Подключение библиотек

Основные уравнения, алгоритмы, зависимости и ф-и

▶ Параметры расчета

Исходные данные

Коэф. запаса: $\text{safety} = 1.3$

Степень двухконтурности: $m2 = 6$

РТ: Воздух

$\text{compressor} = \text{"КНД"}$

Число Маха: $M = 0$

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

Массовый расход (кг/с):

$$G = \left| \begin{array}{l} 35.65 + 213.93 \;\; \text{if compressor} = \text{"Вл"} \\ 35.65 \;\; \text{if compressor} = \text{"КНД"} \\ 34.81 \;\; \text{if compressor} = \text{"КВД"} \end{array} \right. = 35.65$$

Полная температура на входе в К (К):

$$T^*_{К1} = \left| \begin{array}{l} 418.2 \;\; \text{if compressor} = \text{"КВД"} \\ 288.2 \;\; \text{otherwise} \end{array} \right. = 288.2$$

Полное давление на входе в К (Па):

$$P^*_{К1} = \left| \begin{array}{l} 316.2 \cdot 10^{3} \;\; \text{if compressor} = \text{"КВД"} \\ 101325 \;\; \text{otherwise} \end{array} \right. = 101.3 \cdot 10^{3}$$

Степень повышения давления КВД:

$$\pi^*_{К} = \left| \begin{array}{l} 1.6 \;\; \text{if compressor} = \text{"Вл"} \\ \frac{3.2}{1.6} \;\; \text{if compressor} = \text{"КНД"} \\ 9 \;\; \text{if compressor} = \text{"КВД"} \end{array} \right. = 2.000$$

Ожидаемый адиабатический КПД ОК: $\eta^*_K = \begin{vmatrix} 0.86 \text{ if compressor} = \text{"Вл"} \\ 0.87 \text{ if compressor} = \text{"КНД"} \\ 0.88 \text{ if compressor} = \text{"КВД"} \end{vmatrix} = 87.00 \cdot \%$

Частота вращения ротора (c^{-1}): $\omega = \begin{vmatrix} 1570.8 \text{ if compressor} = \text{"КВД"} \\ 555 \text{ otherwise} \end{vmatrix} = 555.0$

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

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

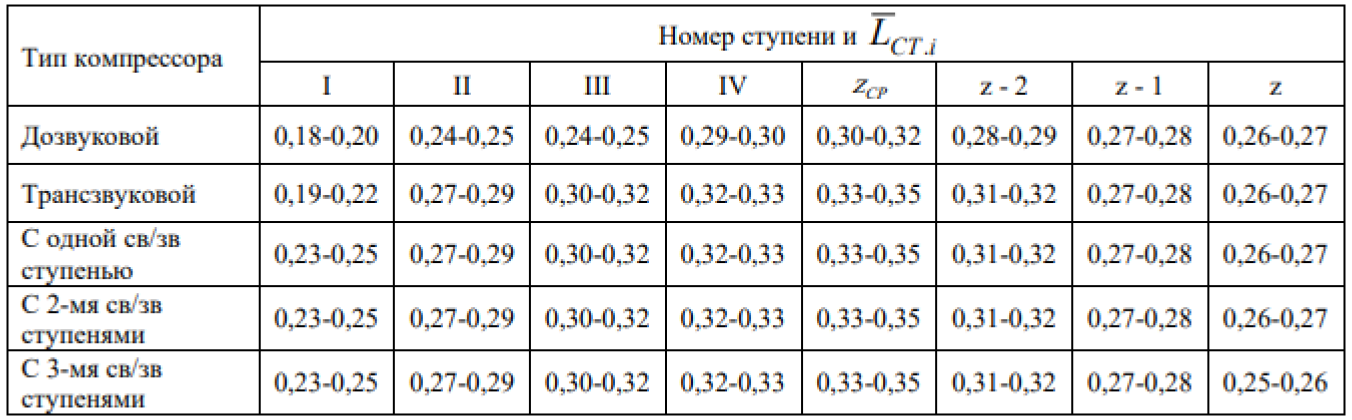
Частота вращения ротора (об/мин): $n = \frac{60 \cdot \omega}{2 \cdot \pi} = 5300$

Закон профилирования проточной части (ЗППЧ):

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

Относ. параметры по относительным ступеням:

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



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

[16, с. 60]

[18, с. 24]

Уточнение параметров:

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

увеличение несущественно увеличивает π

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

понижение существенно увеличивает π

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

увеличение несущественно увеличивает π

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

[16, с. 234]

увеличение существенно увеличивает π

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

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

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

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

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

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

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

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

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

Исходные данные

Распределение основных параметров ОК по ступеням

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

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

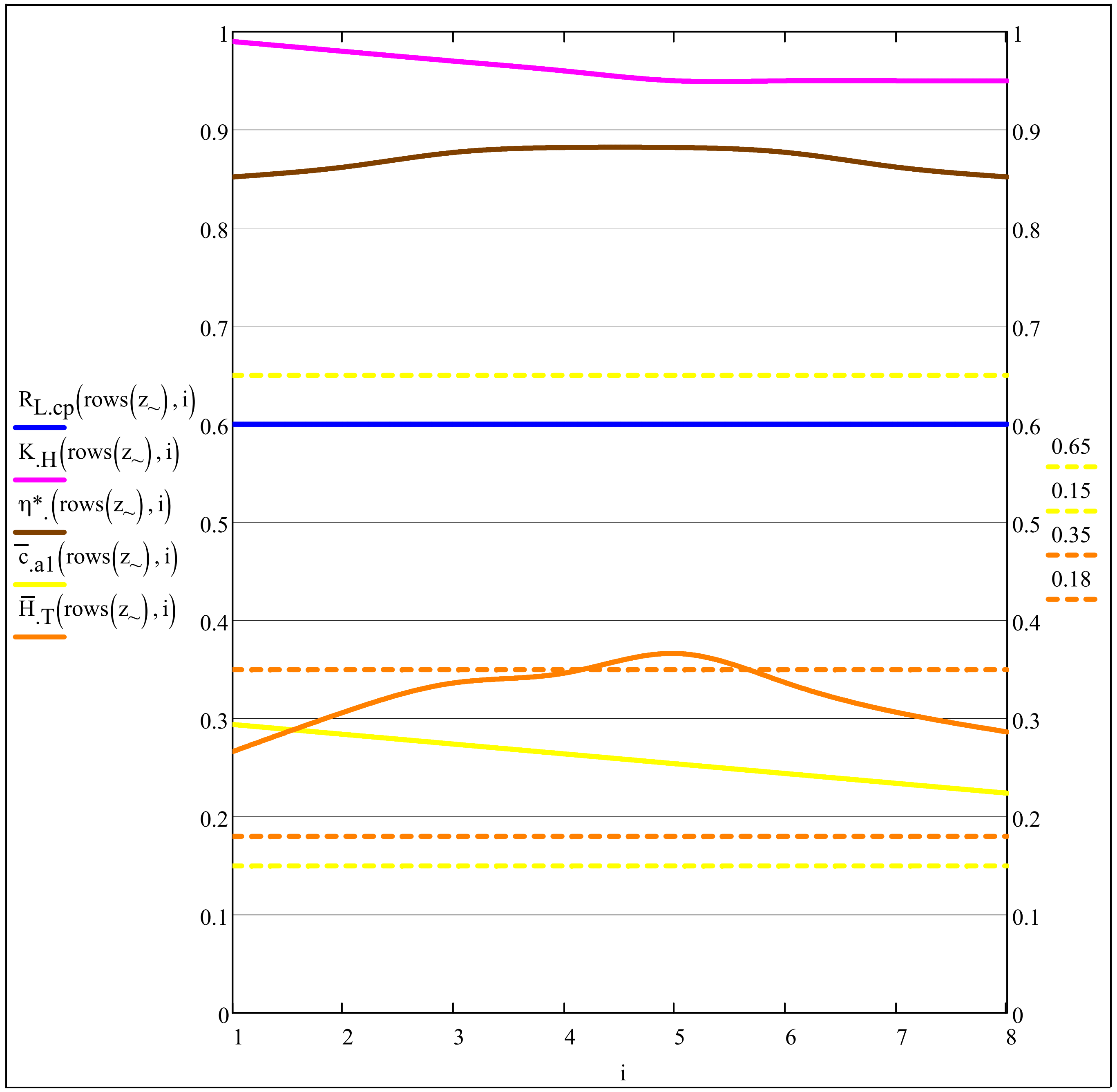
Коэф. расхода: $\overline{c}_{\sim a1}(i) = \mathrm{interp}\left(\mathrm{lspline}\left(\frac{z_{\sim}}{\mathrm{rows}(z_{\sim})}, \overline{c}_{\sim a1}\right), \frac{z_{\sim}}{\mathrm{rows}(z_{\sim})}, \overline{c}_{\sim a1}, i\right)$

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

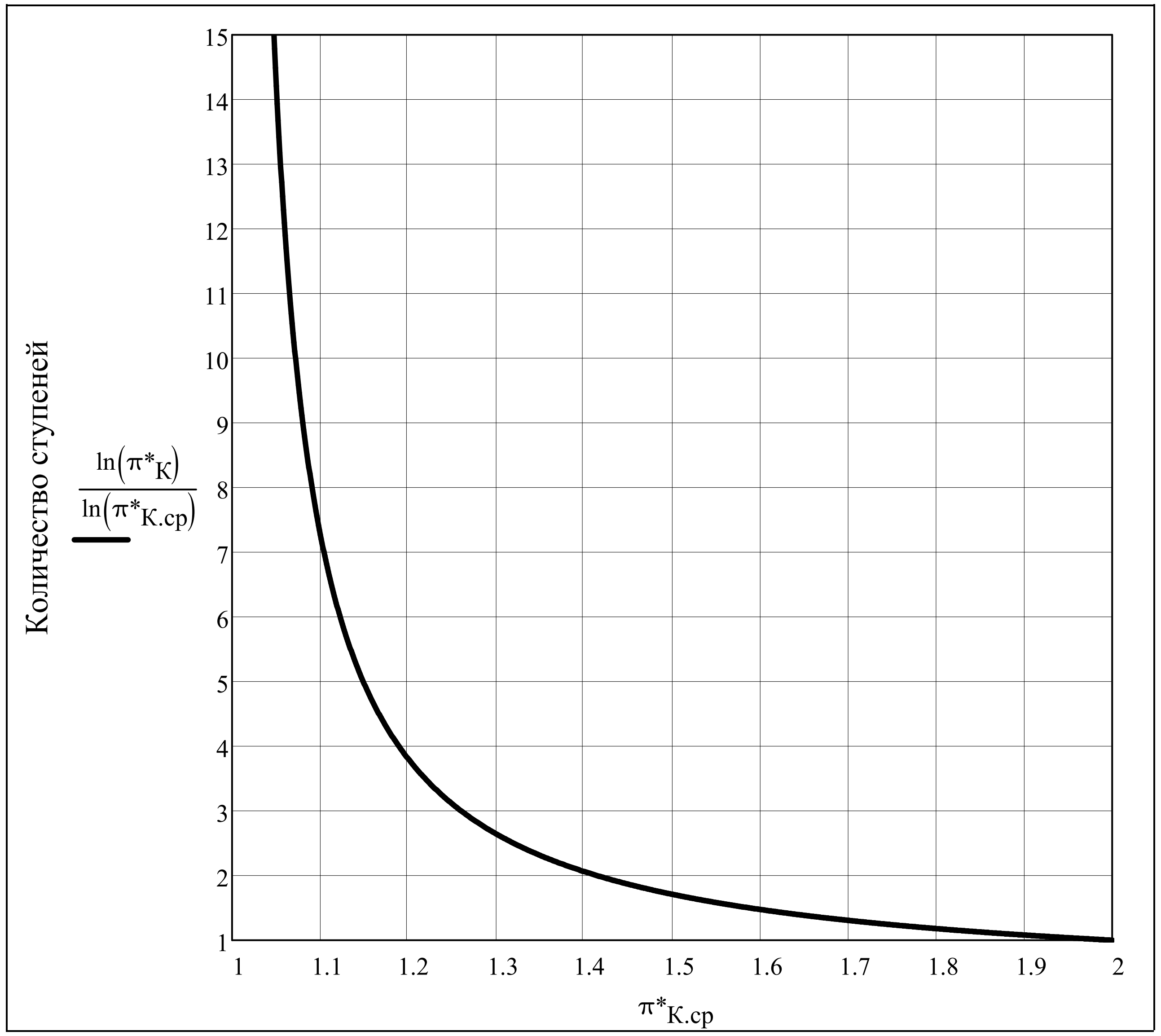
$$\begin{pmatrix} R_{L.cp} \\ K_{.H} \\ \eta^*_{.} \\ \bar{c}_{.a1} \\ \bar{H}_{.T} \end{pmatrix} = \left| \begin{array}{l}
R_{L.cp}(Z,i) = \left| \begin{array}{ll} R_{L\sim cp}\left(\dfrac{1}{\mathrm{rows}(z_\sim)}\right) & \text{if } i<1 \\ R_{L\sim cp}(1) \ \ \text{if } i>Z & \\ R_{L\sim cp}\left(\dfrac{i}{Z}\right)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

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

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



▲ Распределение основных параметров ОК по ступеням


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

Нулевые приближения

Показатель адиаьаты перед К []: $k_{К1} = k_{ад}\left(Cp_{воздух}\left(P^*_{К1}, T^*_{К1}\right), R_в\right) = 1.401$

Полное давление после К [Па]: $P^*_{К3} = \pi^*_К \cdot P^*_{К1} = 203 \cdot 10^3$

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

Количество итераций []: $iteration_3 = 1$

Полная температура после К [К]: $T^*_{К3} = 360.9$

Показатель адиаьаты после К []: $k_{К3} = 1.398$

Полная плотность перед и после К [кг/м^3]: $\begin{pmatrix} \rho^*_{К1} \\ \rho^*_{К3} \end{pmatrix} = \frac{1}{R_в} \cdot \begin{pmatrix} \frac{P^*_{К1}}{T^*_{К1}} \\ \frac{P^*_{К3}}{T^*_{К3}} \end{pmatrix} = \begin{pmatrix} 1.224 \\ 1.955 \end{pmatrix}$

Критические скорости перед и после К [м/с]: $\begin{pmatrix} a^*_{с.вх} \\ a^*_{с.вых} \end{pmatrix} = \begin{pmatrix} a_{кр}\left(k_{К1}, R_в, T^*_{К1}\right) \\ a_{кр}\left(k_{К3}, R_в, T^*_{К3}\right) \end{pmatrix} = \begin{pmatrix} 310.8 \\ 347.6 \end{pmatrix}$

Ср. показатель адиабаты К []: $k_{ср} = k_{ад}\left(Cp_{воздух.ср}\left(P^*_{К1}, P^*_{К3}, T^*_{К1}, T^*_{К3}\right), R_в\right) = 1.4$

Теоретический напор [Дж/кг]: $H_{ТК} = \frac{Cp_{воздух.ср}\left(P^*_{К1}, P^*_{К3}, T^*_{К1}, T^*_{К3}\right) \cdot T^*_{К1} \cdot \left(\pi^{*\frac{k_{ср}-1}{k_{ср}}}_К - 1\right)}{\eta^*_К} = 72.9 \cdot 10^3$

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

Окружная скорость на перифкрии перед К [м/с]: $u_{1\text{пер}} = 283.8$

Рекомендуемое количество ступеней []: $Z_{\text{recomend}} = 3$

Абс. скорость перед К [м/с]: $c_{\text{вх}} = 83.4$

Приведенная скорость перед К []: $\lambda_{\text{вх}} = 0.2685$

Плотность перед К [кг/м^3]: $\rho_{\text{К}1} = 1.188$

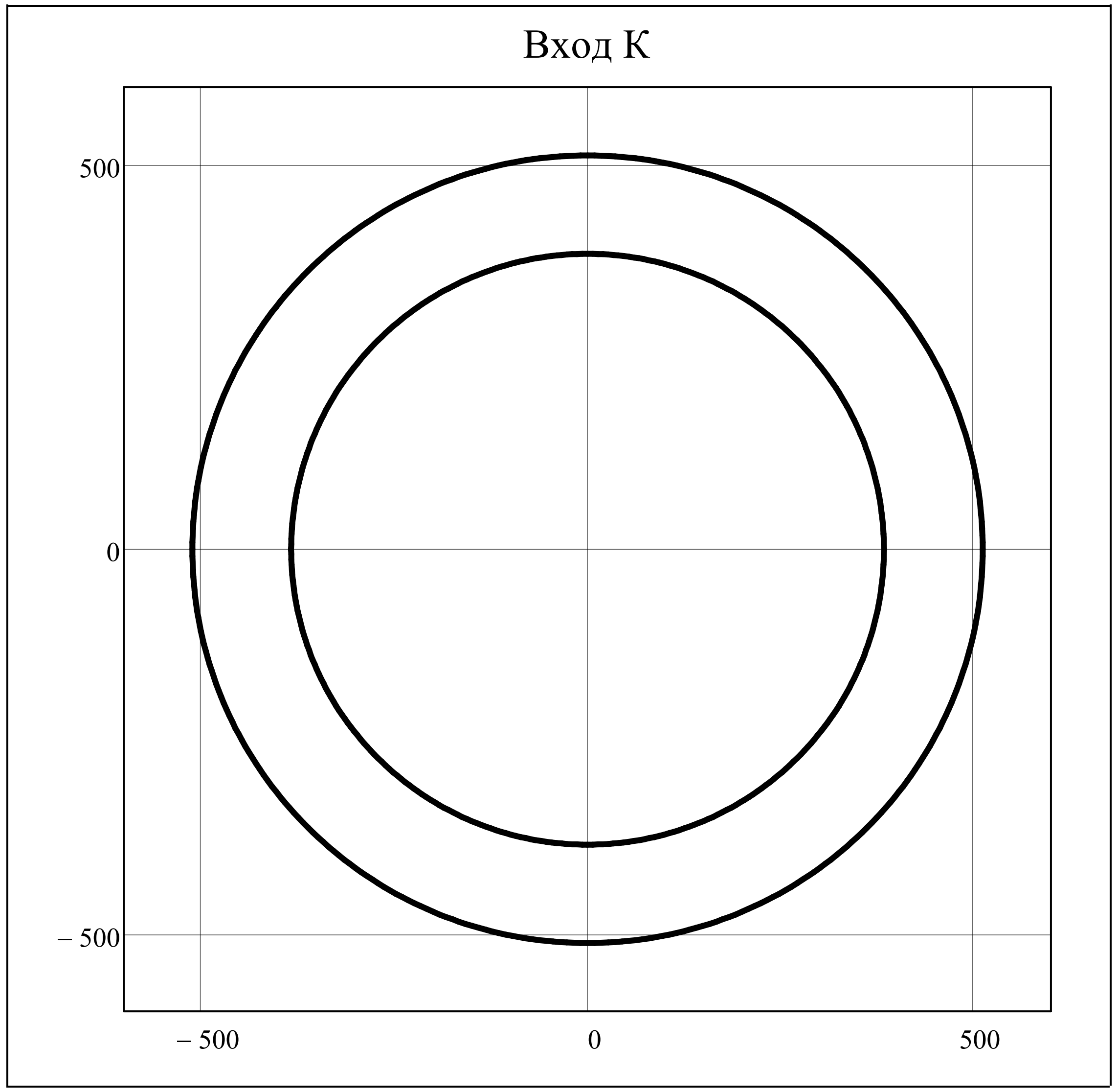
Кольцевая площадь перед К [м^2]: $F_{\text{вх}} = \dfrac{G \cdot \sqrt{R_{\text{в}} \cdot T^*_{\text{К}1}}}{m_q\left(k_{\text{К}1}\right) \cdot P^*_{\text{К}1} \cdot \text{ГДФ}\left(\text{"G"}, \lambda_{\text{вх}}, k_{\text{К}1}\right)} = 0.3596$

$$D'_{\text{пер}1} = \frac{2 \cdot u_{1\text{пер}}}{\omega} = 1022.8 \cdot 10^{-3}$$

Диамтеры перед К [м]: $D'_{\text{ср}1} = \overline{r}_{\text{ср}}\left(\overline{d}_1\right) \cdot D'_{\text{пер}1} = 904 \cdot 10^{-3}$

$$D'_{\text{кор}1} = \overline{d}_1 \cdot D'_{\text{пер}1} = 767.1 \cdot 10^{-3}$$

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



Вход К

Рекомендуемое количество ступеней []: $Z_{recomend} = 3$

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

▲ Нулевые приближения

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

Расчет ВНА:

$$\begin{pmatrix} \alpha_{1ВНА} & \alpha_{3ВНА} \\ \sigma_{ВНА} & \sigma_{ВНА} \\ \overline{d}_{1ВНА} & \overline{d}_{3ВНА} \\ T^*_{1ВНА} & T^*_{3ВНА} \\ P^*_{1ВНА} & P^*_{3ВНА} \\ \rho^*_{1ВНА} & \rho^*_{3ВНА} \\ k_{1ВНА} & k_{3ВНА} \\ a_{кр1ВНА} & a_{кр3ВНА} \\ \overline{c}_{a1ВНА} & \overline{c}_{a3ВНА} \\ \overline{c}_{u1ВНА} & \overline{c}_{u3ВНА} \\ c_{a1ВНА} & c_{a3ВНА} \\ c_{u1ВНА} & c_{u3ВНА} \\ c_{1ВНА} & c_{3ВНА} \\ \lambda_{c1ВНА} & \lambda_{c3ВНА} \\ F_{1ВНА} & F_{3ВНА} \\ \varepsilon_{ВНА} & \varepsilon_{ВНА} \end{pmatrix} = \left| \; \text{for } r \in av(N_r) \right.$$

$$\alpha_{1ВНА_r} = 90°$$

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

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

$$T^*_{1ВНА_r} = T^*_{К1}$$

$$T^*_{3ВНА_r} = T^*_{1ВНА_r}$$

$$P^*_{1ВНА_r} = P^*_{К1}$$

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

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

$$a_{кр1ВНА_r} = a_{кр}\left(k_{1ВНА_r}, R_в, T^*_{1ВНА_r}\right)$$

$$\overline{c}_{a1ВНА_r} = \overline{c}_{.a1}(Z,0)$$

$$\overline{c}_{u1ВНА_r} = \left| \begin{array}{l} \overline{r}_{ср}\left(\overline{d}_{1ВНА}\right)\cdot\left(1 - R_{L.ср}(Z,0)\right) - \dfrac{\overline{H}_{.T}(Z,0)}{2\cdot\overline{r}_{ср}\left(\overline{d}_{1ВНА}\right)} \;\; \text{if ВНА} = 1 \\ 0 \;\; \text{otherwise} \end{array} \right.$$

$$c_{a1ВНА_r} = \overline{c}_{a1ВНА_r} \cdot u_{1пер}$$

$$\sigma_{ВНА} = 1.0000$$

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

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

$$\text{submatrix}\left(\alpha_{3ВНА}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (90.00)\cdot deg$$

$$\begin{pmatrix} \overline{d}_{1ВНА} \\ \overline{d}_{3ВНА} \end{pmatrix} = \begin{pmatrix} 0.7500 \\ 0.7500 \end{pmatrix} \qquad \begin{pmatrix} F_{1ВНА} \\ F_{3ВНА} \end{pmatrix} = \begin{pmatrix} 0.3596 \\ 0.3596 \end{pmatrix}$$

$$c_{u1ВНА_r} = \frac{c_{a1ВНА_r}}{\tan\left(\alpha_{1ВНА_r}\right)}$$

$$c_{1ВНА_r} = \frac{c_{a1ВНА_r}}{\sin\left(\alpha_{1ВНА_r}\right)}$$

$$\lambda_{c1ВНА_r} = \frac{c_{1ВНА_r}}{a_{кр1ВНА_r}}$$

$$\sigma_{ВНА} = \begin{cases} \left[1 + \text{mean}(0.03,0.06)\cdot ГДФ\left(\text{"ρ"},\lambda_{c1ВНА_r},k_{1ВНА_r}\right)\cdot\frac{k_{1ВНА_r}}{k_{1ВНА_r}+1}\cdot\left(\lambda_{c1ВНА_r}\right)^2\right]^{-1} & \text{if } ВНА = 1 \\ 1 & \text{otherwise} \end{cases}$$

$$P*_{3ВНА_r} = P*_{1ВНА_r}\cdot\sigma_{ВНА}$$

$$\rho*_{3ВНА_r} = \frac{P*_{3ВНА_r}}{R_{в}\cdot T*_{3ВНА_r}}$$

$$k_{3ВНА_r} = k_{ад}\left(Cp_{воздух}\left(P*_{3ВНА_r},T*_{3ВНА_r}\right),R_{в}\right)$$

$$a_{кр3ВНА_r} = a_{кр}\left(k_{3ВНА_r},R_{в},T*_{3ВНА_r}\right)$$

$$\bar{c}_{a3ВНА_r} = \begin{cases} \bar{c}_{.a1}(Z,1) & \text{if } ВНА = 1 \\ \bar{c}_{a1ВНА_r} & \text{otherwise} \end{cases}$$

$$\bar{c}_{u3ВНА_r} = \begin{cases} \bar{r}_{cp}\left(d_{3ВНА}\right)\cdot\left(1 - R_{L.cp}(Z,1)\right) - \frac{\bar{H}_{.T}(Z,1)}{2\cdot\bar{r}_{cp}\left(d_{3ВНА}\right)} & \text{if } ВНА = 1 \\ 0 & \text{otherwise} \end{cases}$$

$$\alpha_{3ВНА_r} = \begin{cases} \text{triangle}\left(\bar{c}_{a1ВНА_r},\bar{c}_{u1ВНА_r}\right) & \text{if } ВНА = 1 \\ \frac{\pi}{2} & \text{otherwise} \end{cases}$$

$$c_{a3ВНА_r} = \bar{c}_{a1ВНА_r}\cdot u_{1пер}$$

$$c_{u3ВНА_r} = \frac{c_{a3ВНА_r}}{\tan\left(\alpha_{3ВНА_r}\right)}$$

$$c_{3ВНА_r} = \frac{c_{a3ВНА_r}}{\sin\left(\alpha_{3ВНА_r}\right)}$$

$$\lambda_{c3ВНА_r} = \frac{c_{3ВНА_r}}{a_{кр3ВНА}}$$

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

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

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

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

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

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

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

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

$\text{submatrix}\left(a_{кр1ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (310.8)$

$\text{submatrix}\left(a_{кр3ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (310.8)$

$\text{submatrix}\left(\bar{c}_{a1ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.294)$

$\text{submatrix}\left(\bar{c}_{a3ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.294)$

$\text{submatrix}\left(\bar{c}_{u1ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.000)$

$\text{submatrix}\left(\bar{c}_{u3ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.000)$

$\text{submatrix}\left(c_{a1ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (83.4)$

$\text{submatrix}\left(c_{a3ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (83.4)$

$\text{submatrix}\left(c_{u1ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.0)$

$\text{submatrix}\left(c_{u3ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.0)$

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

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

$\text{submatrix}\left(\lambda_{c1ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.268)$

$\text{submatrix}\left(\lambda_{c3ВНА},av\left(N_r\right),av\left(N_r\right),1,1\right) = (0.268)$

кр3ВНА_r

$$\begin{pmatrix} F_{1ВНА} \\ F_{3ВНА} \end{pmatrix} = G\cdot\sqrt{R_в}\cdot\begin{pmatrix} \dfrac{\sqrt{T^*_{1ВНА_r}}}{m_q\left(k_{1ВНА_r}\right)\cdot P^*_{1ВНА_r}\cdot ГДФ\left("G", \lambda_{c1ВНА_r}, k_{1ВНА_r}\right)\cdot\sin\left(\alpha_{1ВНА_r}\right)} \\ \dfrac{\sqrt{T^*_{3ВНА_r}}}{m_q\left(k_{3ВНА_r}\right)\cdot P^*_{3ВНА_r}\cdot ГДФ\left("G", \lambda_{c3ВНА_r}, k_{3ВНА_r}\right)\cdot\sin\left(\alpha_{3ВНА_r}\right)} \end{pmatrix}$$

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

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

▲ Расчет ВНА:

Поступенчатый расчет ОК по ср. ЛТ

$$\begin{pmatrix} R_L & \pi^* \\ K_H & \eta^* \\ Cp & k \\ \overline{H}_T & H_T \\ L^* & L \\ T^* & T \\ P^* & P \\ \rho^* & \rho \\ a^*{}_c & a_{зв} \\ \lambda_c & \lambda_c \\ F & F \\ D & R \\ \overline{d} & h \\ \overline{c}_a & \overline{c}_u \\ c_a & c_u \\ u & w_u \\ c & w \\ M_c & M_w \\ \alpha & \beta \\ \varepsilon_{rotor} & \varepsilon_{stator} \end{pmatrix} = \left| \begin{array}{l} r = av(N_r) \\ T^*{}_{st(1,1),r} = T^*{}_{3BHA_r} \\ P^*{}_{st(1,1),r} = P^*{}_{3BHA_r} \\ \rho^*{}_{st(1,1),r} = \rho^*{}_{3BHA_r} \\ Cp_{st(1,1),r} = Cp_{воздух}\left(P^*{}_{st(1,1),r}, T^*{}_{st(1,1),r}\right) \\ k_{st(1,1),r} = k_{ад}\left(Cp_{st(1,1),r}, R_в\right) \\ a^*{}_{c_{st(1,1),r}} = a_{кр}\left(k_{st(1,1),r}, R_в, T^*{}_{st(1,1),r}\right) \\ \overline{c}_{a_{st(1,1),r}} = \overline{c}_{a3BHA_r} \\ \overline{c}_{u_{st(1,1),r}} = \overline{c}_{u3BHA_r} \\ c_{a_{st(1,1),r}} = c_{a3BHA_r} \\ u_{st(1,1),N_r} = u_{1пер} \\ \alpha_{st(1,1),r} = \alpha_{3BHA_r} \\ c_{st(1,1),r} = \dfrac{c_{a_{st(1,1),r}}}{\sin\left(\alpha_{st(1,1),r}\right)} \\ \lambda_{c_{st(1,1),r}} = \dfrac{c_{st(1,1),r}}{a^*{}_{c_{st(1,1),r}}} \\ F_{st(1,1)} = \dfrac{G\cdot\sqrt{R_в\cdot T^*{}_{st(1,1),r}}}{m_q\left(k_{st(1,1),r}\right)\cdot ГДФ\left("G", \lambda_{c_{st(1,1),r}}, k_{st(1,1),r}\right)\cdot\sin\left(\alpha_{st(1,1),r}\right)\cdot P^*{}_{st(1,1),r}} \end{array}\right.$$

```
$D_{st(1,1),N_r} = \frac{2\cdot u_{st(1,1),N_r}}{\omega}$
$D_{st(1,1),1} = \sqrt{\left(D_{st(1,1),N_r}\right)^2 - \frac{4\cdot F_{st(1,1)}}{\pi}}$
$D_{st(1,1),r} = \overline{r}_{cp}\left(\frac{D_{st(1,1),1}}{D_{st(1,1),N_r}}\right)\cdot D_{st(1,1),N_r}$
$\overline{d}_{st(1,1)} = \frac{D_{st(1,1),1}}{D_{st(1,1),N_r}}$
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 $(ЗППЧ_i \ne "пер") \wedge (ЗППЧ_i \ne "кор") \wedge (ЗППЧ_i \ne "ср")$
    $D_{st(i,3),N_r} = D_{st(i,1),N_r} \cdot str2num(ЗППЧ_i)$
    $D_{st(i,3),1} = \sqrt{(D_{st(i,3),N_r})^2 - \frac{4 F_{st(i,3)}}{\pi}}$
  if $ЗППЧ_i = "пер"$
```

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      $D_{st(i,3),N_r} = D_{st(i,1),N_r}$
      $D_{st(i,3),1} = \sqrt{\left(D_{st(i,3),N_r}\right)^2 - \frac{4F_{st(i,3)}}{\pi}}$
  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} = $
      $\mathrm{atan}\left(\frac{\overline{c}_{a_{st(i,3),r}}}{\overline{c}_{u_{st(i,3),r}}}\right)$  if  $\mathrm{atan}\left(\frac{\overline{c}_{a_{st(i,3),r}}}{\overline{c}_{u_{st(i,3),r}}}\right) \ge 0$
      $\mathrm{atan}\left(\frac{\overline{c}_{a_{st(i,3),r}}}{\overline{c}_{u_{st(i,3),r}}}\right) + 2\pi$  otherwise
  $u_{st(i,3),N_r} = u_{st(i,1),N_r}\cdot\frac{D_{st(i,3),N_r}}{D_{st(i,1),N_r}}$
  $c_{a_{st(i,3),r}} = \overline{c}_{a_{st(i,3),r}}\cdot u_{st(i,3),N_r}$
  $c_{st(i,3),r} = \frac{c_{a_{st(i,3),r}}}{\sin\left(\alpha_{st(i,3),r}\right)}$
  $\lambda_{c_{st(i,3),r}} = \frac{c_{st(i,3),r}}{a^*c_{st(i,3),r}}$
  $F'_3 = \frac{G\cdot\sqrt{R_B\cdot T^*_{st(i,3),r}}}{m_q\left(k_{st(i,3),r}\right)\cdot ГДФ\left("G", \lambda_{c_{st(i,3),r}}, k_{st(i,3),r}\right)\cdot\sin\left(\alpha_{st(i,3),r}\right)\cdot P^*_{st(i,3),r}}$
  break  if  $\left(\left|eps\left("rel", F'_3, F_{st(i,3)}\right)\right| < epsilon\right) \wedge \left(iteration_3 = 0\right)$
  $iteration_3 = -1$  if  $\left(\left|eps\left("rel", F'_3, F_{st(i,3)}\right)\right| < epsilon\right)$
```

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

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

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

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

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

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

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

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

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

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

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

for $a \in 1 .. 3$

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

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

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

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

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

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

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

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

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

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

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

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

```
$\begin{pmatrix} H_T \\ R_L \end{pmatrix} =$ for $i \in 1..Z$
    $H_{T.}(r) = \mathrm{interp}\left[\mathrm{pspline}\left[\begin{pmatrix} 1 \\ av(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} H_{T_{i,av(N_r)}} - \frac{\Delta H_T(\overline{d}_{st(i,2)})}{2} \\ H_{T_{i,av(N_r)}} \\ H_{T_{i,av(N_r)}} + \frac{\Delta H_T(\overline{d}_{st(i,2)})}{2} \end{pmatrix}\right], \begin{pmatrix} 1 \\ av(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} H_{T_{i,av(N_r)}} - \frac{\Delta H_T(\overline{d}_{st(i,2)})}{2} \\ H_{T_{i,av(N_r)}} \\ H_{T_{i,av(N_r)}} + \frac{\Delta H_T(\overline{d}_{st(i,2)})}{2} \end{pmatrix}, r\right]$
    $R_{L.}(r) = \mathrm{interp}\left[\mathrm{pspline}\left[\begin{pmatrix} 1 \\ av(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} R_{L_{i,av(N_r)}} - \frac{\Delta R_L(\overline{d}_{st(i,2)})}{2} \\ R_{L_{i,av(N_r)}} \\ R_{L_{i,av(N_r)}} + \frac{\Delta R_L(\overline{d}_{st(i,2)})}{2} \end{pmatrix}\right], \begin{pmatrix} 1 \\ av(N_r) \\ N_r \end{pmatrix}, \begin{pmatrix} R_{L_{i,av(N_r)}} - \frac{\Delta R_L(\overline{d}_{st(i,2)})}{2} \\ R_{L_{i,av(N_r)}} \\ R_{L_{i,av(N_r)}} + \frac{\Delta R_L(\overline{d}_{st(i,2)})}{2} \end{pmatrix}, r\right]$
    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"   = 0
     | 0  otherwise
```

Расчет CA:

```
(α_1CA     α_3CA    )
(σ_CA      σ_CA     )
(d̄_1CA     d̄_3CA    )
(T*_1CA    T*_3CA   )
(P*_1CA    P*_3CA   )
(ρ*_1CA    ρ*_3CA   )
(k_1CA     k_3CA    )
(a_кр1CA   a_кр3CA  )
(c̄_a1CA    c̄_a3CA   )
(c̄_u1CA    c̄_u3CA   )   =  | for r ∈ av(N_r)
(c_a1CA    c_a3CA   )      |   | α_1CA_r = α_st(Z,3),r
(c_u1CA    c_u3CA   )      |   | α_3CA_r = | 90·°  if CA = 1
(c_1CA     c_3CA    )      |   |           | α_1CA_r  otherwise
(λ_1CA     λ_3CA    )      |   | d̄_1CA = d̄_st(Z,3)
(F_1CA     F_3CA    )      |   | d̄_3CA = d̄_1CA
(ε_CA      ε_CA     )      |   | 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
                           |   | σ_CA = 1
                           |   | while 0 < 1
                           |   |   | iterarion_CA = iterarion_CA + 1
                           |   |   | trace(concat("iterarion.CA = ", num2str(iterarion_CA)))
                           |   |   | P*_3CA_r = P*_1CA_r·σ_CA
                           |   |   |
                           |   |   | (ρ*_1CA_r)      1   ( P*_1CA_r / T*_1CA_r )
```

$\sigma_{CA} = 1.0000$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\text{submatrix}\left(a_{кр1CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (347.9)$$

$$\text{submatrix}\left(a_{кр3CA}, \text{av}\left(N_r\right), \text{av}\left(N_r\right), 1, 1\right) = (347.9)$$

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

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

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

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

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

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

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

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

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

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

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

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

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

Расчет СА:

Результаты поступенчатого расчета по ср. ЛТ

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

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

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

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

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

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

Количество ступеней ОК: $Z = 3$

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	1.300	1.297	1.187												

[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												

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

Степень повышения давления в ЛА: $\pi^*_{ЛА} = \dfrac{P^*_{3CA_{av(N_r)}}}{P^*_{1BHA_{av(N_r)}}} = 2.000$ $\pi^*_{ЛА} \ge \pi^*_К = 1$

$$H_T{}^T = \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|} \hline & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 26.51 & 29.08 & 21.26 & & & & & & & & & & & & \\ \hline 2 & 26.51 & 29.08 & 21.26 & & & & & & & & & & & & \\ \hline 3 & 26.51 & 29.08 & 21.26 & & & & & & & & & & & & \\ \hline \end{array} \cdot 10^3$$

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

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

Адиабатная КПД К []: $\eta*_{\text{К}} = \frac{L*_{\text{К}}}{L_{\text{К}}} = 87.02\cdot\%$

Мощность К (Вт): $N_{\text{К}} = G\cdot L_{\text{К}} = 2.62\cdot 10^6$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.60	0.60	0.60												

$K_H^T =$

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

$\eta^{*T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	87.25	88.13	85.20												

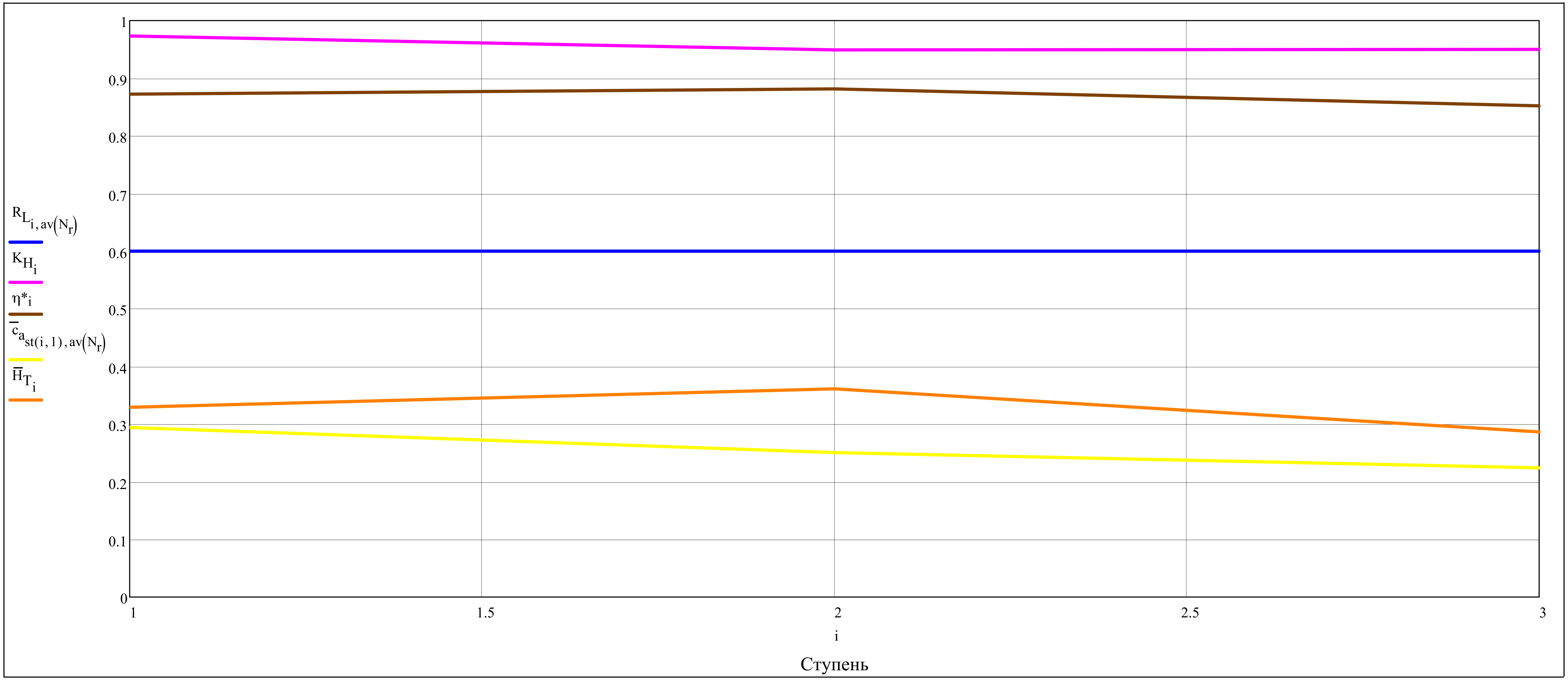
$\cdot\%$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.294	0.272	0.251	0.237	0.224	0.224	0.224													

$\bar{H}_T^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.33	0.36	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	1002.6	1004.1	1004.1	1006.4	1006.4	1008.5	1008.5												

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

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

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

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

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

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

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

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

$\cdot 10^3$

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

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

$\cdot 10^3$

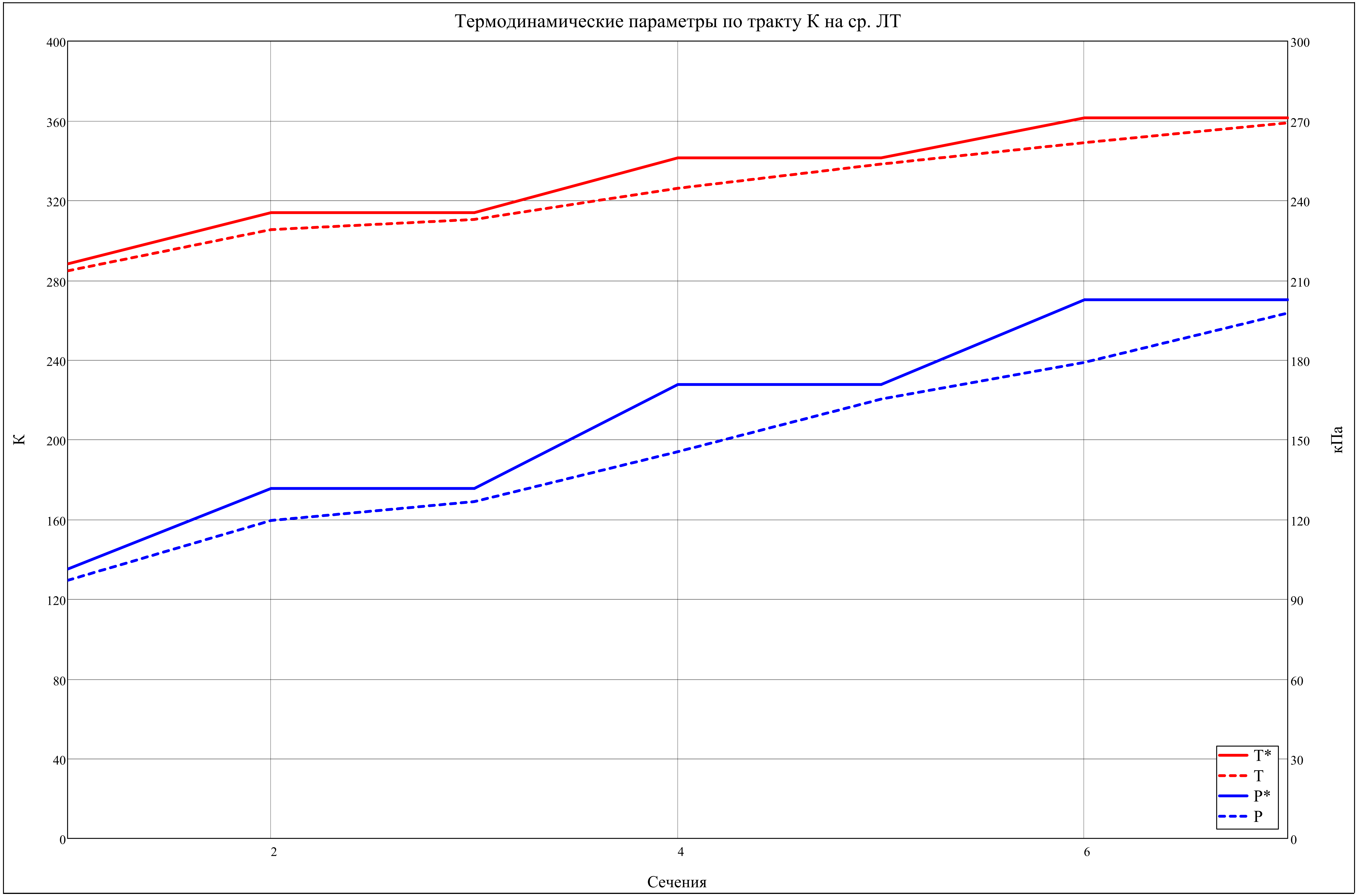
$\text{submatrix}\left(\rho^*, 1, 2Z+1, av\left(N_r\right), av\left(N_r\right)\right)^T =$

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

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

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

$$k_{ср} = k_{ад}\left(Cp_{воздух.ср}\left(P^*_{st(1,1), av\left(N_r\right)}, P^*_{st(Z,3), av\left(N_r\right)}, T^*_{st(1,1), av\left(N_r\right)}, T^*_{st(Z,3), av\left(N_r\right)}\right), R_{в}\right) = 1.400$$


Термодинамические параметры по тракту К на ср. ЛТ
К
кПа
Сечения
400
360
320
280
240
200
160
120
80
40
0
300
270
240
210
180
150
120
90
60
30
0
2
4
6
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	0.3596	0.3382	0.3526	0.3476	0.3433	0.3404	0.331														

$\overline{d}^T =$

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

$\overline{d}_{st(Z,3)} = 0.6953$ $\overline{d}_{st(Z,3)} \le 0.9 = 1$

$D^T =$

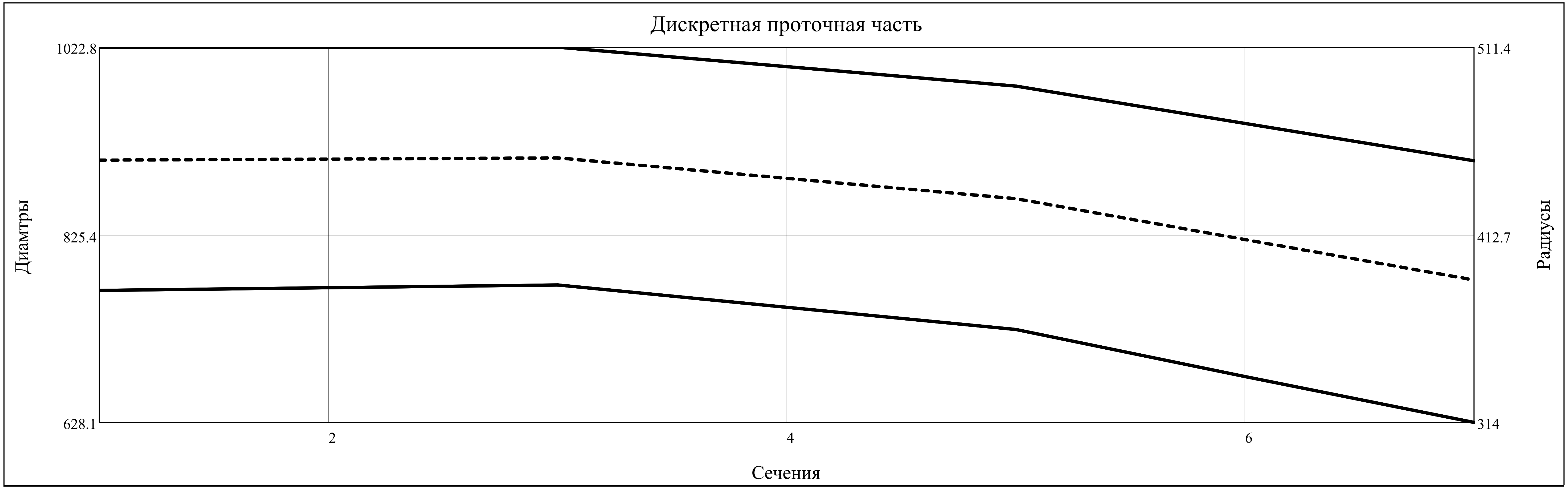
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	766.9	769.8	772.7	749.2	725.9	676.3	628.1														
2	903.9	905.2	906.4	884.8	863.4	820.3	777.9														
3	1022.8	1022.8	1022.8	1002.3	981.8	942.6	903.3														

$\cdot 10^{-3}$

$R^T =$

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

$\cdot 10^{-3}$



Дискретная проточная часть

$h^T =$

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

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	310.8	324.3	324.3	338.2	338.2	347.9	347.9														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	338.5	350.5	353.4	362.0	368.7	374.3	379.6														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	83.4	130.8	83.0	175.2	79.8	158.8	71.8														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	264.4	164.9	220.5	106.2	197.8	99.2															

$u^T =$

	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	212.8	213.6	214.4	207.9	201.4	187.7	174.3																		
2	250.8	251.2	251.5	245.5	239.6	227.6	215.9																		
3	283.8	283.8	283.8	278.1	272.5	261.6	250.7																		

$c_{a_{st(Z,3),av\left(N_r\right)}} = 56.15$ $c_{a_{st(Z,3),av\left(N_r\right)}} \le 130 = 1$ Для КС

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	83.4	77.3	71.1	66.0	61.0	58.6	56.1														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0	105.6	42.8	162.3	51.5	147.6	44.7														

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	250.8	145.6	208.7	83.3	188.1	80.1	171.2														

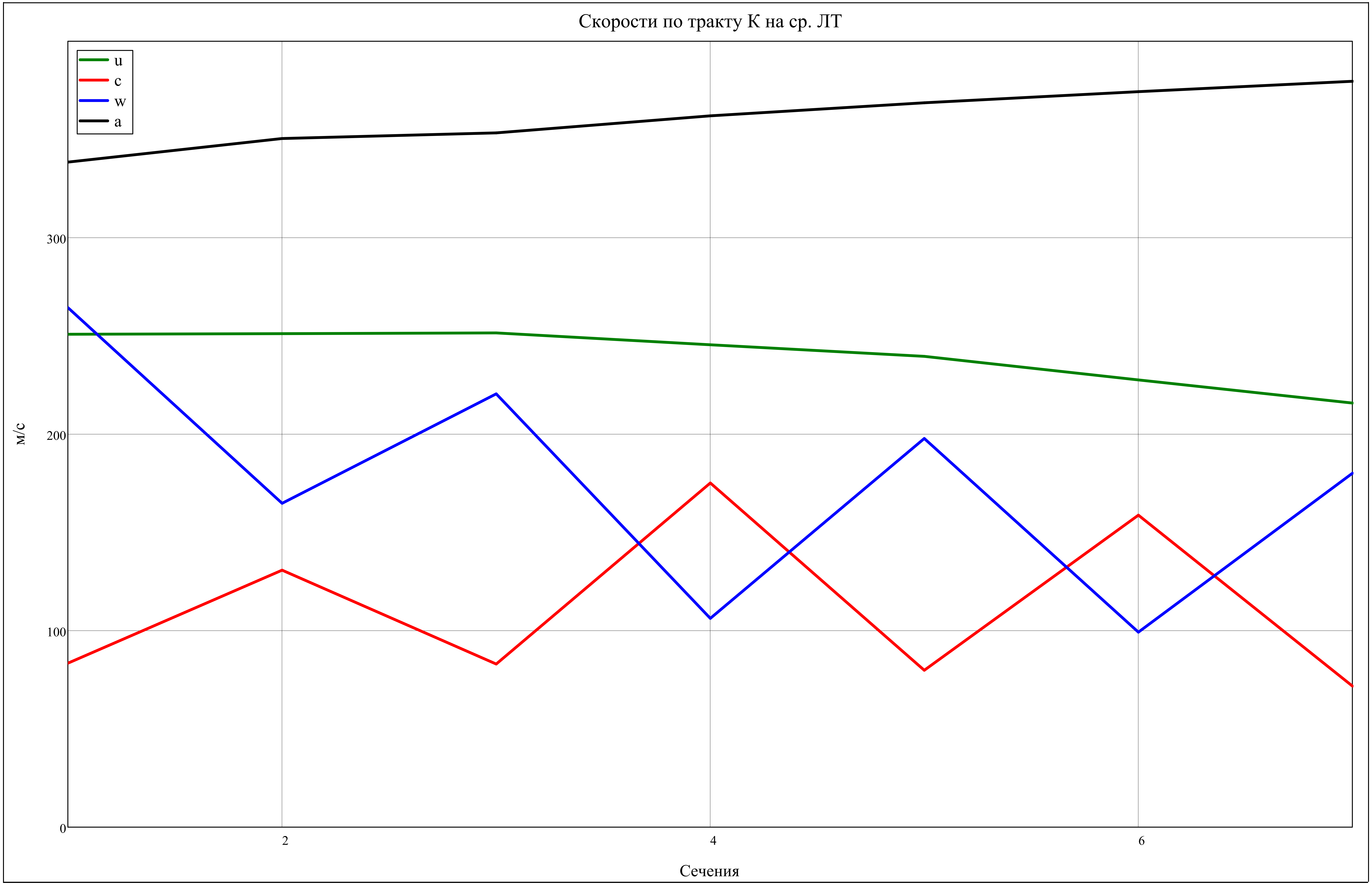
$$\Delta c_{a_{i,av\left(N_r\right)}} = \left(c_{a_{st(i,2),av\left(N_r\right)}} - c_{a_{st(i,1),av\left(N_r\right)}}\right)$$

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

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

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	1	1																											



Скорости по тракту К на ср. ЛТ

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	90.00	36.21	58.97	22.13	49.86	21.65	51.49														

$\cdot {}^{\circ}$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	18.4	27.96	18.82	38.41	17.97	36.19	18.16														

$\cdot {}^{\circ}$

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

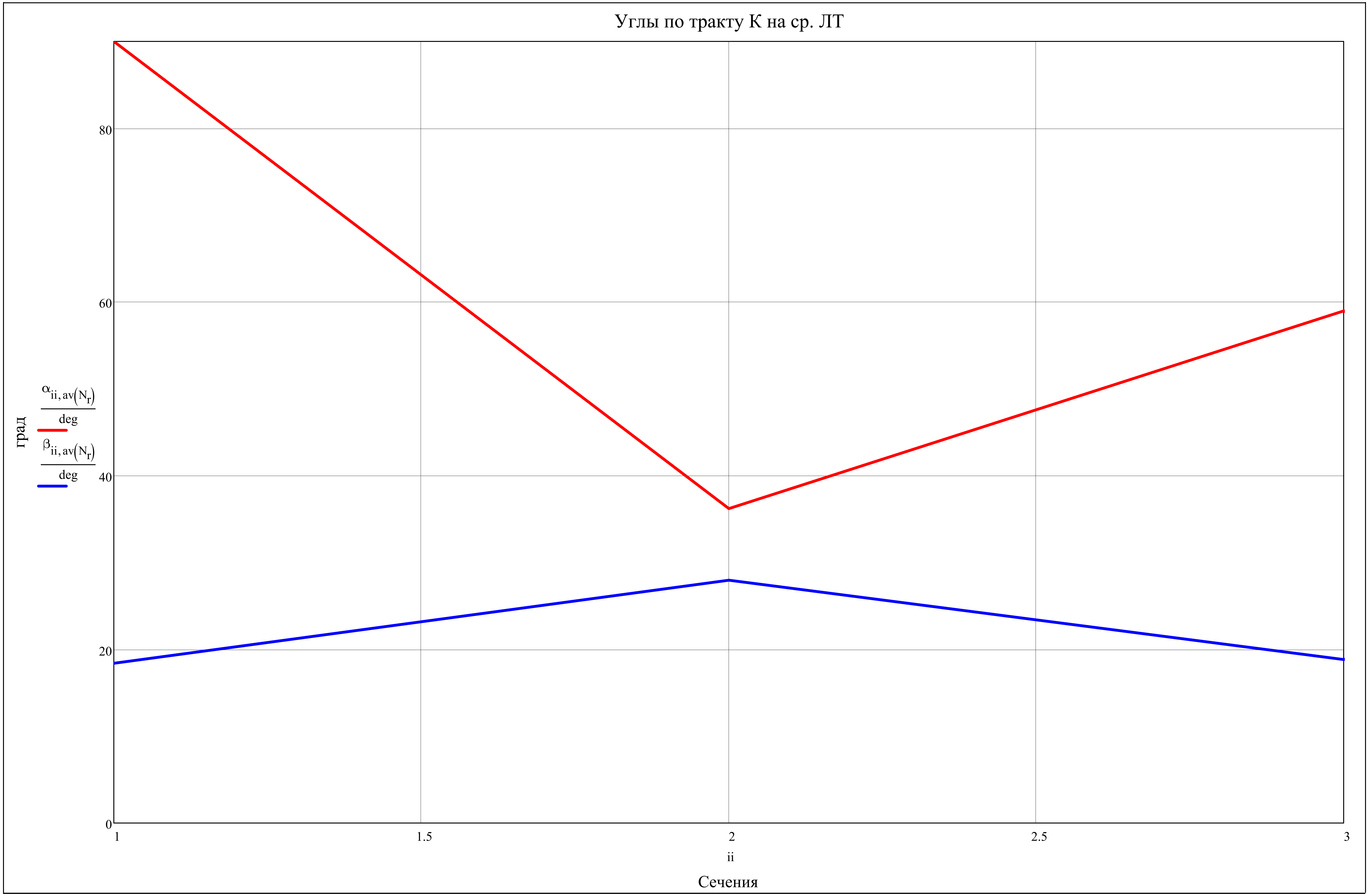
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	9.56	19.59	18.22																		

$\cdot {}^{\circ}$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	22.76	27.72	29.84																		

$\cdot {}^{\circ}$


Углы по тракту К на ср. ЛТ
град
$\frac{\alpha_{ii,av(N_r)}}{deg}$
$\frac{\beta_{ii,av(N_r)}}{deg}$
80
60
40
20
0
1
1.5
2
2.5
3
ii
Сечения

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.2685	0.4034	0.2560	0.5181	0.2361	0.4564	0.2062												

[16, c. 87] $\mathrm{submatrix}\left(\lambda_c, 1, 2Z+1, \mathrm{av}(N_r), \mathrm{av}(N_r)\right)^T \le 0.85 =$

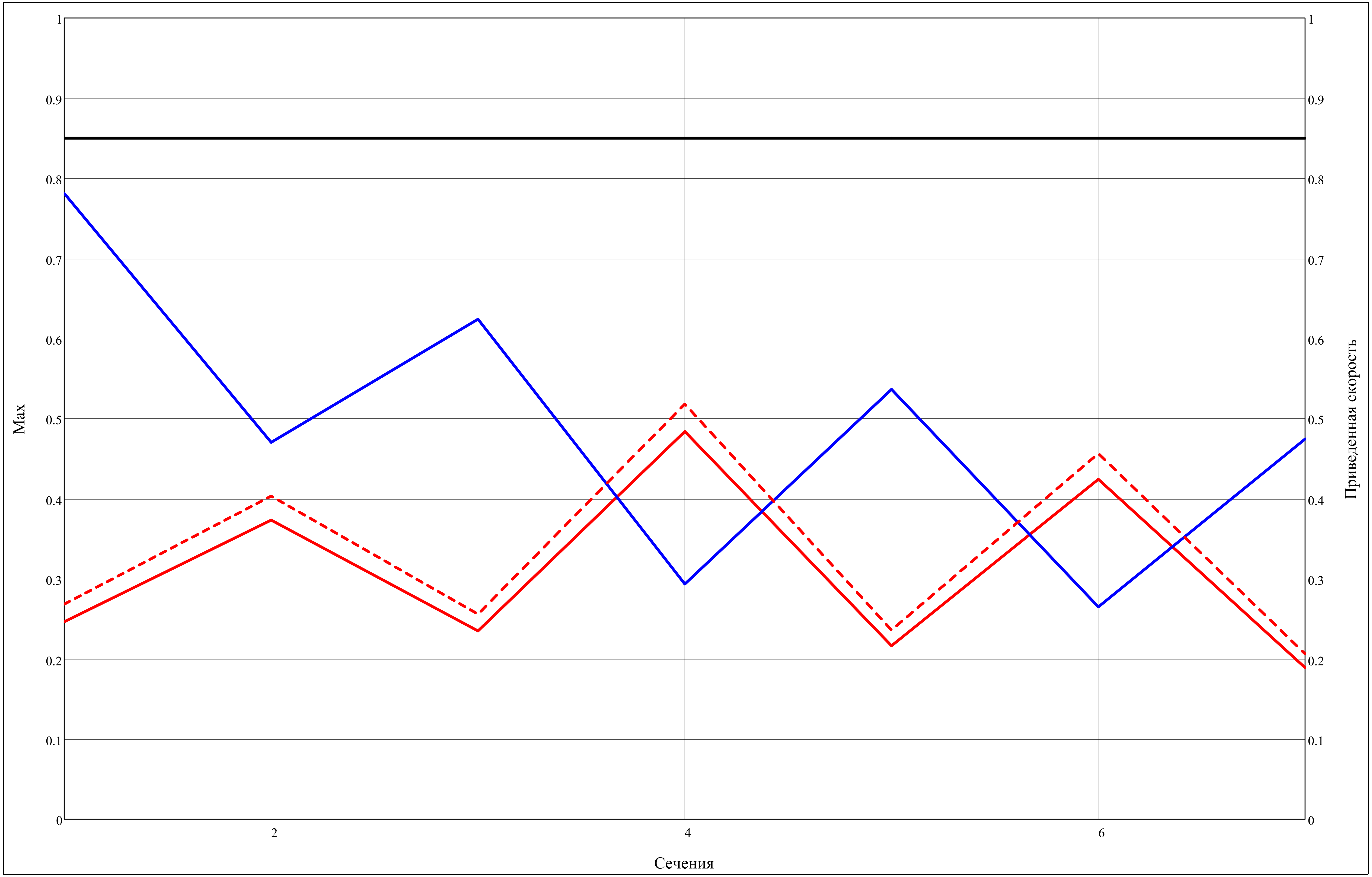
	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.781	0.4704	0.6241	0.2935	0.5365	0.2651													

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.2465	0.3733	0.2349	0.4840	0.2166	0.4242	0.1890												



Max
Приведенная скорость
Сечения
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
4
6

⏶ Результаты поступенчатого расчета по ср. ЛТ

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

Расчет параметров потока по высоте Л

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

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

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

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

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

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

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

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

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

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

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

```
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 $m_i = 0$
```

$$\begin{cases}1 & \text{otherwise}\end{cases}$$

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

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

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

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

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

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

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

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

= triangle(

```
            $\alpha_{st(i,a),r} \leftarrow \text{triangle}\left(c_{a_{st(i,a),r}}, c_{u_{st(i,a),r}}\right)$
            $c_{st(i,a),r} \leftarrow \dfrac{c_{a_{st(i,a),r}}}{\sin\left(\alpha_{st(i,a),r}\right)}$
            $\lambda_{c_{st(i,a),r}} \leftarrow \dfrac{c_{st(i,a),r}}{a^*_{c_{st(i,a),r}}}$
            $\begin{pmatrix} T_{st(i,a),r} \\ P_{st(i,a),r} \\ \rho_{st(i,a),r} \end{pmatrix} \leftarrow \begin{pmatrix} T^*_{st(i,a),r} \cdot ГДФ\left("T", \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right) \\ P^*_{st(i,a),r} \cdot ГДФ\left("P", \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right) \\ \rho^*_{st(i,a),r} \cdot ГДФ\left("\rho", \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right) \end{pmatrix}$
            $a_{зв_{st(i,a),r}} \leftarrow \sqrt{k_{st(i,a),r} \cdot R_в \cdot T_{st(i,a),r}}$
            $\beta_{st(i,a),r} \leftarrow \text{triangle}\left(c_{a_{st(i,a),r}}, u_{st(i,a),r} - c_{u_{st(i,a),r}}\right)$
            $w_{st(i,a),r} \leftarrow \dfrac{c_{a_{st(i,a),r}}}{\sin\left(\beta_{st(i,a),r}\right)}$
            $w_{u_{st(i,a),r}} \leftarrow w_{st(i,a),r} \cdot \cos\left(\beta_{st(i,a),r}\right)$
            $\begin{pmatrix} M_{w_{st(i,a),r}} \\ M_{c_{st(i,a),r}} \end{pmatrix} \leftarrow \dfrac{1}{a_{зв_{st(i,a),r}}} \cdot \begin{pmatrix} w_{st(i,a),r} \\ c_{st(i,a),r} \end{pmatrix}$
        for $r \in 1..N_r$
            $R_{L_{i,r}} \leftarrow 1 - \dfrac{c_{u_{st(i,1),r}} + c_{u_{st(i,2),r}}}{u_{st(i,1),r} + u_{st(i,2),r}}$
            $\begin{pmatrix} \varepsilon_{rotor_{i,r}} \\ \varepsilon_{stator_{i,r}} \end{pmatrix} \leftarrow \begin{pmatrix} \beta_{st(i,2),r} - \beta_{st(i,1),r} \\ \alpha_{st(i,3),r} - \alpha_{st(i,2),r} \end{pmatrix}$
    $\begin{pmatrix} T^* & P^* & \rho^* & Cp & a^*_c & c_u & \alpha & c & \lambda_c & M_w & R_L & \varepsilon_{rotor} \\ T & P & \rho & k & a_{зв} & c_a & \beta & w & w_u & M_c & R_L & \varepsilon_{stator} \end{pmatrix}^T$
```

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

```
for $i \in Z$
  for $r \in 1..N_r$
    $\begin{pmatrix} T^*{}_{1CA_r} \\ T^*{}_{3CA_r} \end{pmatrix} = \begin{pmatrix} T^*{}_{st(i,3),r} \\ T^*{}_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} P^*{}_{1CA_r} \\ P^*{}_{3CA_r} \end{pmatrix} = \begin{pmatrix} P^*{}_{st(i,3),r} \\ P^*{}_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} \rho^*{}_{1CA_r} \\ \rho^*{}_{3CA_r} \end{pmatrix} = \begin{pmatrix} \rho^*{}_{st(i,3),r} \\ \rho^*{}_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} Cp_{1CA_r} \\ Cp_{3CA_r} \end{pmatrix} = \begin{pmatrix} Cp_{воздух}\left(P^*{}_{1CA_r}, T^*{}_{1CA_r}\right) \\ Cp_{воздух}\left(P^*{}_{3CA_r}, T^*{}_{3CA_r}\right) \end{pmatrix}$
    $\begin{pmatrix} k_{1CA_r} \\ k_{3CA_r} \end{pmatrix} = \begin{pmatrix} k_{ад}\left(Cp_{1CA_r}, R_в\right) \\ k_{ад}\left(Cp_{3CA_r}, R_в\right) \end{pmatrix}$
    $\begin{pmatrix} a^*{}_{c1CA_r} \\ a^*{}_{c3CA_r} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{2 \cdot k_{1CA_r}}{k_{1CA_r}+1} \cdot R_в \cdot T^*{}_{1CA_r}} \\ \sqrt{\frac{2 \cdot k_{3CA_r}}{k_{3CA_r}+1} \cdot R_в \cdot T^*{}_{3CA_r}} \end{pmatrix}$
    $A = \left(1 - RL_{i,av(N_r)}\right) \cdot \omega \cdot \left(R_{st(i,3),av(N_r)}\right)^{m_i+1}$
    $B = \frac{H_{T_{i,av(N_r)}}}{2 \cdot \omega}$
    $\begin{pmatrix} c_{u1CA_r} \\ c_{u3CA_r} \end{pmatrix} = \Bigg( c_{u_{st(i,3),r}}$
        $c_{u3CA_{av(N_r)}}$ if $CA = 1$
```

$$u3CA_r \qquad c_{u_{st(i,3),r}} \quad \text{otherwise}$$

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

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

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

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

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

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

▲ Расчет параметров потока по высоте Л

Результаты расчета параметров потока по высоте Л

$$T^*_{1ВНА} = \begin{pmatrix} 288.2 \\ 288.2 \\ 288.2 \end{pmatrix} \qquad T^*_{3ВНА} = \begin{pmatrix} 288.2 \\ 288.2 \\ 288.2 \end{pmatrix} \qquad a^*_{c1ВНА} = \begin{pmatrix} 310.78 \\ 310.78 \\ 310.78 \end{pmatrix} \qquad a^*_{c3ВНА} = \begin{pmatrix} 310.78 \\ 310.78 \\ 310.78 \end{pmatrix} \qquad \alpha_{1ВНА} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ° \qquad \alpha_{3ВНА} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot °$$

$$P^*_{1ВНА} = \begin{pmatrix} 101.3 \\ 101.3 \\ 101.3 \end{pmatrix} \cdot 10^3 \qquad P^*_{3ВНА} = \begin{pmatrix} 101.3 \\ 101.3 \\ 101.3 \end{pmatrix} \cdot 10^3 \qquad c_{1ВНА} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix} \qquad c_{3ВНА} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix} \qquad \varepsilon_{ВНА} = \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot °$$

$$\rho^*_{1ВНА} = \begin{pmatrix} 1.224 \\ 1.224 \\ 1.224 \end{pmatrix} \qquad \rho^*_{3ВНА} = \begin{pmatrix} 1.224 \\ 1.224 \\ 1.224 \end{pmatrix} \qquad c_{u1ВНА} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \qquad c_{u3ВНА} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix}$$

$$Cp_{1ВНА} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix} \qquad Cp_{3ВНА} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix} \qquad c_{a1ВНА} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix} \qquad c_{a3ВНА} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix} \qquad \lambda_{c1ВНА} = \begin{pmatrix} 0.268 \\ 0.268 \\ 0.268 \end{pmatrix} \qquad \lambda_{c3ВНА} = \begin{pmatrix} 0.268 \\ 0.268 \\ 0.268 \end{pmatrix}$$

$$k_{1ВНА} = \begin{pmatrix} 1.401 \\ 1.401 \\ 1.401 \end{pmatrix} \qquad k_{3ВНА} = \begin{pmatrix} 1.401 \\ 1.401 \\ 1.401 \end{pmatrix}$$

$T*^{T} =$

	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	288.2	313.9	313.9	341.4	341.4	361.5	361.5																		
2	288.2	313.9	313.9	341.4	341.4	361.5	361.5																		
3	288.2	313.9	313.9	341.4	341.4	361.5	361.5																		

$T^{T} =$

	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	284.7	303.3	310.2	321.6	337.7	345.4	358.9																		
2	284.7	305.4	310.5	326.5	338.3	349.8	359.3																		
3	284.7	306.6	310.7	329.3	338.6	352.1	359.4																		

$P*^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	101.3	131.7	131.7	170.8	170.8	202.7	202.7														
2	101.3	131.7	131.7	170.8	170.8	202.7	202.7														
3	101.3	131.7	131.7	170.8	170.8	202.7	202.7														

$\cdot 10^{3}$

$P^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	97.1	116.7	126.2	138.5	164.3	172.7	197.6														
2	97.1	119.6	126.7	146.0	165.3	180.5	198.3														
3	97.1	121.2	127.0	150.4	165.8	184.7	198.6														

$\cdot 10^{3}$

$\rho*^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.224	1.461	1.461	1.742	1.742	1.952	1.952														
2	1.224	1.461	1.461	1.742	1.742	1.952	1.952														
3	1.224	1.461	1.461	1.742	1.742	1.952	1.952														

$\rho^{T} =$

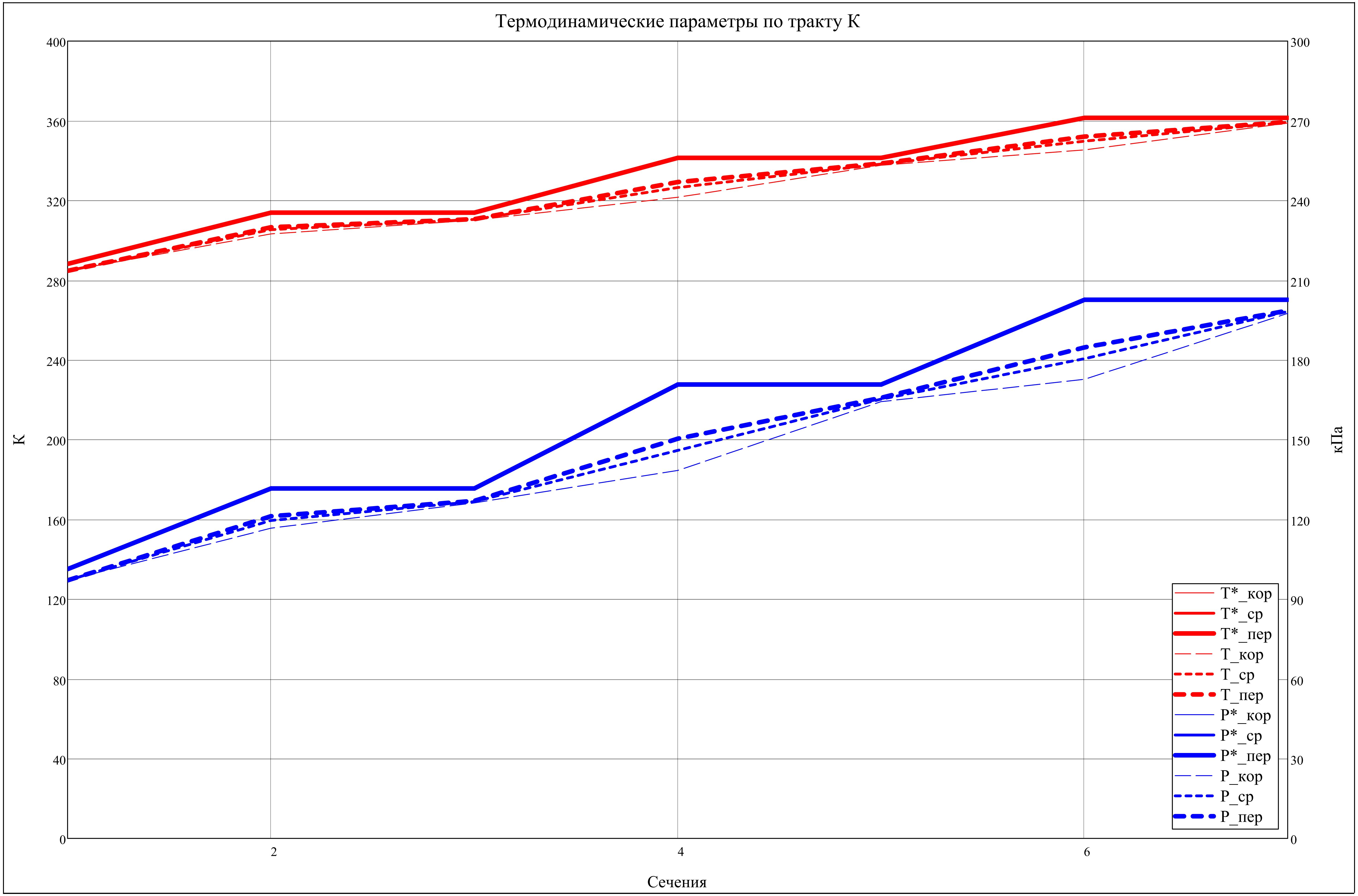
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.188	1.340	1.417	1.499	1.695	1.742	1.917														
2	1.188	1.364	1.421	1.557	1.702	1.797	1.922														
3	1.188	1.377	1.423	1.591	1.705	1.827	1.925														

$Cp^{T} =$

	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	1003	1004	1004	1006	1006	1009	1009																		
2	1003	1004	1004	1006	1006	1009	1009																		
3	1003	1004	1004	1006	1006	1009	1009																		

$k^{T} =$

	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	1.401	1.401	1.401	1.399	1.399	1.398	1.398																		
2	1.401	1.401	1.401	1.399	1.399	1.398	1.398																		
3	1.401	1.401	1.401	1.399	1.399	1.398	1.398																		


Термодинамические параметры по тракту К
К
кПа
Сечения
400
360
320
280
240
200
160
120
80
40
0
300
270
240
210
180
150
120
90
60
30
0
2
4
6
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	310.8	324.3	324.3	338.2	338.2	347.9	347.9																		
2	310.8	324.3	324.3	338.2	338.2	347.9	347.9																		
3	310.8	324.3	324.3	338.2	338.2	347.9	347.9																		

$a_{\text{зв}}^{T} =$

	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	338.5	349.2	353.2	359.5	368.4	372.4	379.6																		
2	338.5	350.5	353.4	362.2	368.7	374.7	379.8																		
3	338.5	351.1	353.5	363.7	368.8	376.0	379.9																		

$c^{T} =$

	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	83.4	146.2	87.1	199.8	86.4	180.1	72.6																		
2	83.4	130.8	83.0	173.3	79.8	153.9	67.3																		
3	83.4	121.2	80.6	156.4	76.0	137.8	64.6																		

$w^{T} =$

	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	228.6	118.3	179.0	68.8	152.9	61.1	140.1																		
2	264.4	164.9	220.5	107.9	197.8	103.5	187.4																		
3	295.8	205.5	256.0	151.5	235.3	148.8	225.8																		

$u^{T} =$

	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	212.8	213.6	214.4	207.9	201.4	187.7	174.3																		
2	250.8	251.2	251.5	245.5	239.6	227.6	215.9																		
3	283.8	283.8	283.8	278.1	272.5	261.6	250.7																		

$c_{a}^{T} =$

	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	83.4	77.3	71.1	66.0	61.0	58.6	56.1																		
2	83.4	77.3	71.1	66.0	61.0	58.6	56.1																		
3	83.4	77.3	71.1	66.0	61.0	58.6	56.1																		

$c_{u}^{T} =$

	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	0.0	124.1	50.2	188.6	61.2	170.3	46.0																		
2	0.0	105.6	42.8	160.2	51.5	142.3	37.1																		
3	0.0	93.4	37.9	141.7	45.3	124.7	32.0																		

$w_{u}^{T} =$

	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	212.8	89.5	164.2	19.3	140.2	17.4	128.3																	
2	250.8	145.6	208.7	85.3	188.1	85.3	178.8																	
3	283.8	190.4	245.9	136.4	227.2	136.8	218.7																	

```
$\Delta c_a$ =
  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	-6.15	-6.15	-5.13	-4.98	-2.44	-2.44														
2	0.00	-6.15	-6.15	-5.13	-4.98	-2.44	-2.44														
3	0.00	-6.15	-6.15	-5.13	-4.98	-2.44	-2.44														

[16, c. 81]

$\Delta c_a{}^T \ge -25 =$

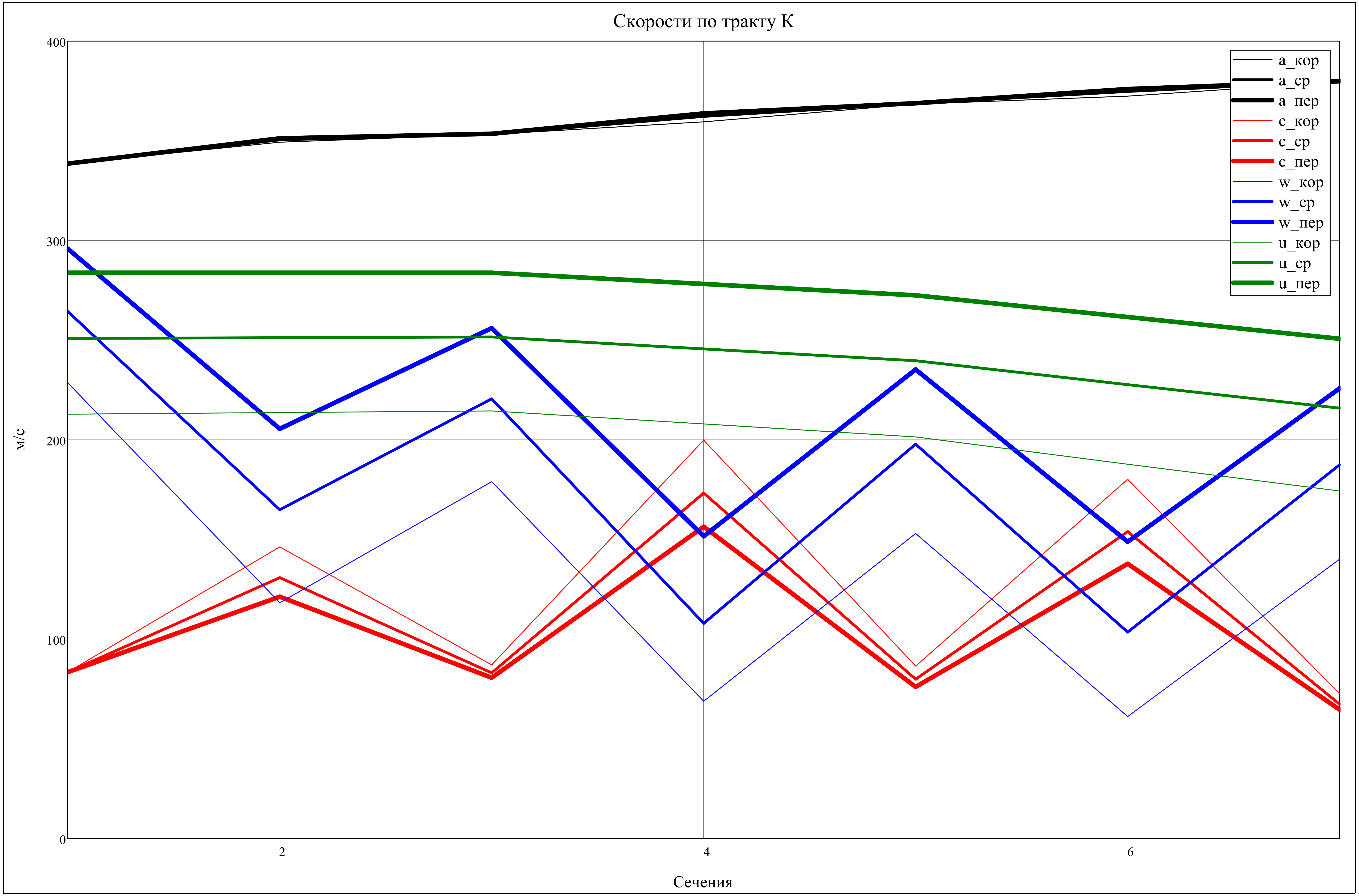
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1	1	1	1	1	1																		
2	1	1	1	1	1	1	1																		
3	1	1	1	1	1	1	1																		

$R_L{}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.7089	0.4346	0.4050									
2	0.7897	0.5916	0.5853									
3	0.8354	0.6803	0.6817									

$R_L{}^T \ge 0 =$

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


Скорости по тракту К
400
300
200
100
0
м/с
2
4
6
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	90.00	31.91	54.79	19.29	44.91	18.98	50.69																		
2	90.00	36.21	58.97	22.39	49.86	22.38	56.54																		
3	90.00	39.60	61.94	24.97	53.44	25.16	60.35																		

$\cdot °$

$\beta^T =$

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

$\cdot °$

$\beta^T \le 91 \cdot ° =$

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

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

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

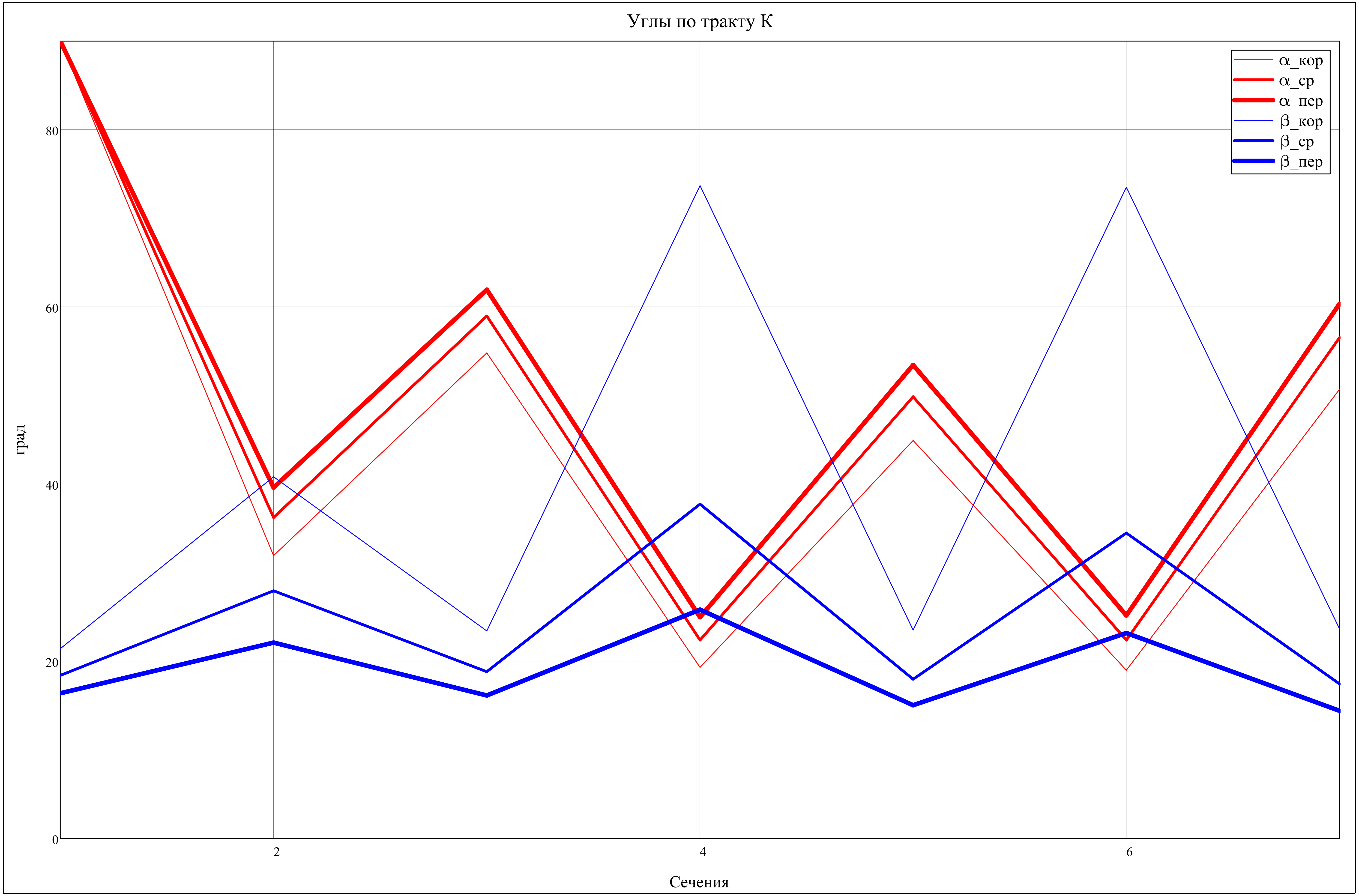
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	19.40	50.26	49.97												
2	9.56	18.91	16.50												
3	5.71	9.69	8.14												

$\cdot °$

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

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

$\cdot °$


Углы по тракту К
α_кор
α_ср
α_пер
β_кор
β_ср
β_пер
град
0
20
40
60
80
2
4
6
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	0.2685	0.4508	0.2685	0.5908	0.2556	0.5177	0.2086																
2	0.2685	0.4034	0.2560	0.5125	0.2361	0.4423	0.1935																
3	0.2685	0.3739	0.2486	0.4624	0.2247	0.3961	0.1857																

[16, c. 87] $\lambda_c{}^T \le 0.85 =$

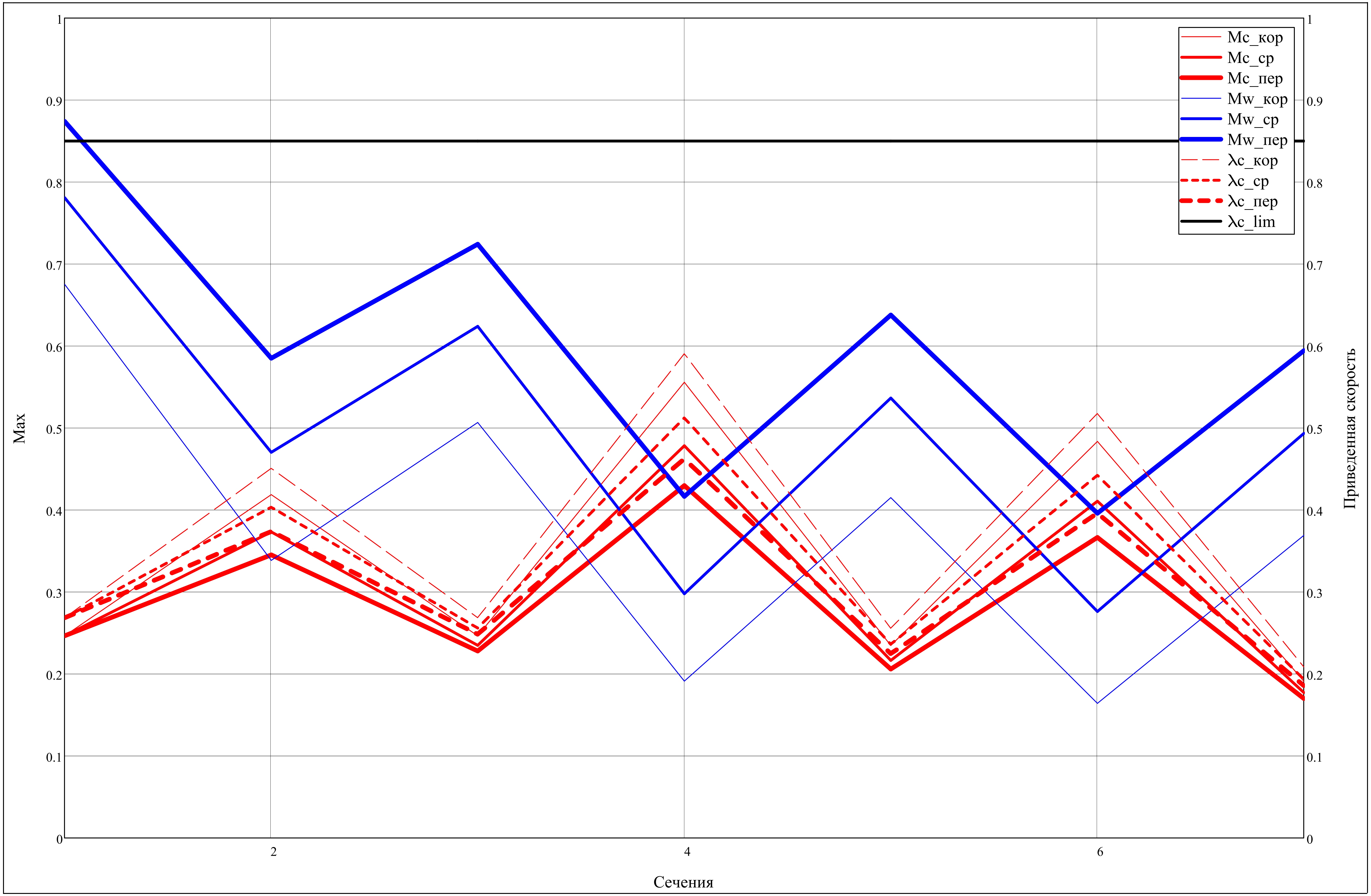
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	1	1	1	1	1	1												
2	1	1	1	1	1	1	1												
3	1	1	1	1	1	1	1												

$M_c{}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.2465	0.4187	0.2465	0.5558	0.2347	0.4837	0.1912																
2	0.2465	0.3733	0.2349	0.4784	0.2166	0.4107	0.1772																
3	0.2465	0.3453	0.2281	0.4299	0.2060	0.3666	0.1701																

$M_w{}^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.6753	0.3386	0.5068	0.1913	0.4152	0.1641	0.3690																
2	0.7810	0.4704	0.6241	0.2978	0.5365	0.2763	0.4934																
3	0.8740	0.5852	0.7242	0.4166	0.6379	0.3959	0.5944																


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Max
2
4
6
Сечения
Приведенная скорость
Mc_кор
Mc_ср
Mc_пер
Mw_кор
Mw_ср
Mw_пер
λc_кор
λc_ср
λc_пер
λc_lim

$$T^*_{1CA} = \begin{pmatrix}361.5\\361.5\\361.5\end{pmatrix} \qquad T^*_{3CA} = \begin{pmatrix}361.5\\361.5\\361.5\end{pmatrix} \qquad a^*_{c1CA} = \begin{pmatrix}347.9\\347.9\\347.9\end{pmatrix} \qquad a^*_{c3CA} = \begin{pmatrix}347.9\\347.9\\347.9\end{pmatrix} \qquad \alpha_{1CA} = \begin{pmatrix}50.69\\56.54\\60.35\end{pmatrix}\cdot{}^\circ \qquad \alpha_{3CA} = \begin{pmatrix}50.69\\56.54\\60.35\end{pmatrix}\cdot{}^\circ$$

$$P^*_{1CA} = \begin{pmatrix}202.7\\202.7\\202.7\end{pmatrix}\cdot 10^3 \qquad P^*_{3CA} = \begin{pmatrix}202.7\\202.7\\202.7\end{pmatrix}\cdot 10^3 \qquad c_{1CA} = \begin{pmatrix}72.6\\67.3\\64.6\end{pmatrix} \qquad c_{3CA} = \begin{pmatrix}72.6\\67.3\\64.6\end{pmatrix} \qquad \varepsilon_{CA} = \begin{pmatrix}0.00\\0.00\\0.00\end{pmatrix}\cdot{}^\circ$$

$$\rho^*_{1CA} = \begin{pmatrix}1.952\\1.952\\1.952\end{pmatrix} \qquad \rho^*_{3CA} = \begin{pmatrix}1.952\\1.952\\1.952\end{pmatrix} \qquad c_{u1CA} = \begin{pmatrix}46.0\\37.1\\32.0\end{pmatrix} \qquad c_{u3CA} = \begin{pmatrix}46.0\\37.1\\32.0\end{pmatrix}$$

$$Cp_{1CA} = \begin{pmatrix}1008.5\\1008.5\\1008.5\end{pmatrix} \qquad Cp_{3CA} = \begin{pmatrix}1008.5\\1008.5\\1008.5\end{pmatrix} \qquad c_{a1CA} = \begin{pmatrix}56.1\\56.1\\56.1\end{pmatrix} \qquad c_{a3CA} = \begin{pmatrix}56.1\\56.1\\56.1\end{pmatrix} \qquad \lambda_{c1CA} = \begin{pmatrix}0.209\\0.193\\0.186\end{pmatrix} \qquad \lambda_{c3CA} = \begin{pmatrix}0.209\\0.193\\0.186\end{pmatrix}$$

$$k_{1CA} = \begin{pmatrix}1.398\\1.398\\1.398\end{pmatrix} \qquad k_{3CA} = \begin{pmatrix}1.398\\1.398\\1.398\end{pmatrix}$$

▲ Результаты расчета параметров потока по высоте Л

Вывод результатов 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

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

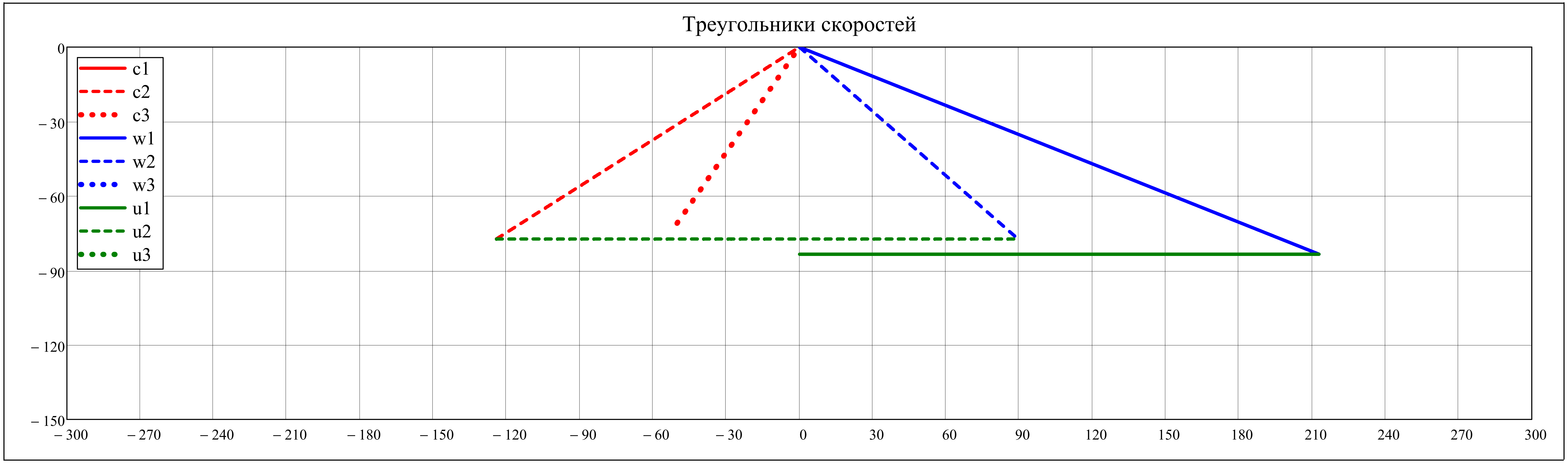
$$\Delta_w(v,i,j,r) = \left| \begin{array}{l} -\tan\left(\beta_{st(i,j),r}\right)\cdot v \ \text{ if } \left(-\tan\left(\beta_{st(i,j),r}\right) \ge 0\right) \wedge \left(-\left|w_{st(i,j),r}\cdot\cos\left(\beta_{st(i,j),r}\right)\right| \le v \le 0\right) \wedge (j \ne 3) \\ -\tan\left(\beta_{st(i,j),r}\right)\cdot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

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

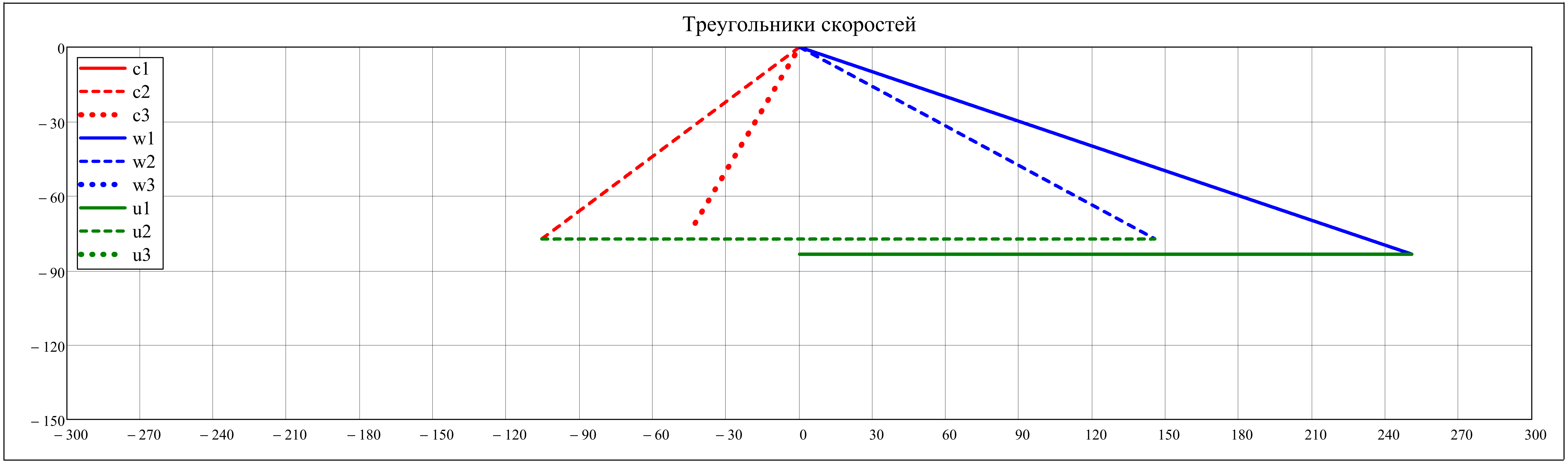
$$v_{lim} = \text{ceil}\left(\frac{\max(c,w,u)}{10^2}\right)\cdot 10^2 = 300$$

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

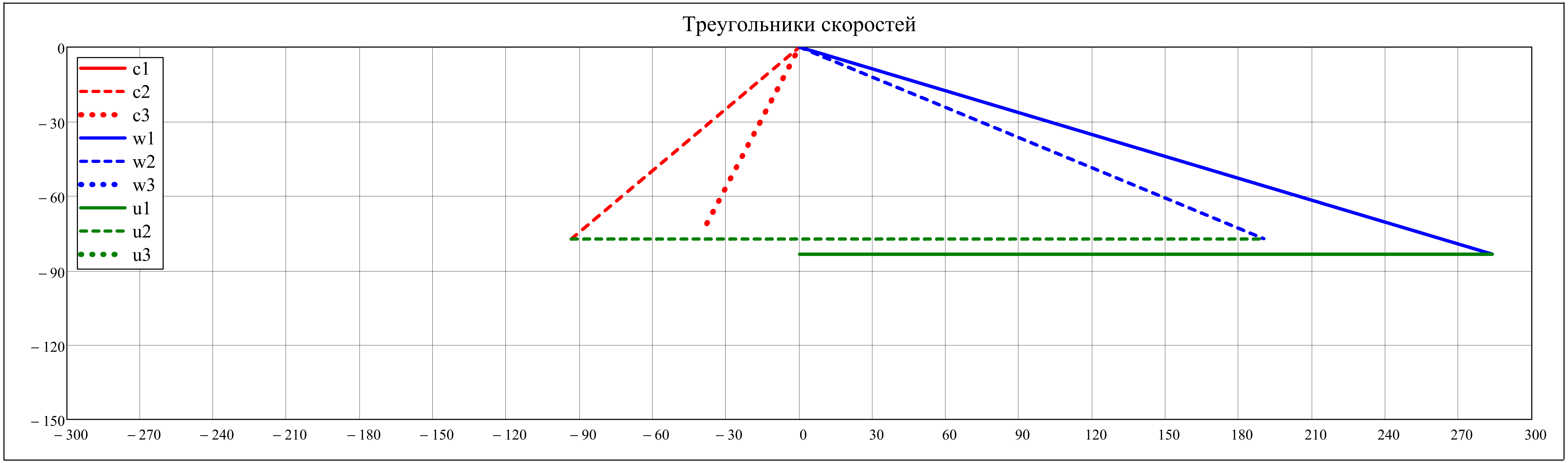
$r = 1$


Треугольники скоростей
c1
c2
c3
w1
w2
w3
u1
u2
u3
0
– 30
– 60
– 90
– 120
– 150
– 300
– 270
– 240
– 210
– 180
– 150
– 120
– 90
– 60
– 30
0
30
60
90
120
150
180
210
240
270
300

$r = av(N_r)$


Треугольники скоростей
c1
c2
c3
w1
w2
w3
u1
u2
u3
0
– 30
– 60
– 90
– 120
– 150
– 300
– 270
– 240
– 210
– 180
– 150
– 120
– 90
– 60
– 30
0
30
60
90
120
150
180
210
240
270
300

$r = N_r$



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

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	0.0514	0.0509	0.0504	0.0497	0.0490	0.0484	0.0473												
2	0.3083	0.3053	0.3023	0.2985	0.2942	0.2902	0.2837												
3	0.3596	0.3382	0.3526	0.3476	0.3433	0.3404	0.3310												

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	404.2	405.4	406.6	395.2	383.9	360.2	337.1												
2	808.4	810.8	813.1	790.3	767.7	720.4	674.3												

$\cdot 10^{-3}$

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

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

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

$\prod_{i=1}^{Z} \pi*_{I_i} = 2.000$

$\prod_{i=1}^{Z} \pi*_{II_i} = 2.000$

▲ Определение степени повышения полного давлеия по 2ум контурам

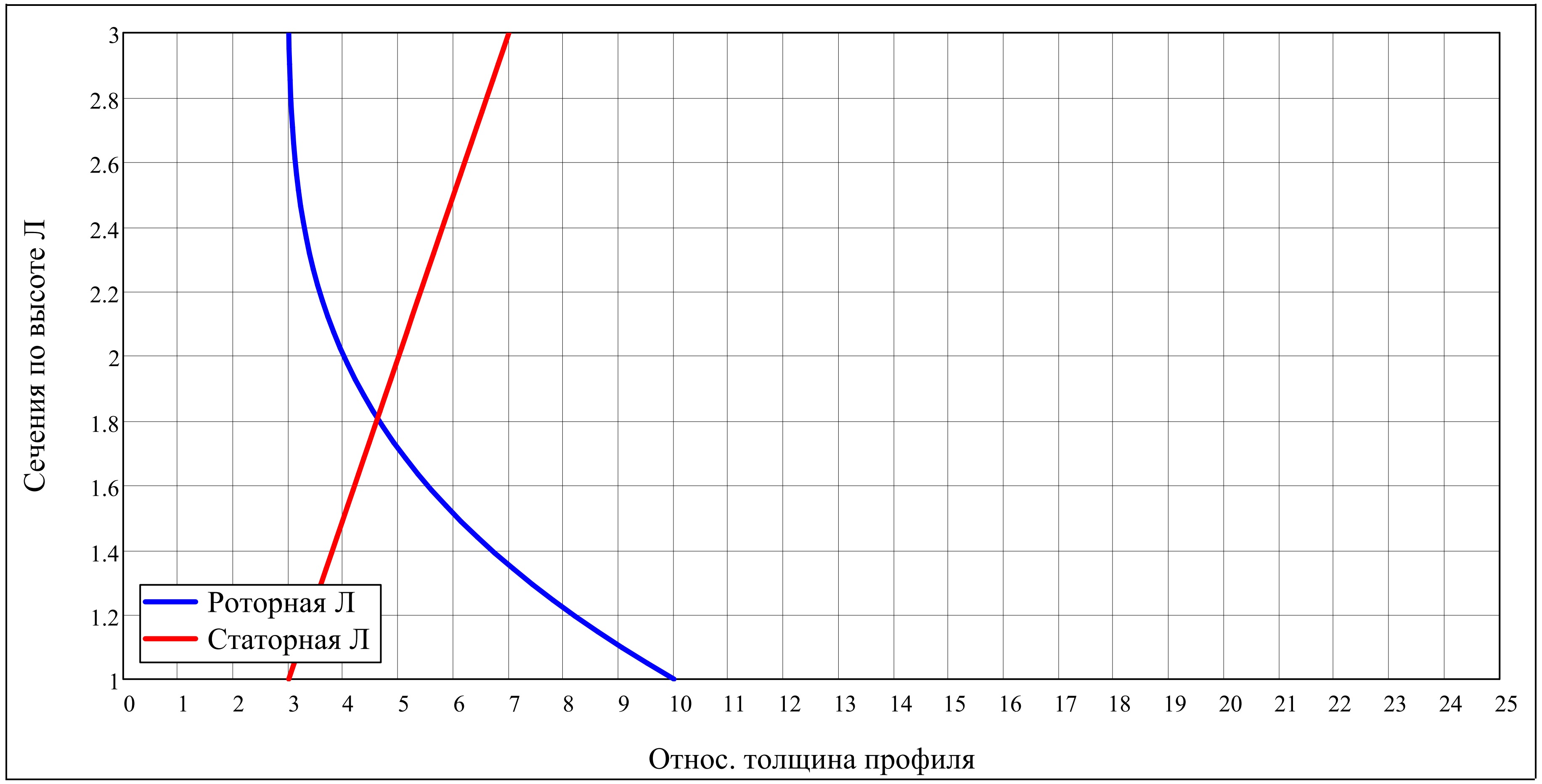
Относ. толщины и радиусы профилей

Относ. толщины Л РК и СА:

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

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

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



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

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

	1
1	3.00
2	5.00
3	7.00

$\cdot\%$

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

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

	1	2	3
1	3.00	3.00	3.00
2	5.00	5.00	5.00
3	7.00	7.00	7.00

$\cdot\%$

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

	1	2	3
1	10.00	10.00	10.00
2	4.00	4.00	4.00
3	3.00	3.00	3.00

$\cdot\%$

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

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

	1
1	3.00
2	5.00
3	7.00

$\cdot\%$

```
$\begin{pmatrix} \overline{r}\_inlet_{BHA} \\ \overline{r}\_outlet_{BHA} \end{pmatrix} =$  | for $r \in 1..N_r$                                                              if $BHA = 1$
                                                    |     $\begin{pmatrix} \overline{r}\_inlet_{BHA_r} \\ \overline{r}\_outlet_{BHA_r} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c}_{stator.}(r)$
                                                    | $\begin{pmatrix} \overline{r}\_inlet_{BHA} \\ \overline{r}\_outlet_{BHA} \end{pmatrix}$
```

```
$\begin{pmatrix} \overline{r}\_inlet_{CA} \\ \overline{r}\_outlet_{CA} \end{pmatrix} =$  | for $r \in 1..N_r$                                                              if $CA = 1$
                                                  |     $\begin{pmatrix} \overline{r}\_inlet_{CA_r} \\ \overline{r}\_outlet_{CA_r} \end{pmatrix} = \begin{pmatrix} 0.2 \\ 0.1 \end{pmatrix} \cdot \overline{c}_{stator.}(r)$
                                                  | $\begin{pmatrix} \overline{r}\_inlet_{CA} \\ \overline{r}\_outlet_{CA} \end{pmatrix}$
```

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

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

	1	2	3
1	0.600	0.600	0.600
2	1.000	1.000	1.000
3	1.400	1.400	1.400

$\cdot \%$

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

	1	2	3
1	0.300	0.300	0.300
2	0.500	0.500	0.500
3	0.700	0.700	0.700

$\cdot \%$

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

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

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

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

	1	2	3
1	2.000	2.000	2.000
2	0.800	0.800	0.800
3	0.600	0.600	0.600

$\cdot \%$

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

	1	2	3
1	1.000	1.000	1.000
2	0.400	0.400	0.400
3	0.300	0.300	0.300

$\cdot \%$

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

▲ Относ. толщины и радиусы профилей

▾ Распределение параметров по высоте Л

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

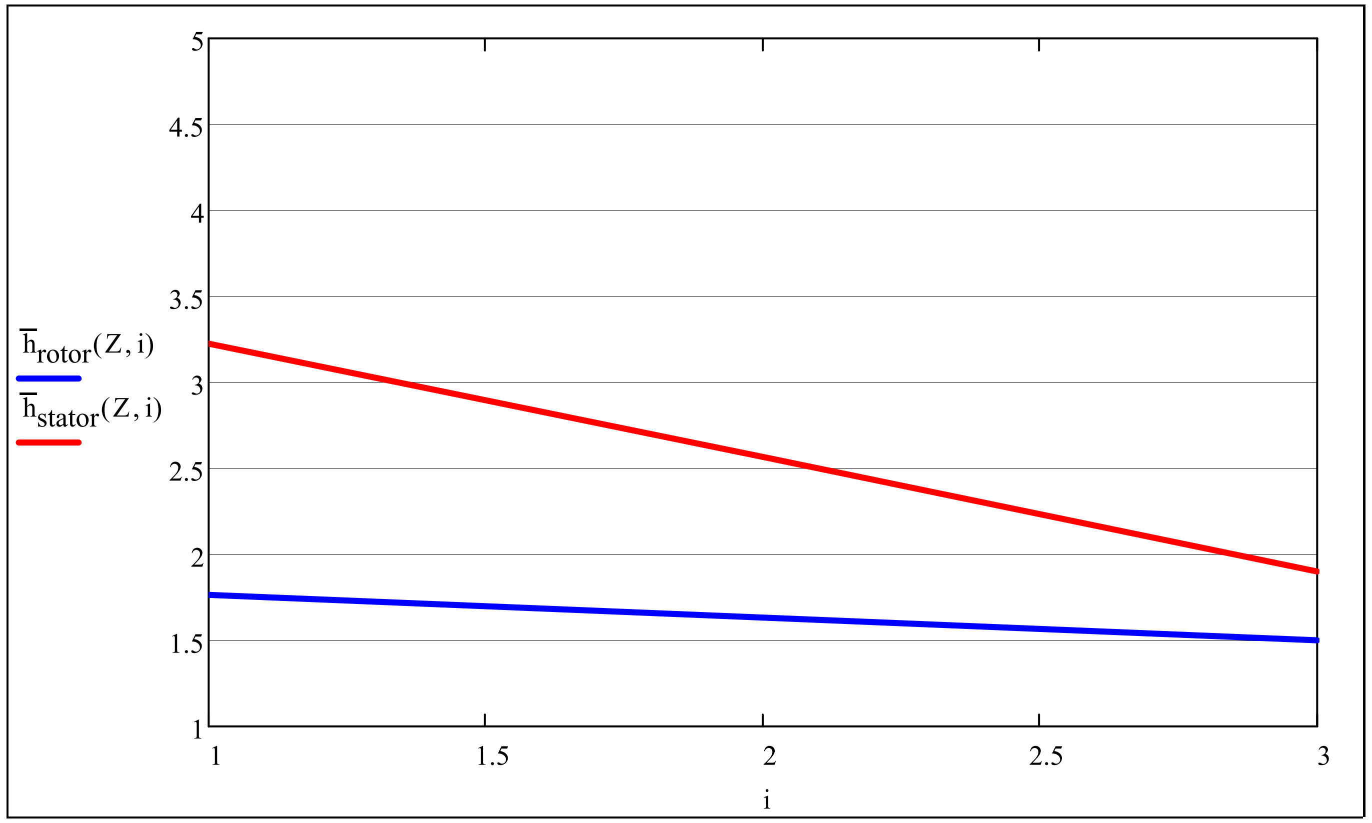
$$\overline{h}_{\sim rotor} = (2\ \ 1.9\ \ 1.85\ \ 1.8\ \ 1.75\ \ 1.7\ \ 1.65\ \ 1.6)^{T} + \left| \begin{array}{l} 1.1 \ \text{ if } \ compressor = \text{"Вл"} \\ -0.1 \ \text{ if } \ compressor = \text{"КНД"} \\ -0.55 \ \text{ if } \ compressor = \text{"КВД"} \end{array} \right.$$

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

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

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

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



Для компрессора газогенератора

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

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

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

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

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

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

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
        $\left(r\_inlet_{BHA_r} \;\; r\_outlet_{BHA_r}\right) = chord_{BHA_r} \cdot \left(\overline{r\_inlet}_{BHA_r} \;\; \overline{r\_outlet}_{BHA_r}\right)$
        $t_{BHA_r} = \frac{D_{st(1,1),r}}{Z_{BHA}}$
        $i_{BHA_r} = 2.5 \cdot \left(\frac{chord_{BHA_r}}{t_{BHA_r}} - 2\right) \cdot {}^\circ$
        $m_{BHA} = 0.23 \cdot \left(2 \cdot \overline{x}_f\right)^2 + 0.18 - \frac{0.002}{\;} \cdot \left(\alpha_{3BHA}\right)$
```

$$\theta_{\text{ВНА}_r} = \frac{\varepsilon_{\text{ВНА}_r} - i_{\text{ВНА}_r}}{1 - m_{\text{ВНА}_r}\cdot\sqrt{\dfrac{t_{\text{ВНА}_r}}{\text{chord}_{\text{ВНА}_r}}}}$$

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

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

$$\upsilon_{\text{ВНА}_r} = \chi_{\text{ВНА}_r} + \alpha_{1\text{ВНА}_r} + i_{\text{ВНА}_r}$$

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

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

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

$$\left(\varepsilon_{\text{ВНА(b/t)=1}}\ \ Z_{\text{ВНА}}\ \ \text{r\_inlet}_{\text{ВНА}}\ \ \text{r\_outlet}_{\text{ВНА}}\ \ t_{\text{ВНА}}\ \ i_{\text{ВНА}}\ \ m_{\text{ВНА}}\ \ \theta_{\text{ВНА}}\ \ \delta_{\text{ВНА}}\ \ \chi_{\text{ВНА}}\ \ \upsilon_{\text{ВНА}}\ \ R_{\text{СЛ.ВНА}}\ \ K_{\text{ВНА}}\ \ D_{\text{ВНА}}\right)^T$$

$$\begin{pmatrix} \varepsilon_{\text{РК(b/t)=1}} & \varepsilon_{\text{НА(b/t)=1}} \\ Z_{\text{rotor}} & Z_{\text{stator}} \\ \text{r\_inlet}_{\text{rotor}} & \text{r\_inlet}_{\text{stator}} \\ \text{r\_outlet}_{\text{rotor}} & \text{r\_outlet}_{\text{stator}} \\ t_{\text{rotor}} & t_{\text{stator}} \\ i_{\text{rotor}} & i_{\text{stator}} \\ m_{\text{rotor}} & m_{\text{stator}} \\ \theta_{\text{rotor}} & \theta_{\text{stator}} \\ \delta_{\text{rotor}} & \delta_{\text{stator}} \\ \chi_{\text{rotor}} & \chi_{\text{stator}} \\ \upsilon_{\text{rotor}} & \upsilon_{\text{stator}} \\ R_{\text{СЛ.rotor}} & R_{\text{СЛ.stator}} \\ K_{\text{rotor}} & K_{\text{stator}} \\ D_{\text{rotor}} & D_{\text{stator}} \\ \zeta_{\text{rotor}} & \zeta_{\text{stator}} \\ \text{quality}_{\text{rotor}} & \text{quality}_{\text{stator}} \\ \eta_{\text{stage}} & \eta_{\text{stage}} \end{pmatrix} =$$

```
for  $i \in 1..Z$
    for  $r \in av(N_r)$
        $\begin{pmatrix} \varepsilon_{\text{РК(b/t)=1}_{i,r}} \\ \varepsilon_{\text{НА(b/t)=1}_{i,r}} \end{pmatrix} = \begin{pmatrix} \varepsilon_{(b/t)=1}(\beta_{st(i,2),r}) \\ \varepsilon_{(b/t)=1}(\alpha_{st(i,3),r}) \end{pmatrix}$
        $\begin{pmatrix} b/t_{\text{РК}_{i,r}} \\ b/t_{\text{НА}_{i,r}} \end{pmatrix} = \begin{pmatrix} b/t{=}1\left(\dfrac{\varepsilon_{\text{rotor}_{i,r}}}{\varepsilon_{\text{РК(b/t)=1}_{i,r}}}\right) \\ b/t{=}1\left(\dfrac{\varepsilon_{\text{stator}_{i,r}}}{\varepsilon_{\text{НА(b/t)=1}_{i,r}}}\right) \end{pmatrix}$
        $\begin{pmatrix} t_{\text{rotor}_{i,r}} \\ t_{\text{stator}_{i,r}} \end{pmatrix} = \begin{pmatrix} \dfrac{\text{chord}_{\text{rotor}_{i,r}}}{b/t_{\text{РК}_{i,r}}} \\ \dfrac{\text{chord}_{\text{stator}_{i,r}}}{b/t_{\text{НА}_{i,r}}} \end{pmatrix}$
        $\begin{pmatrix} t_{\text{rotor}_{i,r}} \\ t_{\text{stator}_{i,r}} \end{pmatrix} = \dfrac{2}{3}\begin{pmatrix} \text{chord}_{\text{rotor}_{i,r}}\cdot\cos(\beta_{st(i,1),r}) \\ \text{chord}_{\text{stator}_{i,r}}\cdot\cos(\alpha_{st(i,2),r}) \end{pmatrix}$
        $Z_{\text{stator}_i} =$
            $\text{round}\left(\dfrac{\pi\cdot\text{mean}(D_{st(i,2),r}, D_{st(i,3),r})}{t_{\text{stator}_{i,r}}}\right)$  if  $\text{mod}\left(\text{round}\left(\dfrac{\pi\cdot\text{mean}(D_{st(i,2),r}, D_{st(i,3),r})}{t_{\text{stator}_{i,r}}}\right), 2\right) = 0$
            $\text{round}\left(\dfrac{\pi\cdot\text{mean}(D_{st(i,2),r}, D_{st(i,3),r})}{t_{\text{stator}_{i,r}}}\right) + 1$  otherwise
        $Z_{\text{rotor}_i} =$
            $Z_{\text{rotor}_i} = \text{round}\left(\dfrac{\pi\cdot\text{mean}(D_{st(i,1),r}, D_{st(i,2),r})}{t_{\text{rotor}_{i,r}}}\right)$
```

```
            while $\gcd\left(Z_{rotor_i}, Z_{stator_i}\right) \neq 1$
                $Z_{rotor_i} = Z_{rotor_i} + 1$
    for $r \in 1 .. N_r$
        $\begin{pmatrix} r\_inlet_{stator_{i,r}} & r\_outlet_{stator_{i,r}} \\ r\_inlet_{rotor_{i,r}} & r\_outlet_{rotor_{i,r}} \end{pmatrix} = \begin{pmatrix} \overline{r}\_inlet_{stator_{i,r}} \cdot chord_{stator_{i,r}} & \overline{r}\_outlet_{stator_{i,r}} \cdot chord_{stator_{i,r}} \\ \overline{r}\_inlet_{rotor_{i,r}} \cdot chord_{rotor_{i,r}} & \overline{r}\_outlet_{rotor_{i,r}} \cdot chord_{rotor_{i,r}} \end{pmatrix}$
        $\begin{pmatrix} t_{rotor_{i,r}} \\ t_{stator_{i,r}} \end{pmatrix} = \pi \cdot \begin{pmatrix} \dfrac{mean\left(D_{st(i,1),r}, D_{st(i,2),r}\right)}{Z_{rotor_i}} \\ \dfrac{mean\left(D_{st(i,2),r}, D_{st(i,3),r}\right)}{Z_{stator_i}} \end{pmatrix}$
        $\begin{pmatrix} i_{rotor_{i,r}} \\ i_{stator_{i,r}} \end{pmatrix} = 2.5 \cdot \begin{pmatrix} \dfrac{chord_{rotor_{i,r}}}{t_{rotor_{i,r}}} - 1 \\ \dfrac{chord_{stator_{i,r}}}{t_{stator_{i,r}}} - 2 \end{pmatrix} \cdot {}^{\circ}$
        $\begin{pmatrix} m_{rotor_{i,r}} \\ m_{stator_{i,r}} \end{pmatrix} = 0.23 \cdot \left(2 \cdot \overline{x}_f\right)^2 + 0.18 - \dfrac{0.002}{deg} \cdot \begin{pmatrix} \beta_{st(i,2),r} \\ \alpha_{st(i,3),r} \end{pmatrix}$
        $\begin{pmatrix} \theta_{rotor_{i,r}} \\ \theta_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \dfrac{\varepsilon_{rotor_{i,r}} - i_{rotor_{i,r}}}{1 - m_{rotor_{i,r}} \cdot \sqrt{\dfrac{t_{rotor_{i,r}}}{chord_{rotor_{i,r}}}}} \\ \dfrac{\varepsilon_{stator_{i,r}} - i_{stator_{i,r}}}{1 - m_{stator_{i,r}} \cdot \sqrt{\dfrac{t_{stator_{i,r}}}{chord_{stator_{i,r}}}}} \end{pmatrix}$
        $\begin{pmatrix} \delta_{rotor_{i,r}} \\ \delta_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} m_{rotor_{i,r}} \cdot \theta_{rotor_{i,r}} \cdot \sqrt{\dfrac{t_{rotor_{i,r}}}{chord_{rotor_{i,r}}}} \\ m_{stator_{i,r}} \cdot \theta_{stator_{i,r}} \cdot \sqrt{\dfrac{t_{stator_{i,r}}}{chord_{stator_{i,r}}}} \end{pmatrix}$
        $\begin{pmatrix} \chi_{rotor_{i,r}} \\ \chi_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \theta_{rotor_{i,r}} \\ \theta_{stator_{i,r}} \end{pmatrix} \cdot \dfrac{1 + 2 \cdot \left(1 - 2 \cdot \overline{x}_f\right)}{2}$
        $\begin{pmatrix} \upsilon_{rotor} \end{pmatrix} \quad \begin{pmatrix} \chi_{rotor} + \beta_{st(i,1),r} + i_{rotor} \end{pmatrix}$
```

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

▲ Определение количества Л РК и НА

Результаты расчета количества Л и параметров решеток РК и НА

Длина хорды Л (м):

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

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

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

$\cdot 10^{-3}$

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

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

$\cdot 10^{-3}$

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

Радисы входных и выходных кромок профилей Л (мм):

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

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

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

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

$\cdot 10^{-3}$

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

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

$\cdot 10^{-3}$

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

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

$\cdot 10^{-3}$

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

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

$\cdot 10^{-3}$

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

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

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

Угол поворота потока:

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7.51	10.23	9.22												

$\cdot°$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	19.44	14.94	18.16												

$\cdot°$

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

$\frac{chord_{BHA}}{t_{BHA}} = ■$

Густота решетки:

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-305.947	-411.265	-1019.428												
2	288.710	387.361	956.340												
3	1.926	2.868	8.574												

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

	1	2	3
1	76.676	100.764	172.184
2	-63.250	-83.302	-143.804
3	8.424	11.159	19.786

$\frac{chord_{CA}}{t_{CA}} = ■$

$Z_{BHA} = 0$

Количество Л:

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	63	59	49												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	136	90	58												

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

$Z_{CA} = 0$

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

$t_{rotor}^{T} =$

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

$\cdot 10^{-3}$

Шаг решетки (м):

$t_{stator}^{T} =$

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

$\cdot 10^{-3}$

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

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

$i_{rotor}^{T} =$

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

$\cdot ^{\circ}$

Угол атаки:

$i_{stator}^{T} =$

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

$\cdot ^{\circ}$

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

$m_{BHA} = 0.0000$

Коэф. формы ср. линии профиля по Ховеллу:

$m_{rotor}^{T} =$

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

$m_{stator}^{T} =$

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

$m_{CA} = 0.0000$

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

Угол изгиба ср. линии профиля:

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

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

$\cdot {}^{\circ}$

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

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

$\cdot {}^{\circ}$

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

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

Угол отставания:

$$\delta_{rotor}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 6.205 & 12.567 & 12.364 \\ 2 & 3.138 & 6.207 & 5.496 \\ 3 & 1.744 & 3.237 & 2.730 \end{array} \cdot {}^\circ$$

$$\delta_{stator}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 5.391 & 11.847 & 9.540 \\ 2 & 5.491 & 12.423 & 10.553 \\ 3 & 5.469 & 12.636 & 11.030 \end{array} \cdot {}^\circ$$

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

$$\upsilon_{BHA} = 0.00 \cdot {}^\circ$$

Угол установки Л:

$$\upsilon_{rotor}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 34.99 & 55.63 & 55.52 \\ 2 & 25.50 & 32.15 & 29.74 \\ 3 & 20.84 & 23.35 & 21.20 \end{array} \cdot {}^\circ$$

$$\upsilon_{stator}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 44.47 & 43.04 & 39.38 \\ 2 & 48.70 & 46.97 & 44.29 \\ 3 & 51.86 & 49.82 & 47.70 \end{array} \cdot {}^\circ$$

$$\upsilon_{CA} = 0.00 \cdot {}^\circ$$

$R_{СЛ.ВНА} = 0.00\cdot10^{-3}$

$R_{СЛ.rotor}^{T} =$

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

$\cdot10^{-3}$

Радиус дуги ср. линии (м):

$R_{СЛ.stator}^{T} =$

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

$\cdot10^{-3}$

$R_{СЛ.СА} = 0.00\cdot10^{-3}$

$K_{ВНА} = 0.0000$

$K_{rotor}^{T} =$

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

Фактор диффузорности решетки:

$K_{stator}^{T} =$

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

$K_{СА} = 0.0000$

$D_{BHA} = 0.0000$

Диффузорность решетки:

$D_{rotor}{}^{T} =$

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

$D_{stator}{}^{T} =$

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

$D_{CA} = 0.0000$

$D_{BHA} \le 0.6 = 1$

[18, с. 71]

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

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

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

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

$D_{CA} \le 0.6 = 1$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.1642	0.2239	0.2139												
2	0.1334	0.1968	0.1814												
3	0.1167	0.1666	0.1503												

Коэф. потерь полного давления:

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.1062	0.2285	0.2447												
2	0.0831	0.1859	0.1949												
3	0.0692	0.1585	0.1640												

$\mathrm{quality}_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7.867	6.291	6.658												
2	8.757	7.086	8.035												
3	8.768	7.906	9.308												

Качество профилей решеток РК и НА:

$\mathrm{quality}_{stator}{}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	9.639	6.219	6.112												
2	11.373	7.226	7.263												
3	12.814	8.088	8.247												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	76.99	71.59	71.40												
2	76.42	73.27	74.09												
3	74.25	73.18	74.39												

$\cdot\%$

▲ Результаты расчета количества Л и параметров решеток РК и НА

Вывод параметров решеток

Подключение симметричного профиля

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

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

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

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

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

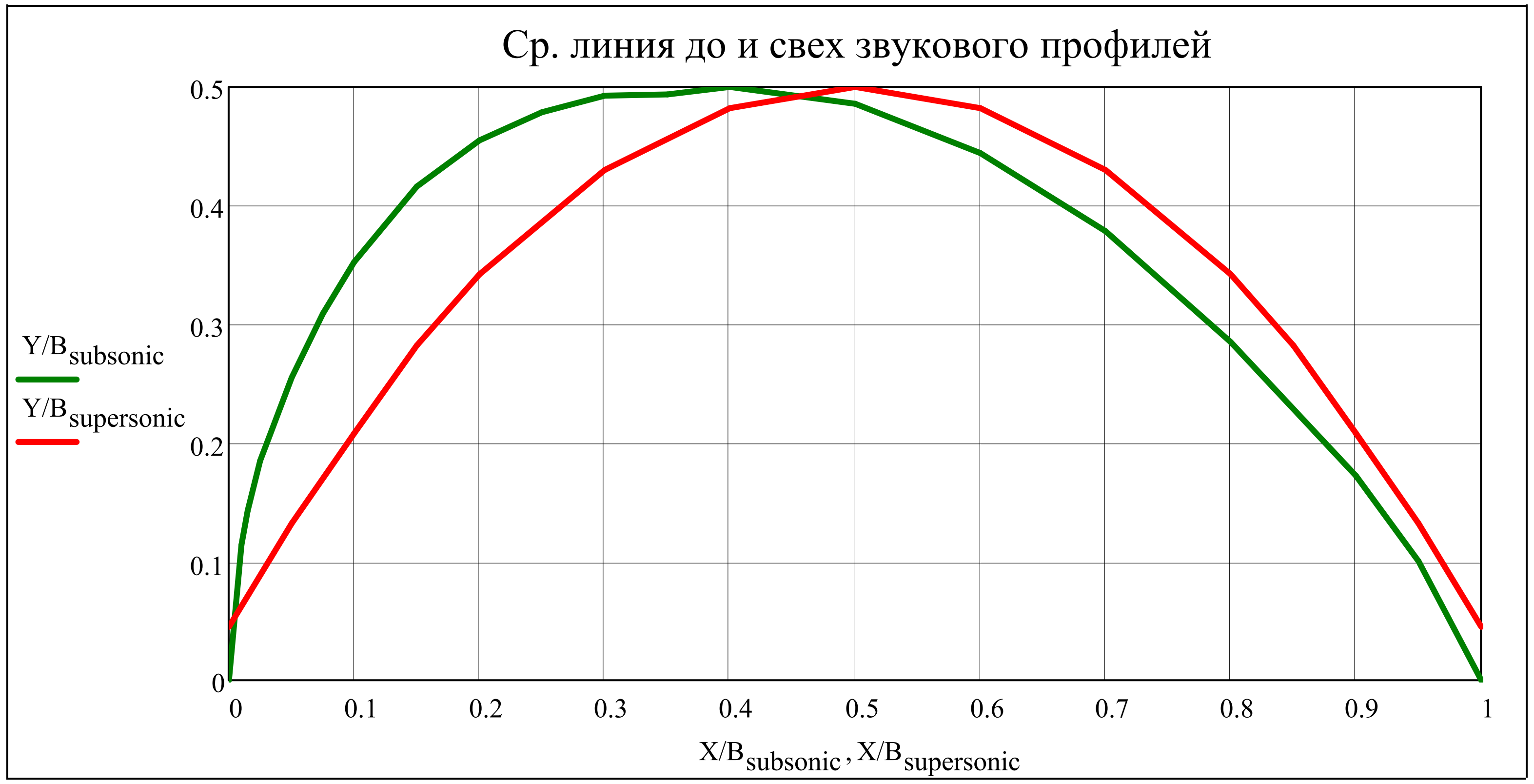
$Y/B_{supersonic} = submatrix\left(EXCEL_{AIRFOIL.supersonic}, 2, rows\left(EXCEL_{AIRFOIL.supersonic}\right), ORIGIN + 1, ORIGIN + 1\right)$

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

	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

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

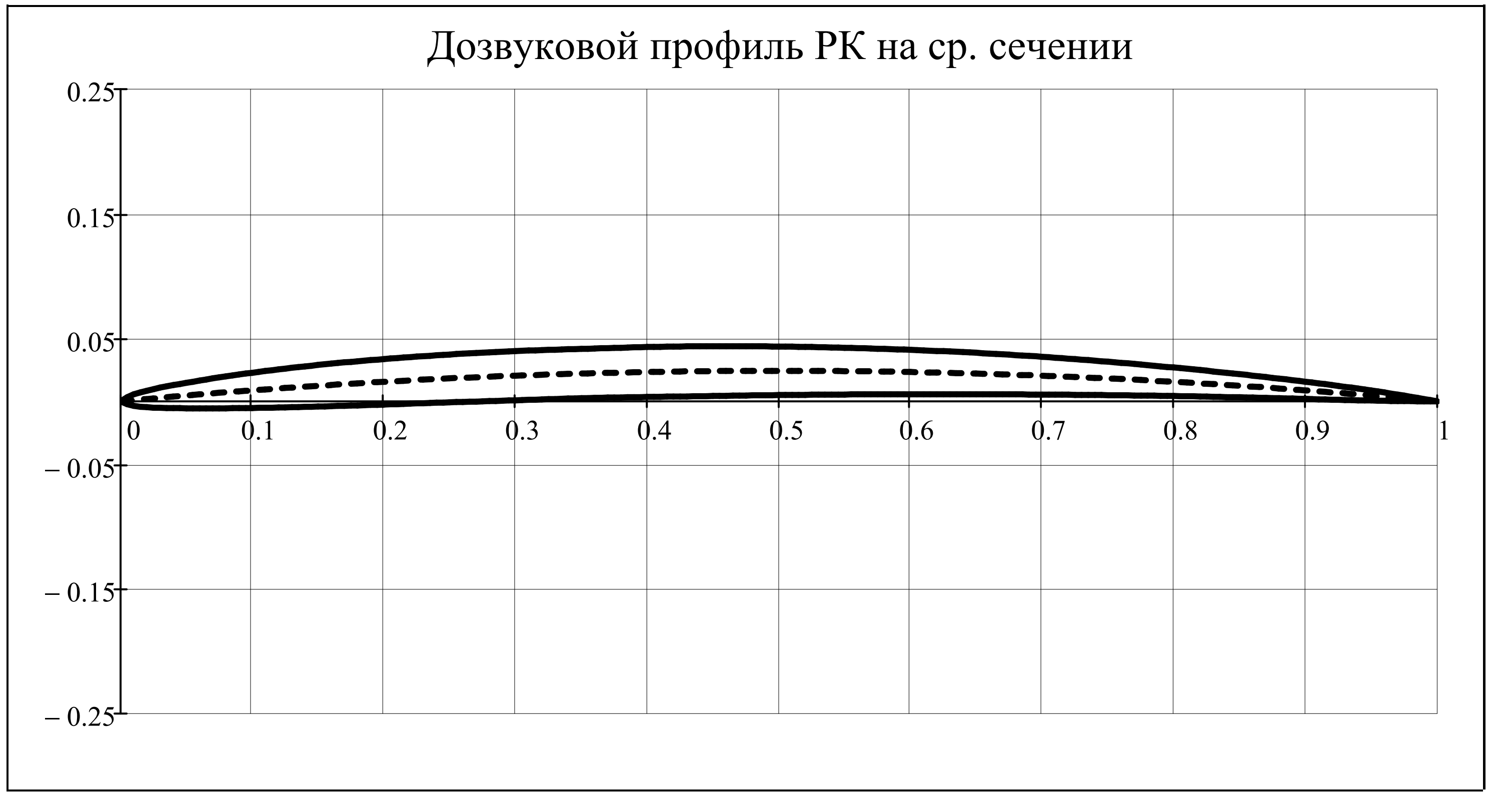
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.000	0.050	0.100	0.150	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.850	0.900	0.950	1.000
2	0.045	0.132	0.208	0.282	0.342	0.430	0.482	0.500	0.482	0.430	0.342	0.282	0.208	0.132	0.045

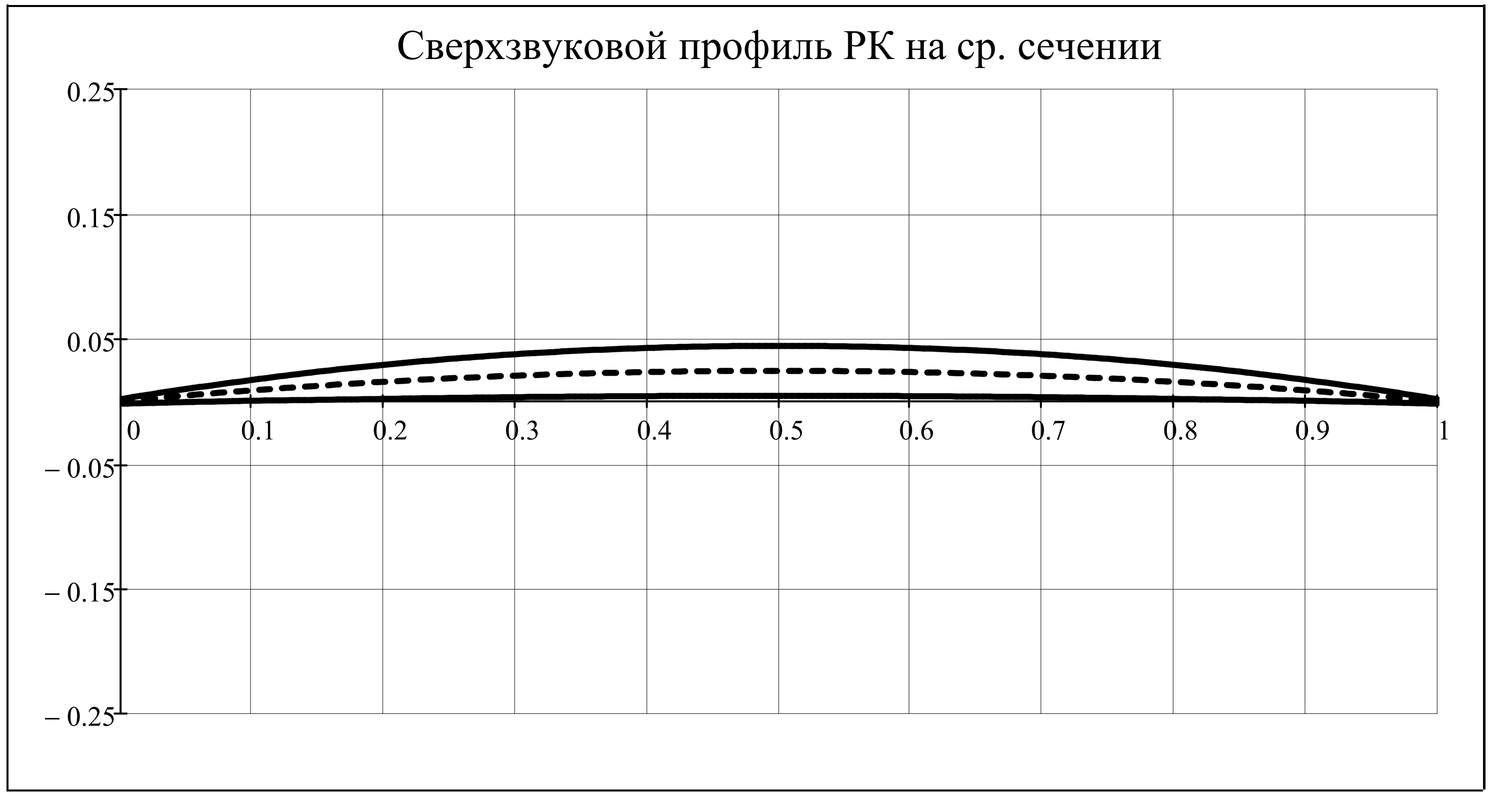

Ср. линия до и свех звукового профилей

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

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

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


Дозвуковой профиль РК на ср. сечении


Сверхзвуковой профиль РК на ср. сечении

Подключение симметричного профиля

▶ Определение относительных геометрических характеристик сечений Л

▶ Результат расчета абсолютных геометрических характеристик сечений Л

▶ Определение абсолютных геометрических характеристик сечений Л

Результат расчета абсолютных геометрических характеристик сечений Л

$$l\_upper_{stator}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 35.57 & 45.89 & 65.57 \\ 2 & 39.55 & 51.20 & 73.27 \\ 3 & 43.08 & 55.90 & 79.95 \end{array} \cdot 10^{-3}$$

$$l\_lower_{stator}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 35.31 & 45.28 & 64.80 \\ 2 & 39.07 & 50.05 & 71.76 \\ 3 & 42.37 & 54.16 & 77.65 \end{array} \cdot 10^{-3}$$

$$area_{stator}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 27.22 & 44.00 & 90.69 \\ 2 & 55.60 & 89.89 & 185.62 \\ 3 & 91.47 & 147.83 & 304.72 \end{array} \cdot 10^{-6}$$

$$Sx_{stator}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 31.7 & 120.5 & 310.6 \\ 2 & 71.8 & 283.1 & 760.0 \\ 3 & 126.4 & 511.5 & 1392.7 \end{array} \cdot 10^{-9}$$

$$Sy_{stator}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 433.1 & 889.8 & 2633.2 \\ 2 & 979.2 & 2012.8 & 5972.5 \\ 3 & 1746.1 & 3587.6 & 10617.2 \end{array} \cdot 10^{-9}$$

$$x0_{stator}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 15.91 & 20.22 & 29.04 \\ 2 & 17.61 & 22.39 & 32.18 \\ 3 & 19.09 & 24.27 & 34.84 \end{array} \cdot 10^{-3}$$

$$y0_{stator}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1.16 & 2.74 & 3.42 \\ 2 & 1.29 & 3.15 & 4.09 \\ 3 & 1.38 & 3.46 & 4.57 \end{array} \cdot 10^{-3}$$

$$l\_upper_{rotor}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 63.84 & 71.14 & 80.24 \\ 2 & 72.47 & 77.89 & 87.86 \\ 3 & 80.95 & 86.62 & 97.69 \end{array} \cdot 10^{-3}$$

$$l\_lower_{rotor}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 62.41 & 67.23 & 75.86 \\ 2 & 72.13 & 77.16 & 87.14 \\ 3 & 80.77 & 86.30 & 97.38 \end{array} \cdot 10^{-3}$$

$$area_{rotor}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 282.07 & 321.98 & 410.06 \\ 2 & 151.96 & 173.54 & 221.57 \\ 3 & 143.01 & 163.24 & 207.90 \end{array} \cdot 10^{-6}$$

$$Sx_{rotor}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 567.5 & 1830.2 & 2614.5 \\ 2 & 174.3 & 421.9 & 530.6 \\ 3 & 109.8 & 227.2 & 274.4 \end{array} \cdot 10^{-9}$$

$$Sy_{rotor}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 7911.0 & 9648.4 & 13867.0 \\ 2 & 4946.1 & 6036.3 & 8708.5 \\ 3 & 5214.2 & 6359.3 & 9139.7 \end{array} \cdot 10^{-9}$$

$$x0_{rotor}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 28.05 & 29.97 & 33.82 \\ 2 & 32.55 & 34.78 & 39.30 \\ 3 & 36.46 & 38.96 & 43.96 \end{array} \cdot 10^{-3}$$

$$y0_{rotor}^{\ \ T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 2.01 & 5.68 & 6.38 \\ 2 & 1.15 & 2.43 & 2.39 \\ 3 & 0.77 & 1.39 & 1.32 \end{array} \cdot 10^{-3}$$

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

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

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

$$Jx0_{stator}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 5.51 & 37.05 & 124.93 \\ 2 & 22.05 & 120.53 & 447.85 \\ 3 & 66.00 & 299.59 & 1162.81 \end{array} \cdot 10^{-12}$$

$$Jy0_{stator}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1925 & 5027 & 21360 \\ 2 & 4817 & 12591 & 53687 \\ 3 & 9313 & 24327 & 103364 \end{array} \cdot 10^{-12}$$

$$Jxy0_{stator}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 20.05 & 96.26 & 357.11 \\ 2 & 50.32 & 250.26 & 967.13 \\ 3 & 95.98 & 489.85 & 1918.18 \end{array} \cdot 10^{-12}$$

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

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

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

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

$$Jx0_{rotor}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 774.96 & 1855.03 & 2990.13 \\ 2 & 96.72 & 201.97 & 289.56 \\ 3 & 59.43 & 97.97 & 143.92 \end{array} \cdot 10^{-12}$$

$$Jy0_{rotor}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 61996 & 80784 & 131027 \\ 2 & 44976 & 58657 & 95620 \\ 3 & 53111 & 69207 & 112249 \end{array} \cdot 10^{-12}$$

$$Jxy0_{rotor}^{T} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 633.43 & 2141.99 & 3453.98 \\ 2 & 226.27 & 584.10 & 830.57 \\ 3 & 159.65 & 352.89 & 481.18 \end{array} \cdot 10^{-12}$$

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

$$Ju_{stator}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 5.30 & 35.19 & 118.93 \\ 2 & 21.52 & 115.51 & 430.29 \\ 3 & 65.01 & 289.61 & 1126.82 \end{array} \cdot 10^{-12}$$

$$Jv_{stator}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 1925 & 5029 & 21366 \\ 2 & 4818 & 12596 & 53704 \\ 3 & 9314 & 24337 & 103400 \end{array} \cdot 10^{-12}$$

$$Juv_{stator}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & -0.00 & -0.00 & 0.00 \\ 2 & -0.00 & 0.00 & 0.00 \\ 3 & 0.00 & 0.00 & -0.00 \end{array} \cdot 10^{-12}$$

$$Jp_{stator}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 1930 & 5064 & 21485 \\ 2 & 4839 & 12711 & 54135 \\ 3 & 9379 & 24627 & 104527 \end{array} \cdot 10^{-12}$$

$$Wp_{stator}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 99.7 & 205.0 & 606.5 \\ 2 & 225.9 & 464.4 & 1378.1 \\ 3 & 403.9 & 830.0 & 2456.4 \end{array} \cdot 10^{-9}$$

$$stiffness_{stator}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 7.39 & 19.31 & 82.06 \\ 2 & 51.41 & 134.37 & 572.95 \\ 3 & 194.78 & 508.78 & 2161.75 \end{array} \cdot 10^{-12}$$

$$Ju_{rotor}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 768.40 & 1796.94 & 2897.02 \\ 2 & 95.58 & 196.13 & 282.33 \\ 3 & 58.95 & 96.17 & 141.86 \end{array} \cdot 10^{-12}$$

$$Jv_{rotor}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 62003 & 80842 & 131120 \\ 2 & 44977 & 58663 & 95628 \\ 3 & 53112 & 69209 & 112252 \end{array} \cdot 10^{-12}$$

$$Juv_{rotor}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & -0.00 & 0.00 & 0.00 \\ 2 & 0.00 & 0.00 & 0.00 \\ 3 & 0.00 & 0.00 & 0.00 \end{array} \cdot 10^{-12}$$

$$Jp_{rotor}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 62771 & 82639 & 134017 \\ 2 & 45073 & 58859 & 95910 \\ 3 & 53171 & 69305 & 112393 \end{array} \cdot 10^{-12}$$

$$Wp_{rotor}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 1840.0 & 2244.0 & 3225.2 \\ 2 & 1140.0 & 1391.3 & 2007.2 \\ 3 & 1200.8 & 1464.6 & 2104.9 \end{array} \cdot 10^{-9}$$

$$stiffness_{rotor}^{T} = \begin{array}{c|r|r|r} & 1 & 2 & 3 \\ \hline 1 & 2646.10 & 3448.00 & 5592.45 \\ 2 & 307.19 & 400.64 & 653.10 \\ 3 & 204.05 & 265.89 & 431.26 \end{array} \cdot 10^{-12}$$

$CPx_{stator}^{T} =$

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

$\cdot 10^{-3}$

$CPx_{rotor}^{T} =$

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

$\cdot 10^{-3}$

$CPy_{stator}^{T} =$

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

$\cdot 10^{-3}$

$CPy_{rotor}^{T} =$

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

$\cdot 10^{-3}$

▲ Результат расчета абсолютных геометрических характеристик сечений Л

Вывод результатов расчета геометрических хар-к сечений Л

Профилирование решеток

Абс. координаты профиля:

```
$\mathrm{Airfoil}(type, x, line, i, r) =$
  if type = "BHA"
    $AIRFOIL_{subsonic}\left(x, line, \bar{c}_{BHA_r}, \varepsilon_{BHA_r}\right)$  if $M_{c_{st(1,1),r}} < 1$
    $AIRFOIL_{supersonic}\left(x, line, \bar{c}_{BHA_r}, \varepsilon_{BHA_r}\right)$  otherwise
  if type = "rotor"
    $AIRFOIL_{subsonic}\left(x, line, \bar{c}_{rotor_{i,r}}, \varepsilon_{rotor_{i,r}}\right)$  if $M_{w_{st(i,1),r}} < 1$
    $AIRFOIL_{supersonic}\left(x, line, \bar{c}_{rotor_{i,r}}, \varepsilon_{rotor_{i,r}}\right)$  otherwise
  if type = "stator"
    $AIRFOIL_{subsonic}\left(x, line, \bar{c}_{stator_{i,r}}, \varepsilon_{stator_{i,r}}\right)$  if $M_{c_{st(i,2),r}} < 1$
    $AIRFOIL_{supersonic}\left(x, line, \bar{c}_{stator_{i,r}}, \varepsilon_{stator_{i,r}}\right)$  otherwise
  if type = "CA"
    $AIRFOIL_{subsonic}\left(x, line, \bar{c}_{CA_r}, \varepsilon_{CA_r}\right)$  if $M_{c_{st(Z,3),r}} < 1$
    $AIRFOIL_{supersonic}\left(x, line, \bar{c}_{CA_r}, \varepsilon_{CA_r}\right)$  otherwise
```

Профилирование решеток

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

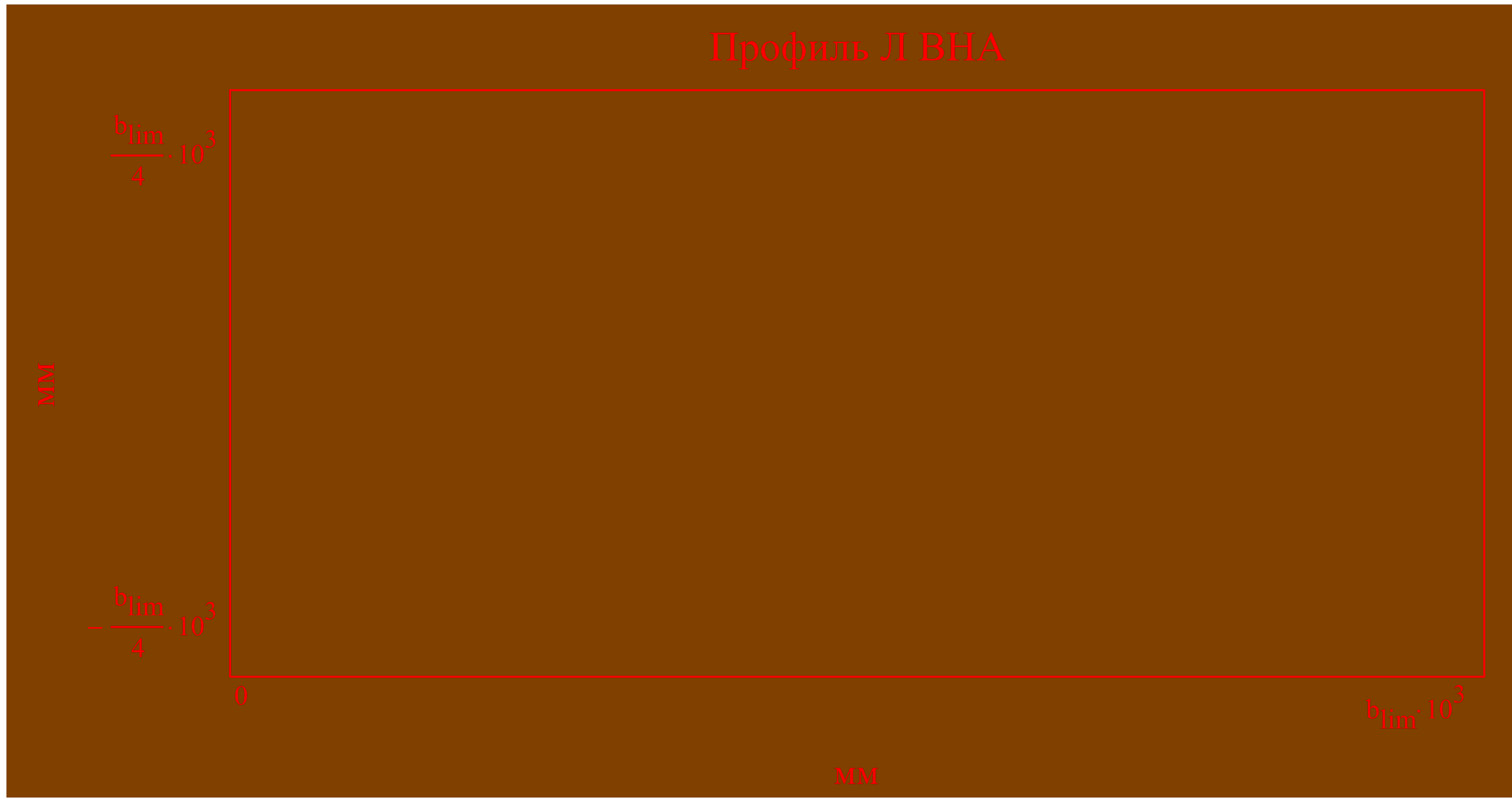
Построение профилей Л РК и НА

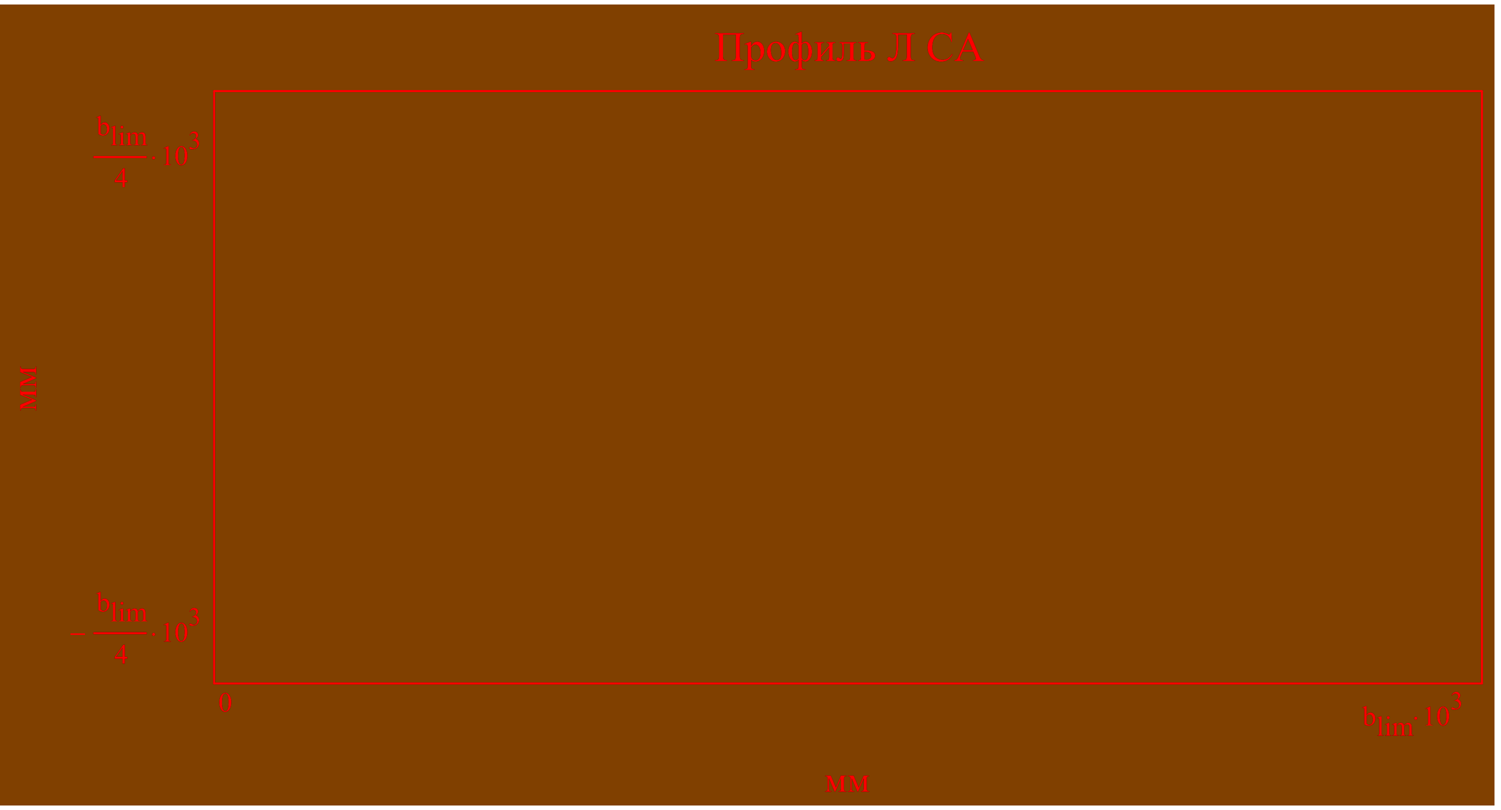
$$\mathrm{AXLE0}(type, x, i, r) = \left| \begin{array}{ll} \dfrac{y0_{rotor_{i,r}}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}}\right) \cdot \left(x - \dfrac{x0_{rotor_{i,r}}}{chord_{rotor_{i,r}}}\right) & \text{if } type = \text{"rotor"} \\ \dfrac{y0_{stator_{i,r}}}{chord_{stator_{i,r}}}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

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

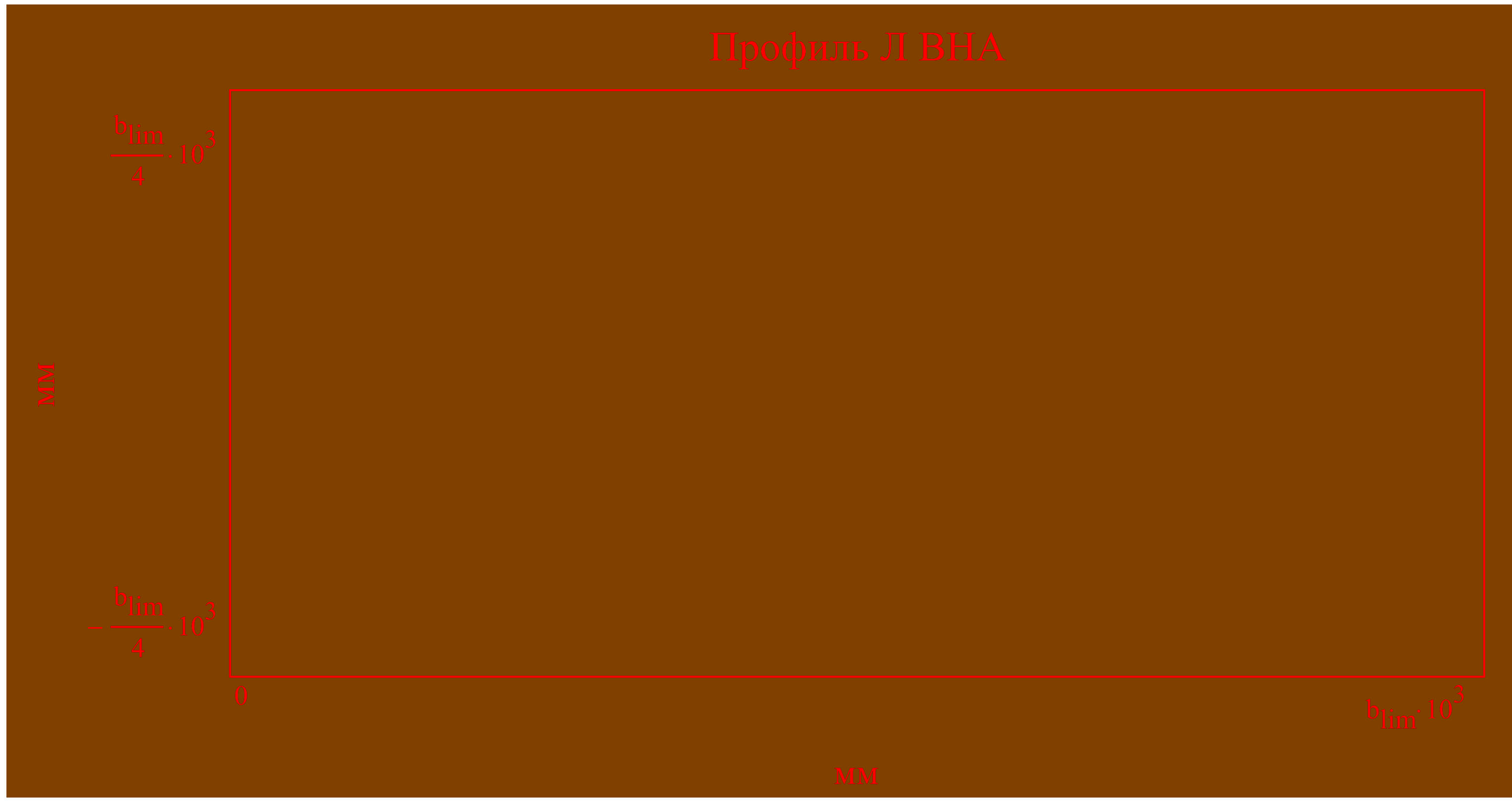
$$\mathrm{AXLE90}(type, x, i, r) = \left| \begin{array}{ll} \dfrac{y0_{rotor_{i,r}}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}} + \dfrac{\pi}{2}\right) \cdot \left(x - \dfrac{x0_{rotor_{i,r}}}{chord_{rotor_{i,r}}}\right) & \text{if } (type = \text{"rotor"}) \wedge \left|\alpha\_major_{rotor_{i,r}}\right|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

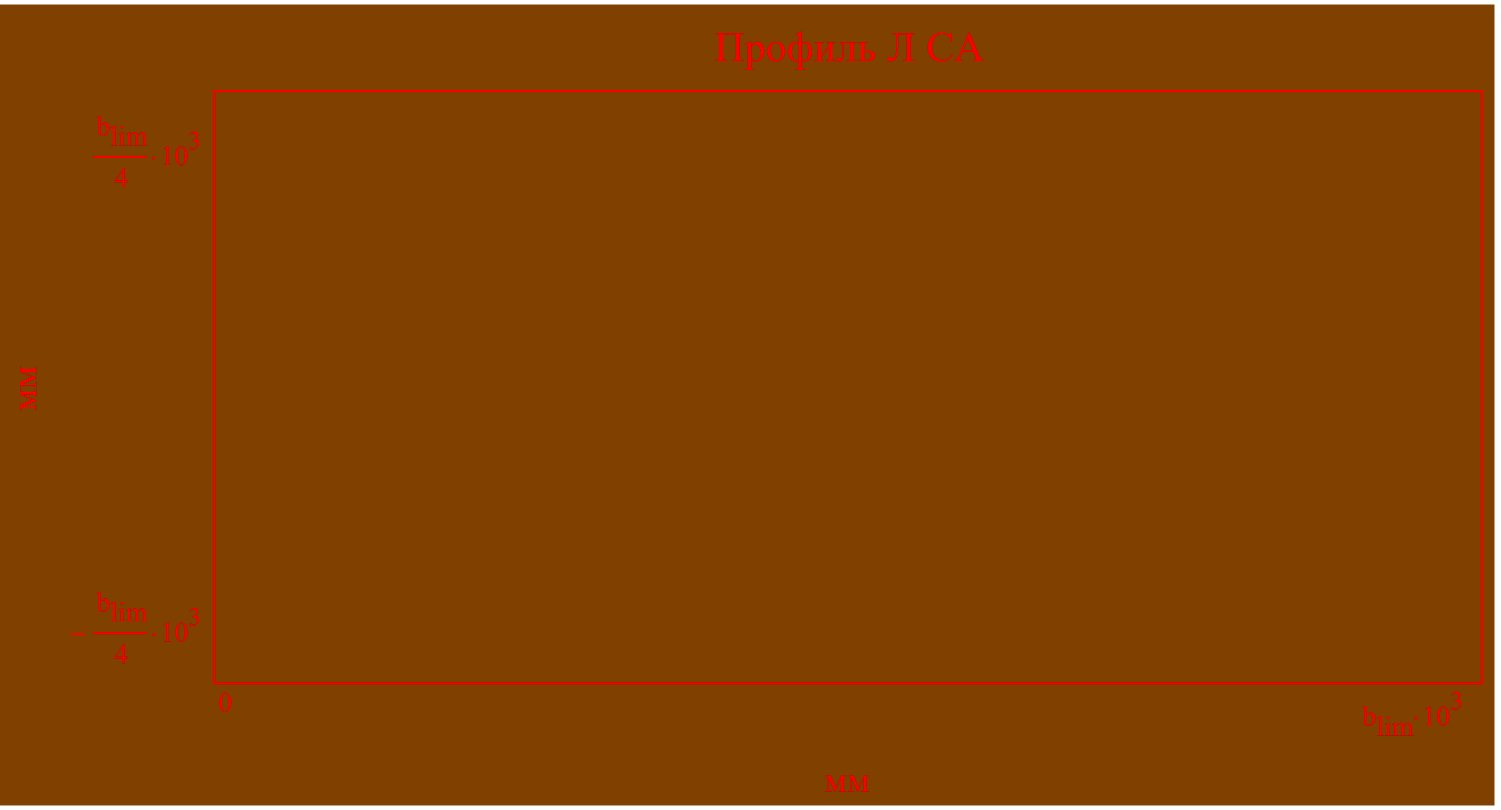
$r = 1$


Профиль Л ВНА
$\frac{b_{lim}}{4} \cdot 10^3$
$-\frac{b_{lim}}{4} \cdot 10^3$
мм
0
$b_{lim} \cdot 10^3$
мм

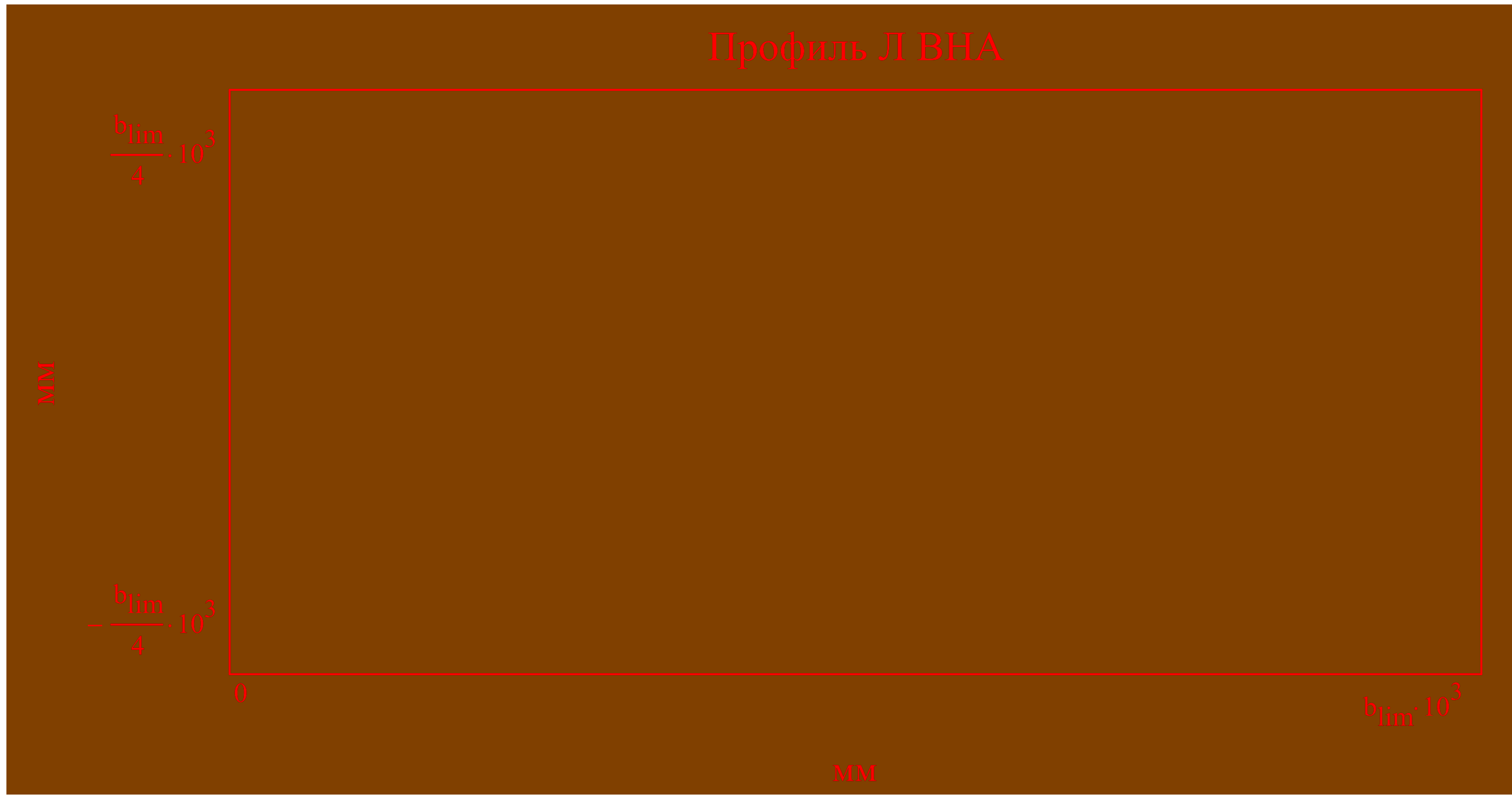

Профиль Л СА
$\frac{b_{lim}}{4} \cdot 10^3$
$-\frac{b_{lim}}{4} \cdot 10^3$
мм
0
$b_{lim} \cdot 10^3$
мм

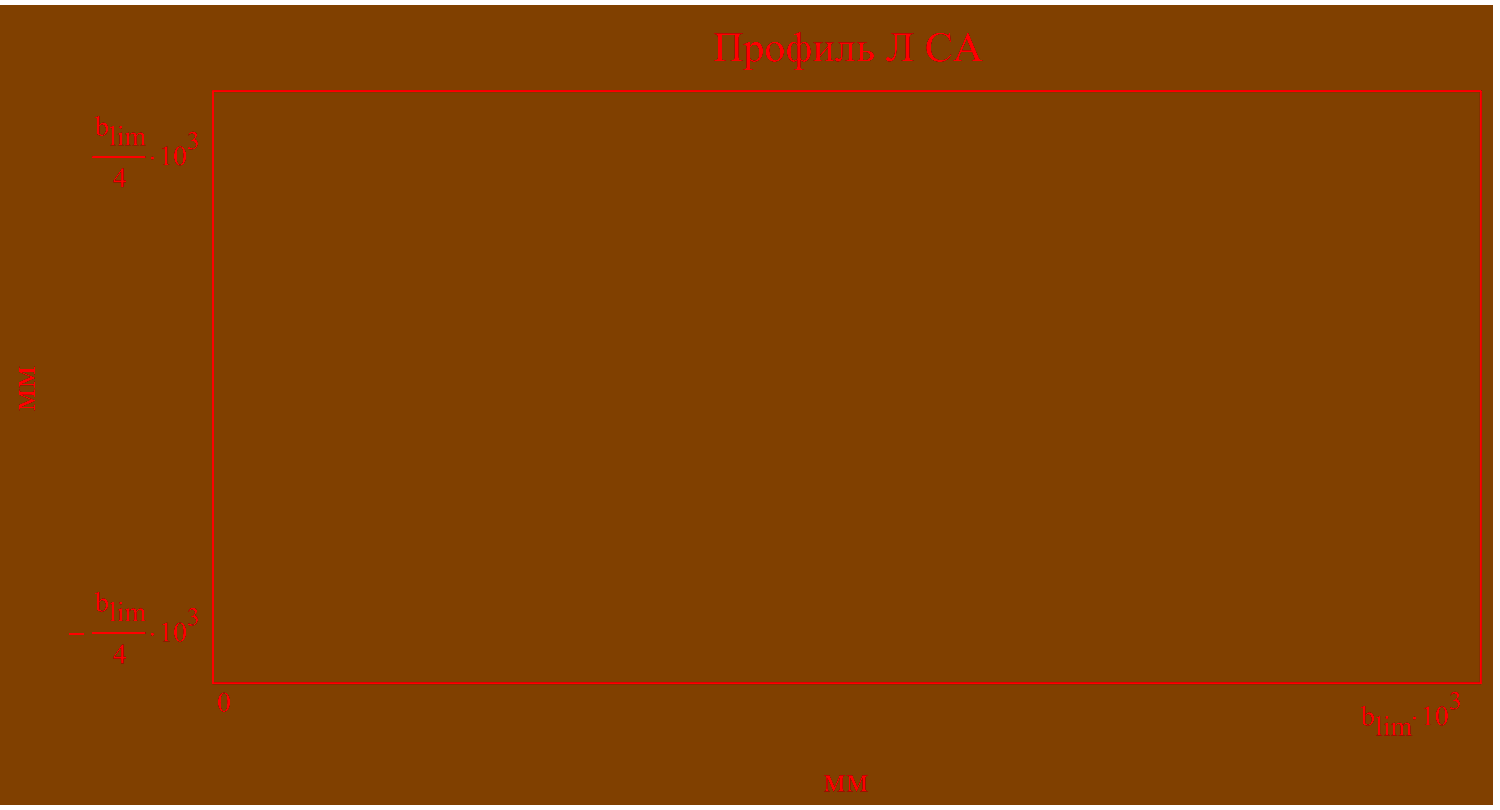
$r = av(N_r)$


Профиль Л ВНА

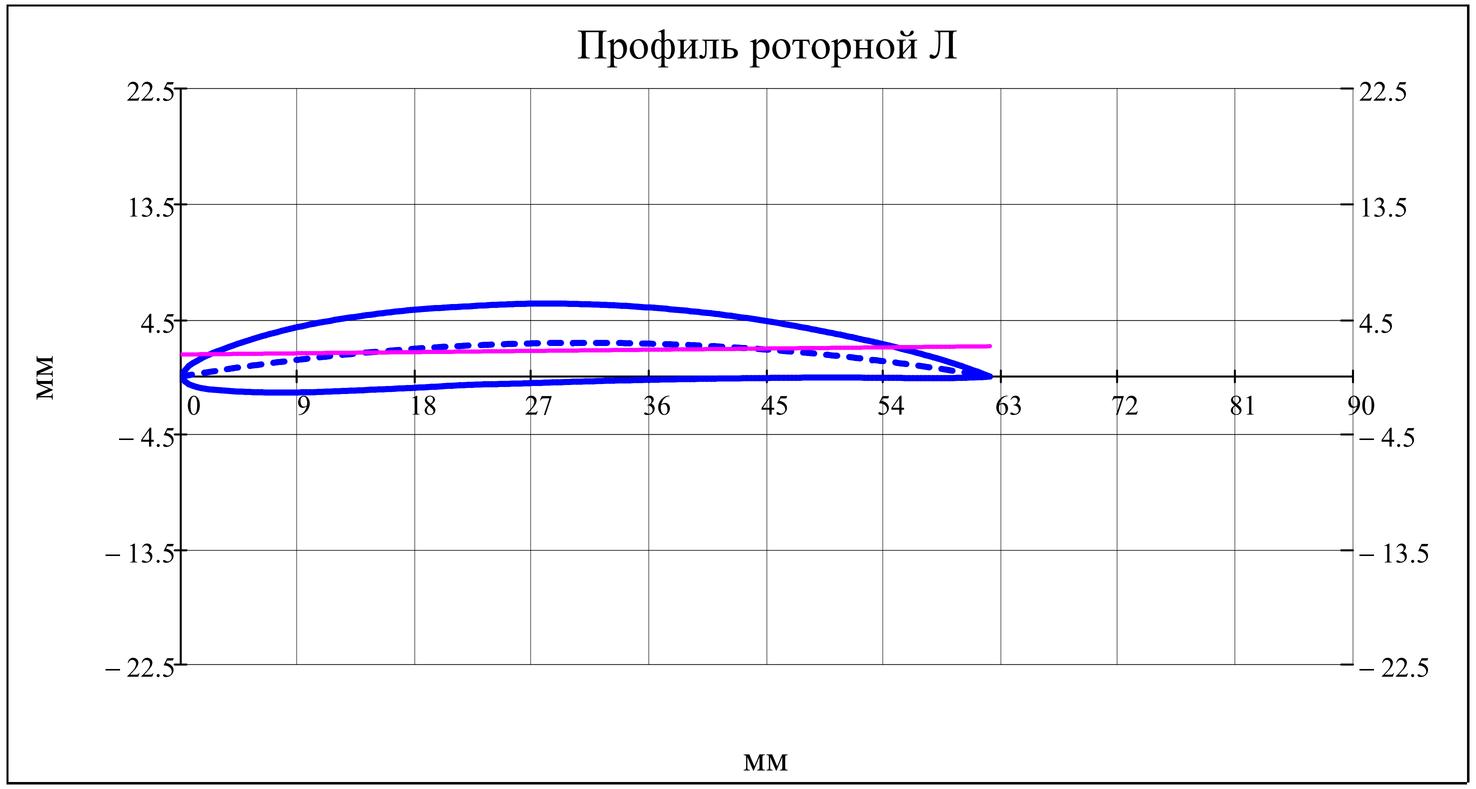

Профиль Л СА

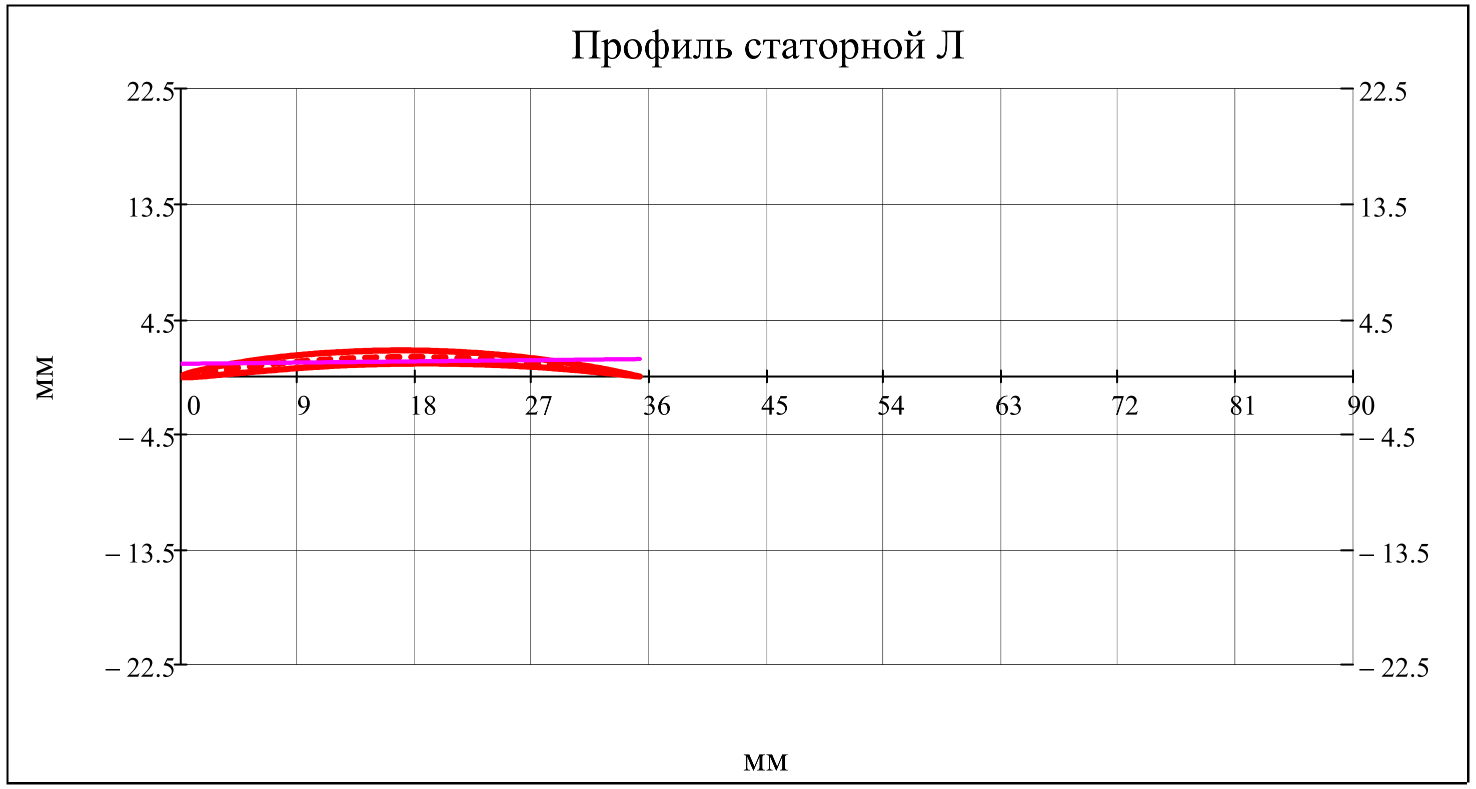
$r = N_r$


Профиль Л ВНА

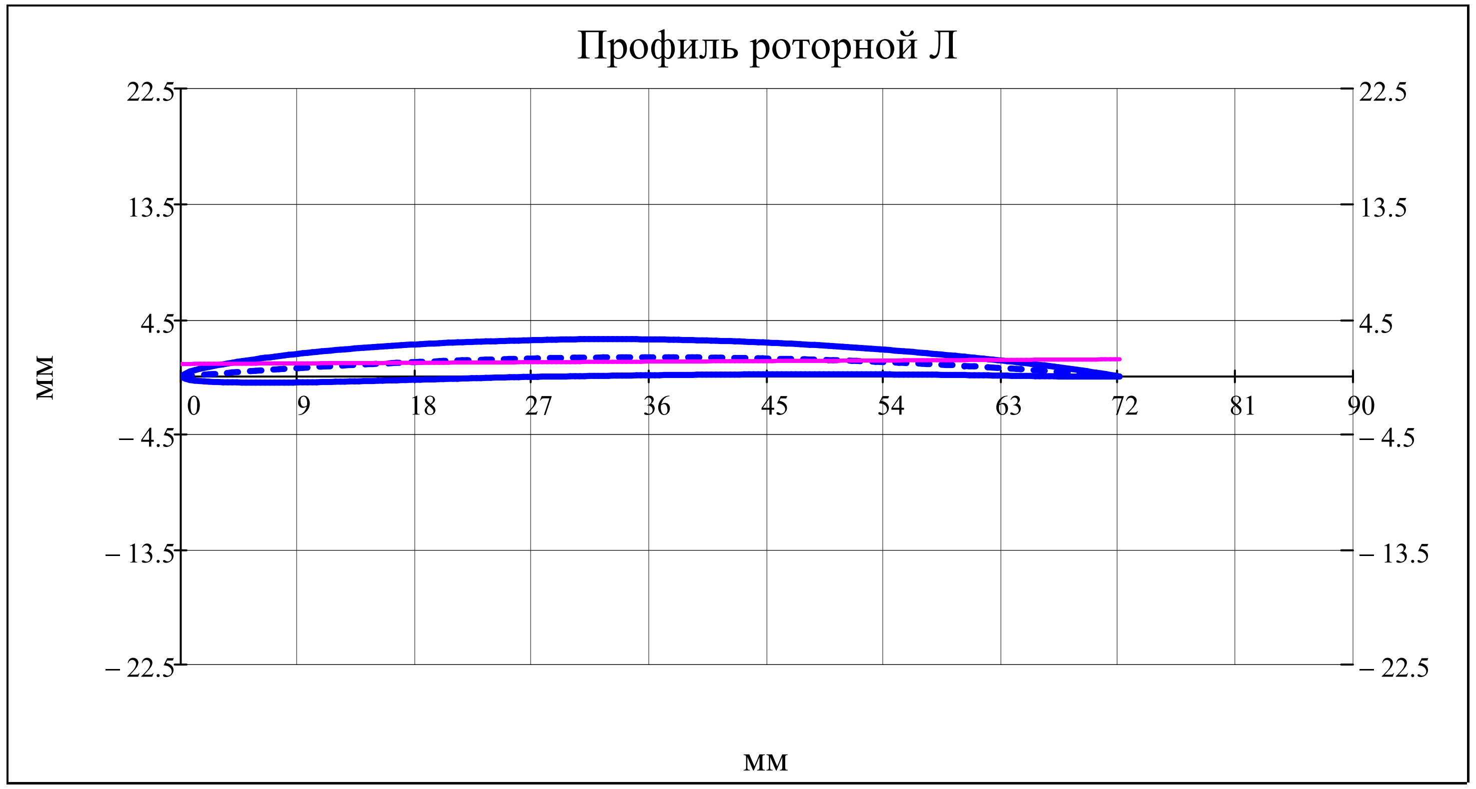

Профиль Л СА

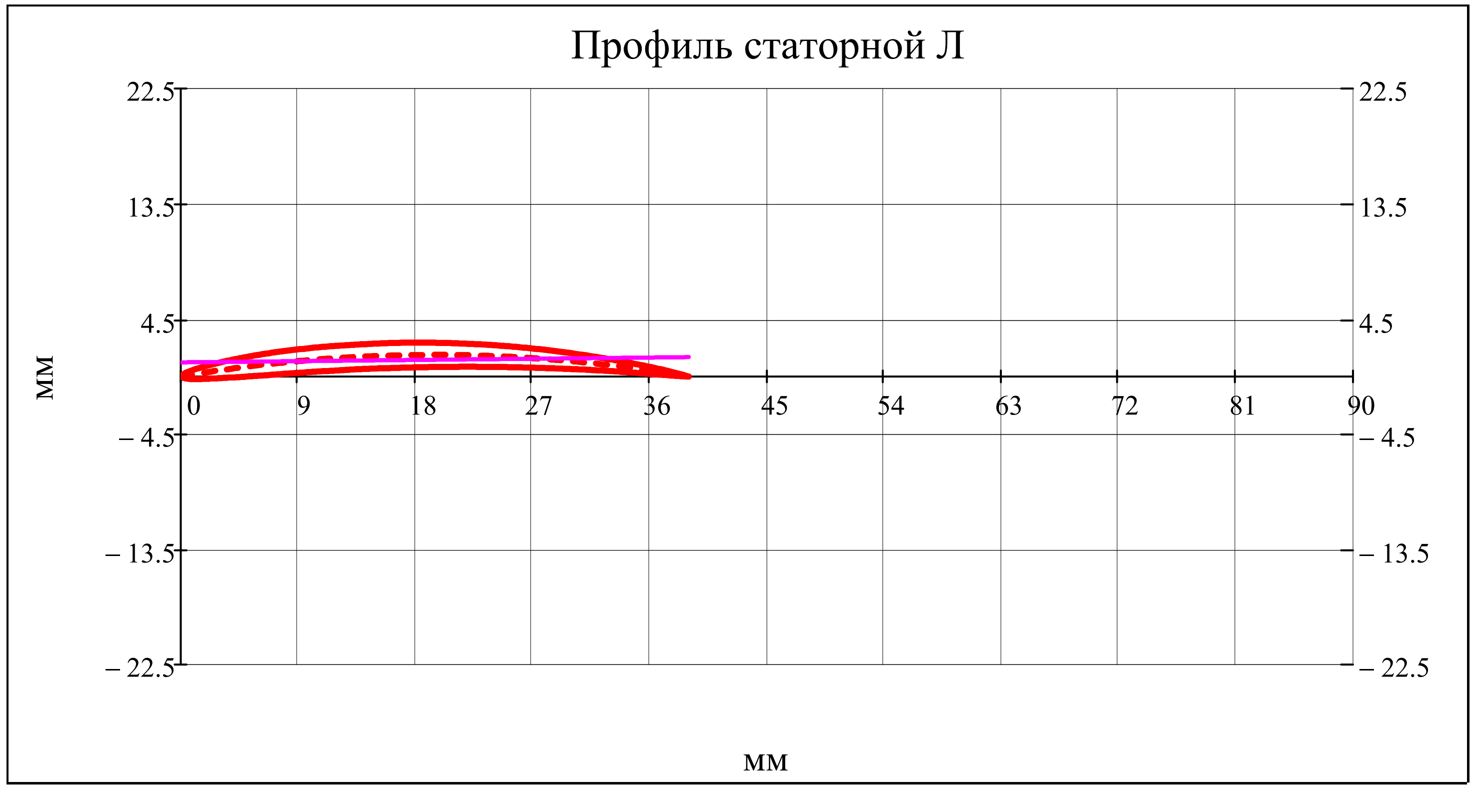
r = 1


Профиль роторной Л
22.5
13.5
4.5
− 4.5
− 13.5
− 22.5
0
9
18
27
36
45
54
63
72
81
90
мм
мм

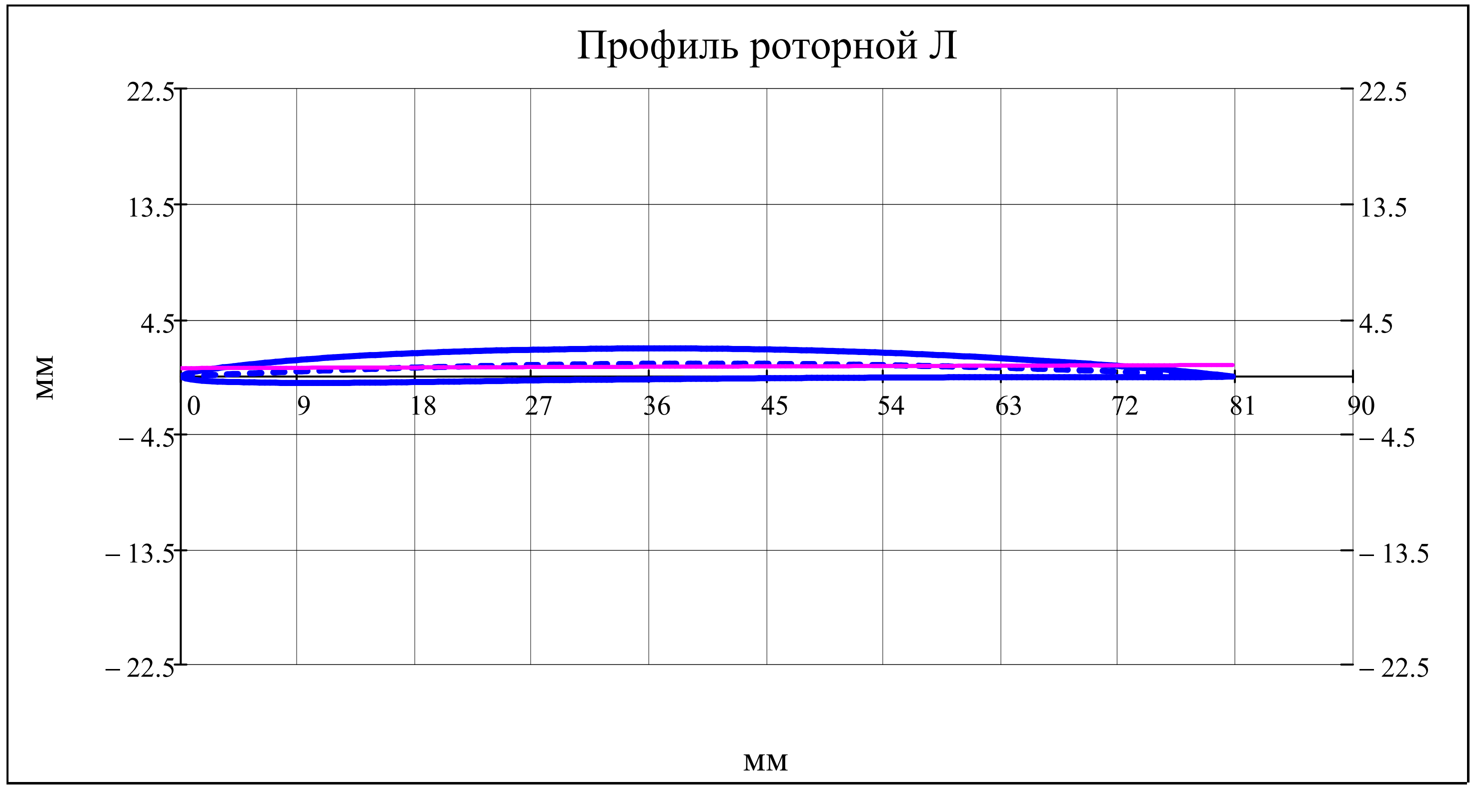

Профиль статорной Л
22.5
13.5
4.5
− 4.5
− 13.5
− 22.5
0
9
18
27
36
45
54
63
72
81
90
мм
мм

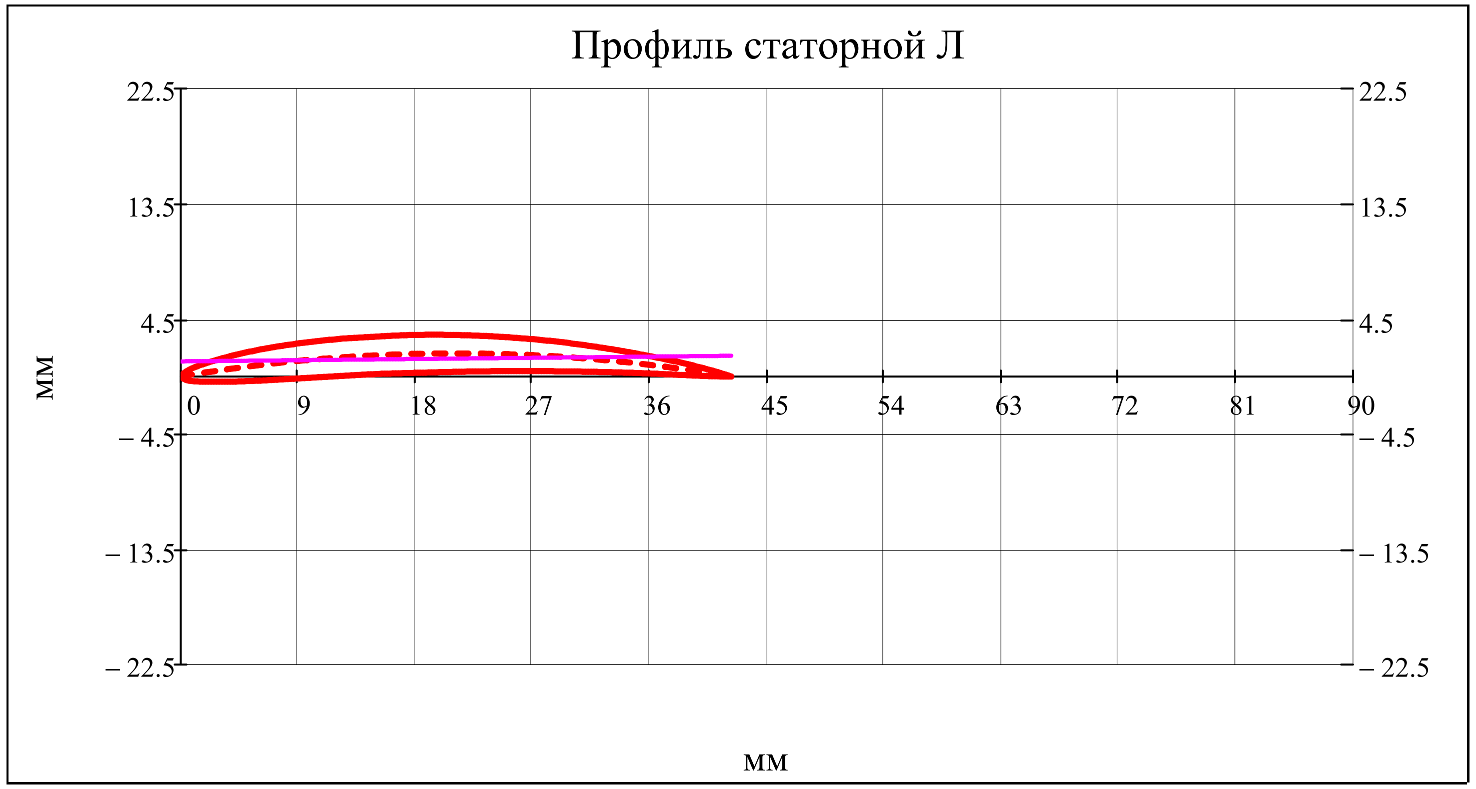
$r = av(N_r)$


Профиль роторной Л
22.5
13.5
4.5
– 4.5
– 13.5
– 22.5
0
9
18
27
36
45
54
63
72
81
90
мм
мм


Профиль статорной Л
22.5
13.5
4.5
– 4.5
– 13.5
– 22.5
0
9
18
27
36
45
54
63
72
81
90
мм
мм

$r = N_r$





Построение профилей Л РК и НА

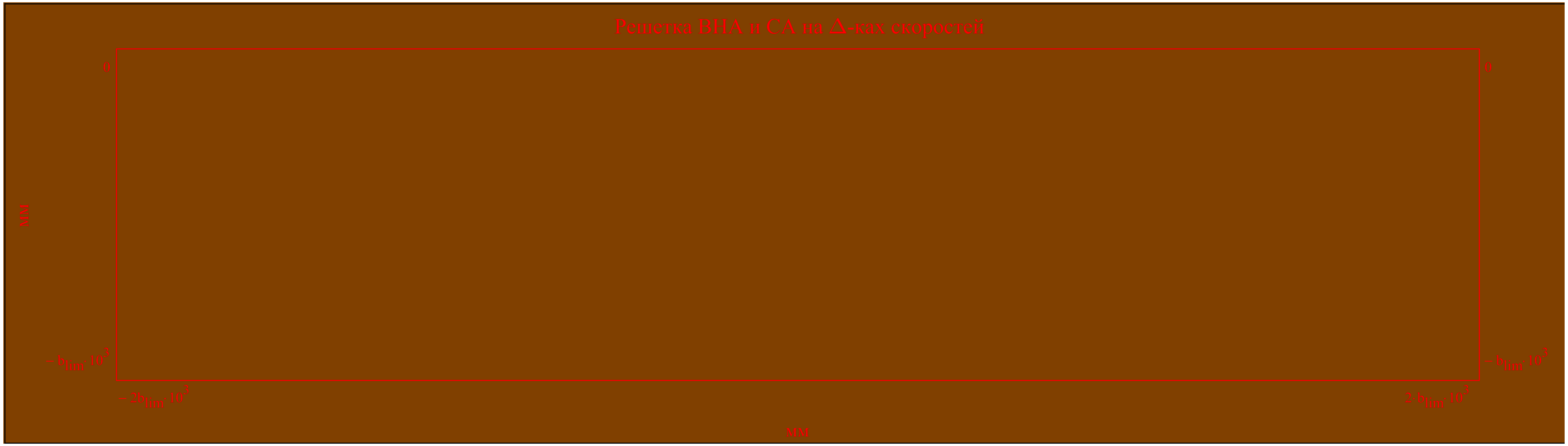
Вывод координат для построения профиля Л

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

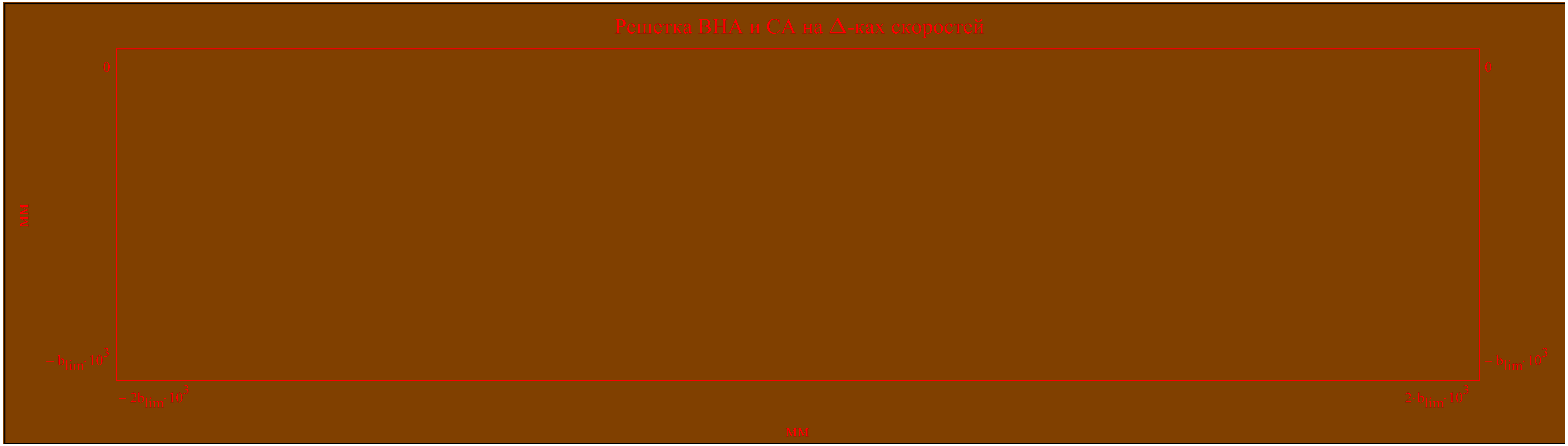
$$b_{lim} = \frac{\text{ceil}\left(\max\left(\text{chord}_{\text{rotor}_{j,N_r}}, \text{chord}_{\text{stator}_{j,N_r}}\right) \cdot 10^2\right)}{10^2} = 90 \cdot 10^{-3}$$

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

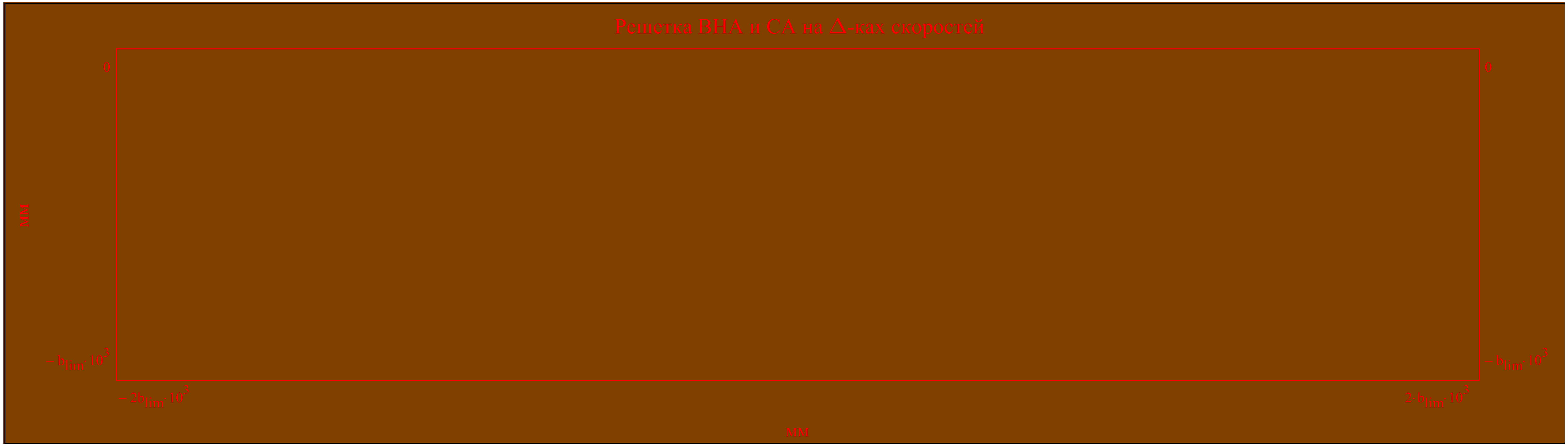
$r = 1$



$r = av\left(N_r\right)$



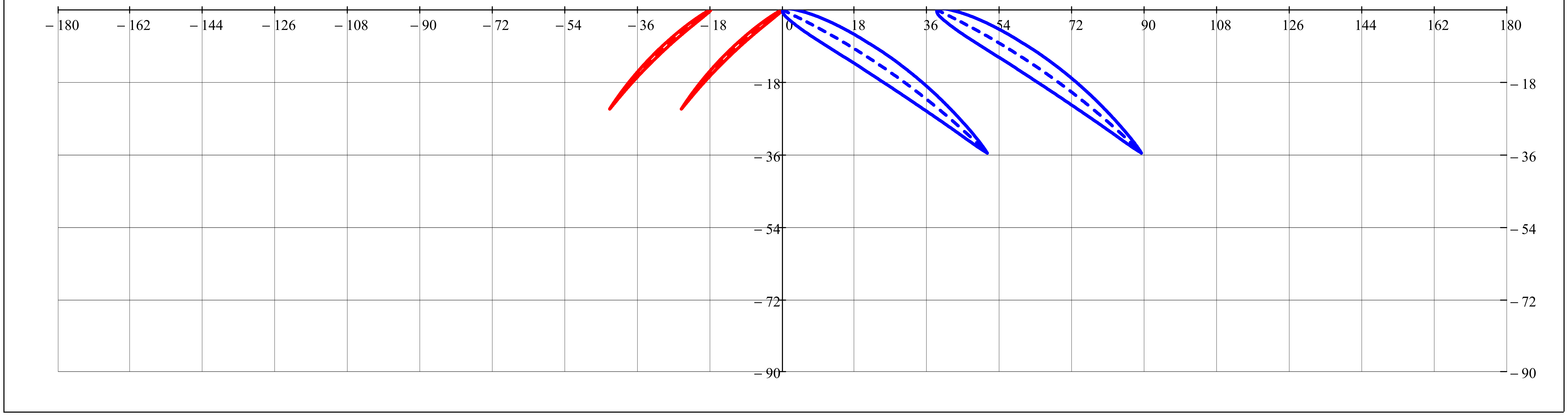
$r = N_r$



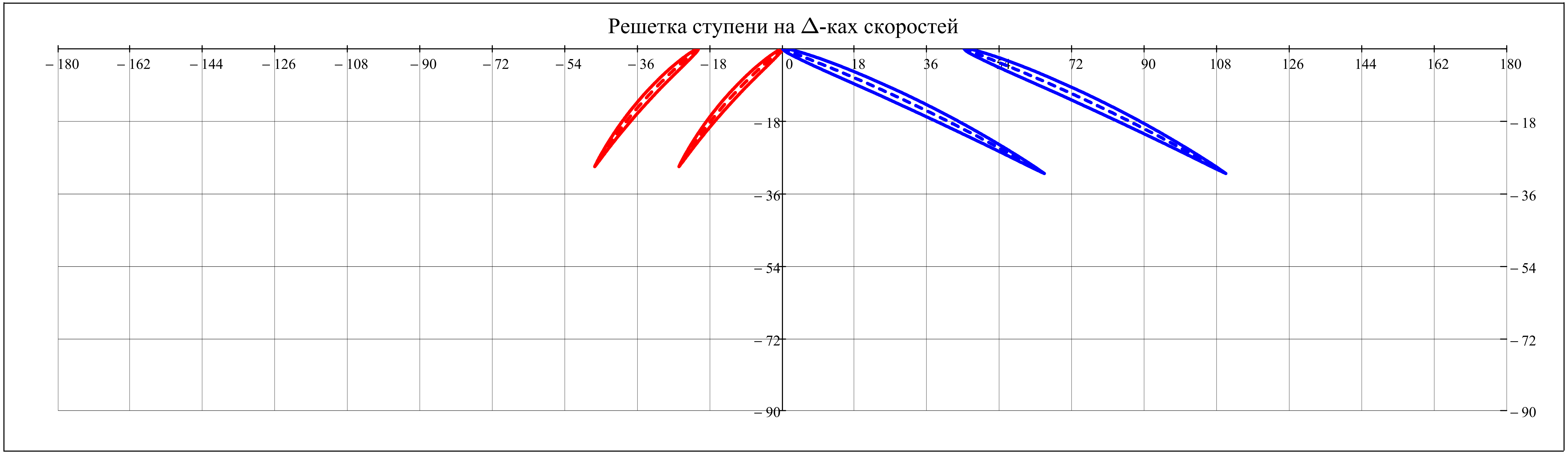
Решетка ВНА и СА на Δ-ках скоростей

r = 1

Решетка ступени на Δ-ках скоростей

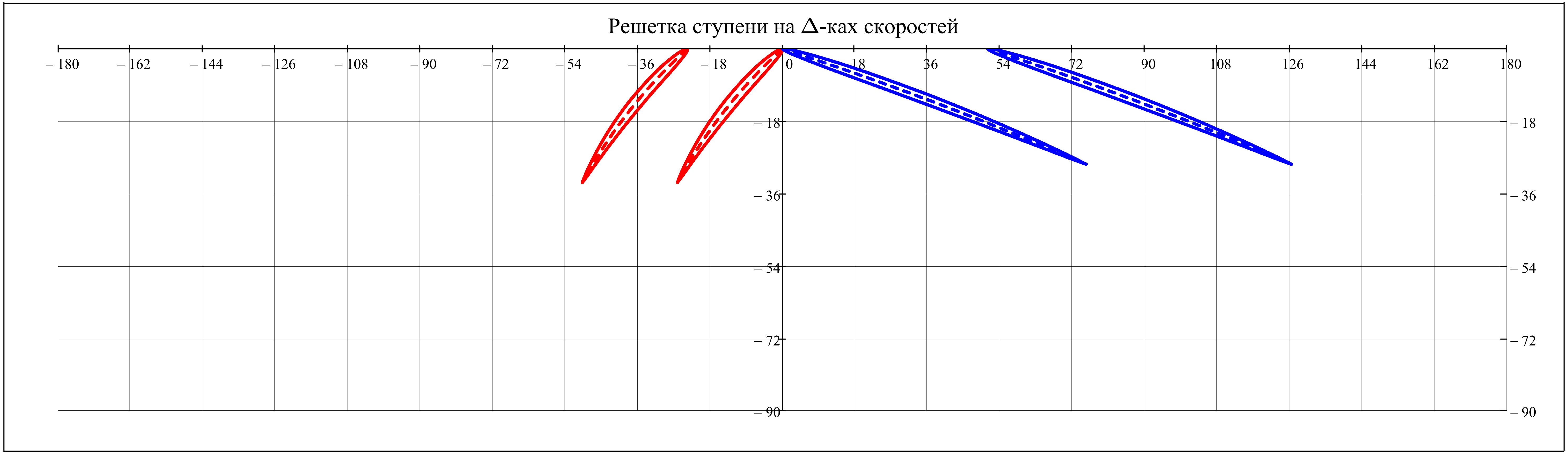


$r = av(N_r)$



Решетка ступени на Δ-ках скоростей

$r = N_r$



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

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

Радиальные и осевые зазоры и длина К

Радиальный зазор (м)
[с.64 казаджан]:

$\overline{\Delta}r = 0.0025$

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

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

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

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

$\overline{\Delta}a = 0.17$

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

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

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

Односторонний осевой зазор (м):

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

Длина ОК (м):

$$Length = \left[\Delta a_1 + \left|\begin{array}{l} chord_{BHA_{av(N_r)}} \cdot \sin\left(\upsilon_{BHA_{av(N_r)}}\right) \text{ if } BHA = 1 \\ 0 \text{ otherwise} \end{array}\right. \ldots \\ + \sum_{i=1}^{Z} \left(chord_{rotor_{i,av(N_r)}} \cdot \sin\left(\upsilon_{rotor_{i,av(N_r)}}\right)\right) + 2 \cdot \sum_{i=1}^{Z} \Delta a_i + \sum_{i=1}^{Z} \left(chord_{stator_{i,av(N_r)}} \cdot \sin\left(\upsilon_{stator_{i,av(N_r)}}\right)\right) \ldots \\ + \left|\begin{array}{l} chord_{CA_{av(N_r)}} \cdot \sin\left(\upsilon_{CA_{av(N_r)}}\right) \text{ if } CA = 1 \\ 0 \text{ otherwise} \end{array}\right. + \Delta a_Z\right] = 337.8 \cdot 10^{-3}$$

Радиальные и осевые зазоры и длина К

Проточная часть

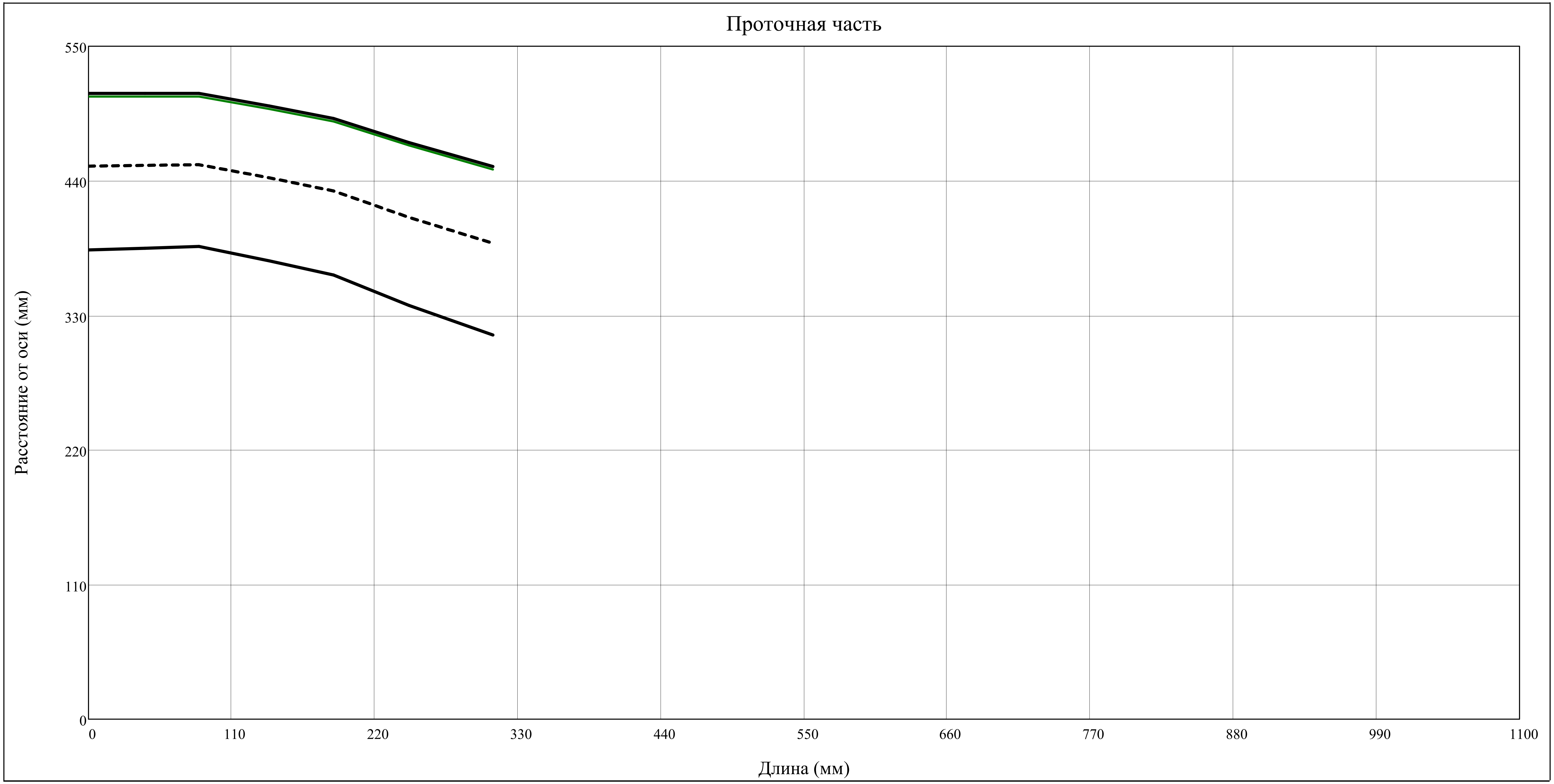
```
$\begin{pmatrix} x_{ПЧ} \\ y_{ПЧпер} \\ y_{ПЧср} \\ y_{ПЧкор} \\ y_{Лпер} \end{pmatrix} =$
    $c = 1$
    $x_{ПЧ_c} =$
        $chord_{BHA_{av(N_r)}} \cdot \sin\left(\upsilon_{BHA_{av(N_r)}}\right)$ if $BHA = 1$
        $0$ otherwise
    $y_{ПЧпер_c} = R_{st(c,1),N_r}$
    $y_{Лпер_c} = y_{ПЧпер_c} - \Delta_{r_c}$
    $y_{ПЧср_c} = R_{st(c,1),av(N_r)}$
    $y_{ПЧкор_c} = R_{st(c,1),ORIGIN}$
    for $i \in 1..Z$
        $c = c + 1$
        $x_{ПЧ_c} = x_{ПЧ_{c-1}} + 0.5 \cdot \Delta a_i + chord_{rotor_{i,av(N_r)}} \cdot \sin\left(\upsilon_{rotor_{i,av(N_r)}}\right) + 0.5 \cdot \Delta a_i$
        $\begin{pmatrix} y_{ПЧпер_c} \\ y_{ПЧср_c} \\ y_{ПЧкор_c} \end{pmatrix} = \begin{pmatrix} R_{st(i,2),N_r} \\ R_{st(i,2),av(N_r)} \\ R_{st(i,2),ORIGIN} \end{pmatrix}$
        $y_{Лпер_c} = y_{ПЧпер_c} - \Delta_{r_i}$
        $c = c + 1$
        $x_{ПЧ_c} = x_{ПЧ_{c-1}} + 0.5 \cdot \Delta a_i + chord_{stator_{i,av(N_r)}} \cdot \sin\left(\upsilon_{stator_{i,av(N_r)}}\right) + 0.5 \cdot \Delta a_i$
        $\begin{pmatrix} y_{ПЧпер_c} \\ y_{ПЧср_c} \\ y_{ПЧкор_c} \end{pmatrix} = \begin{pmatrix} R_{st(i,3),N_r} \\ R_{st(i,3),av(N_r)} \\ R_{st(i,3),ORIGIN} \end{pmatrix}$
        $y_{Лпер_c} = y_{ПЧпер_c} - \Delta_{r_i}$
    $\begin{pmatrix} x_{ПЧ} & y_{ПЧпер} & y_{ПЧср} & y_{ПЧкор} & y_{Лпер} \end{pmatrix}^T$
```

$$y_{ПЧпер}(l) = \operatorname{interp}\left(\operatorname{cspline}\left(x_{ПЧ}, y_{ПЧпер}\right), x_{ПЧ}, y_{ПЧпер}, l\right)$$

$$y_{ПЧср}(l) = \operatorname{interp}\left(\operatorname{cspline}\left(x_{ПЧ}, y_{ПЧср}\right), x_{ПЧ}, y_{ПЧср}, l\right)$$

$$y_{ПЧкор}(l) = \operatorname{interp}\left(\operatorname{cspline}\left(x_{ПЧ}, y_{ПЧкор}\right), x_{ПЧ}, y_{ПЧкор}, l\right)$$

$$y_{Лпер}(l) = \operatorname{interp}\left(\operatorname{cspline}\left(x_{ПЧ}, y_{Лпер}\right), x_{ПЧ}, y_{Лпер}, l\right)$$



▲ 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

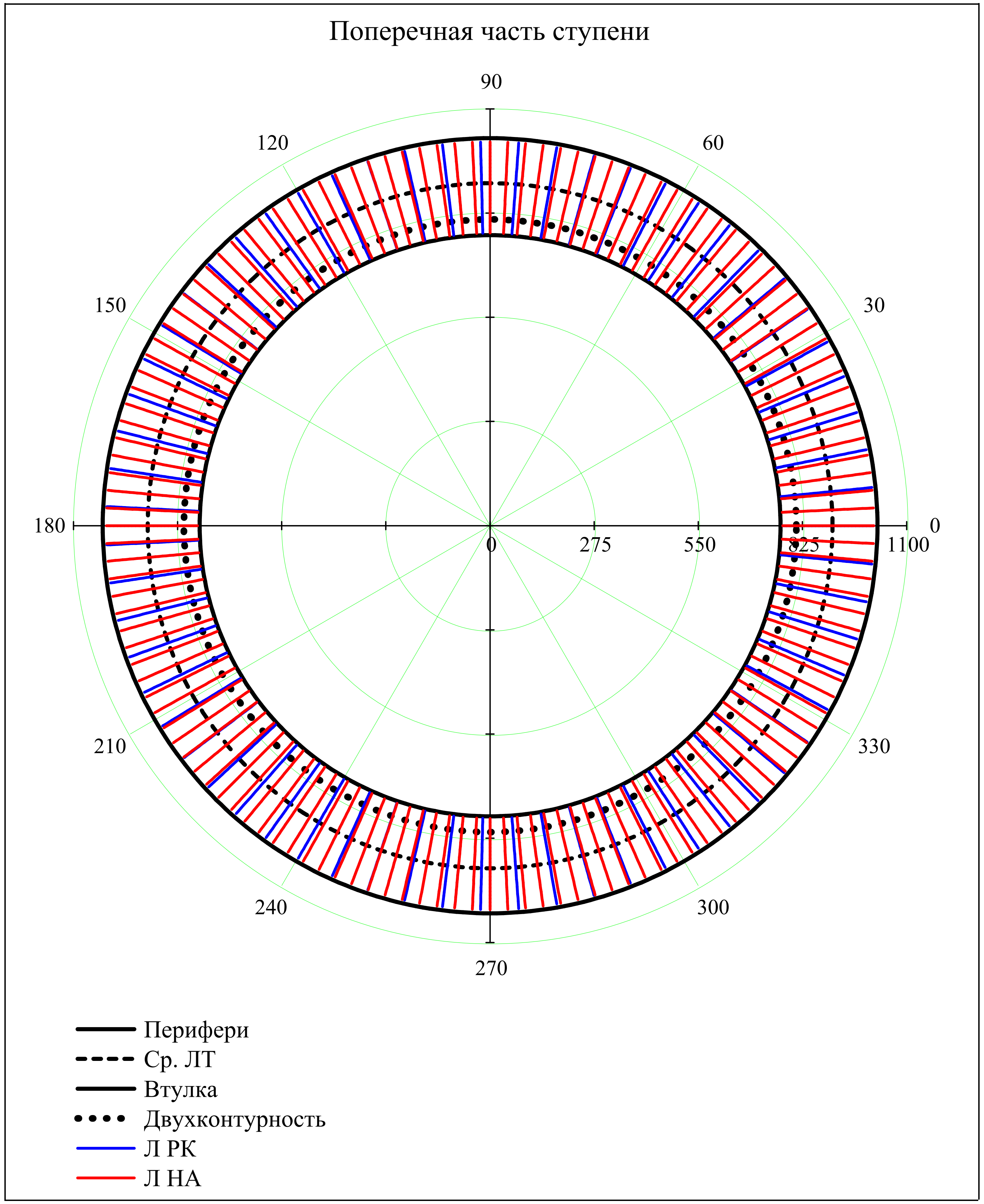
$$r = \min(D), \min(D) + \frac{\max(D) - \min(D)}{N_{dis}} .. \max(D)$$

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

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

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

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



▲ Поперечная часть ступени

▼ Выбор материала Л

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

Выбранный материал Л: $$\text{material\_blade}_i = \begin{cases} \text{"ЖС-6К"} & \text{if } 1123 \le T^*_{st(i,2),av}(N_r) + \Delta T_{safety} \\ \text{"ВТ41"} & \text{if } 873 \le T^*_{st(i,2),av}(N_r) + \Delta T_{safety} < 1123 \\ \text{"ВТ25"} & \text{if } 753 \le T^*_{st(i,2),av}(N_r) + \Delta T_{safety} < 873 \\ \text{"ВТ9"} & \text{otherwise} \end{cases}$$

$$\text{material\_blade}_i = \begin{cases} \text{"ВТ23"} & \text{if compressor} = \text{"Вл"} \\ \text{"ВТ6"} & \text{if compressor} = \text{"КНД"} \\ \text{material\_blade}_i & \text{otherwise} \end{cases}$$

Плотность материала Л (кг/м^3): $$\rho\text{\_blade}_i = \begin{cases} 8393 & \text{if material\_blade}_i = \text{"ЖС-6К"} \\ 7900 & \text{if material\_blade}_i = \text{"ВТ41"} \\ 4500 & \text{if material\_blade}_i = \text{"ВТ25"} \\ 4570 & \text{if material\_blade}_i = \text{"ВТ23"} \\ 4510 & \text{if material\_blade}_i = \text{"ВТ9"} \\ 4430 & \text{if material\_blade}_i = \text{"ВТ6"} \\ \text{NaN} & \text{otherwise} \end{cases}$$

Коэф. формы: $k_n = 6.8$

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

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

Предел длительной прочности Л РК (Па): $$\sigma\text{\_blade\_long}_i = 10^6 \cdot \begin{cases} 125 & \text{if material\_blade}_i = \text{"ЖС-6К"} \\ 123 & \text{if material\_blade}_i = \text{"ВТ41"} \\ 150 & \text{if material\_blade}_i = \text{"ВТ25"} \\ 230 & \text{if material\_blade}_i = \text{"ВТ23"} \\ 200 & \text{if material\_blade}_i = \text{"ВТ9"} \\ 210 & \text{if material\_blade}_i = \text{"ВТ6"} \\ \text{NaN} & \text{otherwise} \end{cases}$$

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

	1	2	3	4	5	6	7	8	9
1	"ВТ6"	"ВТ6"	"ВТ6"						

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

	1	2	3
1	4430	4430	4430

$\sigma\text{\_blade\_long}^T =$

	1	2	3
1	210.0	210.0	210.0

$\cdot 10^6$

▲ Выбор материала Л

Расчет собственных частот колебаний Л

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

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

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

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

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

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

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

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

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

Расчет собственных частот колебаний Л

Вывод результатов расчета собственных частот колебаний Л

Расчетный узел: type = "compressor"

Объем бандажной полки (м^3): $V_{бп} = 0$

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

Расчет Л на прочность

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$CPx_{rotor.axis}(i,z) = \mathrm{axis}_x(CPx_{rotor.}(i,z),CPy_{rotor.}(i,z),x0_{rotor.}(i,z),y0_{rotor.}(i,z),\alpha\_major_{rotor.}(i,z),1)$$

$$CPx_{stator.axis}(i,z) = \mathrm{axis}_x(CPx_{stator.}(i,z),CPy_{stator.}(i,z),x0_{stator.}(i,z),y0_{stator.}(i,z),\alpha\_major_{stator.}(i,z),1)$$

$$CPy_{rotor.axis}(i,z) = \mathrm{axis}_y(CPx_{rotor.}(i,z),CPy_{rotor.}(i,z),x0_{rotor.}(i,z),y0_{rotor.}(i,z),\alpha\_major_{rotor.}(i,z),1)$$

$$CPy_{stator.axis}(i,z) = \mathrm{axis}_y(CPx_{stator.}(i,z),CPy_{stator.}(i,z),x0_{stator.}(i,z),y0_{stator.}(i,z),\alpha\_major_{stator.}(i,z),1)$$

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

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

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

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

$$\tau_{\mathrm{rotor}}(i,z) = \frac{\mathrm{M}\tau_{\mathrm{rotor}}(i,z)}{\mathrm{Wp}_{\mathrm{rotor.}}(i,z)}$$

$$\tau_{\mathrm{stator}}(i,z) = \frac{\mathrm{M}\tau_{\mathrm{stator}}(i,z)}{\mathrm{Wp}_{\mathrm{stator.}}(i,z)}$$

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

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

$$\mathrm{Mu}_{\mathrm{rotor}}(i,z) = \mathrm{axis}_x\left(\mathrm{Mx}_{\mathrm{rotor}}(i,z),\mathrm{My}_{\mathrm{rotor}}(i,z),0,0,\varphi\_uv_{\mathrm{rotor}}(i,z),1\right)$$

$$\mathrm{Mu}_{\mathrm{stator}}(i,z) = \mathrm{axis}_x\left(\mathrm{Mx}_{\mathrm{stator}}(i,z),\mathrm{My}_{\mathrm{stator}}(i,z),0,0,\varphi\_uv_{\mathrm{stator}}(i,z),1\right)$$

$$\mathrm{Mv}_{\mathrm{rotor}}(i,z) = \mathrm{axis}_y\left(\mathrm{Mx}_{\mathrm{rotor}}(i,z),\mathrm{My}_{\mathrm{rotor}}(i,z),0,0,\varphi\_uv_{\mathrm{rotor}}(i,z),1\right)$$

$$\mathrm{Mv}_{\mathrm{stator}}(i,z) = \mathrm{axis}_y\left(\mathrm{Mx}_{\mathrm{stator}}(i,z),\mathrm{My}_{\mathrm{stator}}(i,z),0,0,\varphi\_uv_{\mathrm{stator}}(i,z),1\right)$$

$$\varphi\_neutral_{\mathrm{rotor}}(i,z) = \left|\begin{array}{ll}\mathrm{atan}\left(\dfrac{\mathrm{Mv}_{\mathrm{rotor}}(i,z)\cdot \mathrm{Ju}_{\mathrm{rotor.}}(i,z)}{\mathrm{Mu}_{\mathrm{rotor}}(i,z)\cdot \mathrm{Jv}_{\mathrm{rotor.}}(i,z)}\right) & \text{if } \mathrm{Mu}_{\mathrm{rotor}}(i,z)\cdot \mathrm{Jv}_{\mathrm{rotor.}}(i,z) \neq 0\\ \dfrac{\pi}{2} & \text{otherwise}\end{array}\right.$$

$$\varphi\_neutral_{\mathrm{stator}}(i,z) = \left|\begin{array}{ll}\mathrm{atan}\left(\dfrac{\mathrm{Mv}_{\mathrm{stator}}(i,z)\cdot \mathrm{Ju}_{\mathrm{stator.}}(i,z)}{\mathrm{Mu}_{\mathrm{stator}}(i,z)\cdot \mathrm{Jv}_{\mathrm{stator.}}(i,z)}\right) & \text{if } \mathrm{Mu}_{\mathrm{stator}}(i,z)\cdot \mathrm{Jv}_{\mathrm{stator.}}(i,z) \neq 0\\ \dfrac{\pi}{2} & \text{otherwise}\end{array}\right.$$

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

$$\begin{matrix}
P_1 & \rho_1 \\
P_2 & \rho_2 \\
P_3 & \rho_3 \\
c_{a1} & c_{u1} \\
c_{a2} & c_{u2} \\
c_{a3} & c_{u3} \\
qx_{rotor} & qx_{stator} \\
qy_{rotor} & qy_{stator} \\
Mx_{rotor} & Mx_{stator} \\
My_{rotor} & My_{stator} \\
shift\_x_{rotor} & shift\_y_{rotor} \\
x0_{rotor.} & x0_{stator.} \\
y0_{rotor.} & y0_{stator.} \\
\alpha\_major_{rotor.} & \alpha\_major_{stator.} \\
Ju_{rotor.} & Ju_{stator.} \\
Jv_{rotor.} & Jv_{stator.} \\
CPx_{rotor.} & CPx_{stator.} \\
CPy_{rotor.} & CPy_{stator.} \\
CPx_{rotor.axis} & CPx_{stator.axis} \\
CPy_{rotor.axis} & CPy_{stator.axis} \\
Wp_{rotor.} & Wp_{stator.} \\
M\tau_{rotor} & M\tau_{stator} \\
\tau_{rotor} & \tau_{stator} \\
\varphi\_uv_{rotor} & \varphi\_uv_{stator} \\
Mu_{rotor} & Mu_{stator} \\
Mv_{rotor} & Mv_{stator} \\
\varphi\_neutral_{rotor} & \varphi\_neutral_{stator}
\end{matrix}\Bigg)$$

▲ Расчет Л на прочность

$$\text{neutral\_line}(\text{type},x,i,r) = \left|\begin{array}{ll} \dfrac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \tan\left(\left(\alpha\_\text{major}_{\text{rotor}_{i,r}} + \varphi\_\text{neutral}_{\text{rotor}}\left(i,R_{st(i,2),r}\right)\right)\right)\cdot\left(x - \dfrac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if type = "rotor"} \\ \dfrac{y0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}} + \tan\left(\left(\alpha\_\text{major}_{\text{stator}_{i,r}} + \varphi\_\text{neutral}_{\text{stator}}\left(i,R_{st(i,2),r}\right)\right)\right)\cdot\left(x - \dfrac{x0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}}\right) & \text{if type = "stator"} \end{array}\right.$$

$$\text{epure}(\text{type},x,i,r) = \left|\begin{array}{ll} \dfrac{y0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}} + \dfrac{-1}{\tan\left(\alpha\_\text{major}_{\text{rotor}_{i,r}} + \varphi\_\text{neutral}_{\text{rotor}}\left(i,R_{st(i,2),r}\right) - \dfrac{\pi}{4}\right)}\cdot\left(x - \dfrac{x0_{\text{rotor}_{i,r}}}{\text{chord}_{\text{rotor}_{i,r}}}\right) & \text{if type = "rotor"} \\ \dfrac{y0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}} + \dfrac{-1}{\tan\left(\alpha\_\text{major}_{\text{stator}_{i,r}} + \varphi\_\text{neutral}_{\text{stator}}\left(i,R_{st(i,2),r}\right) - \dfrac{\pi}{4}\right)}\cdot\left(x - \dfrac{x0_{\text{stator}_{i,r}}}{\text{chord}_{\text{stator}_{i,r}}}\right) & \text{if type = "stator"} \end{array}\right.$$

▶ Определение координат точек профиля Л, наиболее удаленных от НЛ

Наиболее удаленные точки от НЛ (мм):

$u\_u_{rotor}^{T} =$

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

$\cdot 10^{-3}$

$v\_u_{rotor}^{T} =$

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

$\cdot 10^{-3}$

$u\_l_{rotor}^{T} =$

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

$\cdot 10^{-3}$

$v\_l_{rotor}^{T} =$

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

$\cdot 10$

$u\_u_{stator}^{T} =$

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

$\cdot 10^{-3}$

$v\_u_{stator}^{T} =$

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

$\cdot 10^{-3}$

$u\_l_{stator}^{T} =$

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

$\cdot 10^{-3}$

$v\_l_{stator}^{T} =$

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

$\cdot 10^{-3}$

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

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

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

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

$\cdot 10^{6}$

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

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

$\cdot 10^{6}$

$\sigma\_p_{rotor}^{\ \ T} \le 70 \cdot 10^{6} =$

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

$\sigma\_p_{stator}^{\ \ T} \le 70 \cdot 10^{6} =$

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

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

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

$\cdot 10^{6}$

$\sigma\_n_{stator}^{\ \ T} =$

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

$\cdot 10^{6}$

$\sigma\_n_{rotor}^{\ \ T} \le 70 \cdot 10^{6} =$

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

$\sigma\_n_{stator}^{\ \ T} \le 70 \cdot 10^{6} =$

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

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

```
$\begin{pmatrix} \sigma_{rotor.} \\ \sigma_{stator.} \end{pmatrix} =$
    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	70.19	58.92	56.20						
2	58.09	59.38	55.97						
3	0.00	3.77	6.96						

$\cdot 10^6$

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

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

$\cdot 10^6$

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

$safety_{rotor}{}^T =$

	1	2	3	4	5	6	
1	2.99	3.56	3.74				
2	3.62	3.54	3.75				
3	00000000000000000000000000000000	55.73	30.15				

$safety_{rotor}{}^T \geq safety =$

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

$safety_{stator}{}^T =$

	1	2	3	4	5
1	20643.93	511.85	309.64		
2	7.37	7.65	16.16		
3	4.65	4.61	10.88		

$safety_{stator}{}^T \geq safety =$

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

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

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

Расстояния от оси ЛМ до рассматриваемой ступени (м): $Rj = \mathrm{submatrix}\left(R, 2 \cdot j - 1, 2 \cdot j + 1, 1, N_r\right) =$

	1	2	3
1	383.4	452.0	511.4
2	384.9	452.6	511.4
3	386.3	453.2	511.4

$\cdot 10^{-3}$

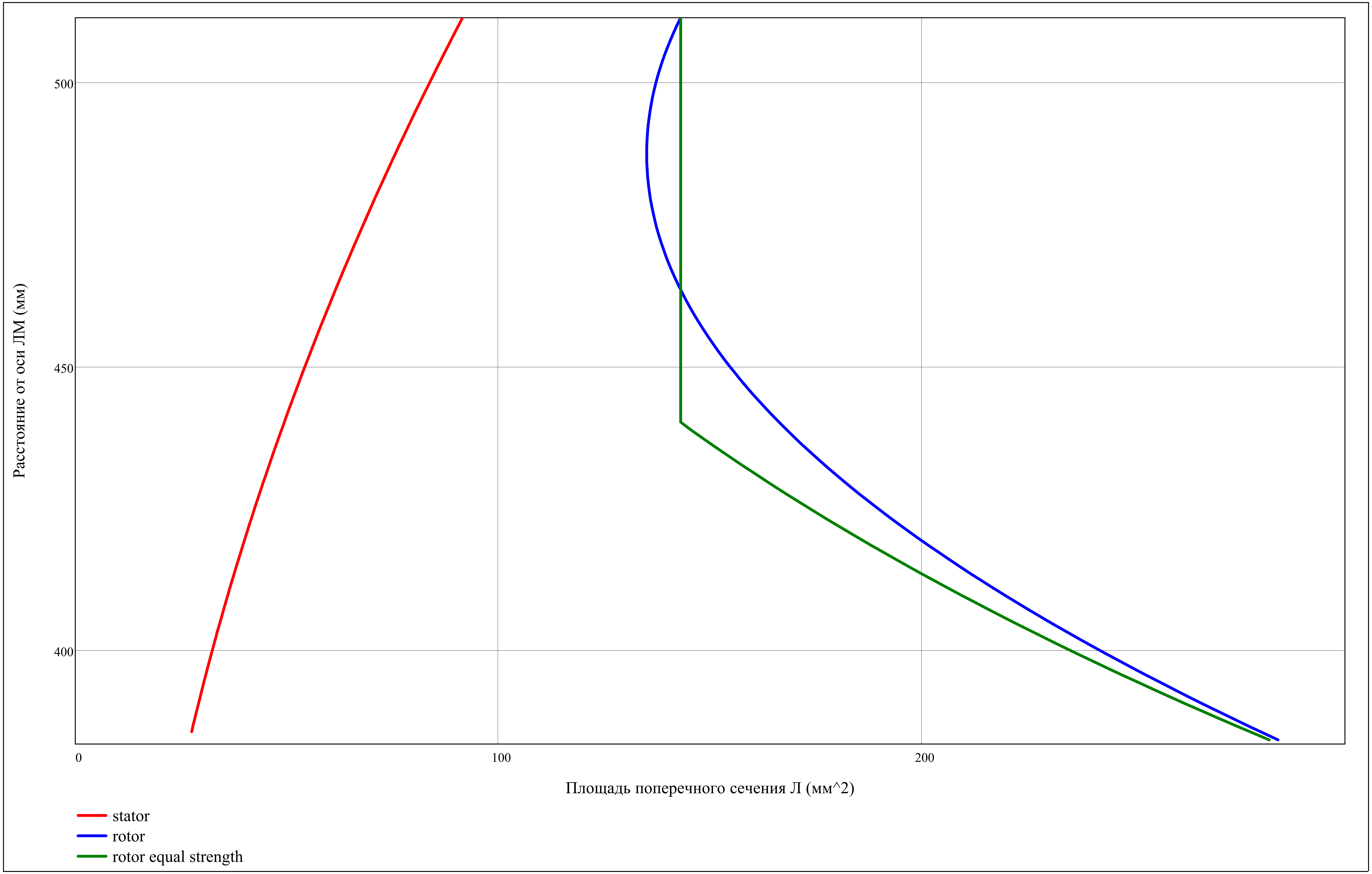
Дискретизация по высоте Л:

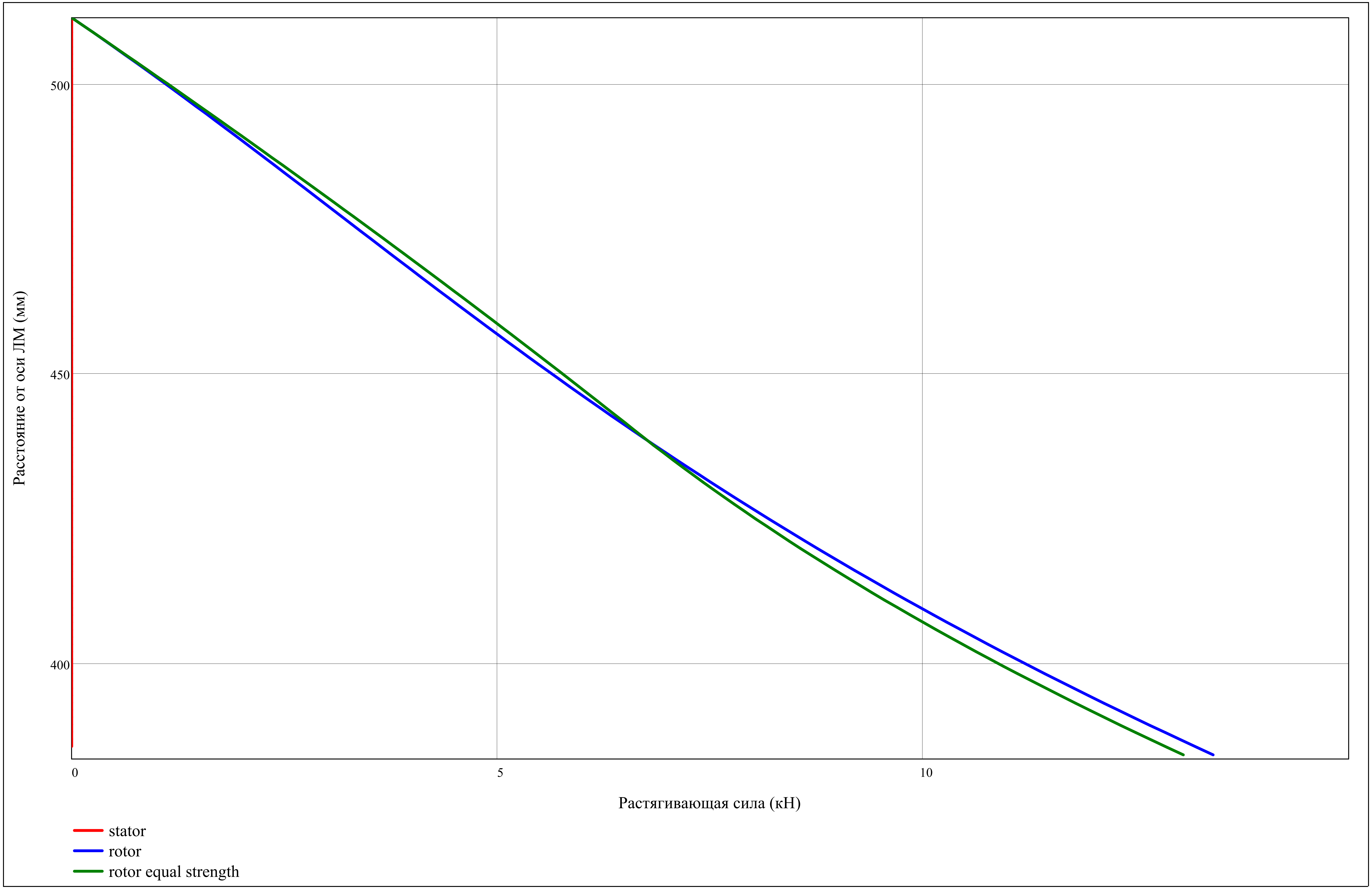
$$z = \min(Rj), \min(Rj) + \frac{\max(Rj) - \min(Rj)}{100} \,..\, \max(Rj)$$

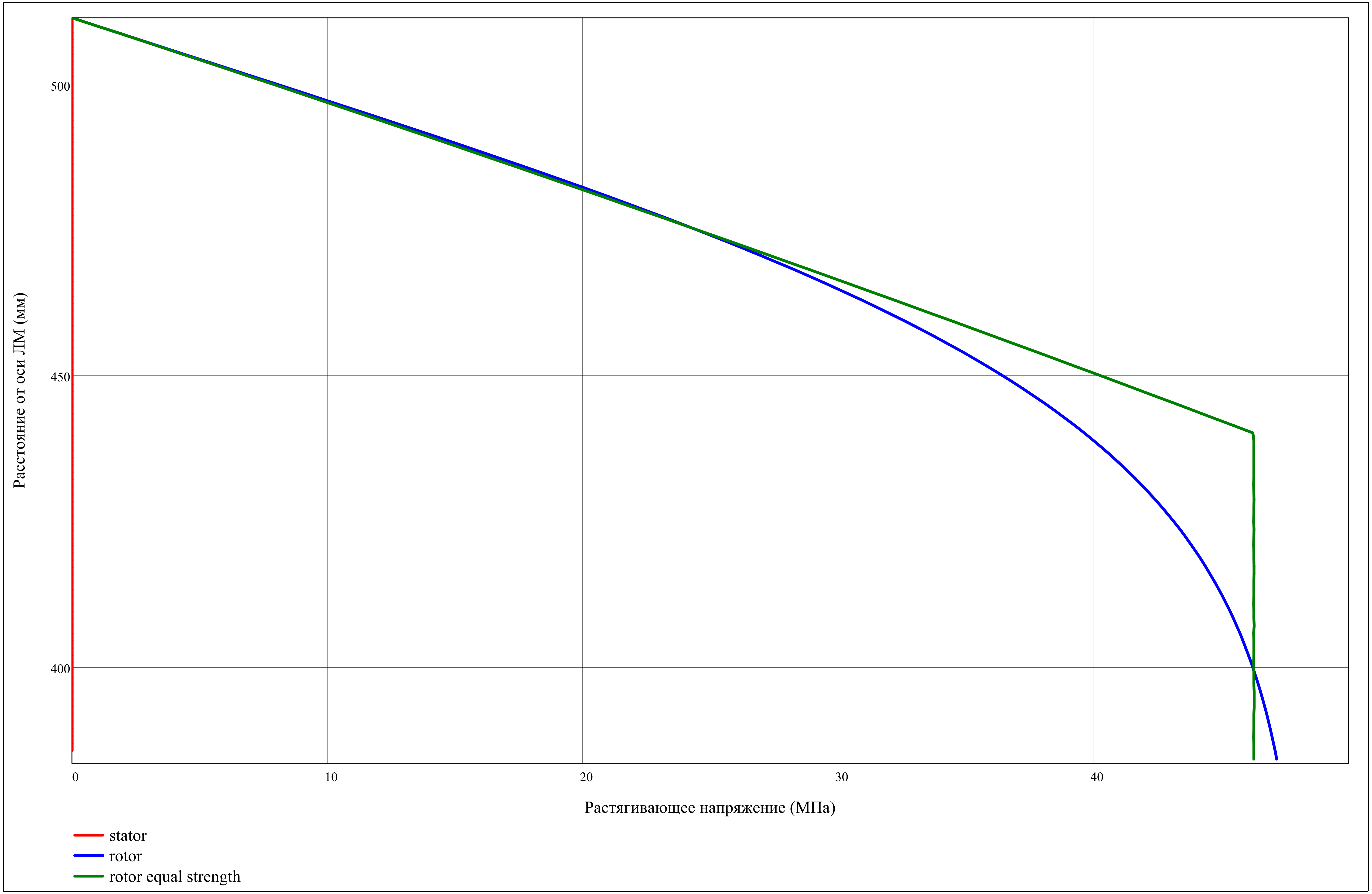
$$z_{rotor} = \left| \begin{array}{l} \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right), \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) - \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right)}{100} \,..\, \mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) \ \text{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

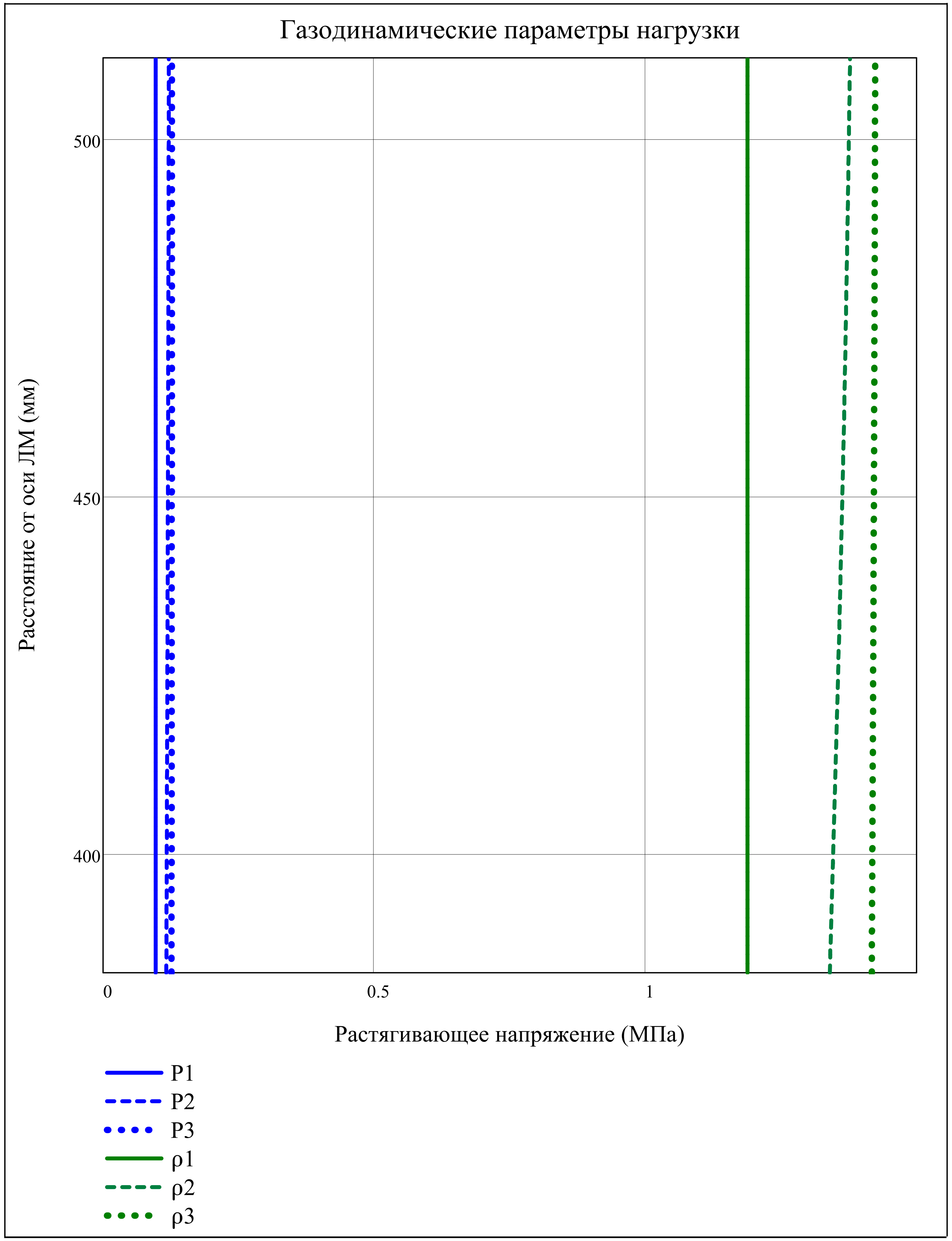
$$z_{stator} = \left| \begin{array}{l} \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right), \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) - \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right)}{100} \,..\, \mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) \ \text{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

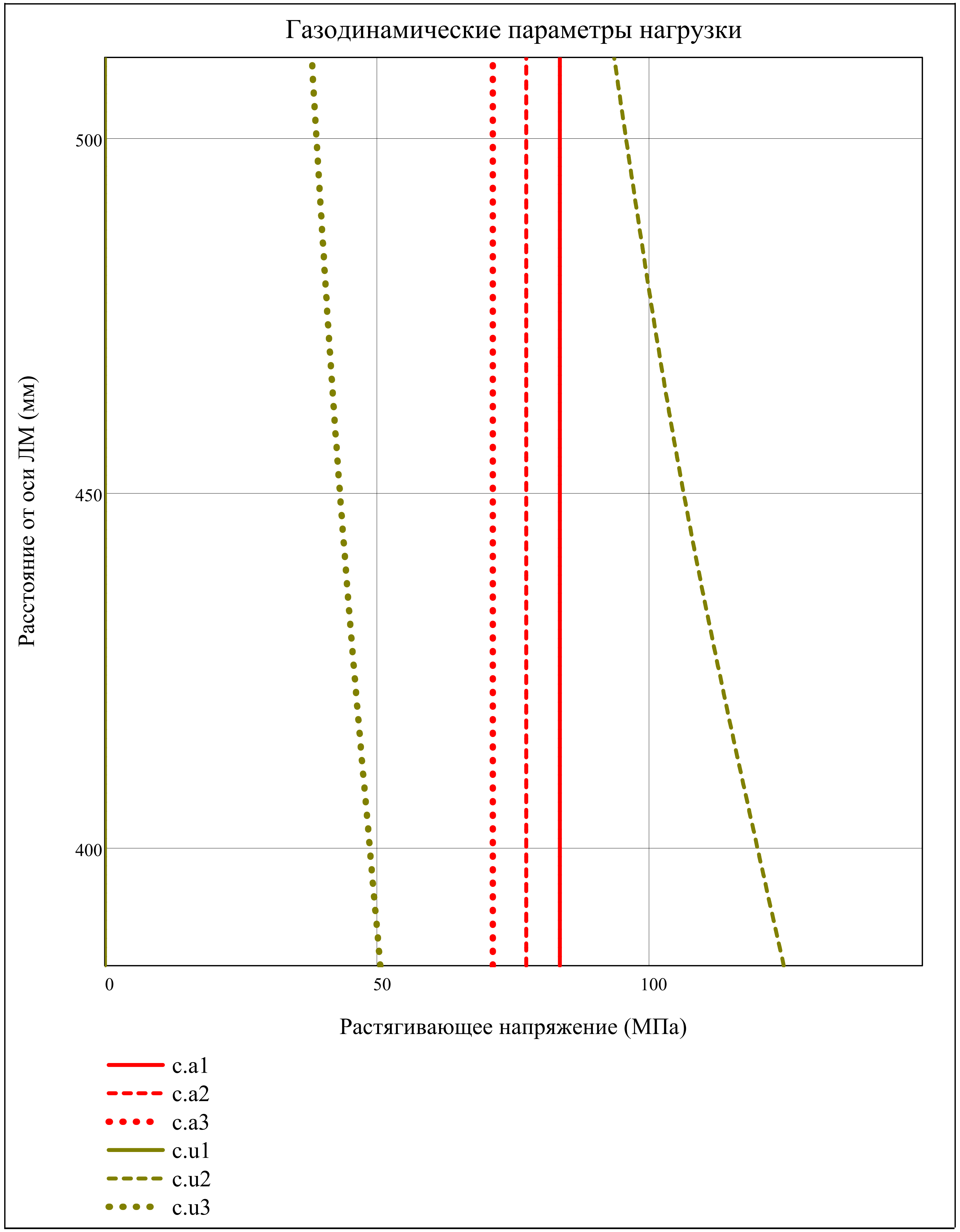
▼ Результаты расчета на прочность Л

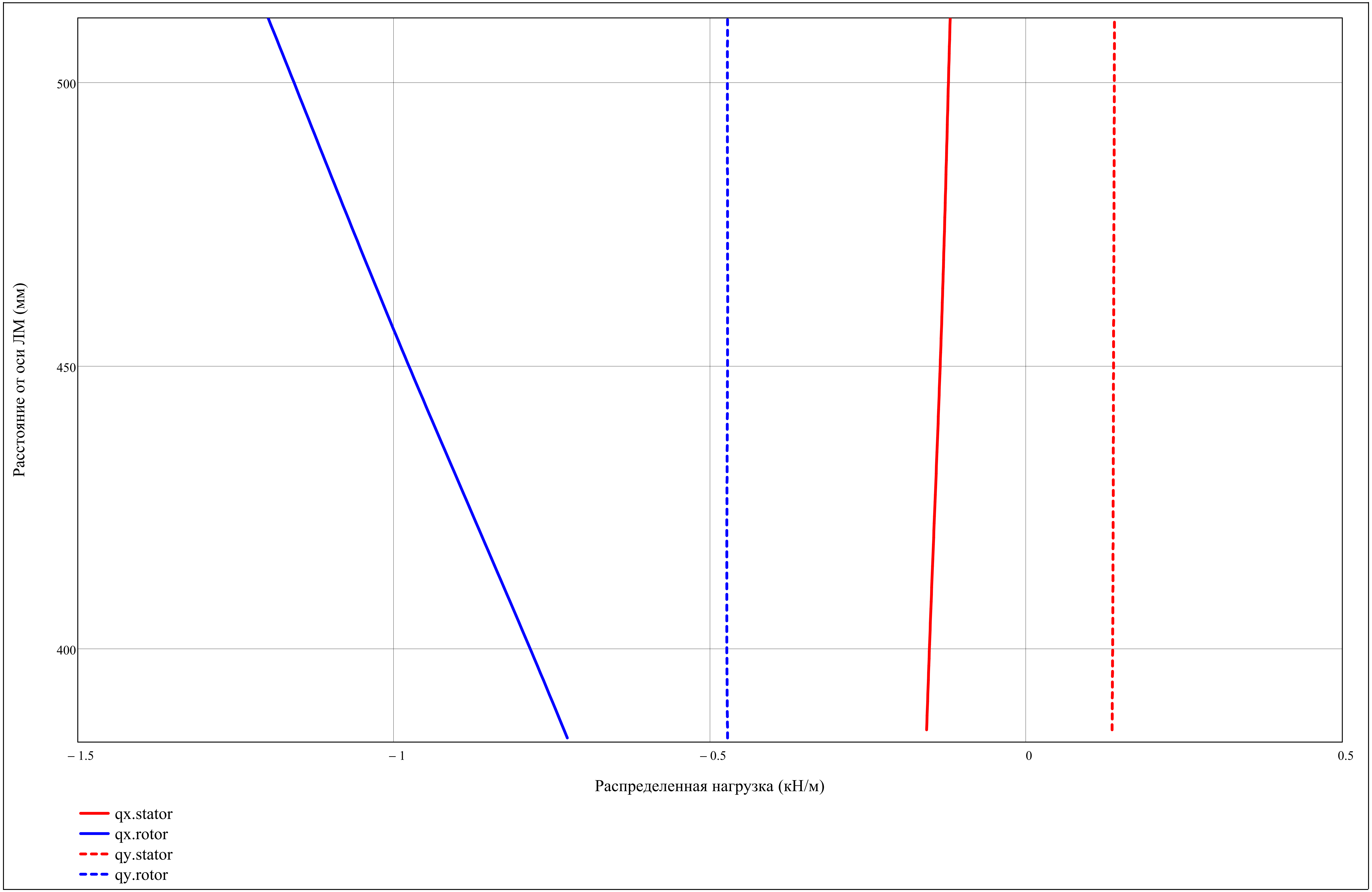

500
450
400
0
100
200
Расстояние от оси ЛМ (мм)
Площадь поперечного сечения Л (мм^2)
stator
rotor
rotor equal strength

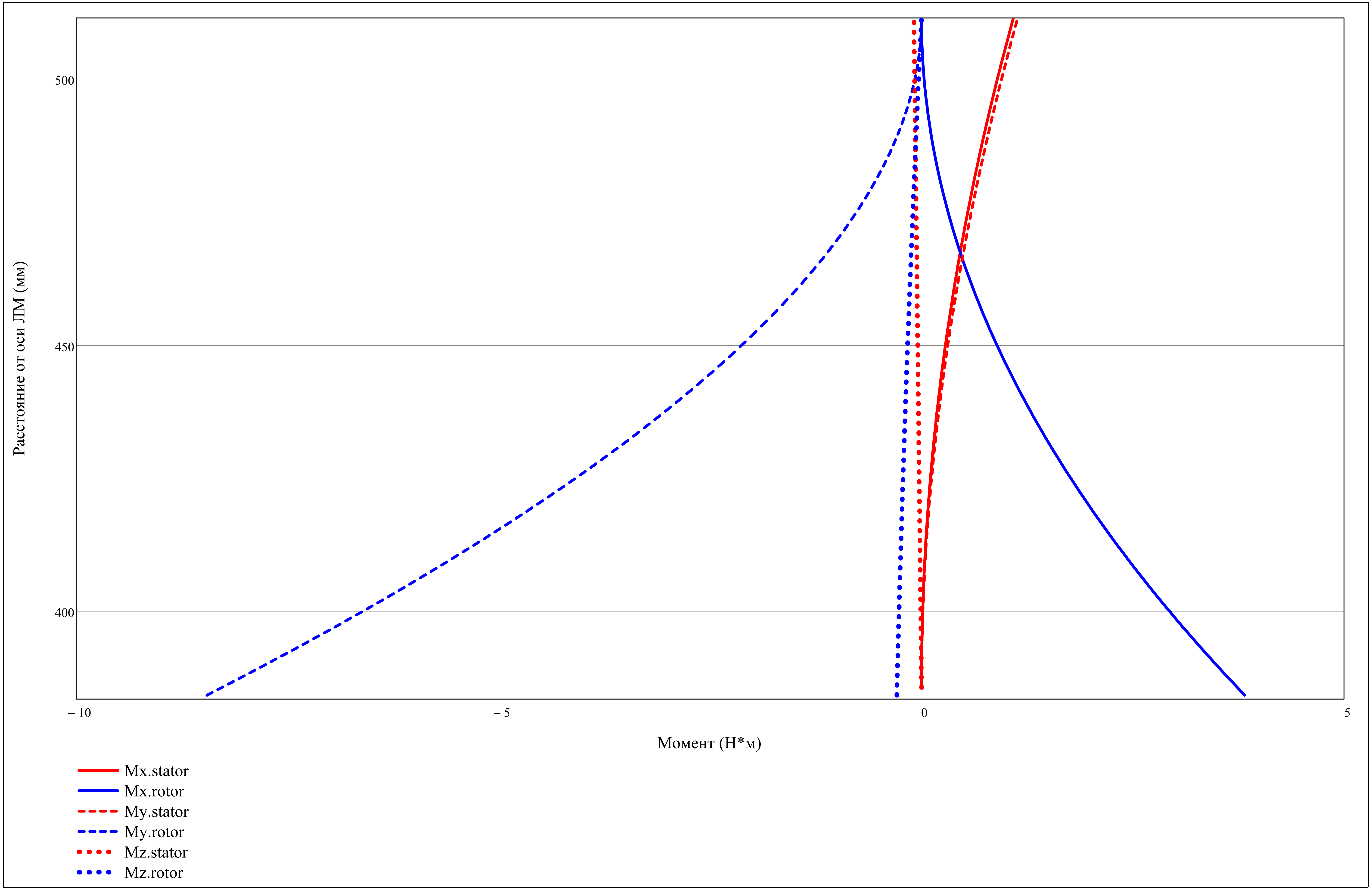

500
450
400
0
5
10
Расстояние от оси ЛМ (мм)
Растягивающая сила (кН)
stator
rotor
rotor equal strength

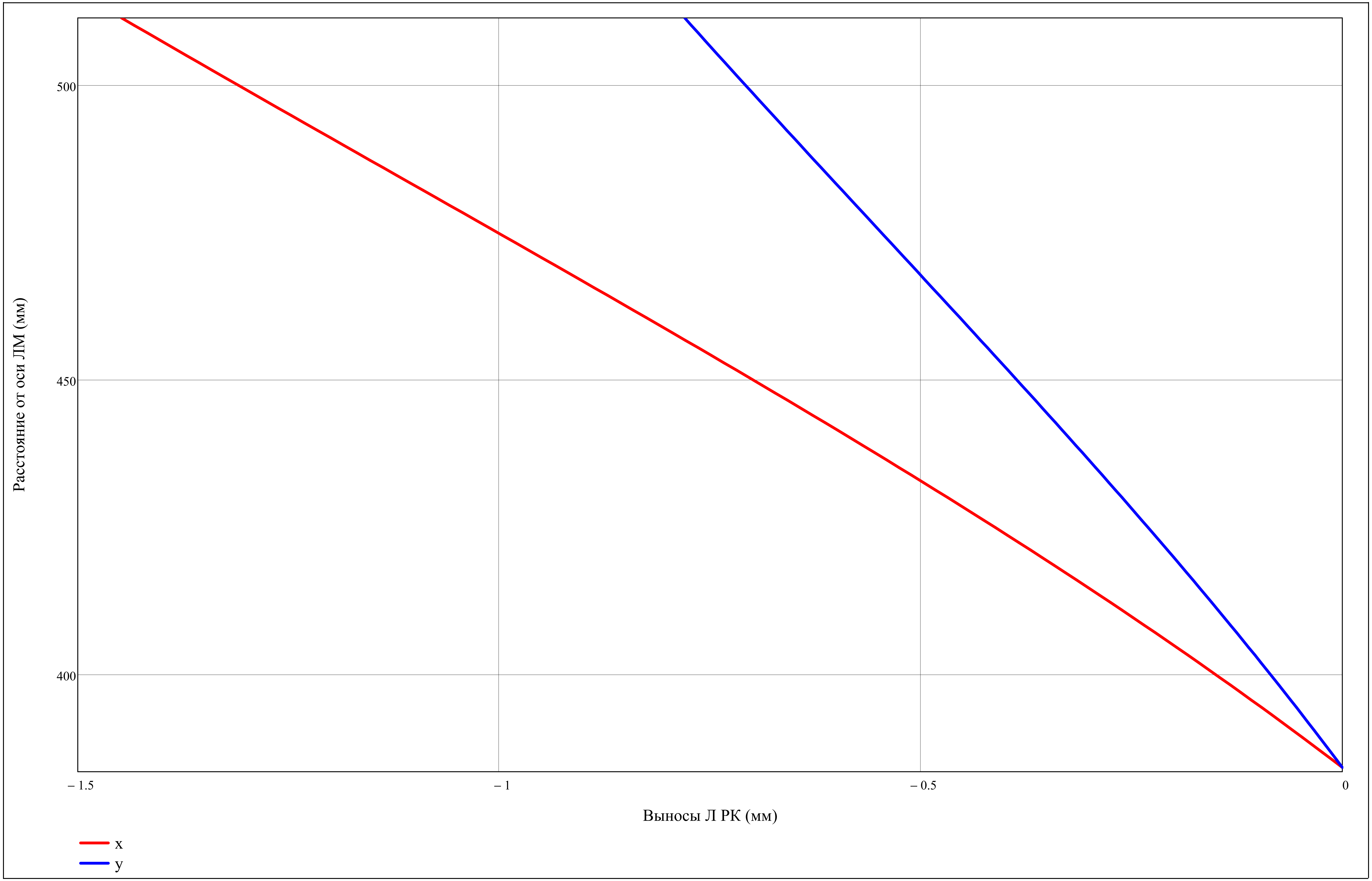

Расстояние от оси ЛМ (мм)
500
450
400
0
10
20
30
40
Растягивающее напряжение (МПа)
stator
rotor
rotor equal strength


Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
500
450
400
0
0.5
1
Растягивающее напряжение (МПа)
P1
P2
P3
ρ1
ρ2
ρ3

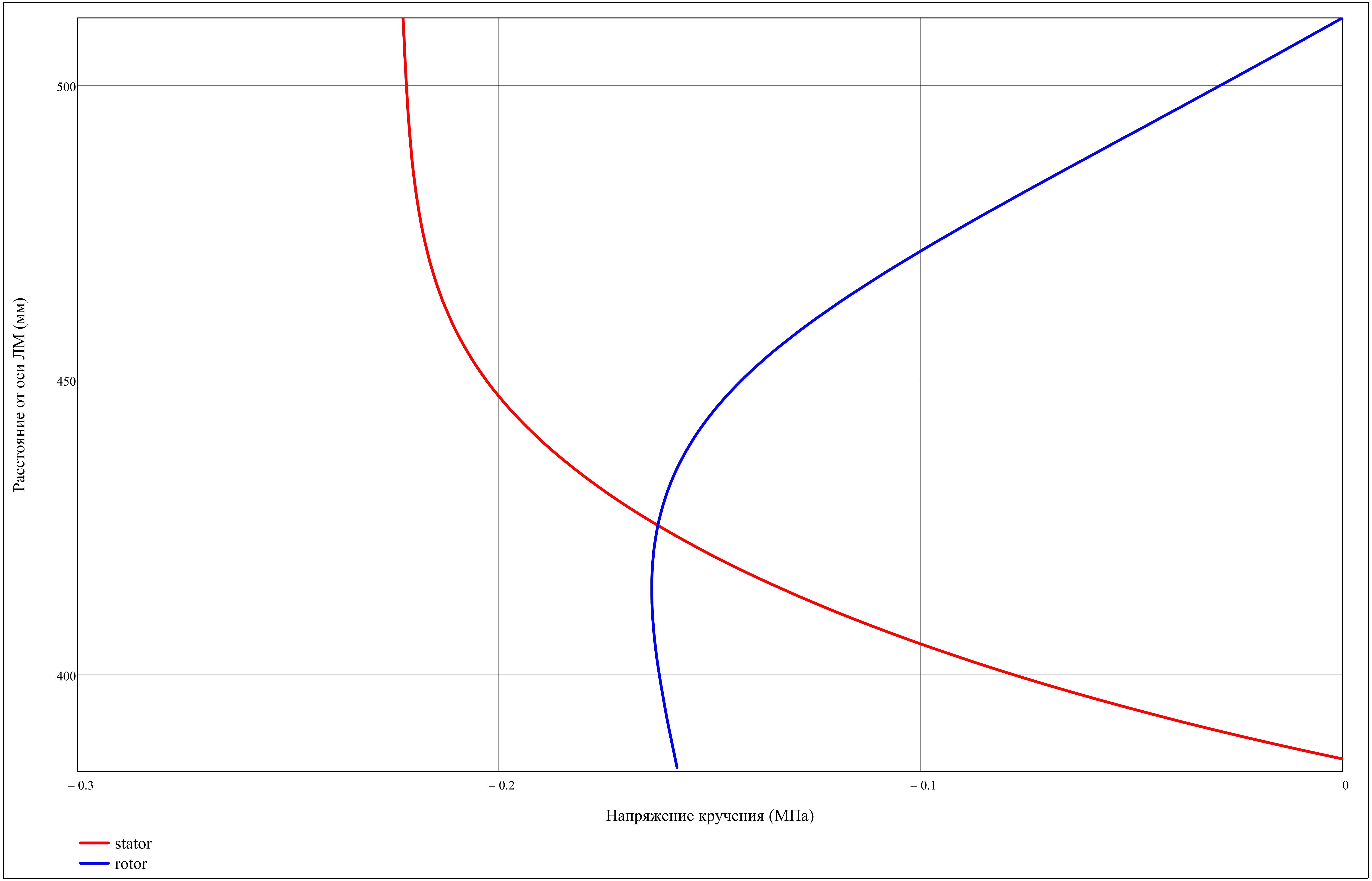

Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
500
450
400
0
50
100
Растягивающее напряжение (МПа)
c.a1
c.a2
c.a3
c.u1
c.u2
c.u3

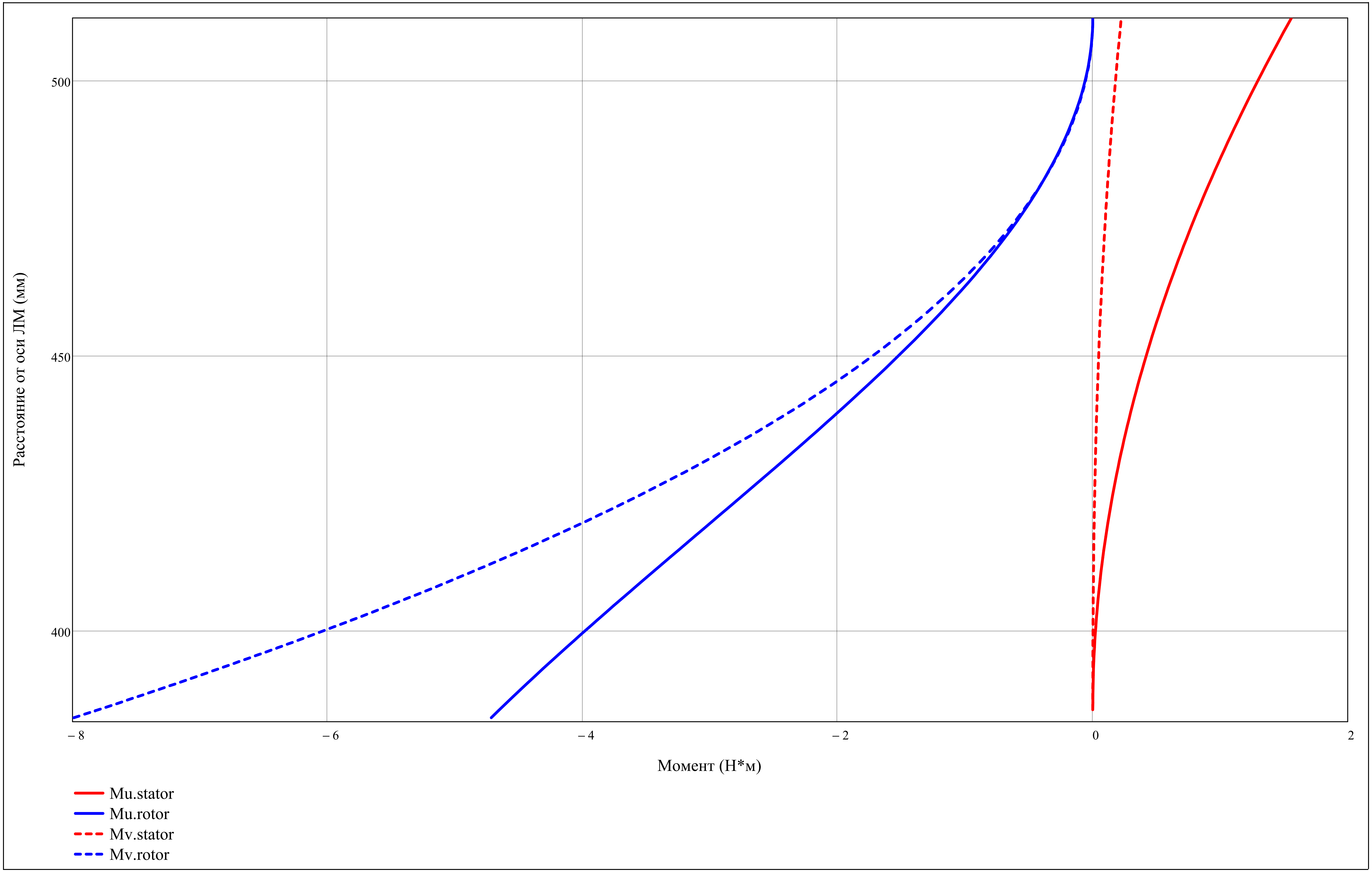

Расстояние от оси ЛМ (мм)
500
450
400
– 1.5
– 1
– 0.5
0
0.5
Распределенная нагрузка (кН/м)
qx.stator
qx.rotor
qy.stator
qy.rotor

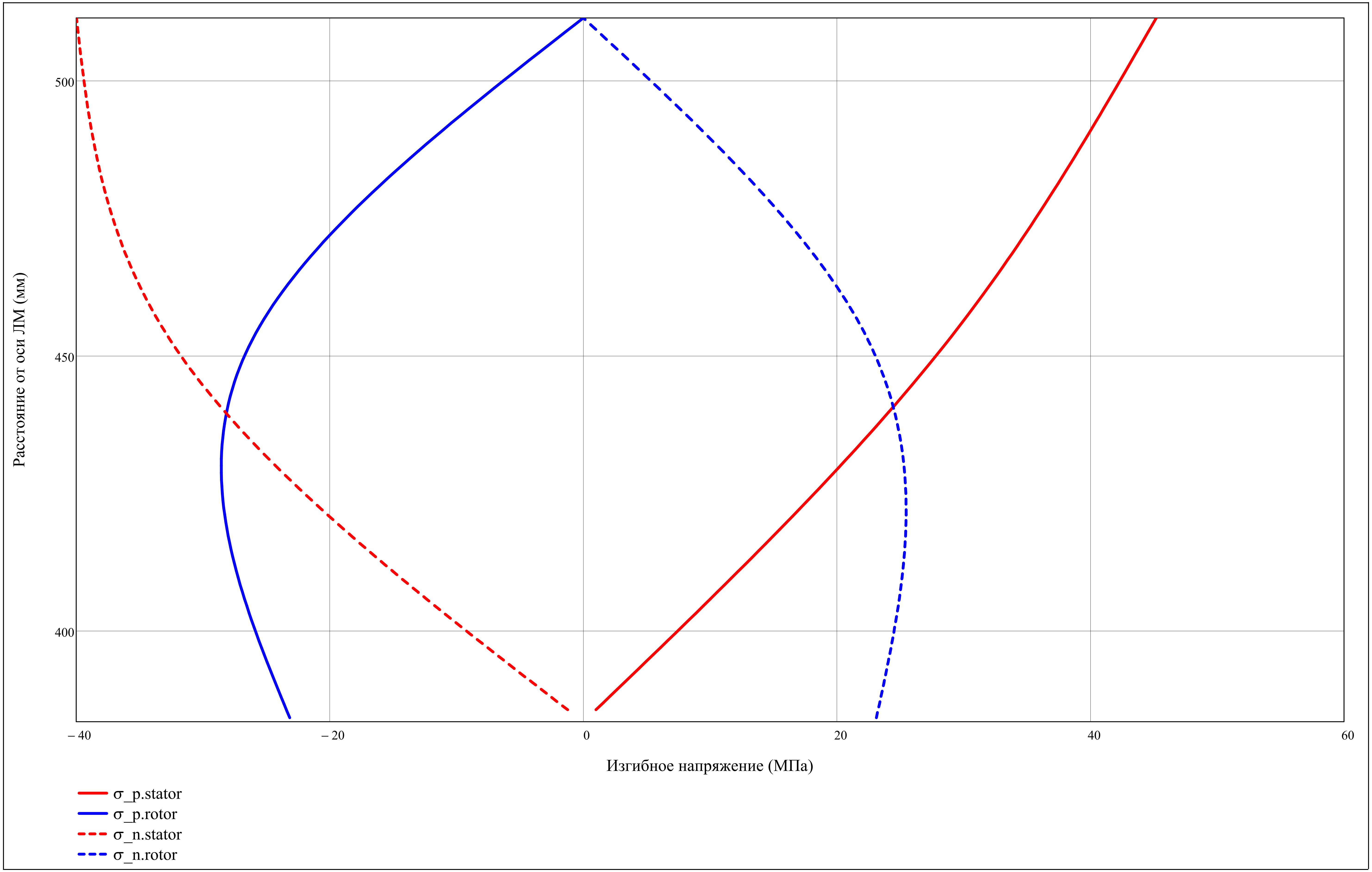

Расстояние от оси ЛМ (мм)
500
450
400
– 10
– 5
0
5
Момент (Н*м)
Mx.stator
Mx.rotor
My.stator
My.rotor
Mz.stator
Mz.rotor

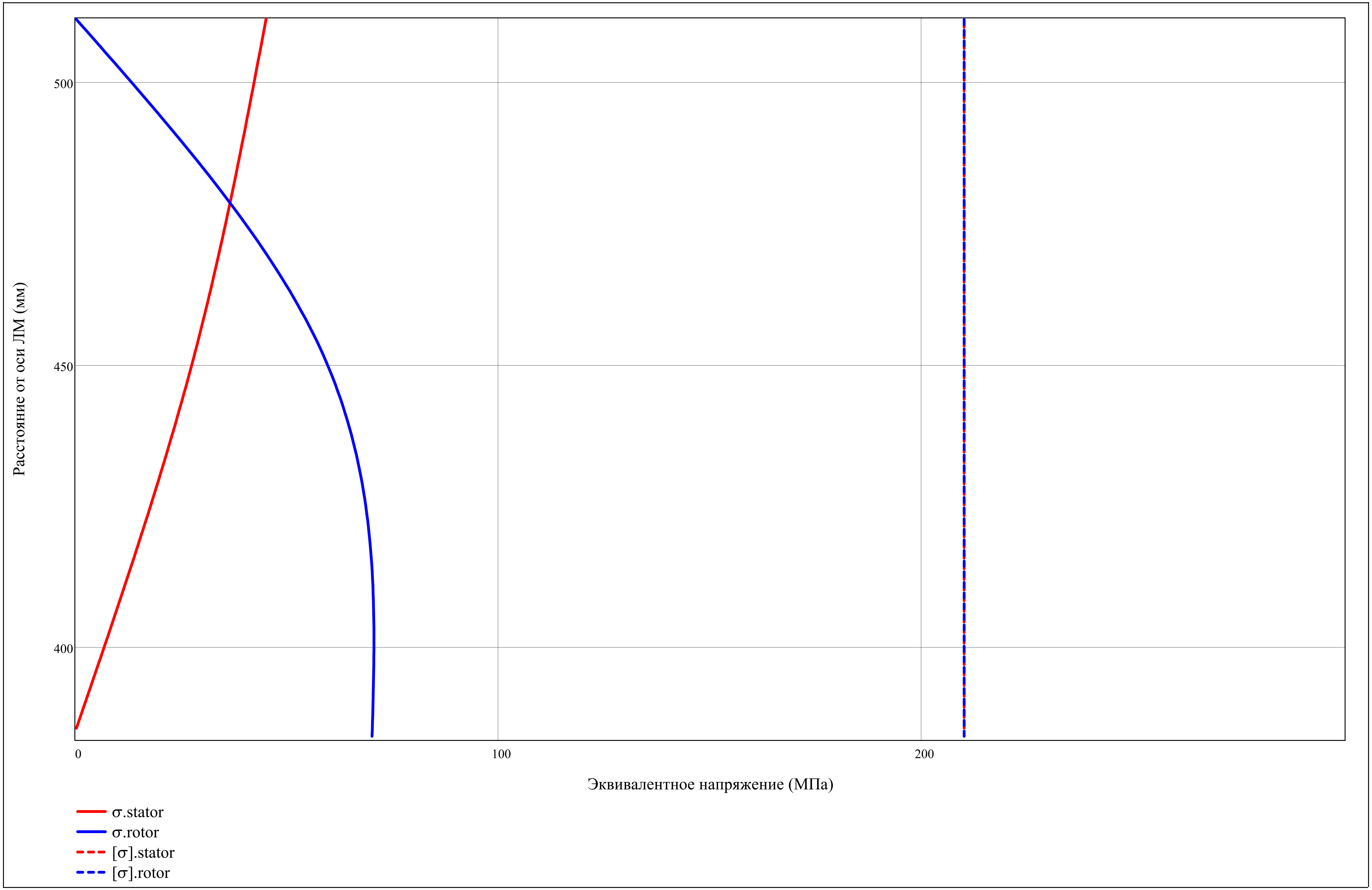


Расстояние от оси ЛМ (мм)
500
450
400
– 1.5
– 1
– 0.5
0
Выносы Л РК (мм)
x
y


500
450
400
Расстояние от оси ЛМ (мм)
– 0.3
– 0.2
– 0.1
0
Напряжение кручения (МПа)
stator
rotor


500
450
400
Расстояние от оси ЛМ (мм)
– 8
– 6
– 4
– 2
0
2
Момент (Н*м)
Mu.stator
Mu.rotor
Mv.stator
Mv.rotor


Расстояние от оси ЛМ (мм)
500
450
400
– 40
– 20
0
20
40
60
Изгибное напряжение (МПа)
σ_p.stator
σ_p.rotor
σ_n.stator
σ_n.rotor

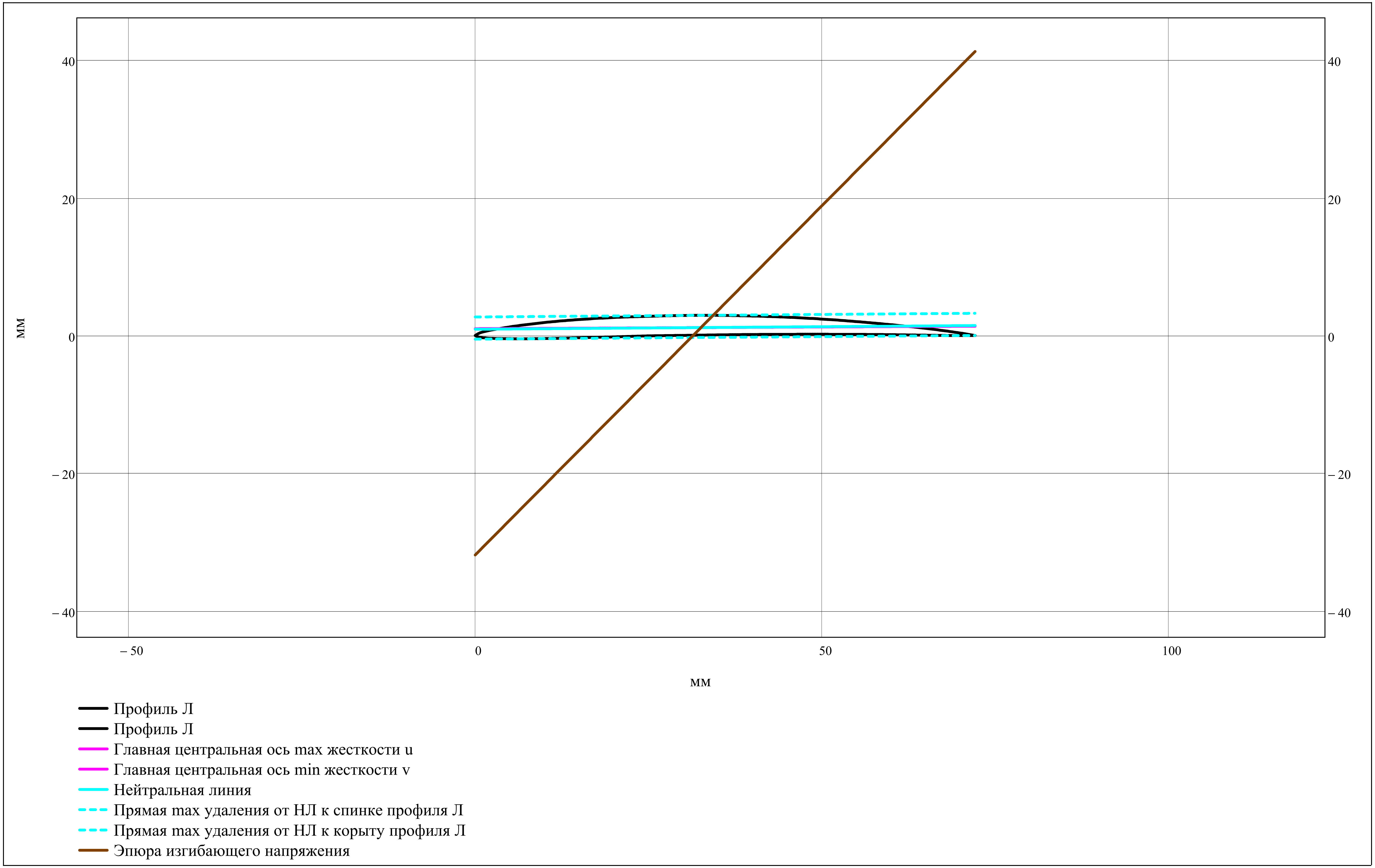

Расстояние от оси ЛМ (мм)
500
450
400
0
100
200
Эквивалентное напряжение (МПа)
σ.stator
σ.rotor
[σ].stator
[σ].rotor

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

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade} = \text{"rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.781 \\ \hline 2 & -1.442 \\ \hline \end{array} \cdot 10^{-3}$$

$$\begin{pmatrix} x0 \\ y0 \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} x0_{rotor_{j,r}} \\ y0_{rotor_{j,r}} \end{pmatrix} & \text{if blade} = \text{"rotor"} \\ \begin{pmatrix} x0_{stator_{j,r}} \\ y0_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 32.549 \\ \hline 2 & 1.147 \\ \hline \end{array} \cdot 10^{-3}$$

$$\text{chord} = \left| \begin{array}{ll} \text{chord}_{rotor_{j,r}} & \text{if blade} = \text{"rotor"} \\ \text{chord}_{stator_{j,r}} & \text{if blade} = \text{"stator"} \end{array} \right. = 72 \cdot 10^{-3}$$


40
20
0
– 20
– 40
– 50
0
50
100
мм
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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} = \begin{array}{c|c|c} & 1 & 2 \\ \hline 1 & -1.55 & 1.78 \\ 2 & 38.79 & -1.44 \\ 3 & -0.05 & 1.35 \\ 4 & 21.37 & -1.53 \end{array} \cdot 10^{-3}$$

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -26.32 & 28.50 \\ 22.63 & -32.34 \end{pmatrix} \cdot 10^{6}$$

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 28.50 \\ 58.09 \end{pmatrix} \cdot 10^{6}$$

$$\begin{pmatrix} safety_{stator_{j,r}} \\ safety_{rotor_{j,r}} \end{pmatrix} = \begin{array}{c|c} & 1 \\ \hline 1 & 7.368 \\ 2 & 3.615 \end{array}$$

▲ Результаты расчета на прочность Л

Вывод результатов расчета Л на прочность

Выбор материала Д

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

Выбранный материал Д:

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

Плотность материала Д (кг/м^3):

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

Предел длительной прочности Д (Па):

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

$material\_disk^T =$

	1	2	3	4	5	6	7	8	9
1	"ВТ6"	"ВТ6"	"ВТ6"						

$\rho\_disk^T =$

	1	2	3
1	4430	4430	4430

$\sigma\_disk\_long^T =$

	1	2	3
1	210	210	210

$\cdot 10^6$

Выбор материала Д

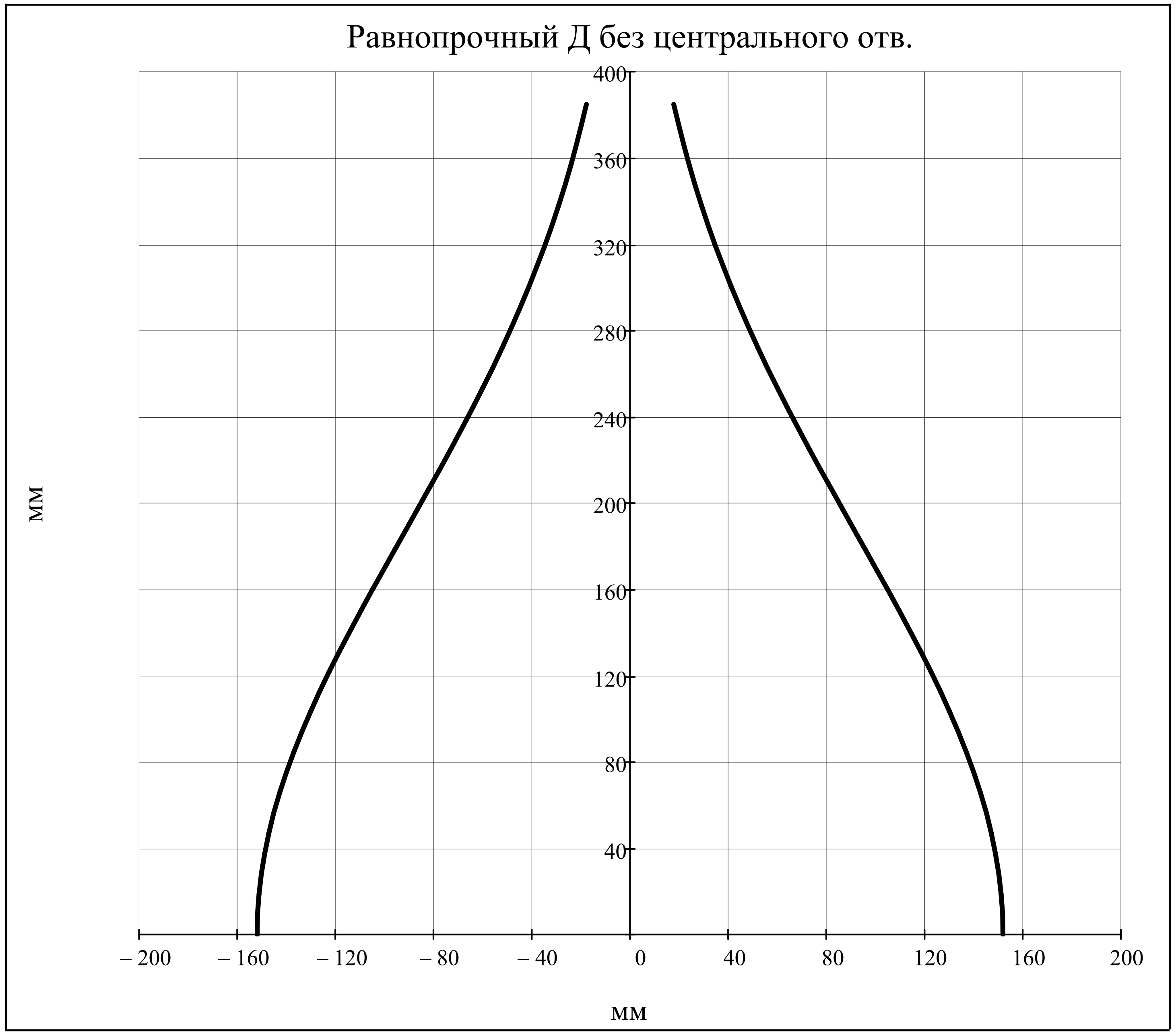
Рассматриваемая ступень:

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

▼ Профилирование равнопрочного Д без центрального отв.

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

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



▲ Профилирование равнопрочного Д без центрального отв.

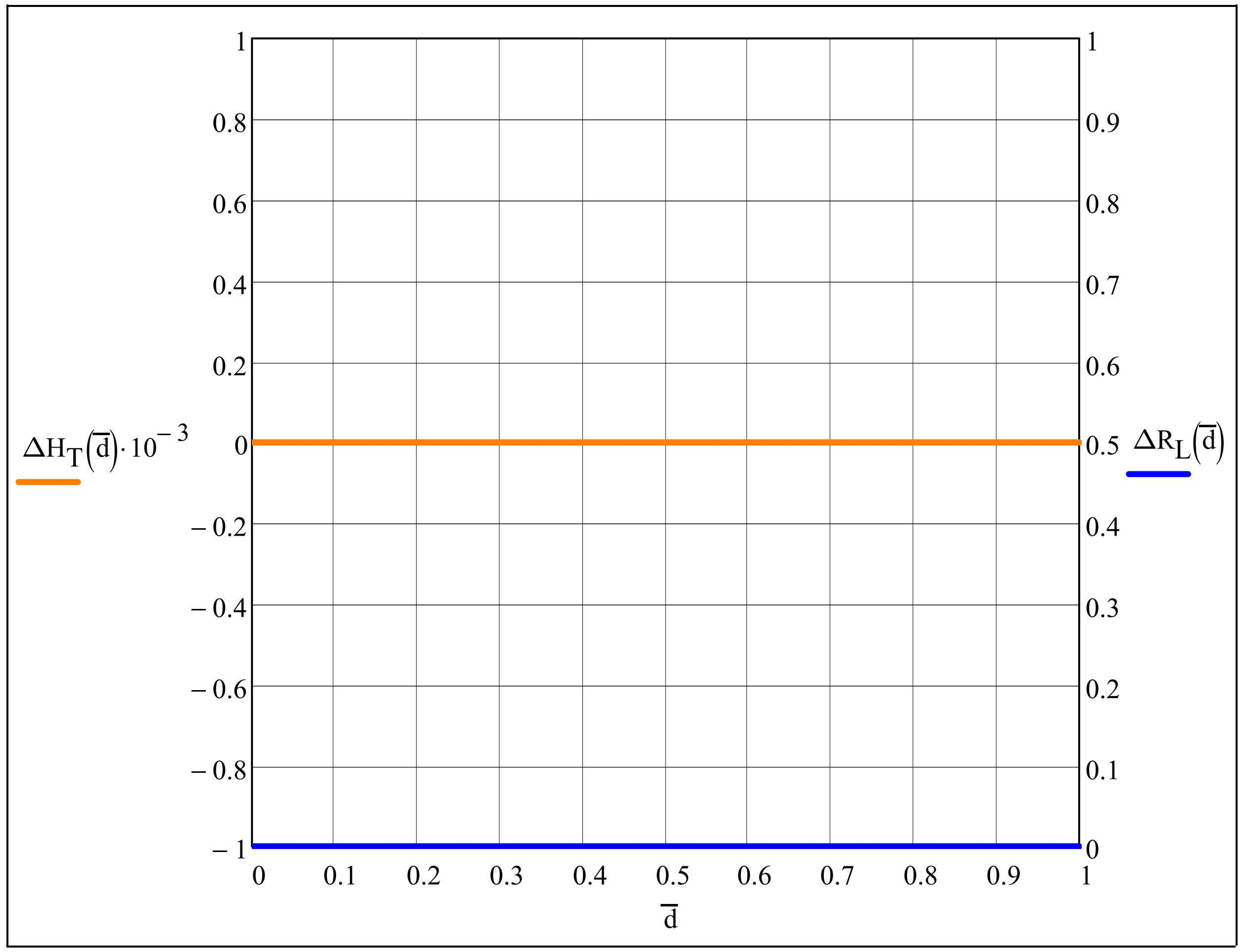
Max разница теор. напора ступени и реактивности
от периферии к корню по высоте Л (Дж/кг)
[16, с.118-119]:

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

$\Delta R_{Lmax} = 0.0$

$\Delta H_T(\overline{d}) = -\Delta H_{Tmax}\cdot\overline{d} + \Delta H_{Tmax}$

$\Delta R_L(\overline{d}) = -\Delta R_{Lmax}\cdot\overline{d} + \Delta R_{Lmax}$



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

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

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

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

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

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

$$\varepsilon_{stator_{j,r}} = 19.79 \cdot ^{\circ}$$

$$\varepsilon_{rotor_{j,r}} = 19.4 \cdot ^{\circ}$$

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

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

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

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

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

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

$$\varepsilon_{stator_{j,r}} = 19.83 \cdot ^\circ$$

$$\varepsilon_{rotor_{j,r}} = 9.56 \cdot ^\circ$$

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

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

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

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

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

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

$$\varepsilon_{stator_{j,r}} = 19.57 \cdot °$$

$$\varepsilon_{rotor_{j,r}} = 5.71 \cdot °$$

MM

MM

$,z\big)$

$\big)^{T},z\big)$

$^{-3}$

7	8	9