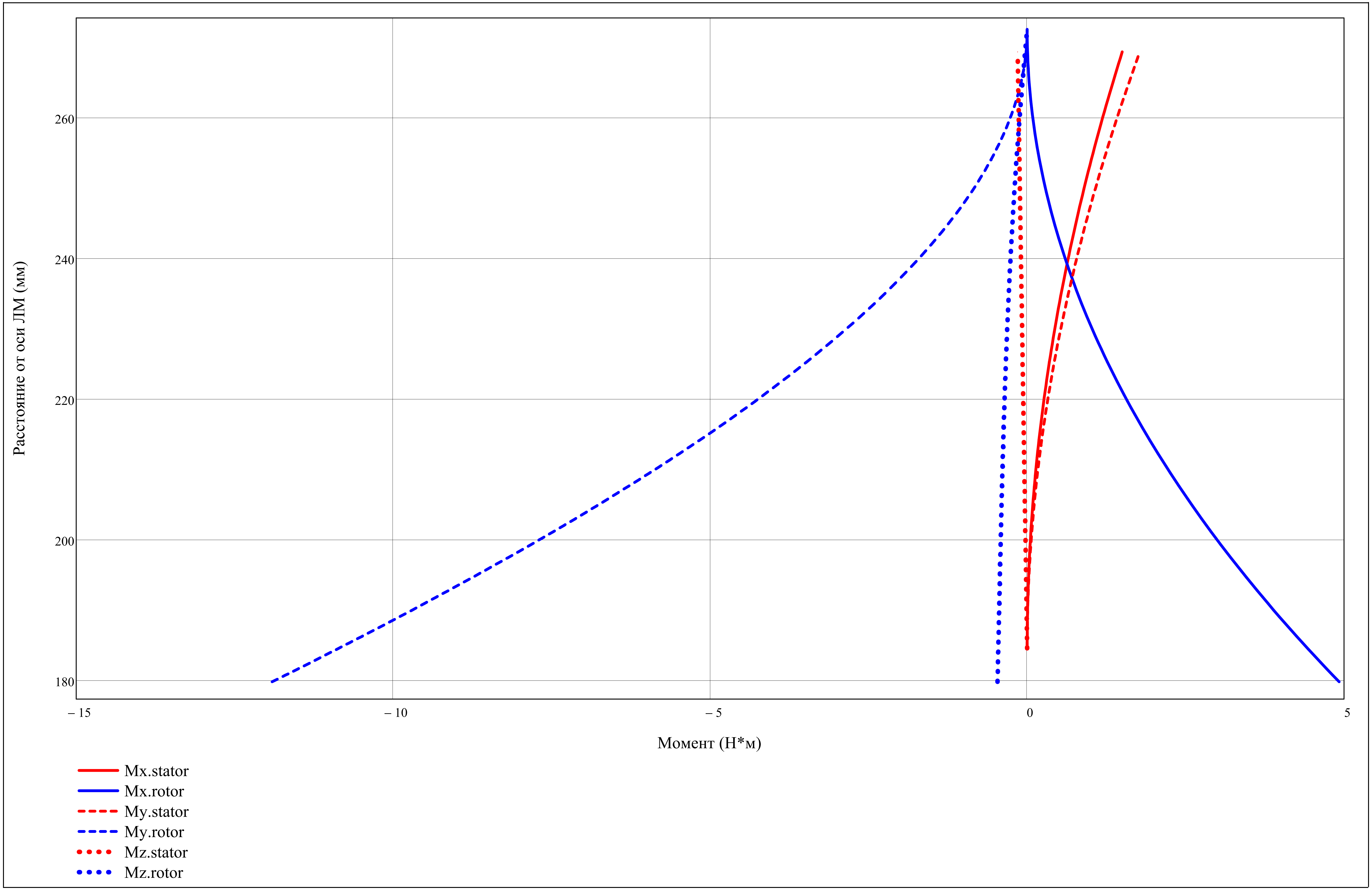


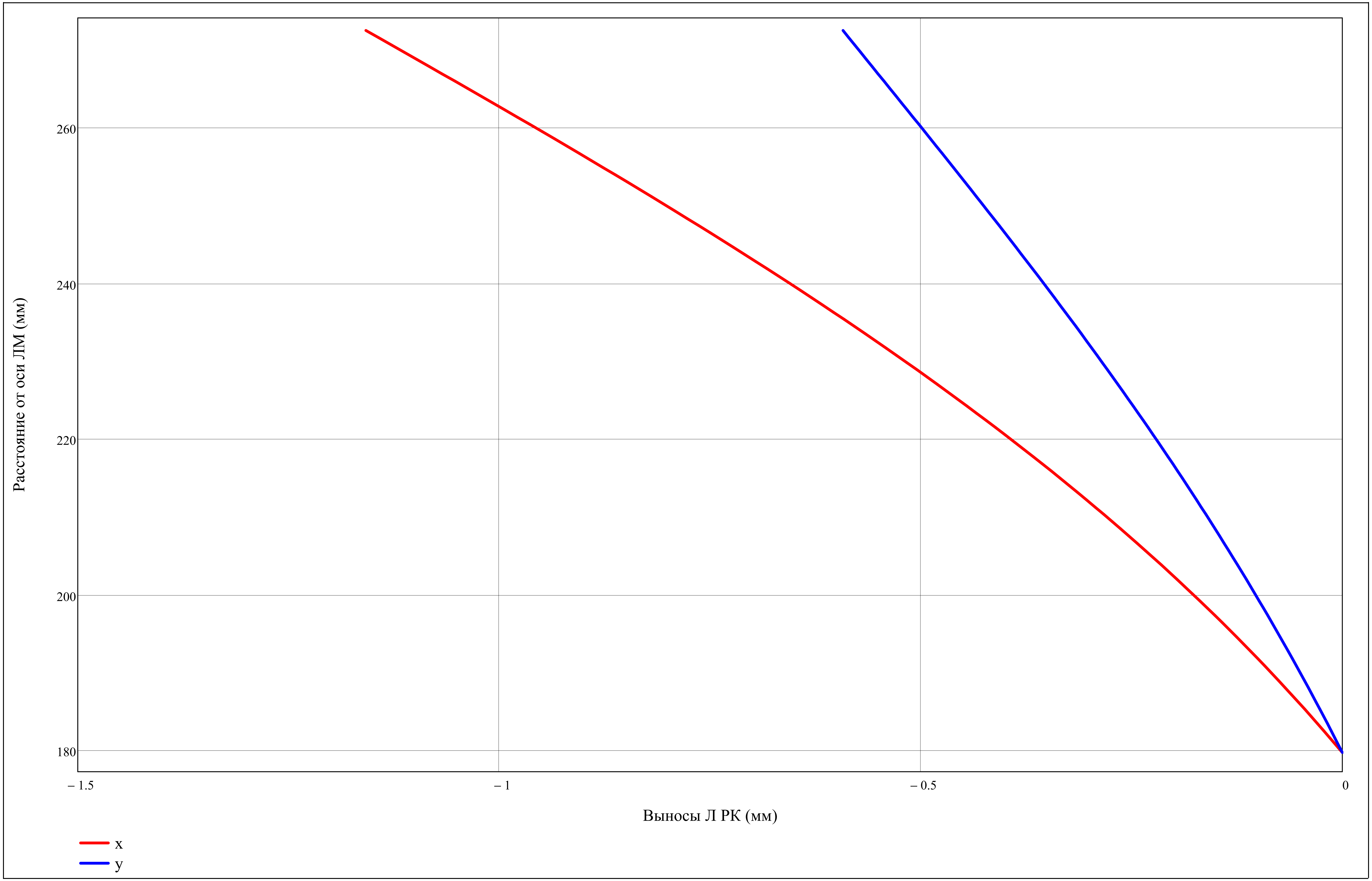
Газодинамические параметры нагрузки

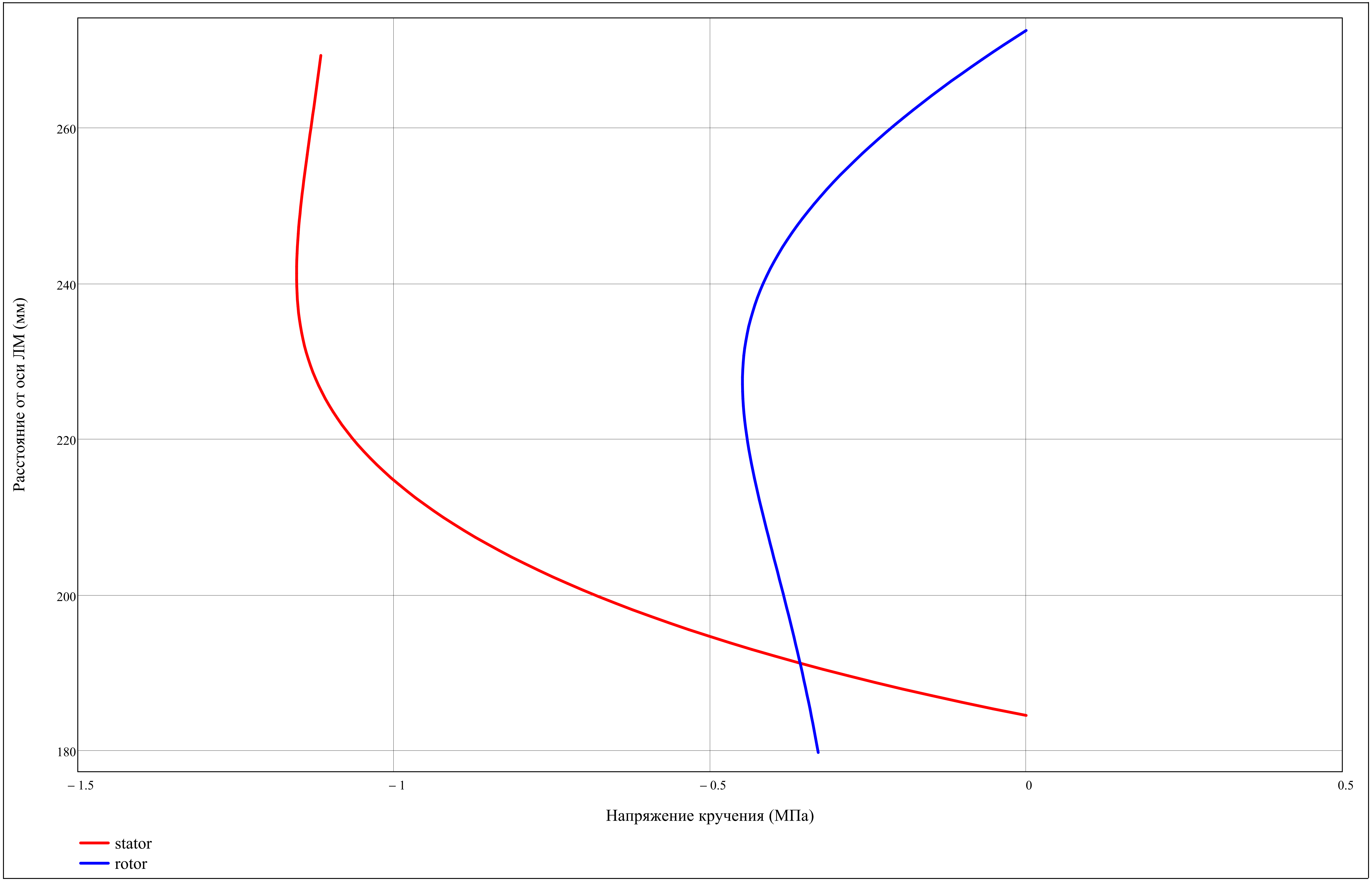


Газодинамические параметры нагрузки

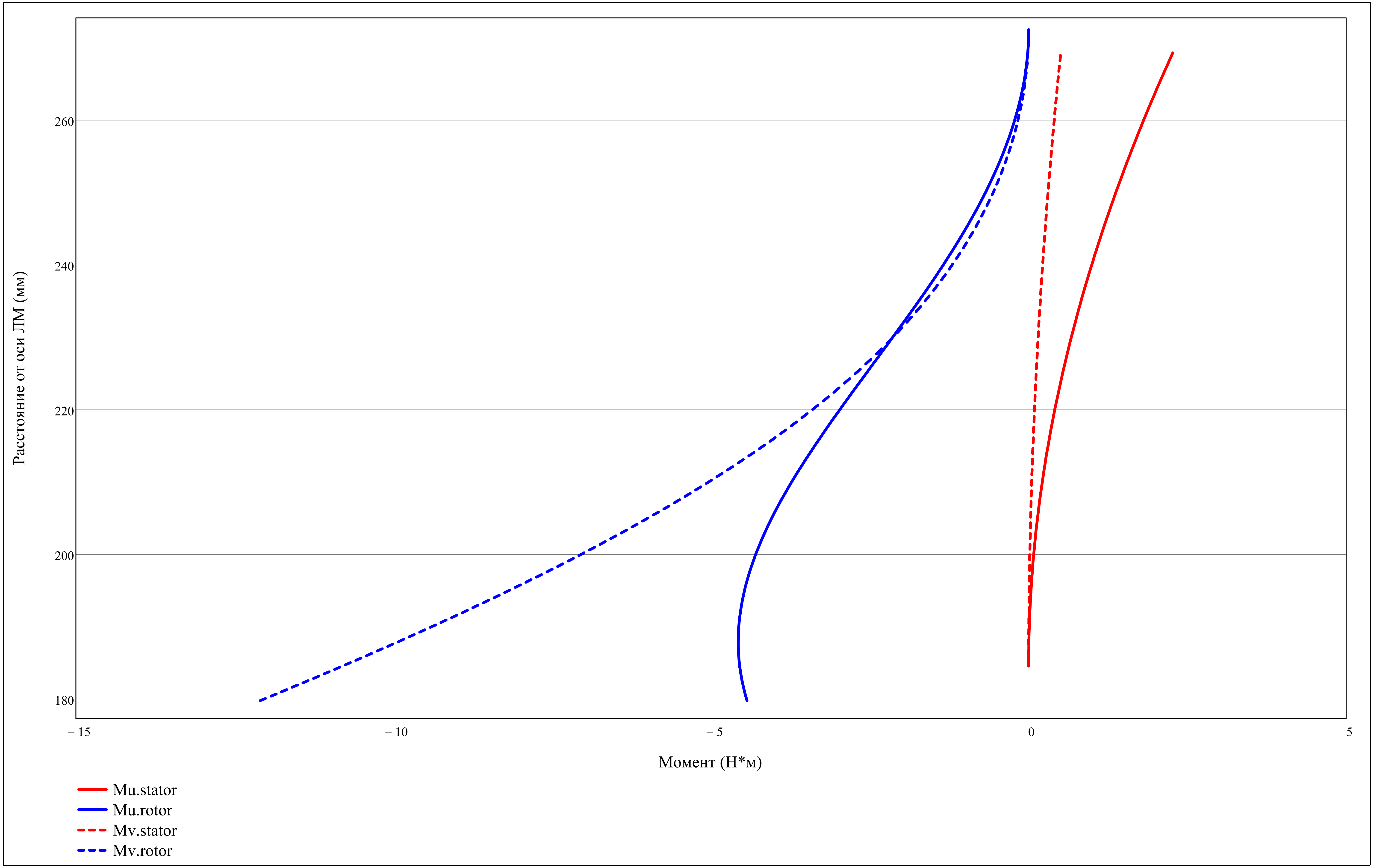

Расстояние от оси ЛМ (мм)
180
200
220
240
260
– 4
– 3
– 2
– 1
0
1
Распределенная нагрузка (кН/м)
qx.stator
qx.rotor
qy.stator
qy.rotor

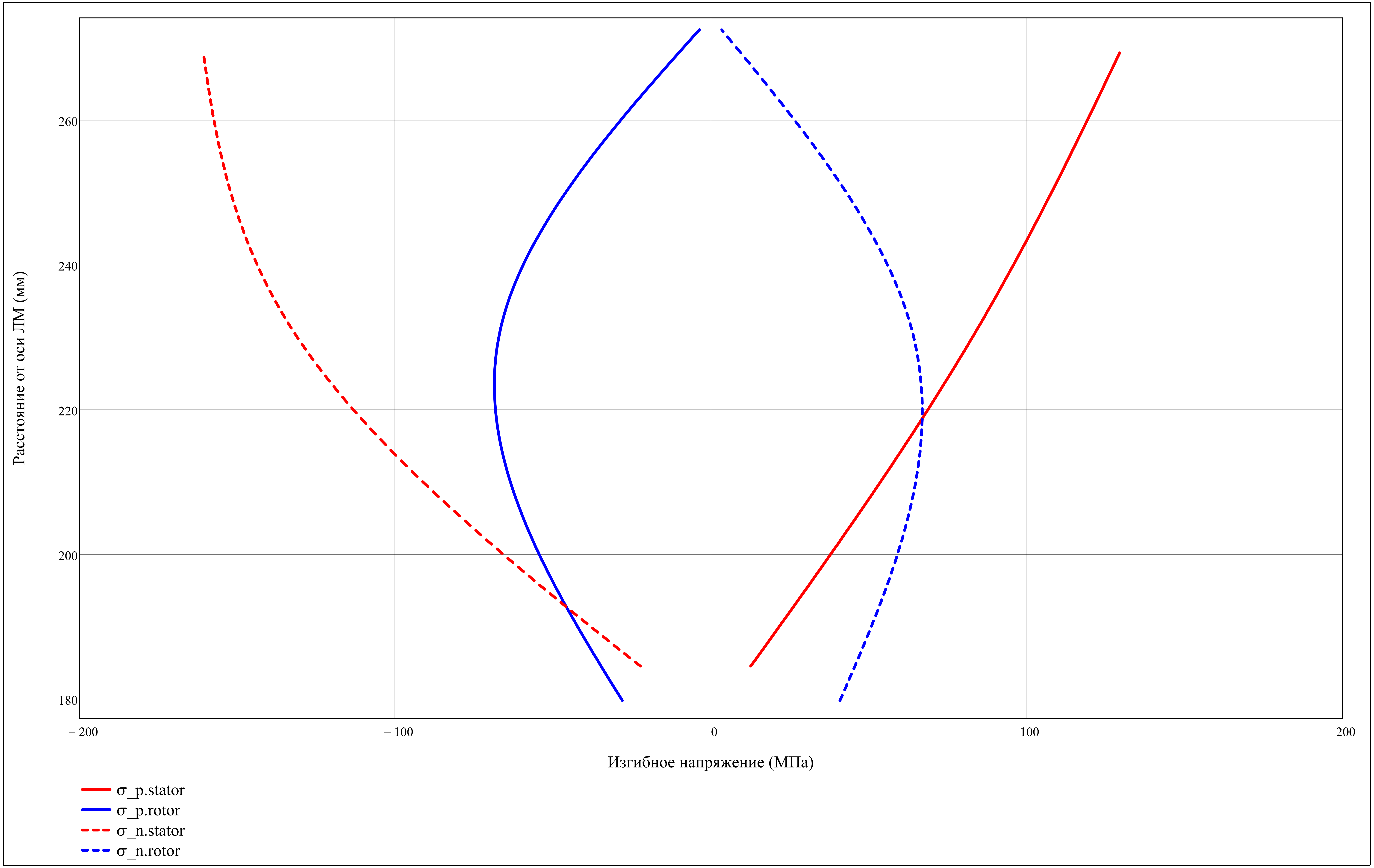

Расстояние от оси ЛМ (мм)
260
240
220
200
180
– 15
– 10
– 5
0
5
Момент (Н*м)
Mx.stator
Mx.rotor
My.stator
My.rotor
Mz.stator
Mz.rotor

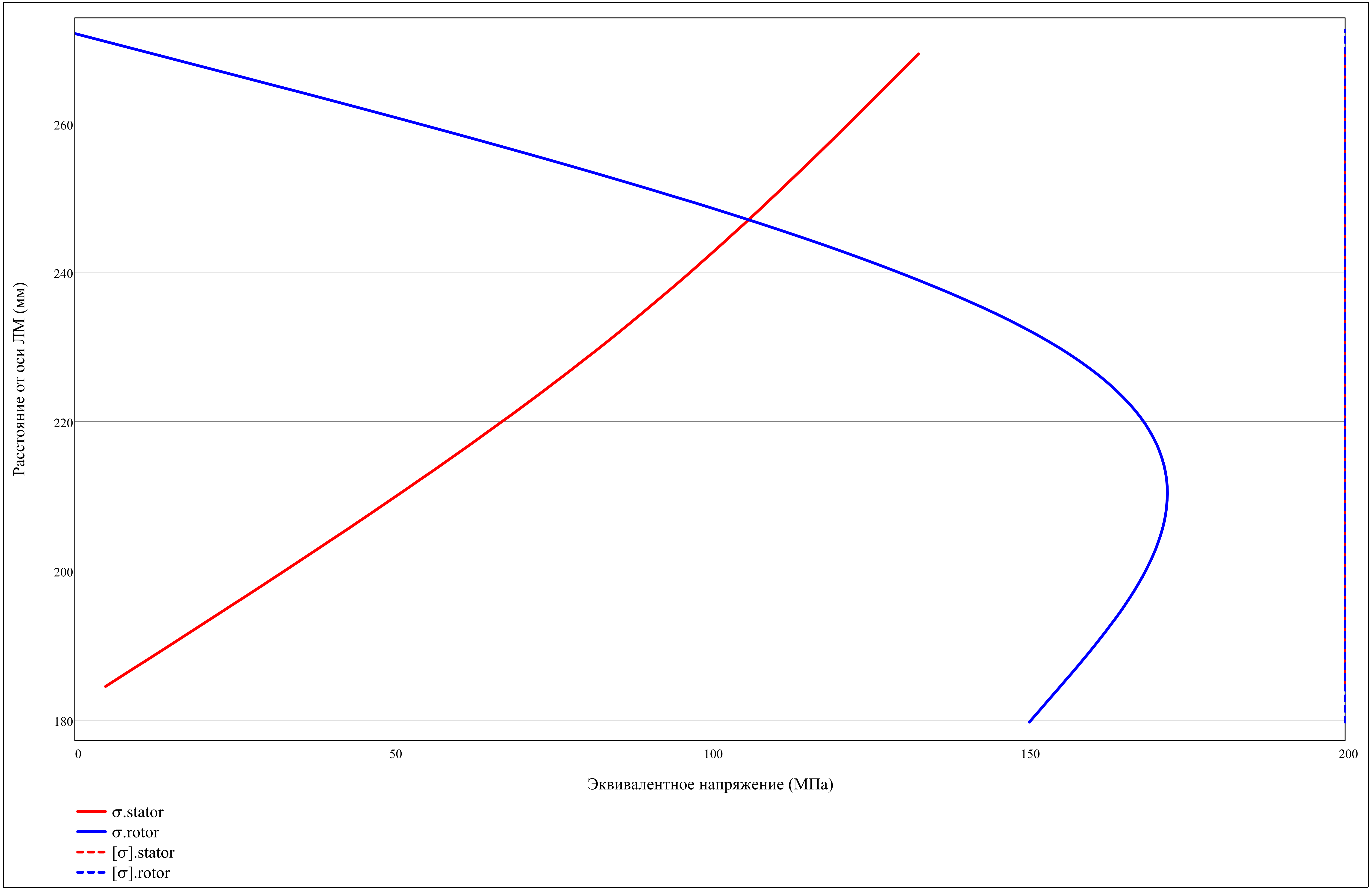

Расстояние от оси ЛМ (мм)
260
240
220
200
180
– 1.5
– 1
– 0.5
0
Выносы Л РК (мм)
x
y



Расстояние от оси ЛМ (мм)
260
240
220
200
180
– 1.5
– 1
– 0.5
0
0.5
Напряжение кручения (МПа)
stator
rotor


Расстояние от оси ЛМ (мм)
260
240
220
200
180
– 15
– 10
– 5
0
5
Момент (Н*м)
Mu.stator
Mu.rotor
Mv.stator
Mv.rotor


Расстояние от оси ЛМ (мм)
260
240
220
200
180
– 200
– 100
0
100
200
Изгибное напряжение (МПа)
σ_p.stator
σ_p.rotor
σ_n.stator
σ_n.rotor


Расстояние от оси ЛМ (мм)
260
240
220
200
180
0
50
100
150
200
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):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & -2.55 & 4.01 \\ \hline 2 & 29.51 & -5.04 \\ \hline 3 & 0.21 & 0.77 \\ \hline 4 & 12.34 & -1.74 \\ \hline \end{array} \cdot 10^{-3}$$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -25 & 1 \\ 38 & -1 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

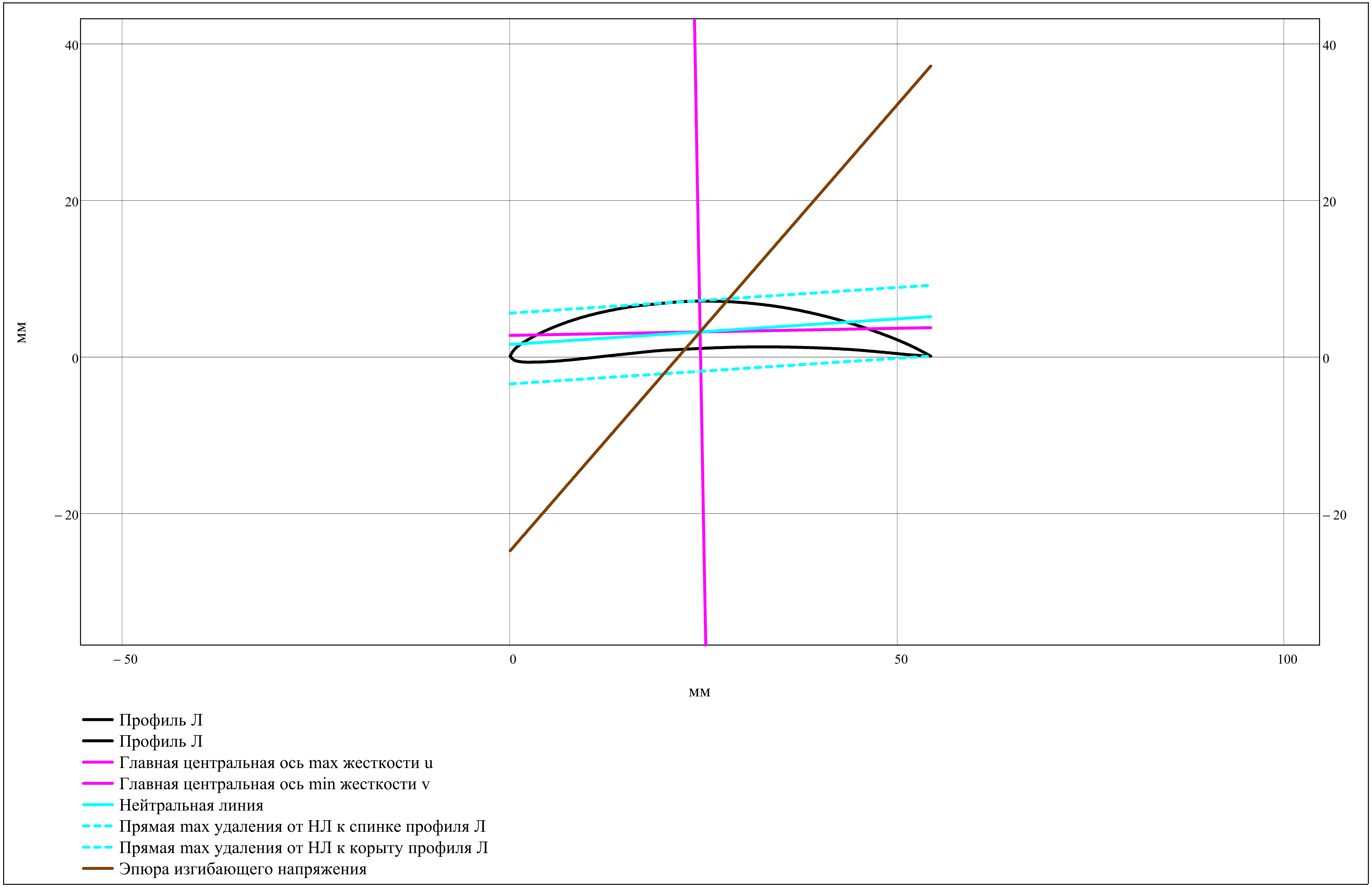
$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 1 \\ 153 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса: $\begin{pmatrix} safety_{stator_{j,r}} \\ safety_{rotor_{j,r}} \end{pmatrix} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 352.115 \\ \hline 2 & 1.309 \\ \hline \end{array}$

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade} = \text{"rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 4.006 \\ \hline 2 & -5.036 \\ \hline \end{array} \cdot 10^{-3}$$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} x0_{rotor_{j,r}} \\ y0_{rotor_{j,r}} \end{pmatrix} & \text{if blade} = \text{"rotor"} \\ \begin{pmatrix} x0_{stator_{j,r}} \\ y0_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 24.522 \\ \hline 2 & 3.097 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{chord} = \left| \begin{array}{ll} \text{chord}_{rotor_{j,r}} & \text{if blade} = \text{"rotor"} \\ \text{chord}_{stator_{j,r}} & \text{if blade} = \text{"stator"} \end{array} \right. = 54 \cdot 10^{-3}$$


40
20
0
– 20
40
20
0
– 20
мм
– 50
0
50
100
мм
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

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

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

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. =$$

	1
1	1.463
2	-1.331

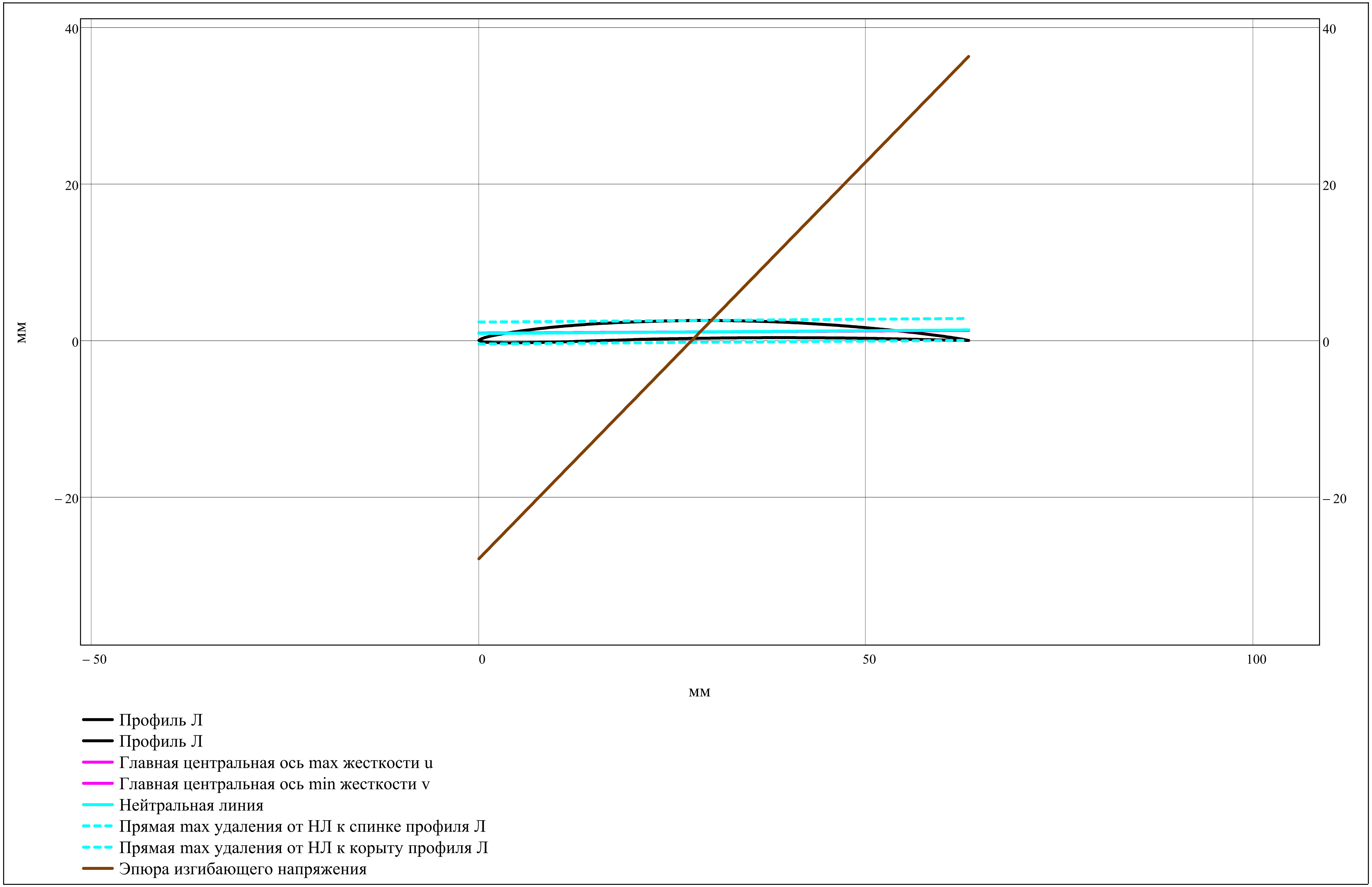
$\cdot 10^{-3}$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} x0_{rotor_{j,r}} \\ y0_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{stator_{j,r}} \\ y0_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. =$$

	1
1	28.557
2	1.079

$\cdot 10^{-3}$

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{array} \right. = 63 \cdot 10^{-3}$$


40
20
0
– 20
мм
– 50
0
50
100
мм
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

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. =$$

	1
1	1.210
2	-1.876

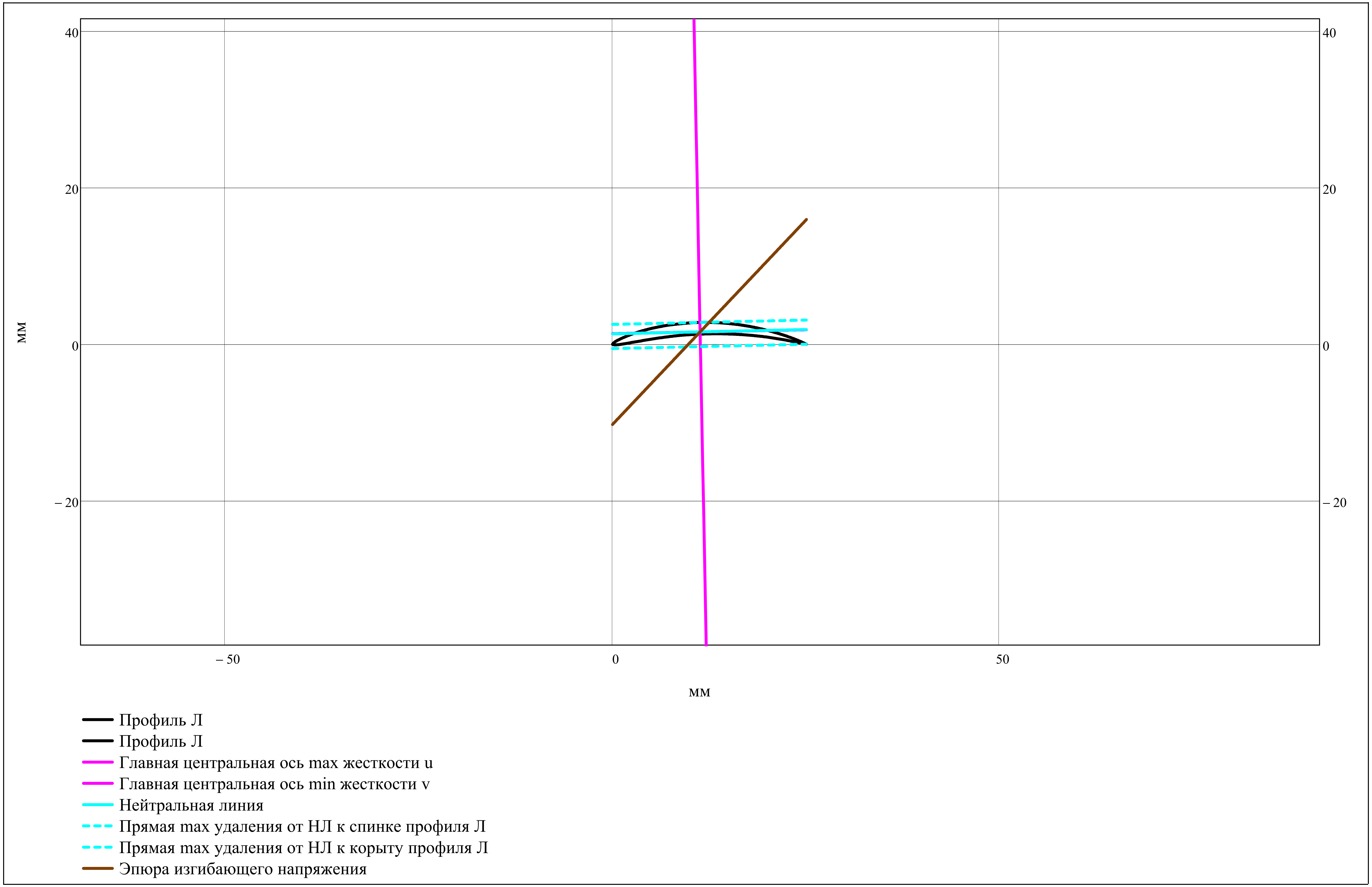
$\cdot 10^{-3}$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} x0_{rotor_{j,r}} \\ y0_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{stator_{j,r}} \\ y0_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. =$$

	1
1	11.312
2	1.573

$\cdot 10^{-3}$

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{array} \right. = 25 \cdot 10^{-3}$$


40
20
0
– 20
40
20
0
– 20
мм
– 50
0
50
мм
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

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

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

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. =$$

	1
1	1.703
2	-2.005

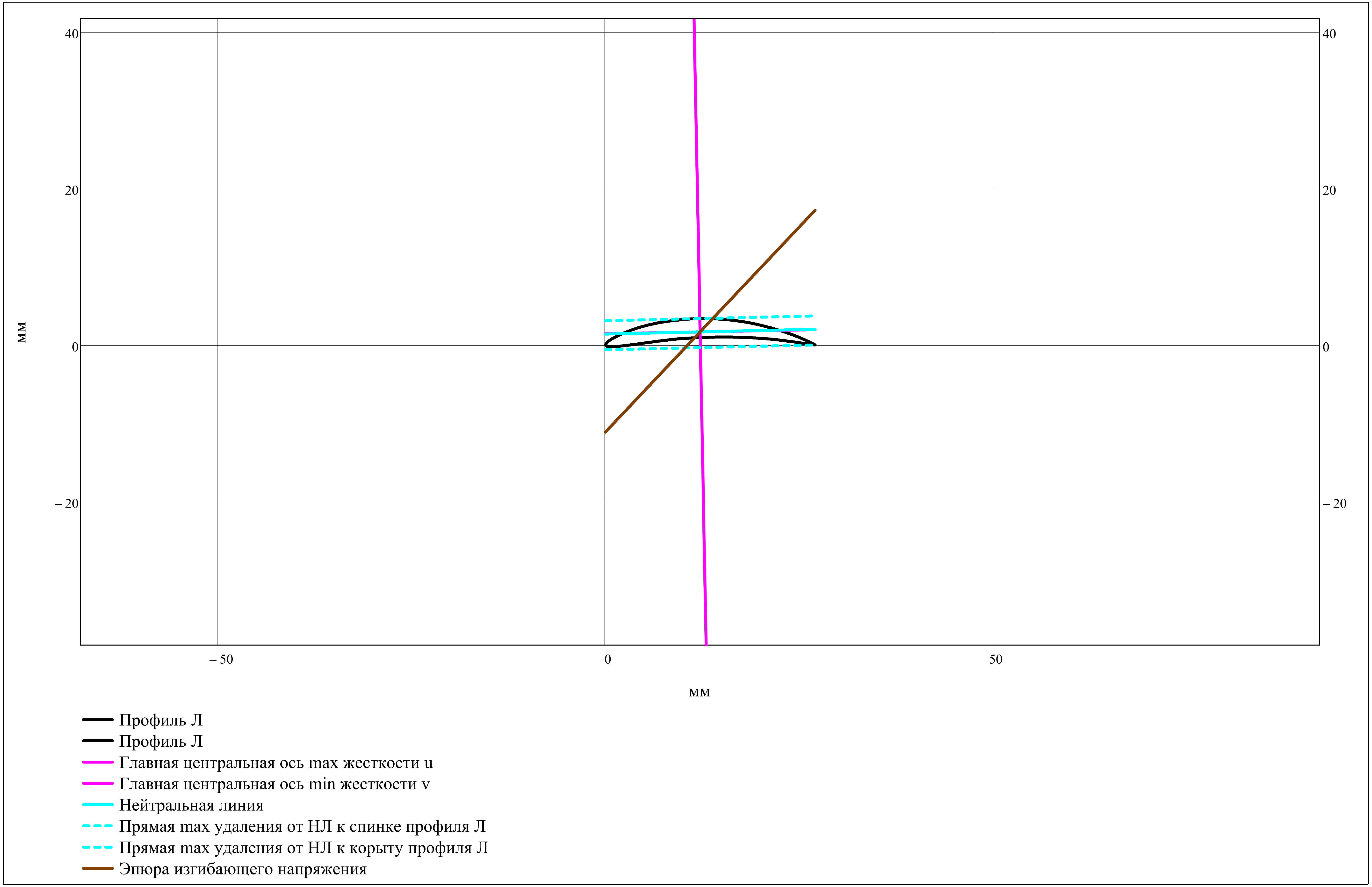
$\cdot 10^{-3}$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} x0_{rotor_{j,r}} \\ y0_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} x0_{stator_{j,r}} \\ y0_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. =$$

	1
1	12.233
2	1.667

$\cdot 10^{-3}$

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{array} \right. = 27 \cdot 10^{-3}$$



Результаты расчета на прочность Л

▼ Выбор материала Д

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

Выбранный материал Д:

$$material\_disk_i = \left| \begin{array}{l} "ВТ23" \quad \text{if} \ compressor = "Вл" \\ "ВТ6" \quad \text{if} \ compressor = "КНД" \\ "ВТ9" \quad \text{if} \ compressor = "КВД" \end{array} \right.$$

Плотность материала Д (кг/м^3):

$$\rho\_disk_i = \left| \begin{array}{l} 8266 \quad \text{if} \ material\_disk_i = "ВЖ175" \\ 8320 \quad \text{if} \ material\_disk_i = "ЭП742" \\ 8393 \quad \text{if} \ material\_disk_i = "ЖС\text{-}6К" \\ 7900 \quad \text{if} \ material\_disk_i = "ВТ41" \\ 4500 \quad \text{if} \ material\_disk_i = "ВТ25" \\ 4570 \quad \text{if} \ material\_disk_i = "ВТ23" \\ 4510 \quad \text{if} \ material\_disk_i = "ВТ9" \\ 4430 \quad \text{if} \ material\_disk_i = "ВТ6" \\ NaN \quad \text{otherwise} \end{array} \right.$$

Предел длительной прочности Д (Па):

$$\sigma\_disk\_long_i = 10^6 \cdot \left| \begin{array}{l} 620 \quad \text{if} \ material\_disk_i = "ВЖ175" \\ 680 \quad \text{if} \ material\_disk_i = "ЭП742" \\ 125 \quad \text{if} \ material\_disk_i = "ЖС\text{-}6К" \\ 123 \quad \text{if} \ material\_disk_i = "ВТ41" \\ 150 \quad \text{if} \ material\_disk_i = "ВТ25" \\ 230 \quad \text{if} \ material\_disk_i = "ВТ23" \\ 200 \quad \text{if} \ material\_disk_i = "ВТ9" \\ 210 \quad \text{if} \ material\_disk_i = "ВТ6" \\ NaN \quad \text{otherwise} \end{array} \right.$$

$material\_disk^T =$

	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

$\cdot 10^6$

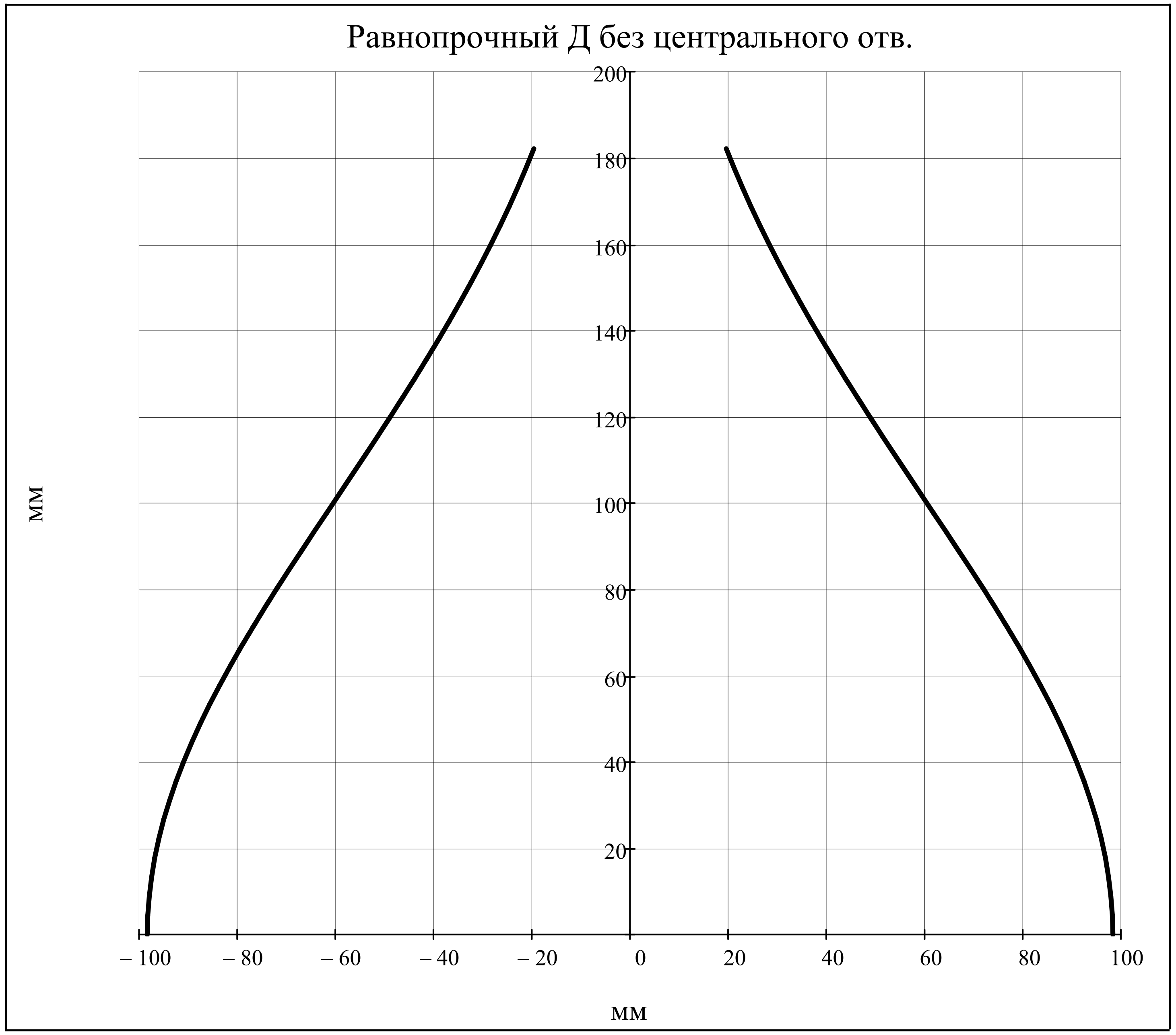
▲ Выбор материала Д

Рассматриваемая ступень: $j = \left| \begin{array}{l} j = 1 \\ j = \left| \begin{array}{ll} \text{"Такой ступени не существует!"} & \text{if } (j < 1) \vee (j > Z) \\ j & \text{otherwise} \end{array} \right. \end{array} \right. = 1$

Профилирование равнопрочного Д без центрального отв.

$$h(i,z) = \left| \begin{array}{ll} \left(\text{chord}_{\text{rotor}_{i,\text{ORIGIN}}} \cdot \sin\left(\upsilon_{\text{rotor}_{i,\text{ORIGIN}}}\right)\right) \cdot e^{\frac{\rho\_\text{disk}_i \cdot \omega^2}{2} \cdot \frac{1}{\sigma\_z_{\text{rotor}}\left(i, R_{\text{st}(i,2),\text{ORIGIN}}\right)} \cdot \left[\left(R_{\text{st}(i,2),\text{ORIGIN}}\right)^2 - z^2\right]} & \text{if } z \le R_{\text{st}(i,2),\text{ORIGIN}} \\ \text{NaN} & \text{otherwise} \end{array} \right.$$

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



Профилирование равнопрочного Д без центрального отв.