Подключение библиотек

Основные уравнения, алгоритмы, зависимости и ф-и

▶ Параметры расчета

Исходные данные

Коэф. запаса: $safety = 1.3$

Степень двухконтурности: $m2 = 6$

РТ: Воздух

$compressor = \text{"КНД"}$

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):

$$T^*_{K1} = \left|\begin{array}{l} 418.2 \ \text{ if } compressor = \text{"КВД"} \\ 288.2 \ \text{ otherwise} \end{array}\right. = 288.2$$

Полное давление на входе в К (Па):

$$P^*_{K1} = \left|\begin{array}{l} 316.2\cdot 10^{3} \ \text{ if } compressor = \text{"КВД"} \\ 101325 \ \text{ otherwise} \end{array}\right. = 101.3\cdot 10^{3}$$

Степень повышения давления КВД:

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

Ожидаемый адиабатический КПД ОК:

$$\eta^*_K = \left| \begin{array}{l} 0.86 \text{ if } compressor = \text{"Вл"} \\ 0.87 \text{ if } compressor = \text{"КНД"} \\ 0.88 \text{ if } compressor = \text{"КВД"} \end{array} \right. = 87.00 \cdot \%$$

Частота вращения ротора (c^{-1}):

$$\omega = \left| \begin{array}{l} 1570.8 \text{ if } compressor = \text{"КВД"} \\ 555 \text{ otherwise} \end{array} \right. = 555.0$$

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

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

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

Частота вращения ротора (об/мин):

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

Закон профилирования проточной части (ЗППЧ):

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

Относ. параметры по относительным ступеням:

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

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

[16, с. 60]

[18, с. 24]

Уточнение параметров:

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

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

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

	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]:

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

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

▲ Исходные данные

Распределение основных параметров ОК по ступеням

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

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

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

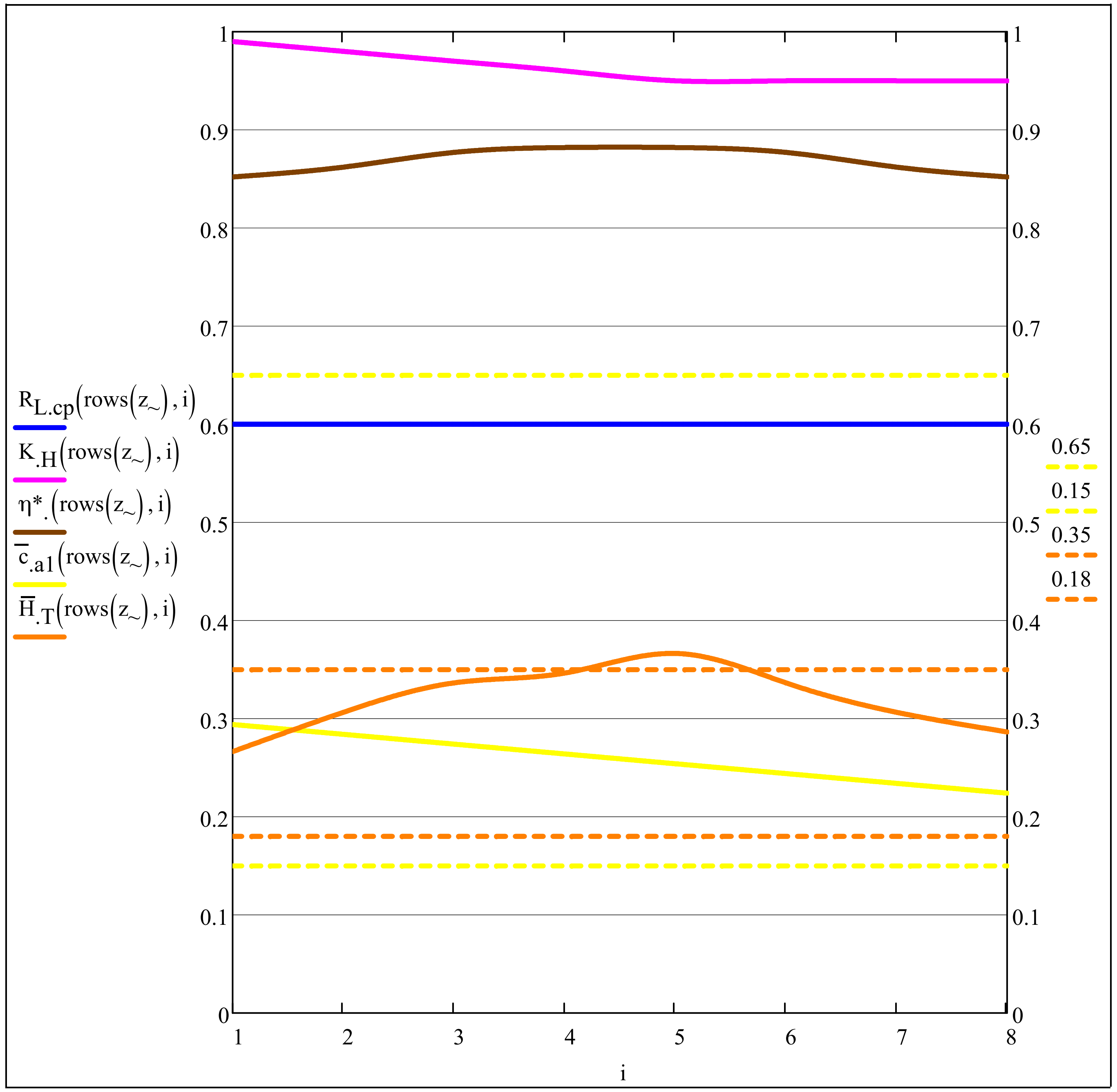
Коэф. расхода: $\bar{c}_{\sim a1}(i) = \text{interp}\left(\text{lspline}\left(\frac{z_{\sim}}{\text{rows}(z_{\sim})}, \bar{c}_{\sim a1}\right), \frac{z_{\sim}}{\text{rows}(z_{\sim})}, \bar{c}_{\sim a1}, i\right)$

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

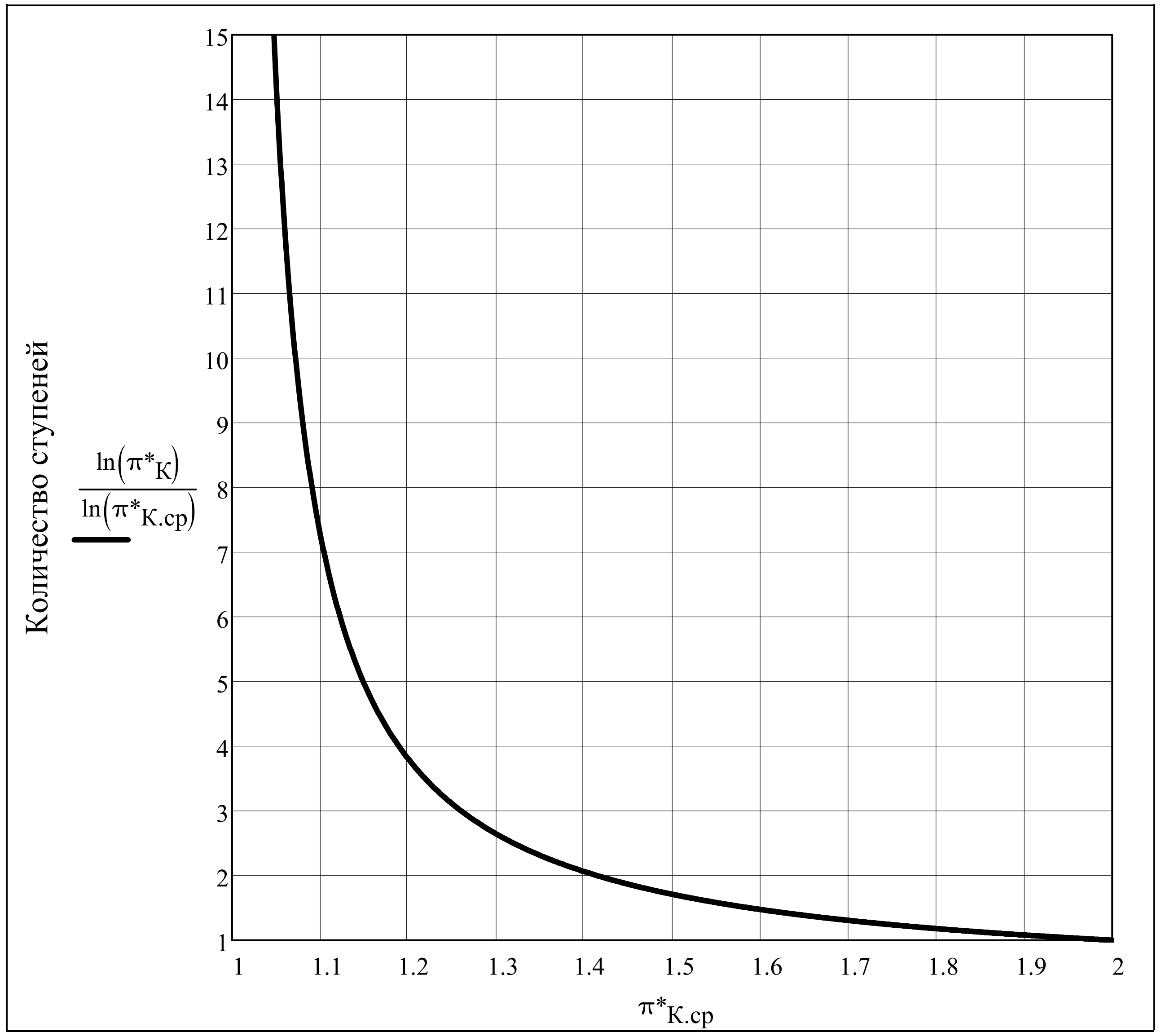
$$\begin{pmatrix} R_{L.cp} \\ K_{.H} \\ \eta^*_{.} \\ \overline{c}_{.a1} \\ \overline{H}_{.T} \end{pmatrix} = \left| \begin{array}{l} R_{L.cp}(Z,i) = \left| \begin{array}{ll} R_{L\sim cp}\left(\frac{1}{rows(z_\sim)}\right) & \text{if } i<1 \\ R_{L\sim cp}(1) & \text{if } i>Z \\ R_{L\sim cp}\left(\frac{i}{Z}\right)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

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

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



Распределение основных параметров ОК по ступеням


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

Нулевые приближения

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

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

Количество итераций []: $iteration_3 = 1$

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]:

$$\begin{pmatrix} \rho^*_{К1} \\ \rho^*_{К3} \end{pmatrix} = \frac{1}{R_в}\cdot\begin{pmatrix} \dfrac{P^*_{К1}}{T^*_{К1}} \\ \dfrac{P^*_{К3}}{T^*_{К3}} \end{pmatrix} = \begin{pmatrix} 1.224 \\ 1.955 \end{pmatrix}$$

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]:

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

```
$\begin{pmatrix} iteration_u \\ u_{1пер} \\ Z_{recomend} \\ c_{вх} \\ \lambda_{вх} \\ \rho_{K1} \end{pmatrix} =$
    $iteration_u = 0$
    $\rho_{K1} = \rho^*_{K1}$
    while $0 < 1$
        $iteration_u = iteration_u + 1$
        trace(concat("iteration.u = ", num2str($iteration_u$)))
        $u_{1пер} = \sqrt[3]{\frac{\pi \cdot G \cdot n^2}{900 \cdot \bar{c}_{.a1}(1,0) \cdot \rho_{K1} \cdot \left[1 - (\bar{d}_1)^2\right]}}$
        $Z_{recomend} = \max\left(\mathrm{round}\left(\frac{H_{TK}}{\bar{H}_{Tcp} \cdot u_{1пер}^2}\right), 1\right)$
        $c_{вх} = \bar{c}_{.a1}(Z_{recomend}, 0) \cdot u_{1пер}$
        $\lambda_{вх} = \frac{c_{вх}}{a^*_{c.вх}}$
        $\rho'_{K1} = \rho^*_{K1} \cdot ГДФ("\rho", \lambda_{вх}, k_{K1})$
        if $\left|eps("rel", \rho'_{K1}, \rho_{K1})\right| \le epsilon$
            $\rho_{K1} = \rho'_{K1}$
            break
        $\rho_{K1} = \rho'_{K1}$
    $\begin{pmatrix} iteration_u \\ u_{1пер} \\ Z_{recomend} \\ c_{вх} \\ \lambda_{вх} \\ \rho_{K1} \end{pmatrix}$
```

Количество итераций []: $iteration_u = 2$

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

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

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

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

Плотность перед К [кг/м^3]: $\rho_{K1} = 1.188$

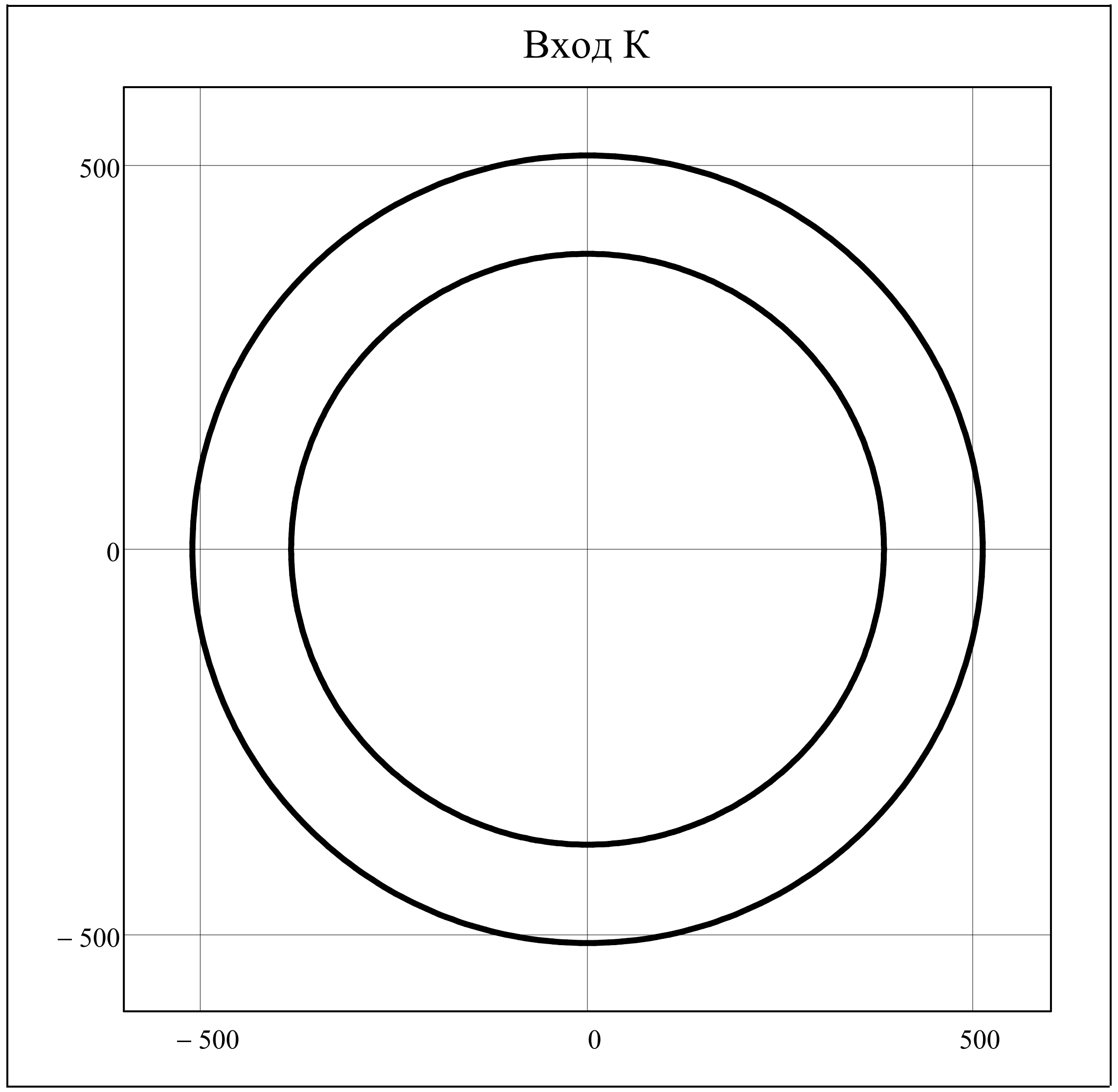
Кольцевая площадь перед К [м^2]: $F_{вх} = \frac{G \cdot \sqrt{R_в \cdot T^*_{K1}}}{m_q(k_{K1}) \cdot P^*_{K1} \cdot ГДФ("G", \lambda_{вх}, k_{K1})} = 0.3596$

$$D'_{пер1} = \frac{2 \cdot u_{1пер}}{\omega} = 1022.8 \cdot 10^{-3}$$

Диамтеры перед К [м]: $D'_{cp1} = \bar{r}_{cp}(\bar{d}_1) \cdot D'_{пер1} = 904 \cdot 10^{-3}$

$$D'_{кор1} = \bar{d}_1 \cdot D'_{пер1} = 767.1 \cdot 10^{-3}$$

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



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

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

▲ Нулевые приближения

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

Расчет ВНА:

$$\begin{pmatrix} \alpha_{1\text{ВНА}} & \alpha_{3\text{ВНА}} \\ \sigma_{\text{ВНА}} & \sigma_{\text{ВНА}} \\ \overline{d}_{1\text{ВНА}} & \overline{d}_{3\text{ВНА}} \\ T^*_{1\text{ВНА}} & T^*_{3\text{ВНА}} \\ P^*_{1\text{ВНА}} & P^*_{3\text{ВНА}} \\ \rho^*_{1\text{ВНА}} & \rho^*_{3\text{ВНА}} \\ k_{1\text{ВНА}} & k_{3\text{ВНА}} \\ a_{\text{кр}1\text{ВНА}} & a_{\text{кр}3\text{ВНА}} \\ \overline{c}_{a1\text{ВНА}} & \overline{c}_{a3\text{ВНА}} \\ \overline{c}_{u1\text{ВНА}} & \overline{c}_{u3\text{ВНА}} \\ c_{a1\text{ВНА}} & c_{a3\text{ВНА}} \\ c_{u1\text{ВНА}} & c_{u3\text{ВНА}} \\ c_{1\text{ВНА}} & c_{3\text{ВНА}} \\ \lambda_{c1\text{ВНА}} & \lambda_{c3\text{ВНА}} \\ F_{1\text{ВНА}} & F_{3\text{ВНА}} \\ \varepsilon_{\text{ВНА}} & \varepsilon_{\text{ВНА}} \end{pmatrix} = \left| \begin{array}{l} \text{for } r \in av(N_r) \\ \quad \left| \begin{array}{l} \alpha_{1\text{ВНА}_r} \leftarrow 90° \\ \overline{d}_{1\text{ВНА}} \leftarrow \overline{d}_1 \\ \overline{d}_{3\text{ВНА}} \leftarrow \overline{d}_{1\text{ВНА}} \\ T^*_{1\text{ВНА}_r} \leftarrow T^*_{К1} \\ T^*_{3\text{ВНА}_r} \leftarrow T^*_{1\text{ВНА}_r} \\ P^*_{1\text{ВНА}_r} \leftarrow P^*_{К1} \\ \rho^*_{1\text{ВНА}_r} \leftarrow \dfrac{P^*_{1\text{ВНА}_r}}{R_в \cdot T^*_{1\text{ВНА}_r}} \\ k_{1\text{ВНА}_r} \leftarrow k_{\text{ад}}\left(Cp_{\text{воздух}}\left(P^*_{1\text{ВНА}_r}, T^*_{1\text{ВНА}_r}\right), R_в\right) \\ a_{\text{кр}1\text{ВНА}_r} \leftarrow a_{\text{кр}}\left(k_{1\text{ВНА}_r}, R_в, T^*_{1\text{ВНА}_r}\right) \\ \overline{c}_{a1\text{ВНА}_r} \leftarrow \overline{c}_{.a1}(Z,0) \\ \overline{c}_{u1\text{ВНА}_r} \leftarrow \left| \begin{array}{ll} \overline{r}_{cp}\left(\overline{d}_{1\text{ВНА}}\right)\cdot\left(1 - R_{L.cp}(Z,0)\right) - \dfrac{\overline{H}_{.T}(Z,0)}{2\cdot\overline{r}_{cp}\left(\overline{d}_{1\text{ВНА}}\right)} & \text{if ВНА} = 1 \\ 0 & \text{otherwise} \end{array} \right. \\ c_{a1\text{ВНА}_r} \leftarrow \overline{c}_{a1\text{ВНА}_r} \cdot u_{1\text{пер}} \end{array} \right. \end{array} \right.$$

$\sigma_{\text{ВНА}} = 1.0000$

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

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

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

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

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

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

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

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

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

$$\rho^*_{3BHA_r} = \frac{P^*_{3BHA_r}}{R_{\text{в}}\cdot T^*_{3BHA_r}}$$

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

$$a_{\text{кр}3BHA_r} = a_{\text{кр}}\left(k_{3BHA_r}, R_{\text{в}}, T^*_{3BHA_r}\right)$$

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

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

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

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

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

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

$$\lambda_{c3BHA_r} = \frac{c_{3BHA_r}}{a_{\text{кр}3BHA}}$$

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

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

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

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

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

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

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

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

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

$$\text{submatrix}\left(a_{\text{кр}3BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (310.8)$$

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

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

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

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

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

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

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

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

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

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

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

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

$кр3ВНА_r$

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

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

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

Расчет ВНА:

Поступенчатый расчет ОК по ср. ЛТ

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

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

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

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

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

if $ЗППЧ_i = \text{"кор"}$

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

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

if $ЗППЧ_i = \text{"ср"}$

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

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

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

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

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

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

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

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

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

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

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

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

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

```
        $F_{st(i,3)} = F'_3$
    $\overline{c}_{a_{st(i,2),r}} = mean(\overline{c}_{a_{st(i,1),r}}, \overline{c}_{a_{st(i,3),r}})$
    $iteration_2 = 0$
    $F_{st(i,2)} = mean(F_{st(i,1)}, F_{st(i,3)})$
    while $0 < 1$
        $iteration_2 = iteration_2 + 1$
        trace(concat("    iteration.2 = ", num2str($iteration_2$)))
        if $(ЗППЧ_i \neq "пер") \wedge (ЗППЧ_i \neq "кор") \wedge (ЗППЧ_i \neq "ср")$
            $D_{st(i,2),N_r} = mean(D_{st(i,1),N_r}, D_{st(i,3),N_r})$
            $\overline{d}_{st(i,2)} = \sqrt{2 \cdot mean(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$
            $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}(\overline{d}_{st(i,2)})$
            $D_{st(i,2),1} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$
        if $ЗППЧ_i = "пер"$
            $D_{st(i,2),N_r} = D_{st(i,1),N_r}$
            $\overline{d}_{st(i,2)} = \sqrt{2 \cdot mean(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$
            $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}(\overline{d}_{st(i,2)})$
            $D_{st(i,2),1} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$
        if $ЗППЧ_i = "кор"$
            $D_{st(i,2),1} = D_{st(i,1),1}$
            $\overline{d}_{st(i,2)} = \sqrt{2 \cdot mean(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$
            $D_{st(i,2),N_r} = \frac{D_{st(i,2),1}}{\overline{d}_{st(i,2)}}$
            $D_{st(i,2),r} = D_{st(i,2),N_r} \cdot \overline{r}_{cp}(\overline{d}_{st(i,2)})$
        if $ЗППЧ_i = "ср"$
            $D_{st(i,2),r} = D_{st(i,1),r}$
            $\overline{d}_{st(i,2)} = \sqrt{2 \cdot mean(\overline{r}_{cp}(\overline{d}_{st(i,1)}), \overline{r}_{cp}(\overline{d}_{st(i,3)}))^2 - 1}$
            $D_{st(i,2),N_r} = \frac{D_{st(i,2),r}}{\overline{r}_{cp}(\overline{d}_{st(i,2)})}$
            $D_{st(i,2),1} = \overline{d}_{st(i,2)} \cdot D_{st(i,2),N_r}$
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    $\overline{c}_{u_{st(i,2),r}} = \frac{1}{\overline{r}_{cp}\left(\overline{d}_{st(i,2)}\right)}\left(\frac{D_{st(i,1),N_r}}{D_{st(i,2),N_r}}\right)\cdot\left(\overline{H}_{T_i} + \overline{c}_{u_{st(i,1),r}}\cdot\frac{D_{st(i,1),r}}{D_{st(i,1),N_r}}\right)$
    $\alpha_{st(i,2),r} = \text{triangle}\left(\overline{c}_{a_{st(i,2),r}}, \overline{c}_{u_{st(i,2),r}}\right)$
    $u_{st(i,2),N_r} = u_{st(i,1),N_r}\cdot\frac{D_{st(i,2),N_r}}{D_{st(i,1),N_r}}$
    $c_{a_{st(i,2),r}} = \overline{c}_{a_{st(i,2),r}}\cdot u_{st(i,2),N_r}$
    $c_{st(i,2),r} = \frac{c_{a_{st(i,2),r}}}{\sin\left(\alpha_{st(i,2),r}\right)}$
    $\lambda_{c_{st(i,2),r}} = \frac{c_{st(i,2),r}}{a*_{c_{st(i,2),r}}}$
    $F'_2 = \frac{G\cdot\sqrt{R_{\text{в}}\cdot T*_{st(i,2),r}}}{m_q\left(k_{st(i,2),r}\right)\cdot \text{ГДФ}\left(\text{"G"}, \lambda_{c_{st(i,2),r}}, k_{st(i,2),r}\right)\cdot\sin\left(\alpha_{st(i,2),r}\right)\cdot P*_{st(i,2),r}}$
    break if $\left(\left|\text{eps}\left(\text{"rel"}, F'_2, F_{st(i,2)}\right)\right| < \text{epsilon}\right) \wedge \left(\text{iteration}_2 = 0\right)$
    $\text{iteration}_2 = -1$ if $\left(\left|\text{eps}\left(\text{"rel"}, F'_2, F_{st(i,2)}\right)\right| < \text{epsilon}\right)$
    $F_{st(i,2)} = F'_2$
  for $a \in 1 .. 3$
    $\rho*_{st(i,a),r} = \frac{P*_{st(i,a),r}}{R_{\text{в}}\cdot T*_{st(i,a),r}}$
    $T_{st(i,a),r} = T*_{st(i,a),r}\cdot \text{ГДФ}\left(\text{"T"}, \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right)$
    $P_{st(i,a),r} = P*_{st(i,a),r}\cdot \text{ГДФ}\left(\text{"P"}, \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right)$
    $\rho_{st(i,a),r} = \rho*_{st(i,a),r}\cdot \text{ГДФ}\left(\text{"}\rho\text{"}, \lambda_{c_{st(i,a),r}}, k_{st(i,a),r}\right)$
    $a_{\text{зв}_{st(i,a),r}} = \sqrt{k_{st(i,a),r}\cdot R_{\text{в}}\cdot T_{st(i,a),r}}$
    $\beta_{st(i,a),r} = \text{triangle}\left(\overline{c}_{a_{st(i,a),r}}, \overline{r}_{cp}\left(\overline{d}_{st(i,a)}\right) - \overline{c}_{u_{st(i,a),r}}\right)$
    $w_{st(i,a),r} = \frac{c_{a_{st(i,a),r}}}{\sin\left(\beta_{st(i,a),r}\right)}$
    $w_{u_{st(i,a),r}} = w_{st(i,a),r}\cdot\cos\left(\beta_{st(i,a),r}\right)$
    $c_{u_{st(i,a),r}} = c_{st(i,a),r}\cdot\cos\left(\alpha_{st(i,a),r}\right)$
    $M_{w_{st(i,a),r}} = \frac{w_{st(i,a),r}}{a_{\text{зв}_{st(i,a),r}}}$
    $c_{st(i,a),r}$
    $M$
```

```
      $M_{c_{st(i,a),r}} = \frac{}{a_{зв_{st(i,a),r}}}$
      $h_{st(i,a)} = 0.5\cdot\left(D_{st(i,a),N_r} - D_{st(i,a),1}\right)$
      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

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

Расчет CA:

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

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

$\sigma_{CA} = 1.0000$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

▲ Расчет CA:

Результаты поступенчатого расчета по ср. ЛТ

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

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

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

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

$\cdot\%$

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

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

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: $\pi^*_{ЛА} = \dfrac{P^*_{3СА_{av(N_r)}}}{P^*_{1ВНА_{av(N_r)}}} = 2.000$ $\pi^*_{ЛА} \ge \pi^*_К = 1$

$H_T^T =$

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

$\cdot 10^3$

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

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

Адиабатная КПД К []: $\eta^*_К = \frac{L^*_К}{L_К} = 87.02 \cdot \%$

Мощность К (Вт): $N_К = G \cdot L_К = 2.62 \cdot 10^6$

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

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

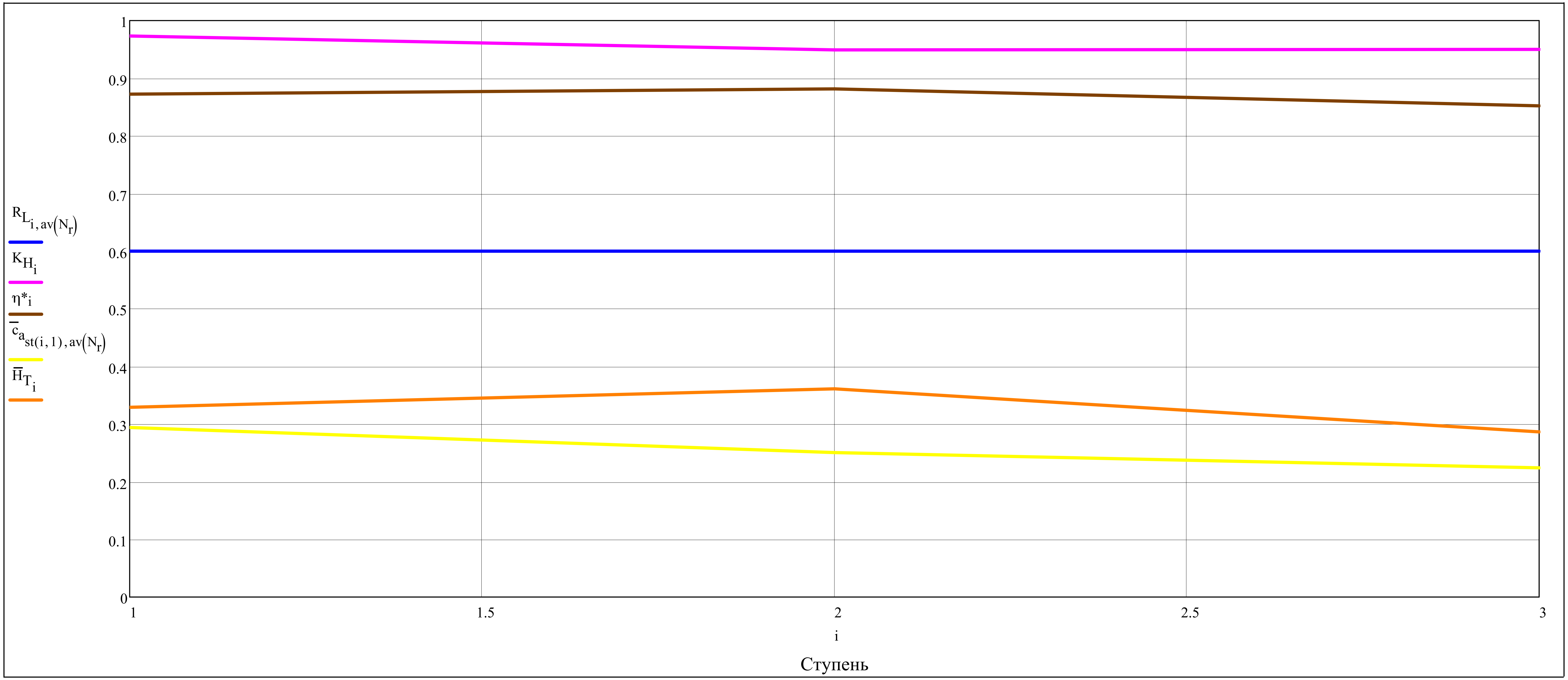
$\cdot\%$

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

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



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

	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												

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

	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														

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

	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														

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

	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														

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

	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											

$\cdot 10^3$

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

	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											

$\cdot 10^3$

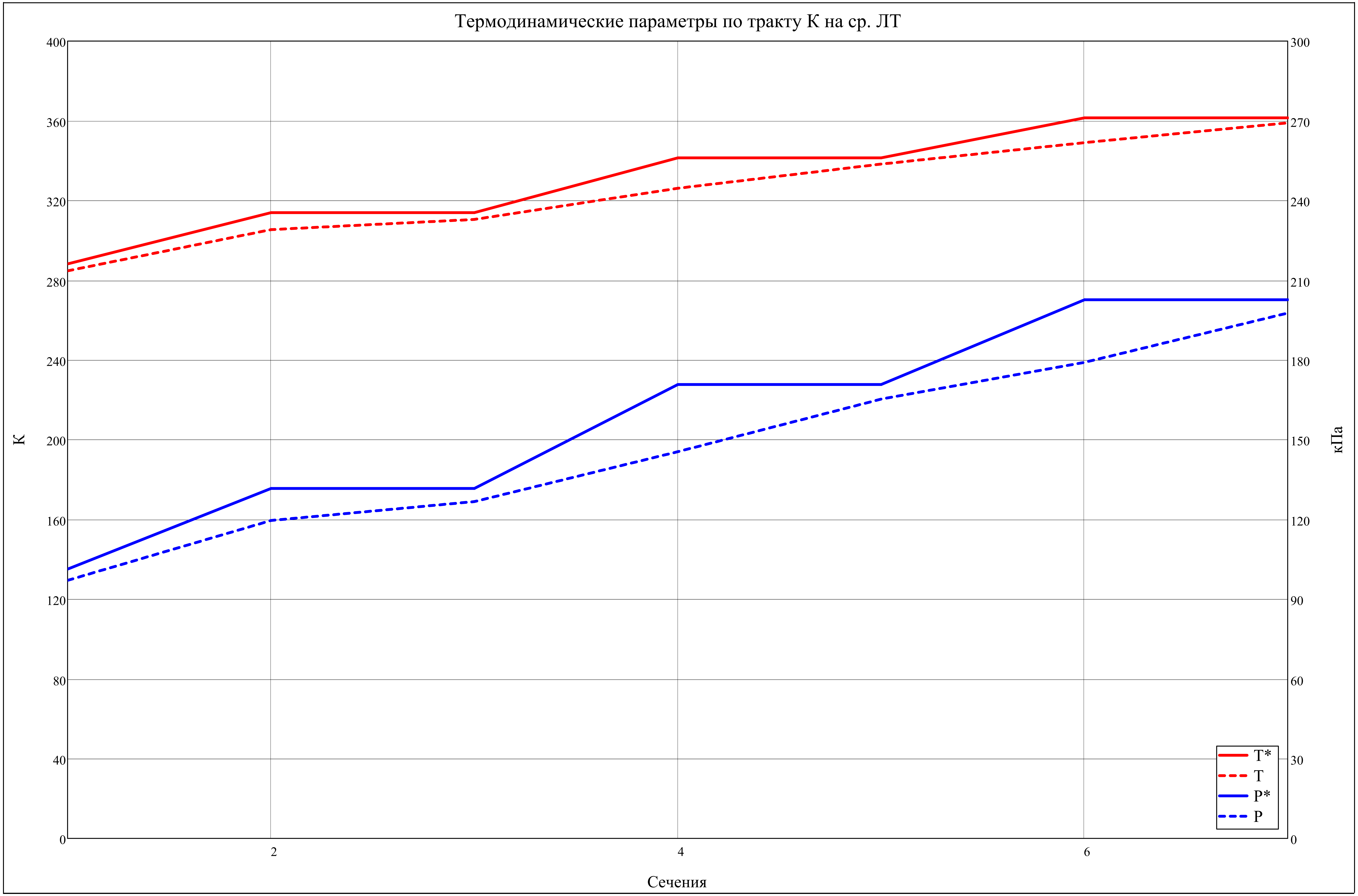
$\mathrm{submatrix}\left(\rho^*,1,2Z+1,av\left(N_r\right),av\left(N_r\right)\right)^T =$

	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												

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

	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
400
360
320
280
240
200
160
120
80
40
0
К
300
270
240
210
180
150
120
90
60
30
0
кПа
2
4
6
Сечения
T*
T
P*
P

$F^{T} =$

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

$\overline{d}^{T} =$

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

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

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

$D^{T} =$

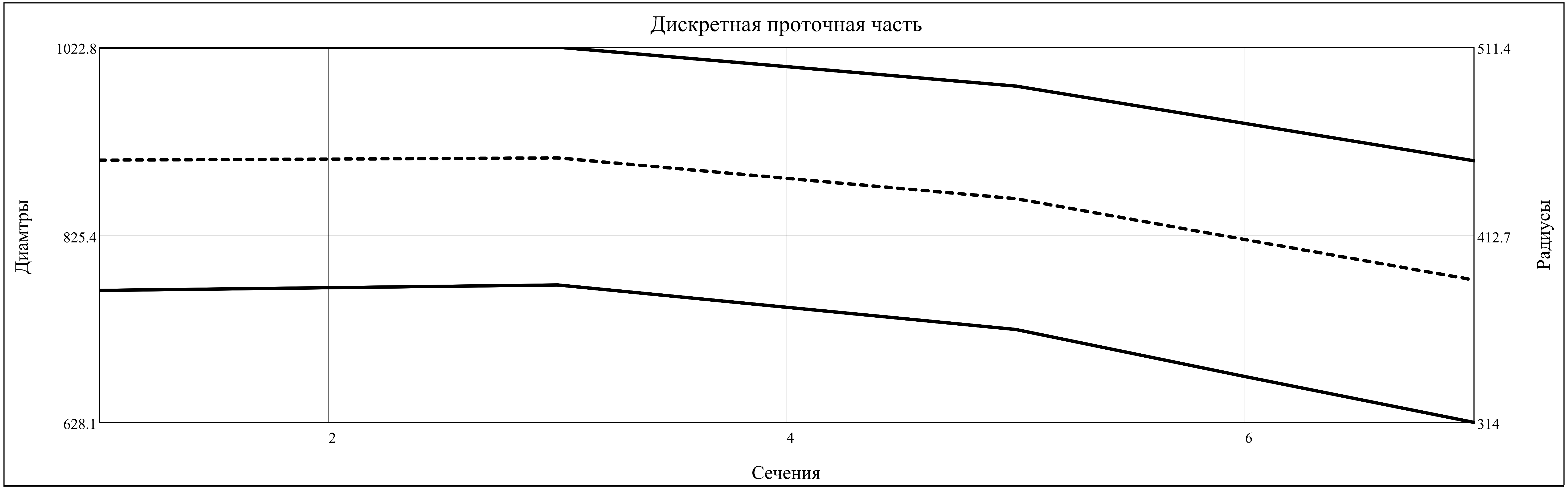
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	766.9	769.8	772.7	749.2	725.9	676.3	628.1														
2	903.9	905.2	906.4	884.8	863.4	820.3	777.9														
3	1022.8	1022.8	1022.8	1002.3	981.8	942.6	903.3														

$\cdot 10^{-3}$

$R^{T} =$

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

$\cdot 10^{-3}$



$h^{T} =$

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

$\cdot 10^{-3}$

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

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

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

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

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

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

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

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

$c_{a_{st(Z,3),\mathrm{av}(N_r)}} = 56.15$

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

Для КС

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

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

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

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

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

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

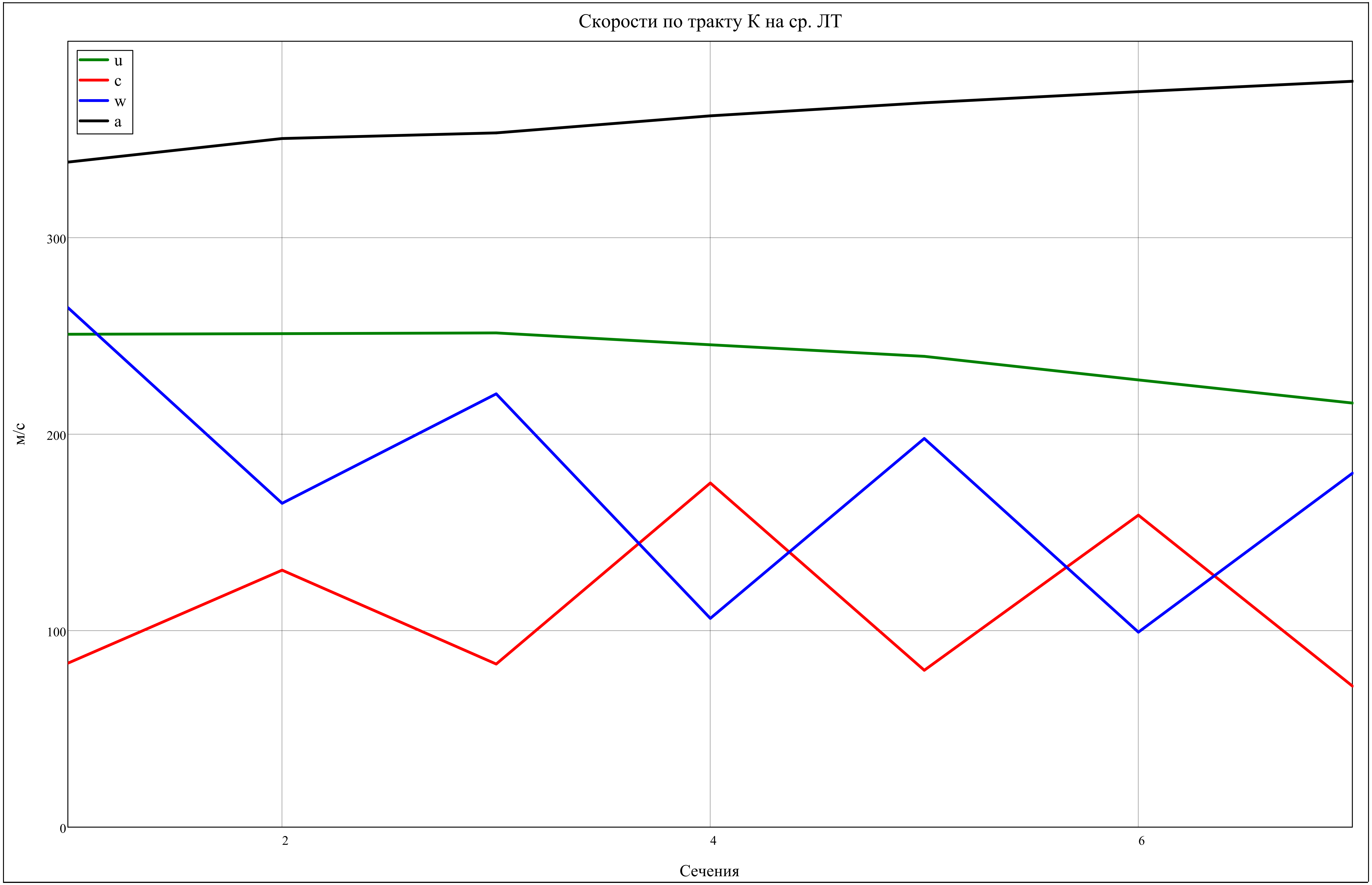
$$\Delta c_{a_{i,\mathrm{av}(N_r)}} = \left(c_{a_{st(i,2),\mathrm{av}(N_r)}} - c_{a_{st(i,1),\mathrm{av}(N_r)}}\right)$$

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

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

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

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


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														

$\cdot{}^\circ$

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

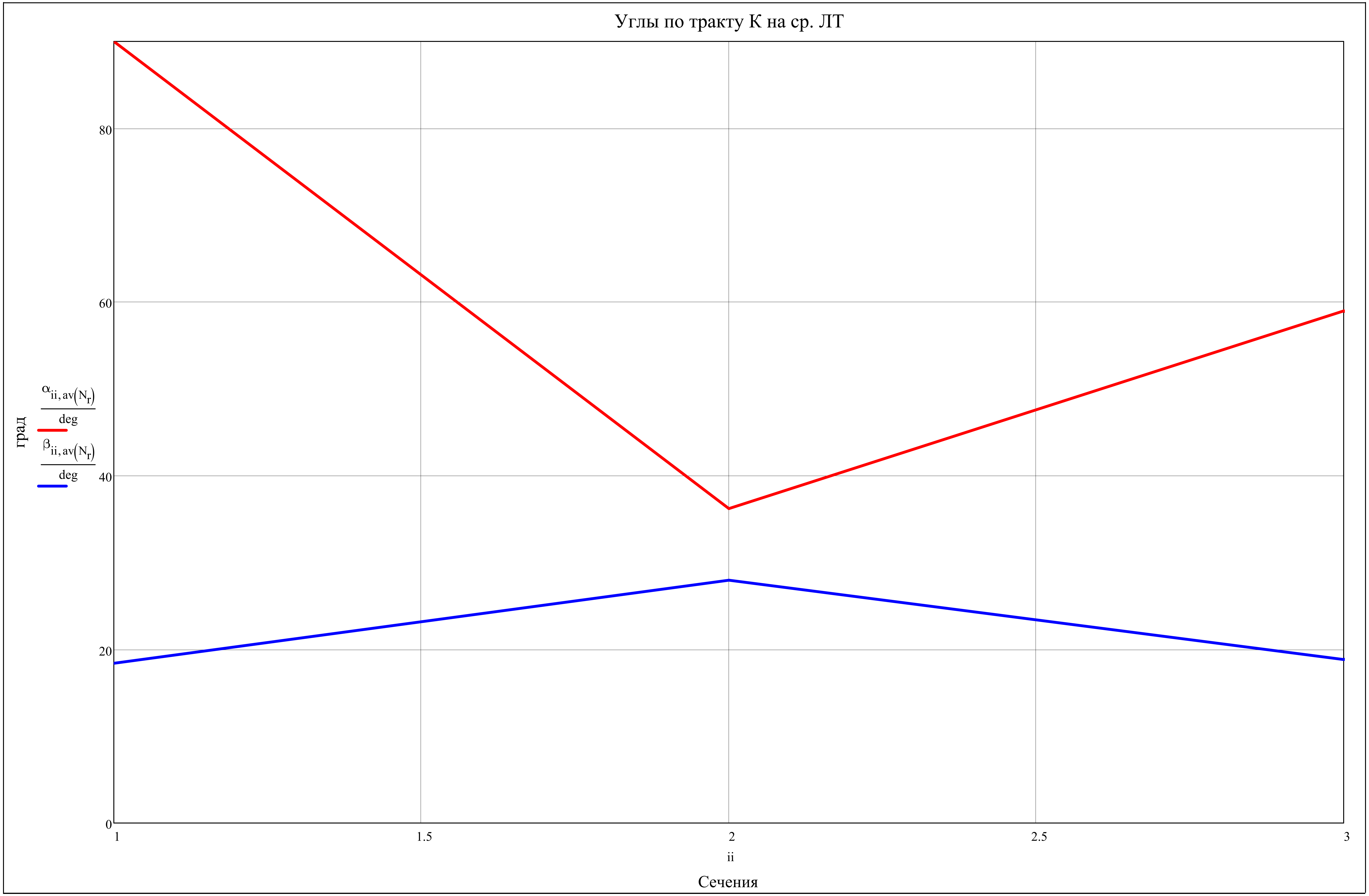
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	9.56	19.59	18.22																		

$\cdot{}^\circ$

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

	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

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

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

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

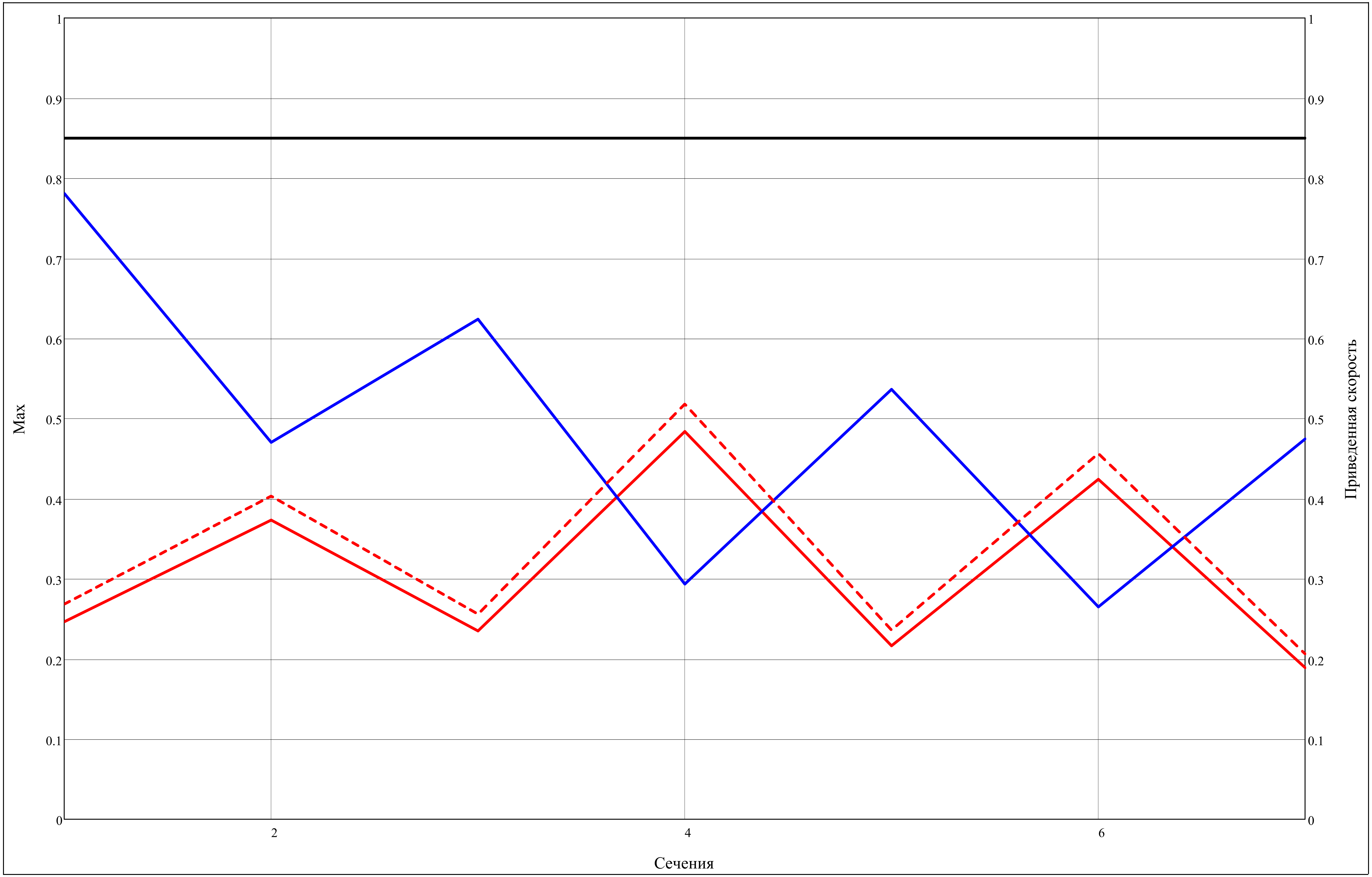
	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1

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

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

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

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



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

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

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

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

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

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

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

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

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

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

```
for  $i \in 1..Z$
    for  $a \in 1..3$
        for  $r \in 1..N_r$
            $T^*_{st(i,a),r} = T^*_{st(i,a),av(N_r)}$
            $P^*_{st(i,a),r} = P^*_{st(i,a),av(N_r)}$
            $\rho^*_{st(i,a),r} = \rho^*_{st(i,a),av(N_r)}$
            $Cp_{st(i,a),r} = Cp_{воздух}(P^*_{st(i,a),r}, T^*_{st(i,a),r})$
            $k_{st(i,a),r} = k_{ад}(Cp_{st(i,a),r}, R_в)$
            $a^*_{c_{st(i,a),r}} = \sqrt{\frac{2 \cdot k_{st(i,a),r}}{k_{st(i,a),r}+1} \cdot R_в \cdot T^*_{st(i,a),r}}$
            if  $\Delta H_{Tmax} = 0$
                $A_{st(i,a)} = \left(1 - R_{L_{i,av(N_r)}}\right) \cdot \omega \cdot \left(R_{st(i,a),av(N_r)}\right)^{m_i+1}$
                $B_{st(i,a)} = \frac{H_{T_{i,av(N_r)}}}{2 \cdot \omega}$
                $c_{u_{st(i,a),r}} =$
                    $c_{u_{st(i,a-1),r}} \cdot \frac{R_{st(i,a),r}}{R_{st(i,a-1),r}} + \frac{H_{T_{i,av(N_r)}}}{\omega \cdot R_{st(i,a),r}}$  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  $m_i = 0$
```

$\sqrt{\left(\quad_{st(i,a),av(N_r)}\right) \quad \left(R_{st(i,a),av(N_r)}\right) \quad \left(R_{st(i,a),r} - R_{st(i,a),av(N_r)}\right)} \quad \big|\ 1 \ \text{otherwise}$

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

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

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

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

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

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

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

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

$\alpha_{st(i,a)} = \text{triangle}(c \quad c)$

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

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

```
for $i \in Z$
  for $r \in 1..N_r$
    $\begin{pmatrix} T^*_{1CA_r} \\ T^*_{3CA_r} \end{pmatrix} = \begin{pmatrix} T^*_{st(i,3),r} \\ T^*_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} P^*_{1CA_r} \\ P^*_{3CA_r} \end{pmatrix} = \begin{pmatrix} P^*_{st(i,3),r} \\ P^*_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} \rho^*_{1CA_r} \\ \rho^*_{3CA_r} \end{pmatrix} = \begin{pmatrix} \rho^*_{st(i,3),r} \\ \rho^*_{3CA_{av(N_r)}} \end{pmatrix}$
    $\begin{pmatrix} Cp_{1CA_r} \\ Cp_{3CA_r} \end{pmatrix} = \begin{pmatrix} Cp_{воздух}\left(P^*_{1CA_r}, T^*_{1CA_r}\right) \\ Cp_{воздух}\left(P^*_{3CA_r}, T^*_{3CA_r}\right) \end{pmatrix}$
    $\begin{pmatrix} k_{1CA_r} \\ k_{3CA_r} \end{pmatrix} = \begin{pmatrix} k_{ад}\left(Cp_{1CA_r}, R_в\right) \\ k_{ад}\left(Cp_{3CA_r}, R_в\right) \end{pmatrix}$
    $\begin{pmatrix} a^*_{c1CA_r} \\ a^*_{c3CA_r} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{2 \cdot k_{1CA_r}}{k_{1CA_r} + 1} \cdot R_в \cdot T^*_{1CA_r}} \\ \sqrt{\frac{2 \cdot k_{3CA_r}}{k_{3CA_r} + 1} \cdot R_в \cdot T^*_{3CA_r}} \end{pmatrix}$
    $A = \left(1 - R_{L_{i,av(N_r)}}\right) \cdot \omega \cdot \left(R_{st(i,3),av(N_r)}\right)^{m_i+1}$
    $B = \frac{H_{T_{i,av(N_r)}}}{2 \cdot \omega}$
    $\begin{pmatrix} c_{u1CA_r} \\ c_{u3CA} \end{pmatrix} = \begin{pmatrix} c_{u_{st(i,3),r}} \\ c_{u3CA_{av(N_r)}} \text{ if } CA = 1 \end{pmatrix}$
```

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

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

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

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

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

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

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

▲ Расчет параметров потока по высоте Л

Результаты расчета параметров потока по высоте Л

$$T^*_{1BHA} = \begin{pmatrix} 288.2 \\ 288.2 \\ 288.2 \end{pmatrix} \qquad T^*_{3BHA} = \begin{pmatrix} 288.2 \\ 288.2 \\ 288.2 \end{pmatrix} \qquad a^*_{c1BHA} = \begin{pmatrix} 310.78 \\ 310.78 \\ 310.78 \end{pmatrix} \qquad a^*_{c3BHA} = \begin{pmatrix} 310.78 \\ 310.78 \\ 310.78 \end{pmatrix} \qquad \alpha_{1BHA} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ^\circ \qquad \alpha_{3BHA} = \begin{pmatrix} 90.00 \\ 90.00 \\ 90.00 \end{pmatrix} \cdot ^\circ$$

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

$$\rho^*_{1BHA} = \begin{pmatrix} 1.224 \\ 1.224 \\ 1.224 \end{pmatrix} \qquad \rho^*_{3BHA} = \begin{pmatrix} 1.224 \\ 1.224 \\ 1.224 \end{pmatrix} \qquad c_{u1BHA} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \qquad c_{u3BHA} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \end{pmatrix}$$

$$Cp_{1BHA} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix} \qquad Cp_{3BHA} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix} \qquad c_{a1BHA} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix} \qquad c_{a3BHA} = \begin{pmatrix} 83.4 \\ 83.4 \\ 83.4 \end{pmatrix} \qquad \lambda_{c1BHA} = \begin{pmatrix} 0.268 \\ 0.268 \\ 0.268 \end{pmatrix} \qquad \lambda_{c3BHA} = \begin{pmatrix} 0.268 \\ 0.268 \\ 0.268 \end{pmatrix}$$

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

$T^{*T} =$

	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														

$\rho^{T} =$

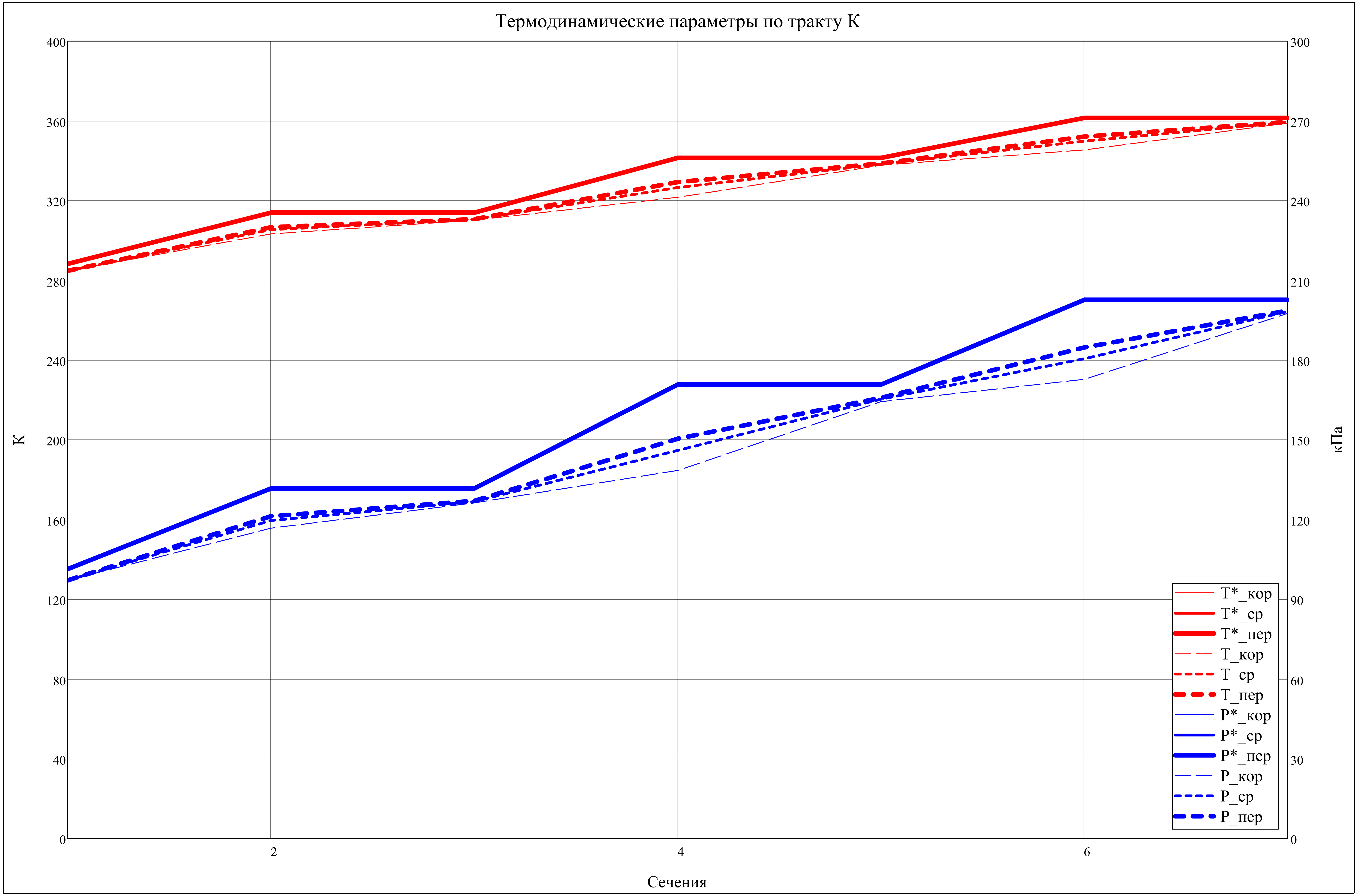
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.188	1.340	1.417	1.499	1.695	1.742	1.917														
2	1.188	1.364	1.421	1.557	1.702	1.797	1.922														
3	1.188	1.377	1.423	1.591	1.705	1.827	1.925														

$Cp^{T} =$

	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
400
360
320
280
240
200
160
120
80
40
0
300
270
240
210
180
150
120
90
60
30
0
К
кПа
2
4
6
Сечения
T*_кор
T*_ср
T*_пер
T_кор
T_ср
T_пер
P*_кор
P*_ср
P*_пер
P_кор
P_ср
P_пер

$a^*{}_c^T =$

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

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

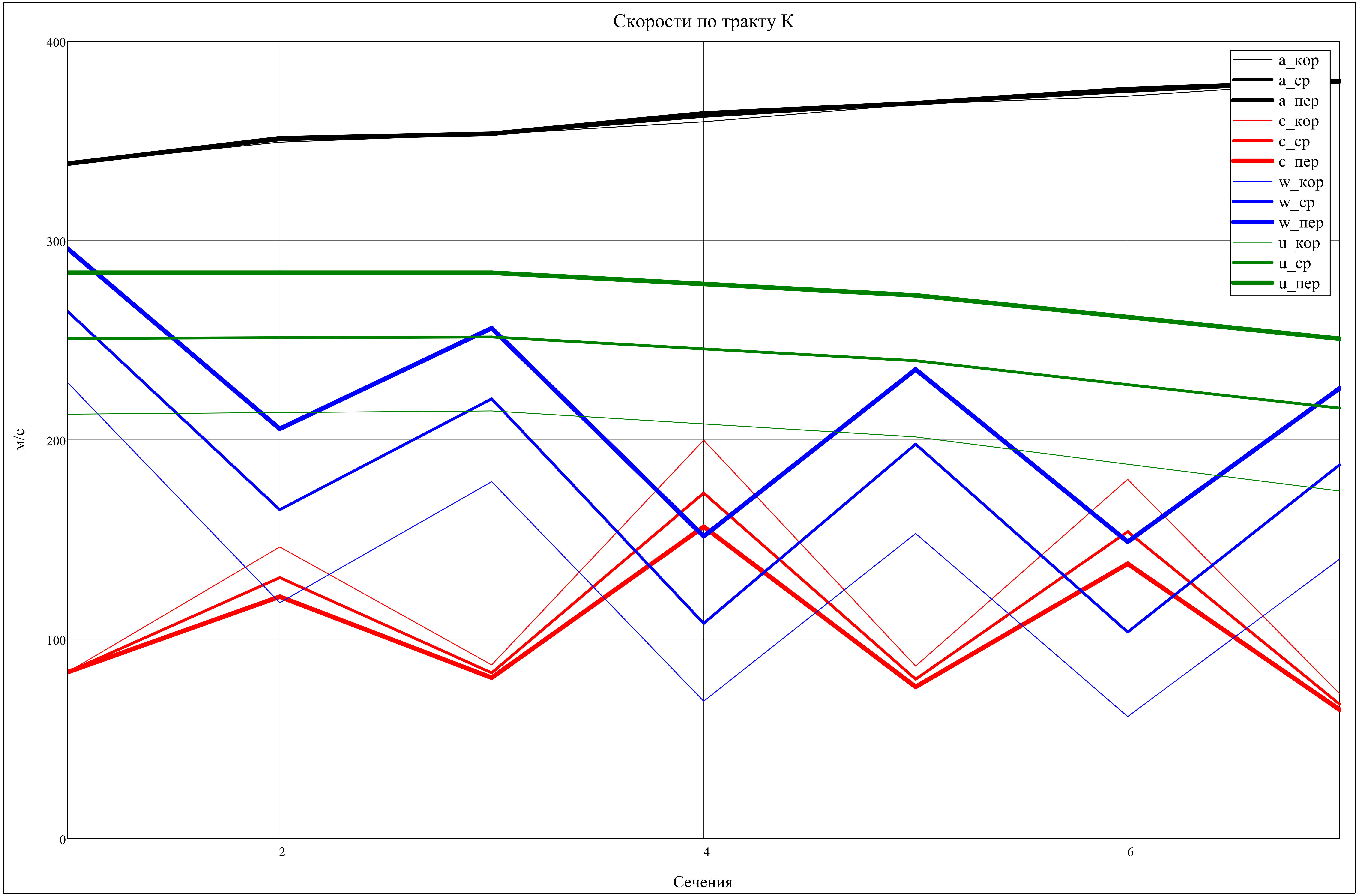
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1	1	1	1	1	1																		
2	1	1	1	1	1	1	1																		
3	1	1	1	1	1	1	1																		

$R_L{}^T =$

	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

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

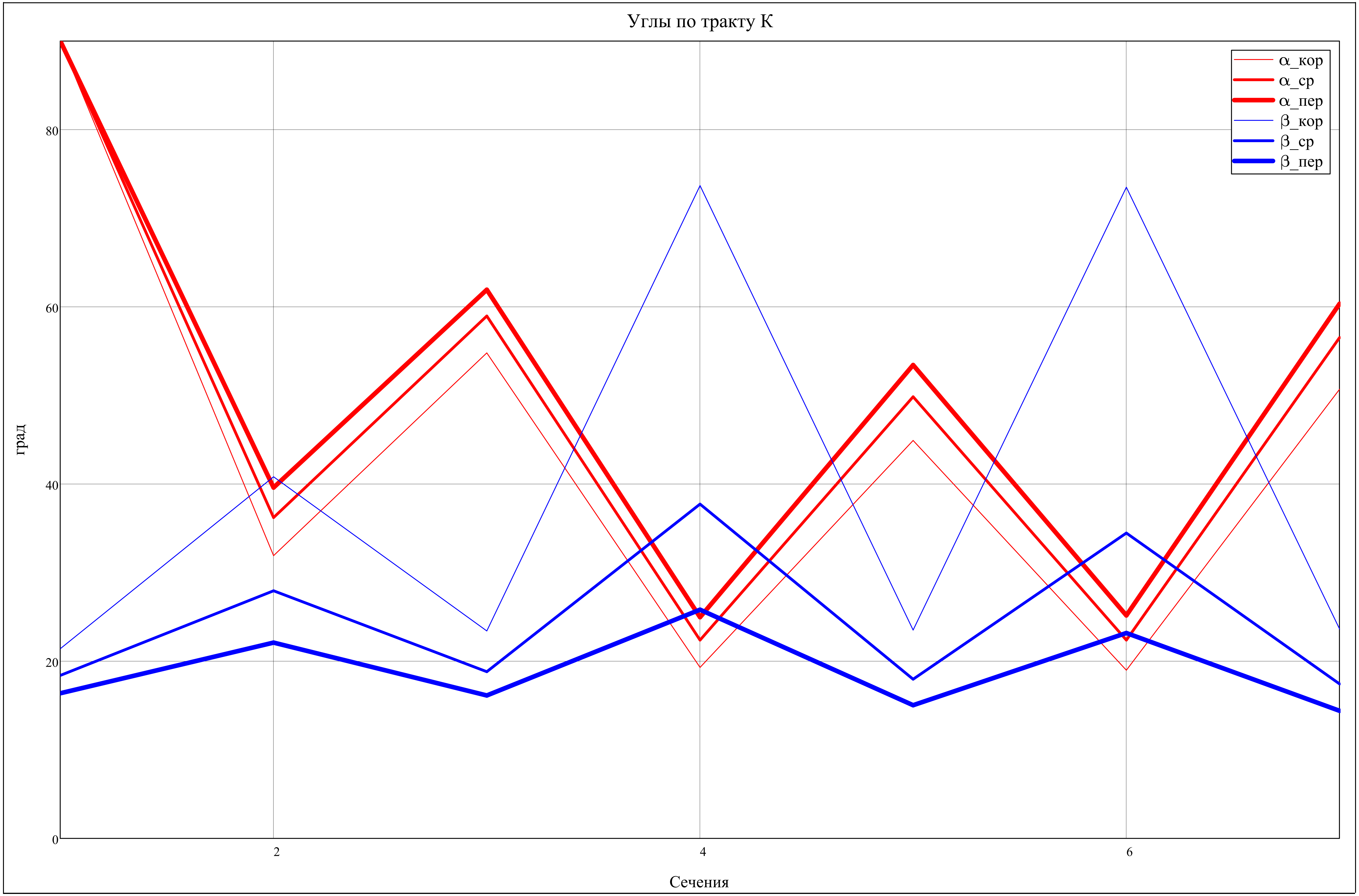
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	19.40	50.26	49.97												
2	9.56	18.91	16.50												
3	5.71	9.69	8.14												

$\cdot°$

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

	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
80
60
40
20
0
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]

$\lambda_c^T \le 0.85 =$

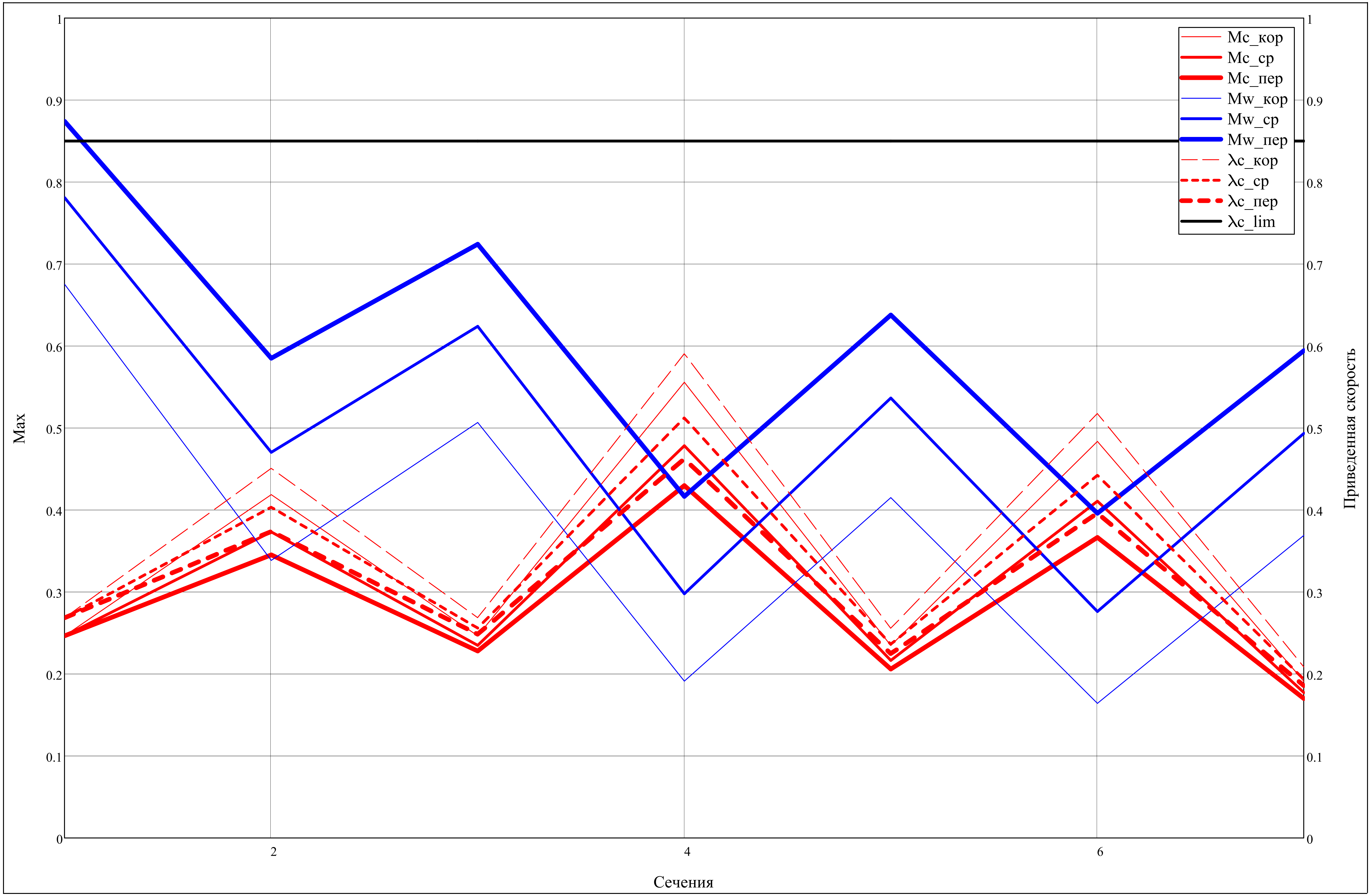
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	1	1	1	1	1	1												
2	1	1	1	1	1	1	1												
3	1	1	1	1	1	1	1												

$M_c^T =$

	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																


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

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

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

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

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

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

▲ 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

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

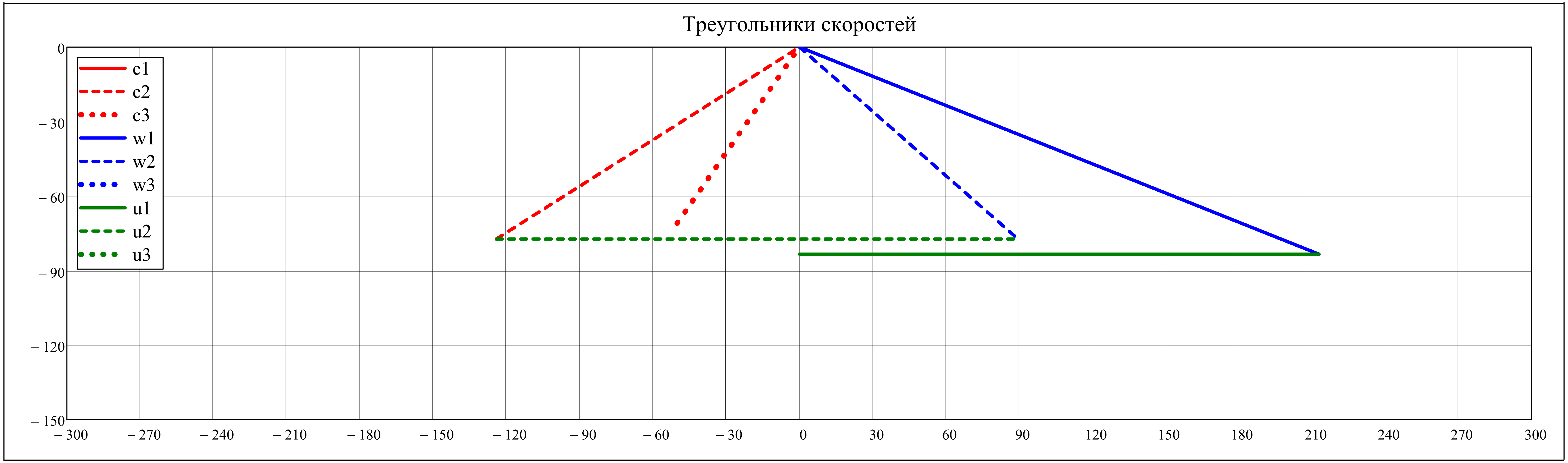
$$\Delta_w(v,i,j,r) = \left| \begin{array}{l} -\tan\left(\beta_{st(i,j),r}\right)\cdot v \;\; \text{if } \left(-\tan\left(\beta_{st(i,j),r}\right) \ge 0\right) \wedge \left(-\left|w_{st(i,j),r}\cdot\cos\left(\beta_{st(i,j),r}\right)\right| \le v \le 0\right) \wedge (j \ne 3) \\ -\tan\left(\beta_{st(i,j),r}\right)\cdot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

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

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

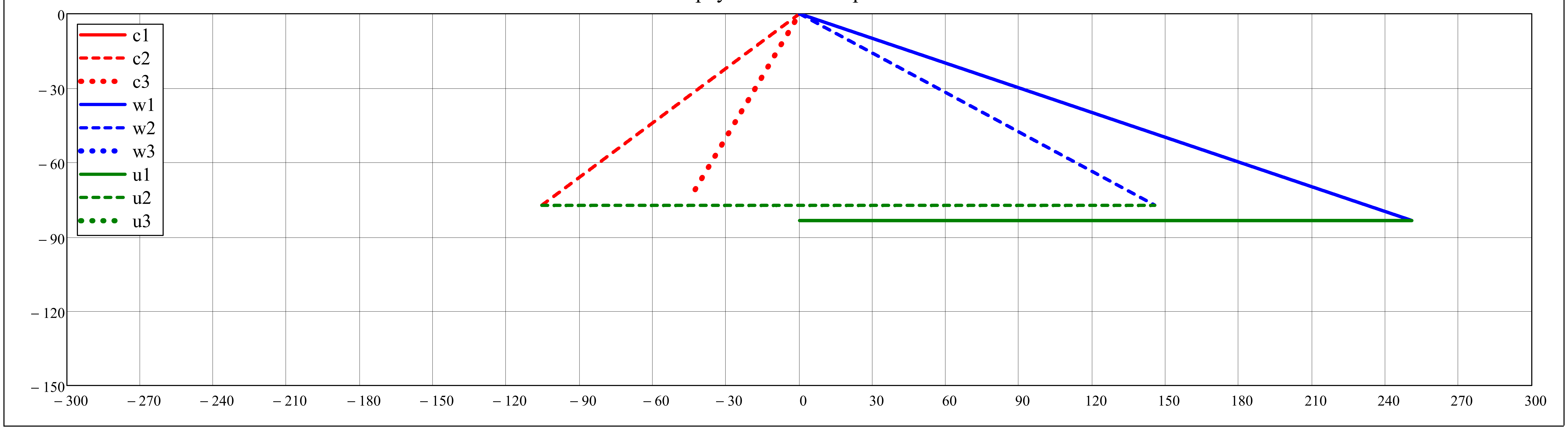
Дискретизация скорости: $v = -v_{lim}, -v_{lim} + \frac{v_{lim}}{3000} .. v_{lim}$

r = 1

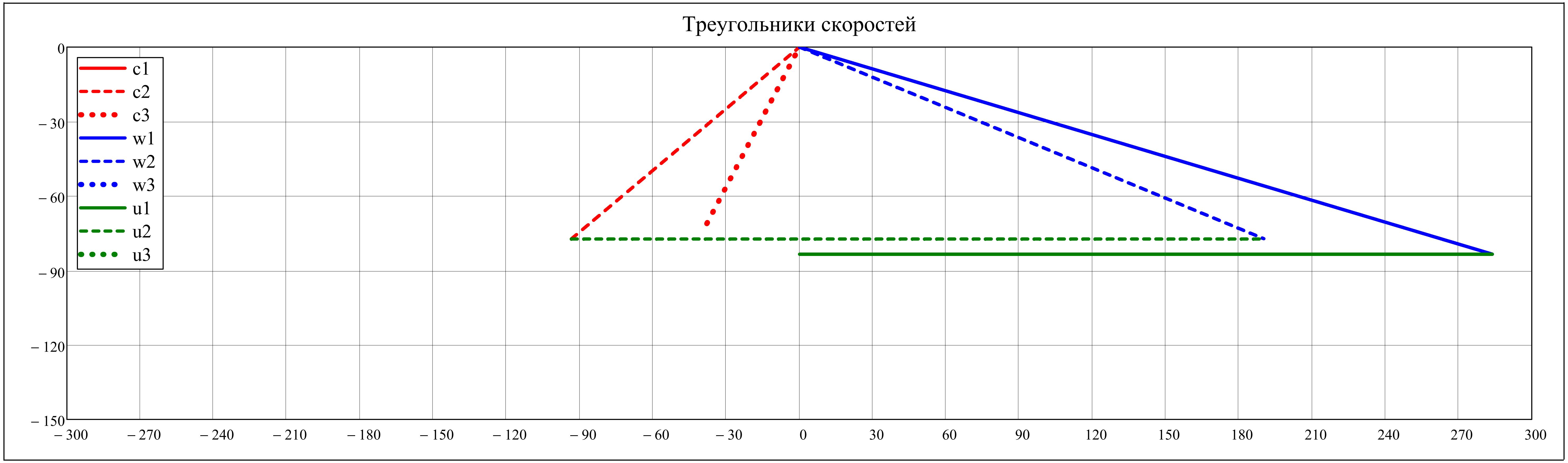

Треугольники скоростей
c1
c2
c3
w1
w2
w3
u1
u2
u3
0
− 30
− 60
− 90
− 120
− 150
− 300
− 270
− 240
− 210
− 180
− 150
− 120
− 90
− 60
− 30
0
30
60
90
120
150
180
210
240
270
300

$r = av(N_r)$

Треугольники скоростей



$r = N_r$



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

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

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

	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

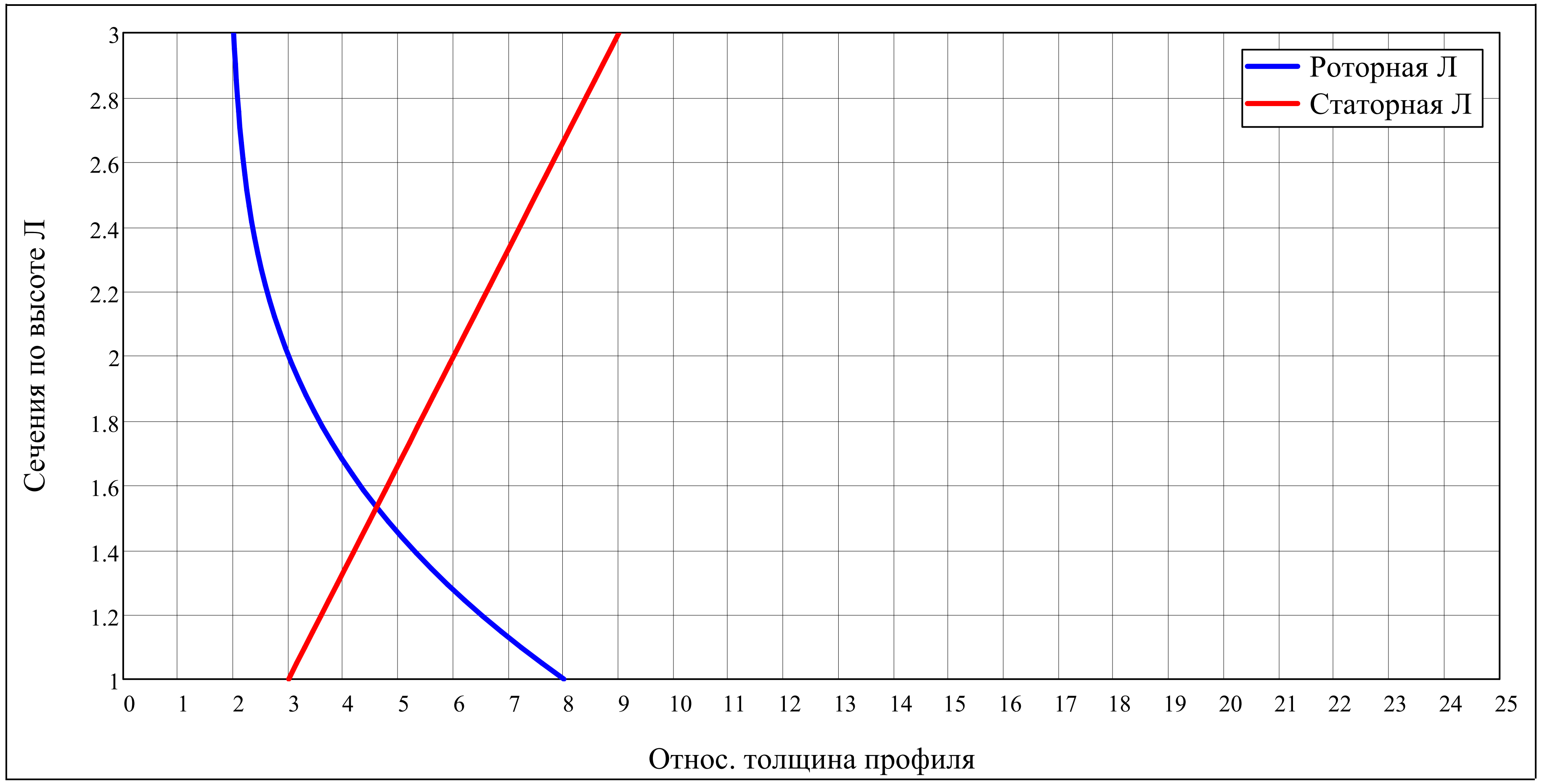
▾ Относ. толщины и радиусы профилей

Относ. толщины Л РК и СА:

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

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

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



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

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

	1
1	3.00
2	6.00
3	9.00

$\cdot\%$

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

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

	1	2	3
1	3.00	3.00	3.00
2	6.00	6.00	6.00
3	9.00	9.00	9.00

$\cdot\%$

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

	1	2	3
1	8.00	8.00	8.00
2	3.00	3.00	3.00
3	2.00	2.00	2.00

$\cdot\%$

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

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

	1
1	3.00
2	6.00
3	9.00

$\cdot\%$

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

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

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

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

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

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

	1	2	3
1	0.300	0.300	0.300
2	0.600	0.600	0.600
3	0.900	0.900	0.900

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

	1	2	3
1	0.800	0.800	0.800
2	0.300	0.300	0.300
3	0.200	0.200	0.200

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

	1	2	3
1	0.150	0.150	0.150
2	0.300	0.300	0.300
3	0.450	0.450	0.450

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

	1	2	3
1	0.400	0.400	0.400
2	0.150	0.150	0.150
3	0.100	0.100	0.100

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

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

Относ. толщины и радиусы профилей

Распределение параметров по высоте Л

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

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

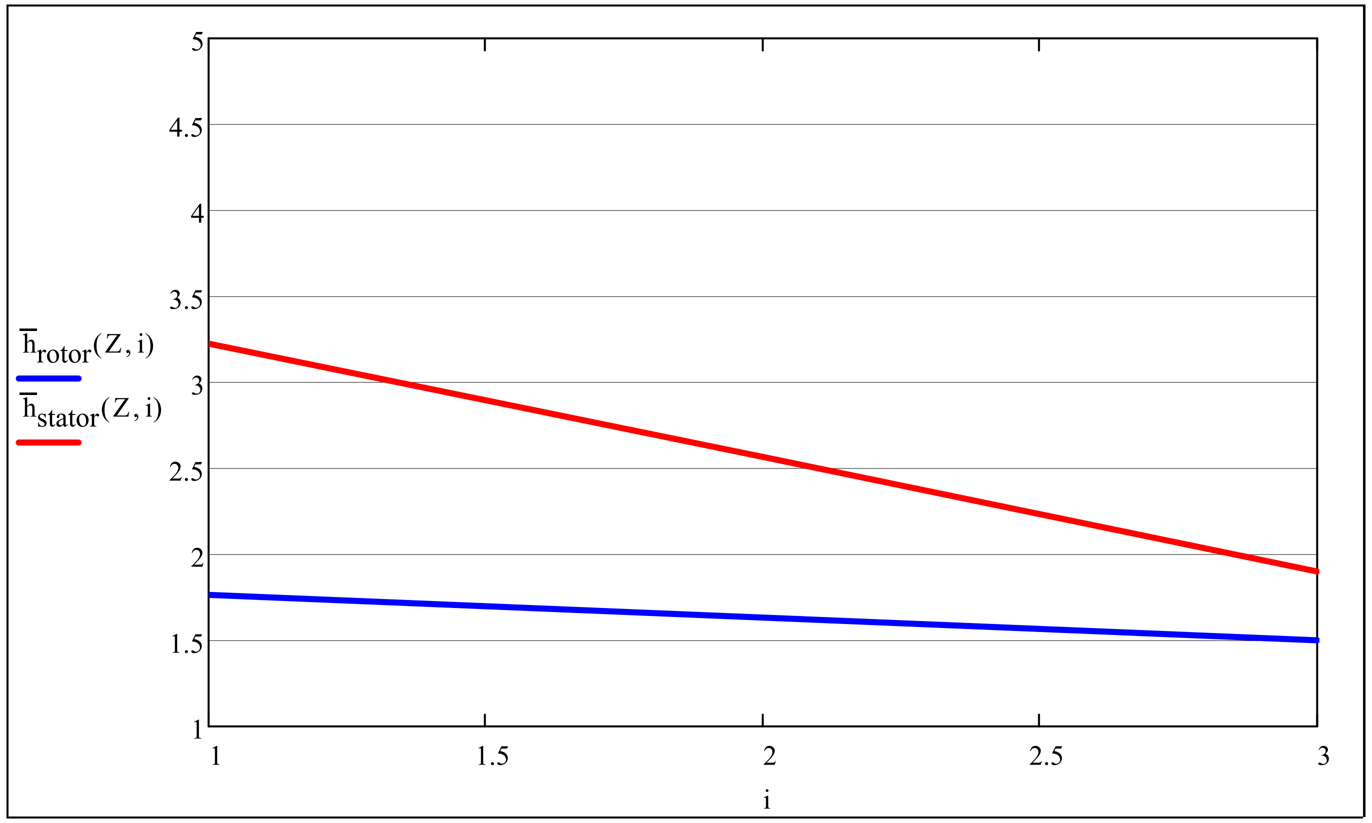
$$\overline{h}_{\sim stator} = \left(4\ \ 3.5\ \ 3.25\ \ 3\ \ 2.75\ \ 2.5\ \ 2.25\ \ 2\right)^{T} + \left| \begin{array}{l} 1.1\ \ \text{if compressor} = \text{"Вл"} \\ -0.1\ \ \text{if compressor} = \text{"КНД"} \\ -0.7\ \ \text{if compressor} = \text{"КВД"} \end{array} \right.$$

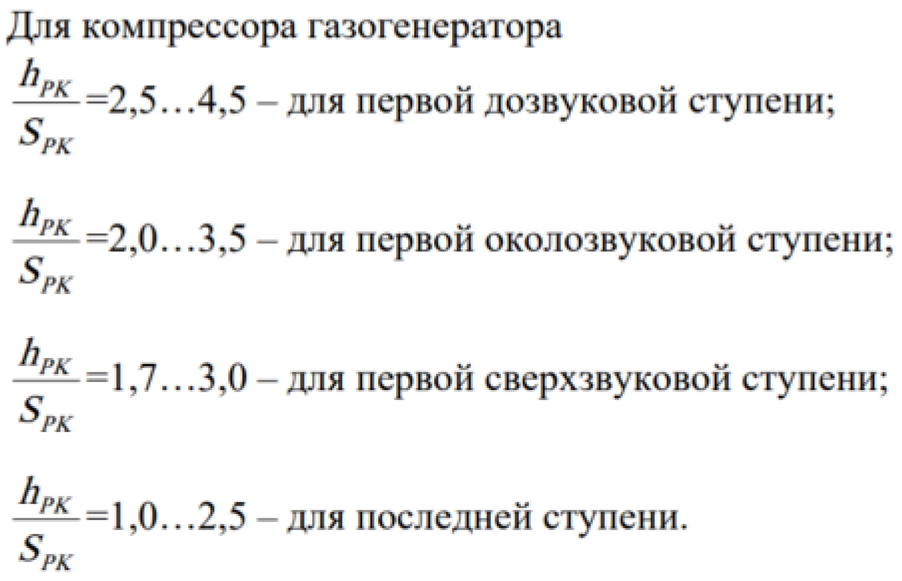
$$\overline{h}_{rotor}(Z,i) = \left| \begin{array}{ll} \overline{h}_{\sim rotor}\left(\dfrac{1}{rows\left(z_{\sim}\right)}\right) & \text{if } i < 1 \\ \overline{h}_{\sim rotor}(1)\ \ \text{if } i > Z & \\ \overline{h}_{\sim rotor}\left(\dfrac{i}{Z}\right) & \text{otherwise} \end{array} \right.$$

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

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

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





Для компрессора газогенератора

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

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

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

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

[16, с. 83-84]

Распределение параметров по высоте Л

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

Расчет длин хорд по высоте Л

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

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

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

▲ Расчет длин хорд по высоте Л

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

$\bar{x}_f = 0.5$

Определение количества Л РК и НА

```
$\begin{pmatrix} \varepsilon_{BHA(b/t)=1} \\ Z_{BHA} \\ r\_inlet_{BHA} \\ r\_outlet_{BHA} \\ t_{BHA} \\ i_{BHA} \\ m_{BHA} \\ \theta_{BHA} \\ \delta_{BHA} \\ \chi_{BHA} \\ \upsilon_{BHA} \\ R_{СЛ.BHA} \\ K_{BHA} \\ D_{BHA} \end{pmatrix} =$
  if BHA = 1
    for $r \in av(N_r)$
      $\varepsilon_{BHA(b/t)=1_r} = \varepsilon_{(b/t)=1}(\alpha_{3BHA_r})$
      $b/t_{BHA_r} = b/t{=}1\left(\frac{\varepsilon_{BHA_r}}{\varepsilon_{BHA(b/t)=1_r}}\right)$
      $t_{BHA_r} = \frac{chord_{BHA_r}}{b/t_{BHA_r}}$
      $Z_{BHA} =$
        $round\left(\frac{\pi\cdot D_{st(1,1),r}}{t_{BHA_r}}\right)$  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 $r \in 1..N_r$
      $\left(r\_inlet_{BHA_r}\ \ r\_outlet_{BHA_r}\right) = chord_{BHA_r}\cdot\left(\overline{r\_inlet}_{BHA_r}\ \ \overline{r\_outlet}_{BHA_r}\right)$
      $t_{BHA_r} = \frac{D_{st(1,1),r}}{Z_{BHA}}$
      $i_{BHA_r} = 2.5\cdot\left(\frac{chord_{BHA_r}}{t_{BHA_r}} - 2\right)\cdot°$
      $m_{BHA_r} = 0.23\cdot(2\cdot\bar{x}_f)^2 + 0.18 - \frac{0.002}{deg}\cdot(\alpha_{3BHA_r})$
```

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

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

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

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

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

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

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

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

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

```
for $i \in 1..Z$
    for $r \in av(N_r)$
        $\begin{pmatrix} \varepsilon_{РК(b/t)=1_{i,r}} \\ \varepsilon_{НА(b/t)=1_{i,r}} \end{pmatrix} = \begin{pmatrix} \varepsilon_{(b/t)=1}(\beta_{st(i,2),r}) \\ \varepsilon_{(b/t)=1}(\alpha_{st(i,3),r}) \end{pmatrix}$
        $\begin{pmatrix} b/t_{РК_{i,r}} \\ b/t_{НА_{i,r}} \end{pmatrix} = \begin{pmatrix} b/t{=}1\left(\frac{\varepsilon_{rotor_{i,r}}}{\varepsilon_{РК(b/t)=1_{i,r}}}\right) \\ b/t{=}1\left(\frac{\varepsilon_{stator_{i,r}}}{\varepsilon_{НА(b/t)=1_{i,r}}}\right) \end{pmatrix}$
        $\begin{pmatrix} t_{rotor_{i,r}} \\ t_{stator_{i,r}} \end{pmatrix} = \begin{pmatrix} \frac{chord_{rotor_{i,r}}}{b/t_{РК_{i,r}}} \\ \frac{chord_{stator_{i,r}}}{b/t_{НА_{i,r}}} \end{pmatrix}$
        $Z_{stator_i} =$
            $round\left(\frac{\pi \cdot mean(D_{st(i,2),r}, D_{st(i,3),r})}{t_{stator_{i,r}}}\right)$  if  $mod\left(round\left(\frac{\pi \cdot mean(D_{st(i,2),r}, D_{st(i,3),r})}{t_{stator_{i,r}}}\right), 2\right) = 0$
            $round\left(\frac{\pi \cdot mean(D_{st(i,2),r}, D_{st(i,3),r})}{t_{stator_{i,r}}}\right) + 1$  otherwise
        $Z_{rotor_i} =$
            $Z_{rotor_i} = round\left(\frac{\pi \cdot mean(D_{st(i,1),r}, D_{st(i,2),r})}{t_{rotor_{i,r}}}\right)$
            while $gcd(Z_{rotor_i}, Z_{stator_i}) \neq 1$
                $Z_{rotor_i} = Z_{rotor_i} + 1$
```

for $r \in 1 .. N_r$

$$\begin{pmatrix} \text{r\_inlet}_{\text{stator}_{i,r}} & \text{r\_outlet}_{\text{stator}_{i,r}} \\ \text{r\_inlet}_{\text{rotor}_{i,r}} & \text{r\_outlet}_{\text{rotor}_{i,r}} \end{pmatrix} = \begin{pmatrix} \overline{\text{r}}\text{\_inlet}_{\text{stator}_{i,r}} \cdot \text{chord}_{\text{stator}_{i,r}} & \overline{\text{r}}\text{\_outlet}_{\text{stator}_{i,r}} \cdot \text{chord}_{\text{stator}_{i,r}} \\ \overline{\text{r}}\text{\_inlet}_{\text{rotor}_{i,r}} \cdot \text{chord}_{\text{rotor}_{i,r}} & \overline{\text{r}}\text{\_outlet}_{\text{rotor}_{i,r}} \cdot \text{chord}_{\text{rotor}_{i,r}} \end{pmatrix}$$

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

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

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

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

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

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

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

$$\Big(\text{chord}_{\text{rotor}}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

⏶ Определение количества Л РК и НА

Результаты расчета количества Л и параметров решеток РК и НА

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

Длина хорды Л (м):

$$\text{chord}_{\text{rotor}}^{\text{T}} = \begin{array}{c|ccccccccccccccc} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 62.10 & 66.35 & 74.88 & & & & & & & & & & & & \\ 2 & 72.07 & 77.02 & 87.03 & & & & & & & & & & & & \\ 3 & 80.73 & 86.26 & 97.34 & & & & & & & & & & & & \end{array} \cdot 10^{-3}$$

$$\text{chord}_{\text{stator}}^{\text{T}} = \begin{array}{c|ccccccccccccccc} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\ \hline 1 & 35.22 & 44.78 & 64.29 & & & & & & & & & & & & \\ 2 & 38.99 & 49.58 & 71.24 & & & & & & & & & & & & \\ 3 & 42.27 & 53.74 & 77.15 & & & & & & & & & & & & \end{array} \cdot 10^{-3}$$

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

Радисы входных и выходных кромок профилей Л (мм):

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

$$\text{r\_inlet}_{\text{rotor}}^{\text{T}} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0.50 & 0.53 & 0.60 \\ 2 & 0.22 & 0.23 & 0.26 \\ 3 & 0.16 & 0.17 & 0.19 \end{array} \cdot 10^{-3} \qquad \text{r\_outlet}_{\text{rotor}}^{\text{T}} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0.25 & 0.27 & 0.30 \\ 2 & 0.11 & 0.12 & 0.13 \\ 3 & 0.08 & 0.09 & 0.10 \end{array} \cdot 10^{-3}$$

$$\text{r\_inlet}_{\text{stator}}^{\text{T}} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0.11 & 0.13 & 0.19 \\ 2 & 0.23 & 0.30 & 0.43 \\ 3 & 0.38 & 0.48 & 0.69 \end{array} \cdot 10^{-3} \qquad \text{r\_outlet}_{\text{stator}}^{\text{T}} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0.05 & 0.07 & 0.10 \\ 2 & 0.12 & 0.15 & 0.21 \\ 3 & 0.19 & 0.24 & 0.35 \end{array} \cdot 10^{-3}$$

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

$\varepsilon_{\mathrm{BHA(b/t)=1}_{\mathrm{av}(N_r)}} = \blacksquare \cdot {}^{\circ}$

Угол поворота потока:

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

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

$\cdot {}^{\circ}$

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

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

$\cdot {}^{\circ}$

$\varepsilon_{\mathrm{CA(b/t)=1}_{\mathrm{av}(N_r)}} = \blacksquare \cdot {}^{\circ}$

$\frac{\mathrm{chord}_{\mathrm{BHA}}}{t_{\mathrm{BHA}}} = \blacksquare$

Густота решетки:

$\left(\frac{\mathrm{chord}_{\mathrm{rotor}}}{t_{\mathrm{rotor}}}\right)^T =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-296.234	-398.209	-987.065												
2	729.114	978.250	2415.163												
3	4.441	6.615	19.774												

$\left(\frac{\mathrm{chord}_{\mathrm{stator}}}{t_{\mathrm{stator}}}\right)^T =$

	1	2	3
1	42.848	56.310	96.221
2	-570.660	-751.566	-1297.432
3	22.076	29.244	51.852

$\frac{\mathrm{chord}_{\mathrm{CA}}}{t_{\mathrm{CA}}} = \blacksquare$

$Z_{\mathrm{BHA}} = 0$

Количество Л:

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

	1	2	3
1	61	149	113

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	76	812	152												

$Z_{\mathrm{CA}} = 0$

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

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

$t_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	39.57	16.04	19.49												
2	46.58	18.88	23.41												
3	52.67	21.35	26.75												

$\cdot 10^{-3}$

Шаг решетки (м):

$t_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	31.88	2.85	13.48												
2	37.44	3.38	16.52												
3	42.28	3.84	19.08												

$\cdot 10^{-3}$

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

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

$i_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.423	7.839	7.103												
2	1.368	7.697	6.796												
3	1.332	7.601	6.597												

$\cdot {}^{\circ}$

Угол атаки:

$i_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-2.238	34.232	6.923												
2	-2.396	31.650	5.784												
3	-2.501	30.000	5.111												

$\cdot {}^{\circ}$

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

$m_{BHA} = 0.0000$

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	24.37	48.71	49.51												
2	11.45	13.44	11.79												
3	6.22	2.54	1.91												

$\cdot {}^{\circ}$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	30.84	2.25	28.87												
2	31.14	6.56	33.11												
3	30.92	8.89	35.13												

$\cdot {}^{\circ}$

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

$\delta_{BHA} = 0.000 \cdot °$

$$\delta_{rotor}^{T} = \begin{array}{c|c|c|c} & 1 & 2 & 3 \\ \hline 1 & 6.388 & 6.291 & 6.644 \\ 2 & 3.260 & 2.226 & 2.085 \\ 3 & 1.837 & 0.453 & 0.365 \end{array} \cdot °$$

Угол отставания:

$$\delta_{stator}^{T} = \begin{array}{c|c|c|c} & 1 & 2 & 3 \\ \hline 1 & 8.813 & 0.182 & 4.079 \\ 2 & 8.913 & 0.531 & 4.733 \\ 3 & 8.848 & 0.720 & 5.054 \end{array} \cdot °$$

$\delta_{CA} = 0.000 \cdot °$

$\upsilon_{BHA} = 0.00 \cdot °$

$$\upsilon_{rotor}^{T} = \begin{array}{c|c|c|c} & 1 & 2 & 3 \\ \hline 1 & 35.02 & 55.62 & 55.38 \\ 2 & 25.49 & 33.24 & 30.66 \\ 3 & 20.82 & 25.01 & 22.59 \end{array} \cdot °$$

Угол установки Л:

$$\upsilon_{stator}^{T} = \begin{array}{c|c|c|c} & 1 & 2 & 3 \\ \hline 1 & 45.09 & 54.65 & 40.34 \\ 2 & 49.39 & 57.32 & 44.72 \\ 3 & 52.56 & 59.42 & 47.84 \end{array} \cdot °$$

$\upsilon_{CA} = 0.00 \cdot °$

$R_{СЛ.ВНА} = 0.00\cdot10^{-3}$

Радиус дуги ср. линии (м):

$R_{СЛ.rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	147.12	80.44	89.40												
2	361.24	329.11	423.80												
3	744.39	1946.18	2916.47												

$\cdot10^{-3}$

$R_{СЛ.stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	66.24	1140.87	128.96												
2	72.63	433.59	125.02												
3	79.28	346.65	127.80												

$\cdot10^{-3}$

$R_{СЛ.СА} = 0.00\cdot10^{-3}$

$K_{ВНА} = 0.0000$

Фактор диффузорности решетки:

$K_{rotor}^{T} =$

	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												

$K_{stator}^{T} =$

	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												

$K_{СА} = 0.0000$

Диффузорность решетки:

$D_{BHA} = 0.0000$

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.6545	0.7136	0.7050												
2	0.5050	0.5794	0.5465												
3	0.4084	0.4609	0.4201												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.6333	0.5876	0.6695												
2	0.5958	0.5607	0.6419												
3	0.5640	0.5361	0.6144												

$D_{CA} = 0.0000$

[18, с. 71]

$D_{BHA} \le 0.6 = 1$

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

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

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

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

$D_{CA} \le 0.6 = 1$

Коэф. потерь полного давления:

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.1620	0.3544	0.3202												
2	0.1311	0.3460	0.3032												
3	0.1143	0.3142	0.2703												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.0848	1.1879	0.4375												
2	0.0668	0.9313	0.3339												
3	0.0557	0.7748	0.2733												

Качество профилей решеток РК и НА:

$quality_{rotor}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7.999	3.499	4.017												
2	8.953	3.138	3.907												
3	9.010	2.930	3.853												

$quality_{stator}^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	12.351	-0.332	2.606												
2	14.371	0.159	3.601												
3	16.133	0.528	4.416												

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

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	78.40	-10.14	52.18												
2	77.51	17.95	56.46												
3	75.27	27.22	55.08												

$\cdot\%$

▲ Результаты расчета количества Л и параметров решеток РК и НА

Вывод параметров решеток

Подключение симметричного профиля

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

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

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

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

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

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

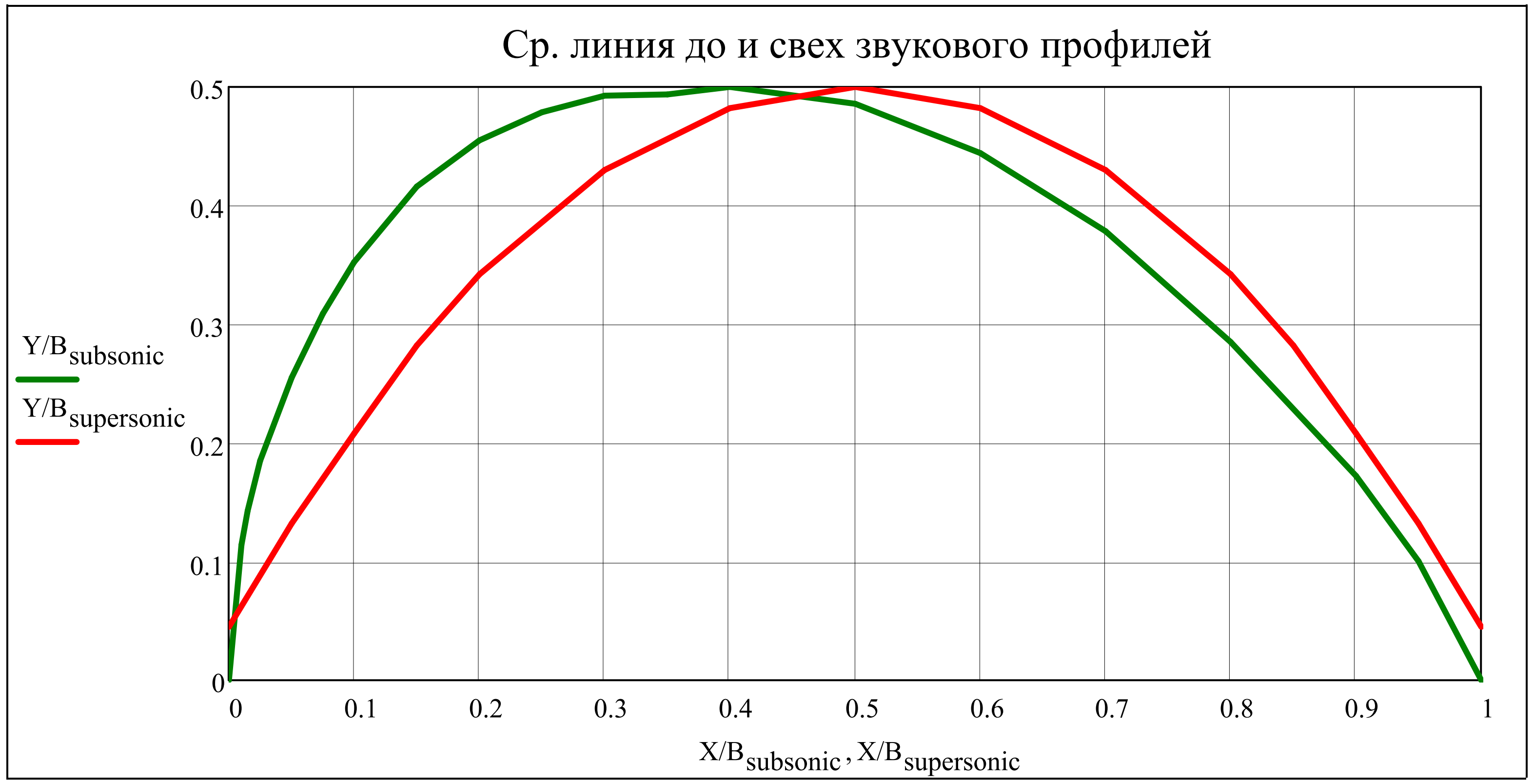
$Y/B_{supersonic} = \mathrm{submatrix}\left(EXCEL_{AIRFOIL.supersonic}, 2, \mathrm{rows}\left(EXCEL_{AIRFOIL.supersonic}\right), ORIGIN + 1, ORIGIN + 1\right)$

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

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

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

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

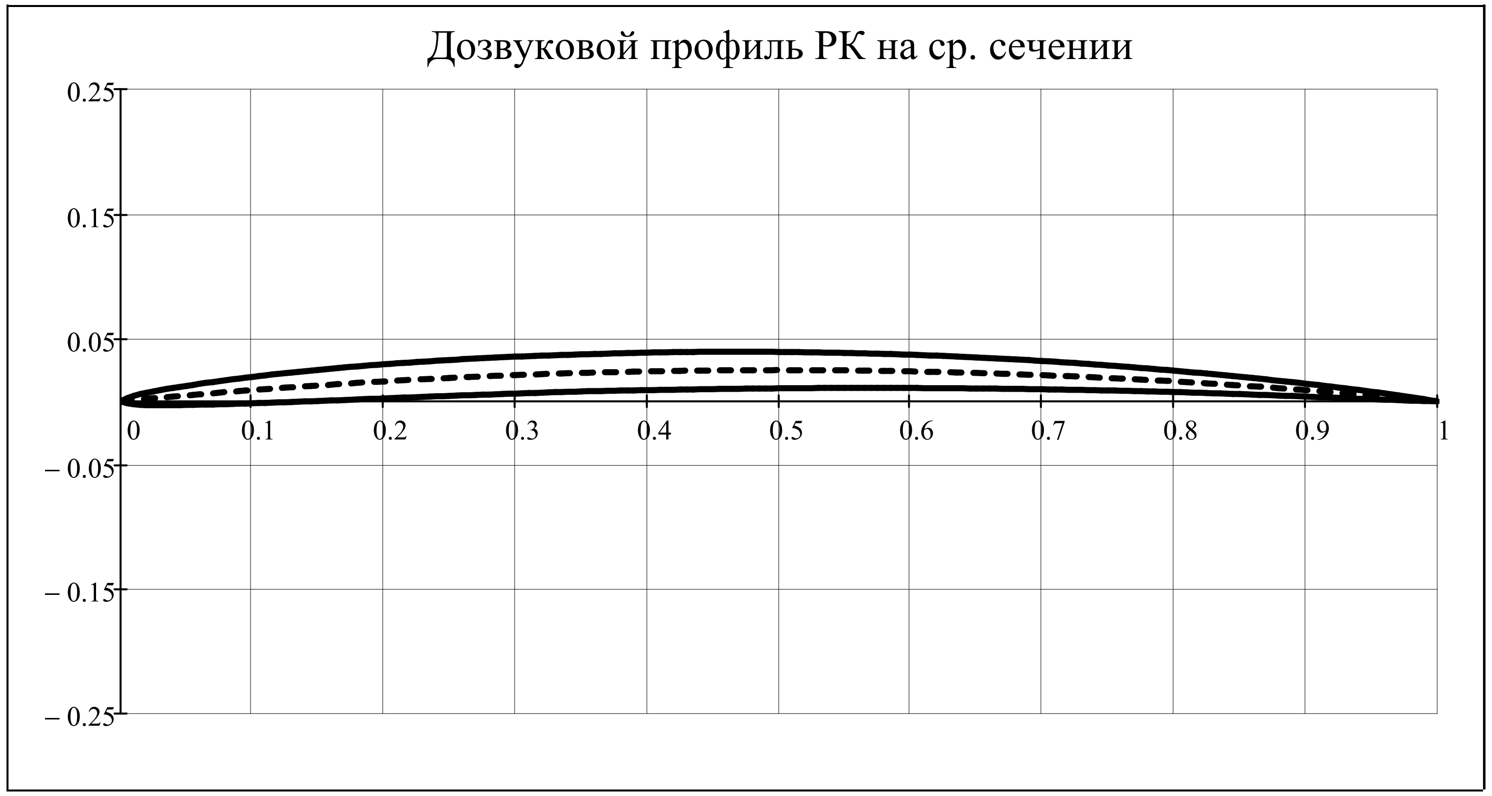


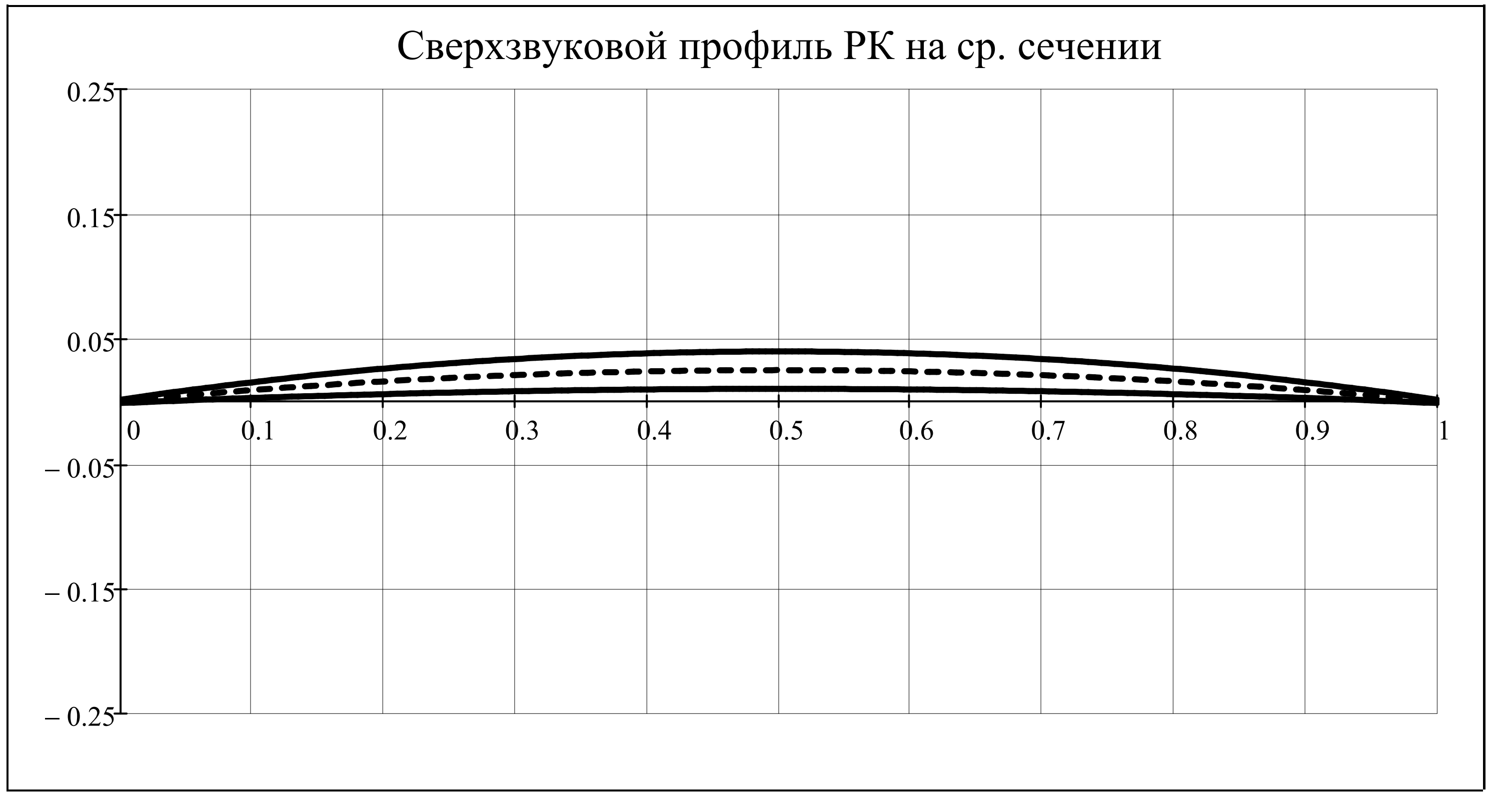
$$\text{AIRFOIL}_{\text{subsonic}}(x, line, \bar{c}, \theta) = \left| \begin{array}{l} \text{if } 0 \le x \le 1 \\ \quad \left| \begin{array}{ll} \text{interp}\left(\text{cspline}\left(X/B_{\text{subsonic}}, y/b_{\text{ср.л}}\left(X/B_{\text{subsonic}}, \theta\right) + Y/B_{\text{subsonic}} \cdot \bar{c}\right),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

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

$x = 0, 0.005 .. 1$

$j = 1$


Дозвуковой профиль РК на ср. сечении


Сверхзвуковой профиль РК на ср. сечении

Подключение симметричного профиля

▶ Определение относительных геометрических характеристик сечений Л

Результат расчета абсолютных геометрических характеристик сечений Л

Определение абсолютных геометрических характеристик сечений Л

Результат расчета абсолютных геометрических характеристик сечений Л

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

	1	2	3
1	35.57	45.89	65.57
2	39.65	51.37	73.50
3	43.33	56.32	80.52

$\cdot 10^{-3}$

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

	1	2	3
1	35.31	45.28	64.80
2	39.07	50.00	71.71
3	42.43	54.12	77.61

$\cdot 10^{-3}$

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

	1	2	3
1	27.22	44.00	90.69
2	66.72	107.87	222.74
3	117.60	190.07	391.78

$\cdot 10^{-6}$

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

	1	2	3
1	31.7	120.5	310.6
2	86.2	339.8	911.9
3	162.5	657.7	1790.7

$\cdot 10^{-9}$

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

	1	2	3
1	433.1	889.8	2633.2
2	1175.0	2415.3	7167.0
3	2244.9	4612.6	13650.7

$\cdot 10^{-9}$

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

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

$\cdot 10^{-3}$

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

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

$\cdot 10^{-3}$

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

	1	2	3
1	63.46	70.54	79.57
2	72.37	77.73	87.70
3	80.87	86.51	97.57

$\cdot 10^{-3}$

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

	1	2	3
1	62.29	67.36	76.00
2	72.11	77.18	87.15
3	80.75	86.30	97.37

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	225.65	257.58	328.05						
2	113.97	130.15	166.18						
3	95.34	108.83	138.60						

$\cdot 10^{-6}$

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

	1	2	3
1	454.0	1464.2	2091.6
2	130.7	316.4	398.0
3	73.2	151.4	182.9

$\cdot 10^{-9}$

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

	1	2	3
1	6328.8	7718.7	11093.6
2	3709.6	4527.2	6531.4
3	3476.1	4239.5	6093.1

$\cdot 10^{-9}$

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

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

$\cdot 10^{-3}$

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

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

$\cdot 10^{-3}$

$Jx_{stator}{}^{T} =$

	1	2	3
1	42	367	1188
2	145	1233	4347
3	350	2767	10133

$\cdot 10^{-12}$

$Jy_{stator}{}^{T} =$

	1	2	3
1	8814	23022	97817
2	26473	69192	295031
3	54829	143219	608525

$\cdot 10^{-12}$

$Jxy_{stator}{}^{T} =$

	1	2	3
1	524	2533	9375
2	1578	7908	30503
3	3225	16590	64856

$\cdot 10^{-12}$

$Jx0_{stator}{}^{T} =$

	1	2	3
1	5.51	37.05	124.93
2	33.25	162.37	613.04
3	125.74	491.68	1947.68

$\cdot 10^{-12}$

$Jy0_{stator}{}^{T} =$

	1	2	3
1	1925	5027	21360
2	5781	15109	64424
3	11974	31278	132897

$\cdot 10^{-12}$

$Jxy0_{stator}{}^{T} =$

	1	2	3
1	20.05	96.26	357.11
2	60.38	300.31	1160.56
3	123.40	628.77	2462.20

$\cdot 10^{-12}$

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

	1	2	3
1	0.60	1.10	0.96
2	0.60	1.15	1.04
3	0.60	1.17	1.08

$\cdot \circ$

$Jx_{rotor}{}^{T} =$

	1	2	3
1	1343	9558	15325
2	197	888	1117
3	77	251	297

$\cdot 10^{-12}$

$Jy_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	227101	295924	479972						
2	154477	201466	328422						
3	162150	211290	342699						

$\cdot 10^{-12}$

$Jxy_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	13241	45588	73495						
2	4425	11445	16265						
3	2774	6135	8363						

$\cdot 10^{-12}$

$Jx0_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	429.29	1235.81	1989.52						
2	47.35	118.62	163.61						
3	20.72	40.70	56.02						

$\cdot 10^{-12}$

$Jy0_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	49597	64627	104822						
2	33732	43993	71715						
3	35408	46138	74833						

$\cdot 10^{-12}$

$Jxy0_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	506.75	1713.59	2763.18						
2	169.70	438.07	622.93						
3	106.43	235.26	320.79						

$\cdot 10^{-1}$

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

	1	2	3
1	0.59	1.55	1.54
2	0.29	0.57	0.50
3	0.17	0.29	0.25

$\cdot \circ$

$Ju_{stator}{}^{T} =$

	1	2	3
1	5.30	35.19	118.93
2	32.61	156.34	591.94
3	124.46	478.84	1901.40

$\cdot 10^{-12}$

$Jv_{stator}{}^{T} =$

	1	2	3
1	1925	5029	21366
2	5781	15115	64445
3	11975	31291	132943

$\cdot 10^{-12}$

$Juv_{stator}{}^{T} =$

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

$\cdot 10^{-12}$

$Jp_{stator}{}^{T} =$

	1	2	3
1	1930	5064	21485
2	5814	15271	65037
3	12100	31770	134844

$\cdot 10^{-12}$

$Wp_{stator}{}^{T} =$

	1	2	3
1	99.7	205.0	606.5
2	271.4	558.0	1655.6
3	521.1	1070.8	3168.9

$\cdot 10^{-9}$

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

	1	2	3
1	7.39	19.31	82.06
2	88.84	232.19	990.06
3	413.97	1081.34	4594.52

$\cdot 10^{-12}$

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

	1	2	3	4	5	6	7	8	9
1	424.07	1189.52	1915.33						
2	46.49	114.24	158.18						
3	20.40	39.50	54.65						

$\cdot 10^{-12}$

$Jv_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	49602	64674	104896						
2	33733	43997	71721						
3	35408	46139	74834						

$\cdot 10^{-12}$

$Juv_{rotor}{}^{T} =$

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

$\cdot 10^{-12}$

$Jp_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	50026	65863	106811						
2	33779	44111	71879						
3	35428	46179	74889						

$\cdot 10^{-12}$

$Wp_{rotor}{}^{T} =$

	1	2	3	4	5	6	7	8	9
1	1466.4	1788.5	2570.5						
2	854.3	1042.7	1504.3						
3	800.1	975.9	1402.5						

$\cdot 10^{-9}$

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

	1	2	3	4	5	6	7	8	9
1	1354.80	1765.38	2863.34						
2	129.60	169.02	275.53						
3	60.46	78.78	127.78						

$\cdot 1$

$CPx_{stator}^{T} =$

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

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

Профилирование решеток

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

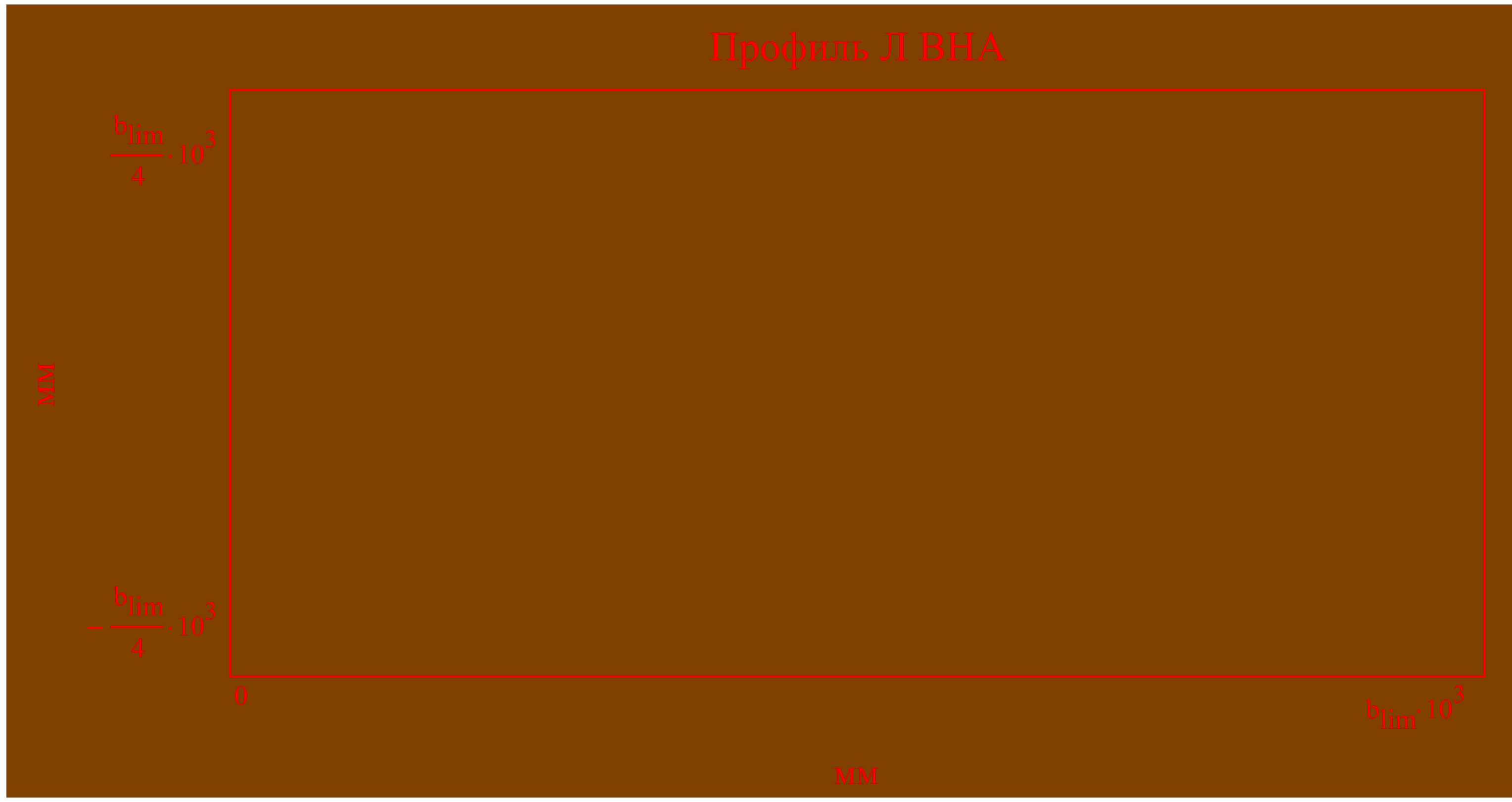
Построение профилей Л РК и НА

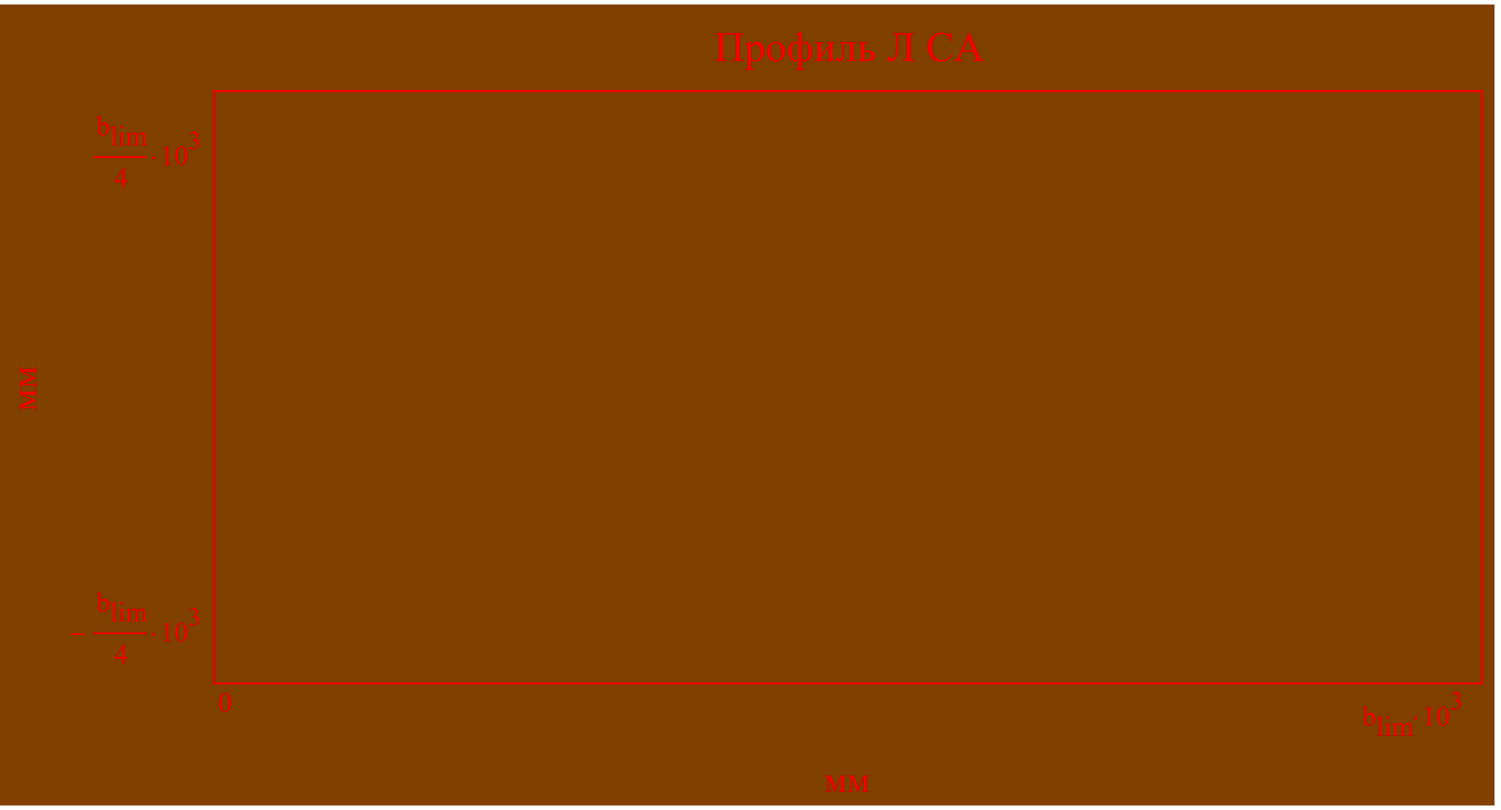
$$AXLE0(type, x, i, r) = \left| \begin{array}{ll} \dfrac{y0rotor_{i,r}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}}\right) \cdot \left(x - \dfrac{x0rotor_{i,r}}{chord_{rotor_{i,r}}}\right) & \text{if } type = \text{"rotor"} \\ \dfrac{y0_{stator_{i,r}}}{chord_{stator_{i,r}}} + \tan\left(\alpha\_major_{stator_{i,r}}\right) \cdot \left(x - \dfrac{x0_{stator_{i,r}}}{chord_{stator_{i,r}}}\right) & \text{if } type = \text{"stator"} \\ NaN & \text{otherwise} \end{array} \right.$$

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

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

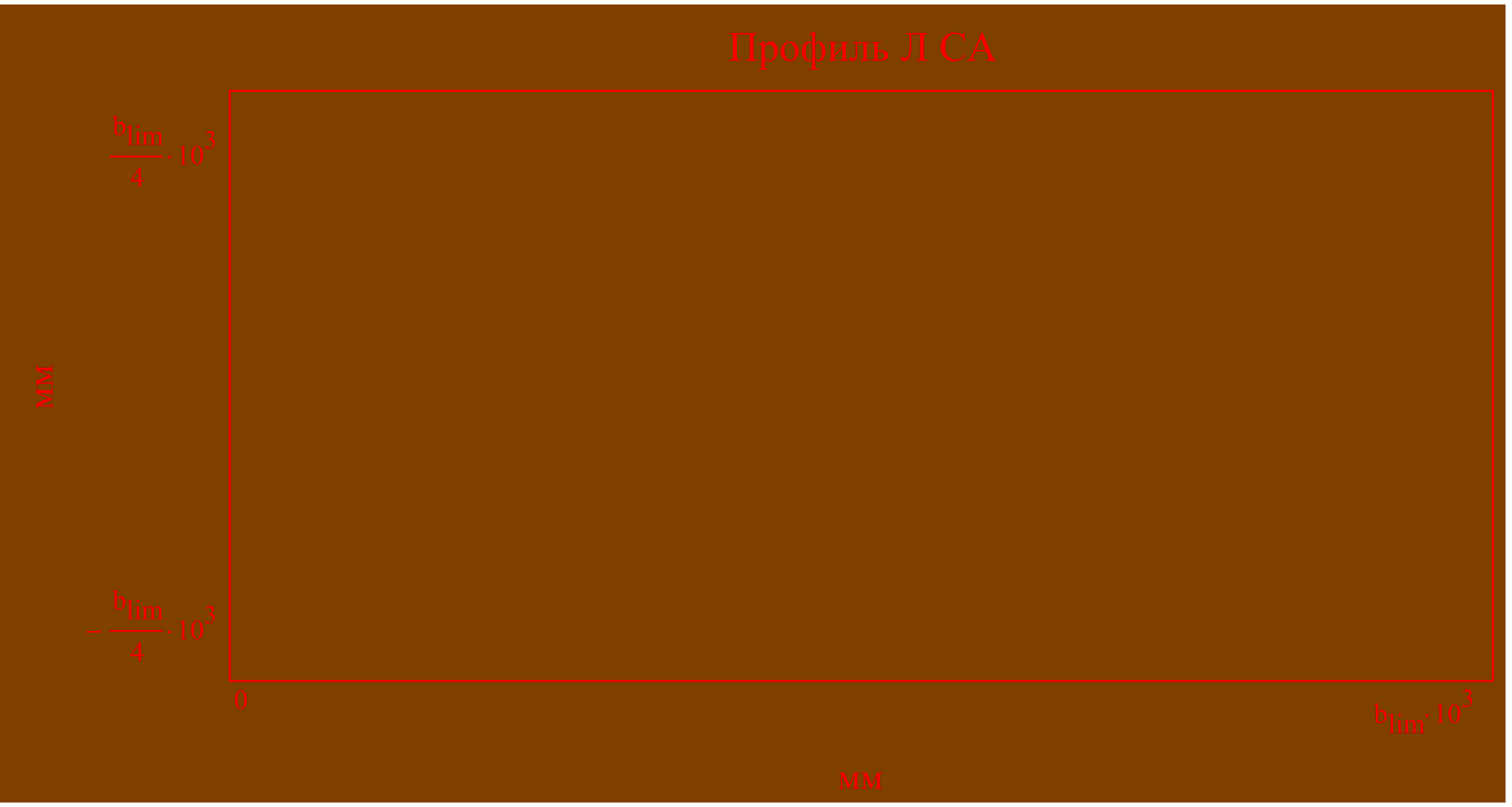
$r = 1$


Профиль Л ВНА

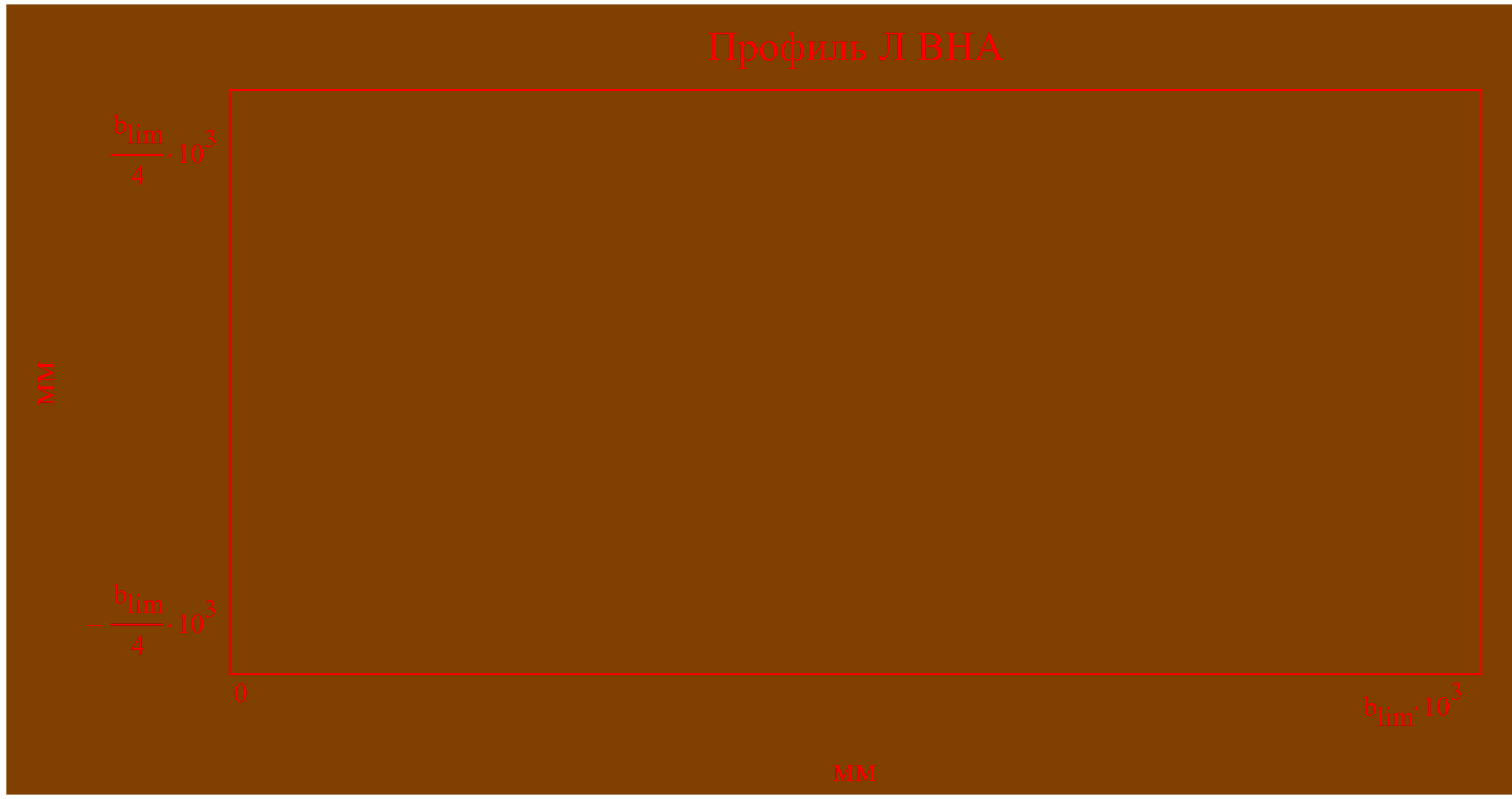

Профиль Л СА

$r = av(N_r)$

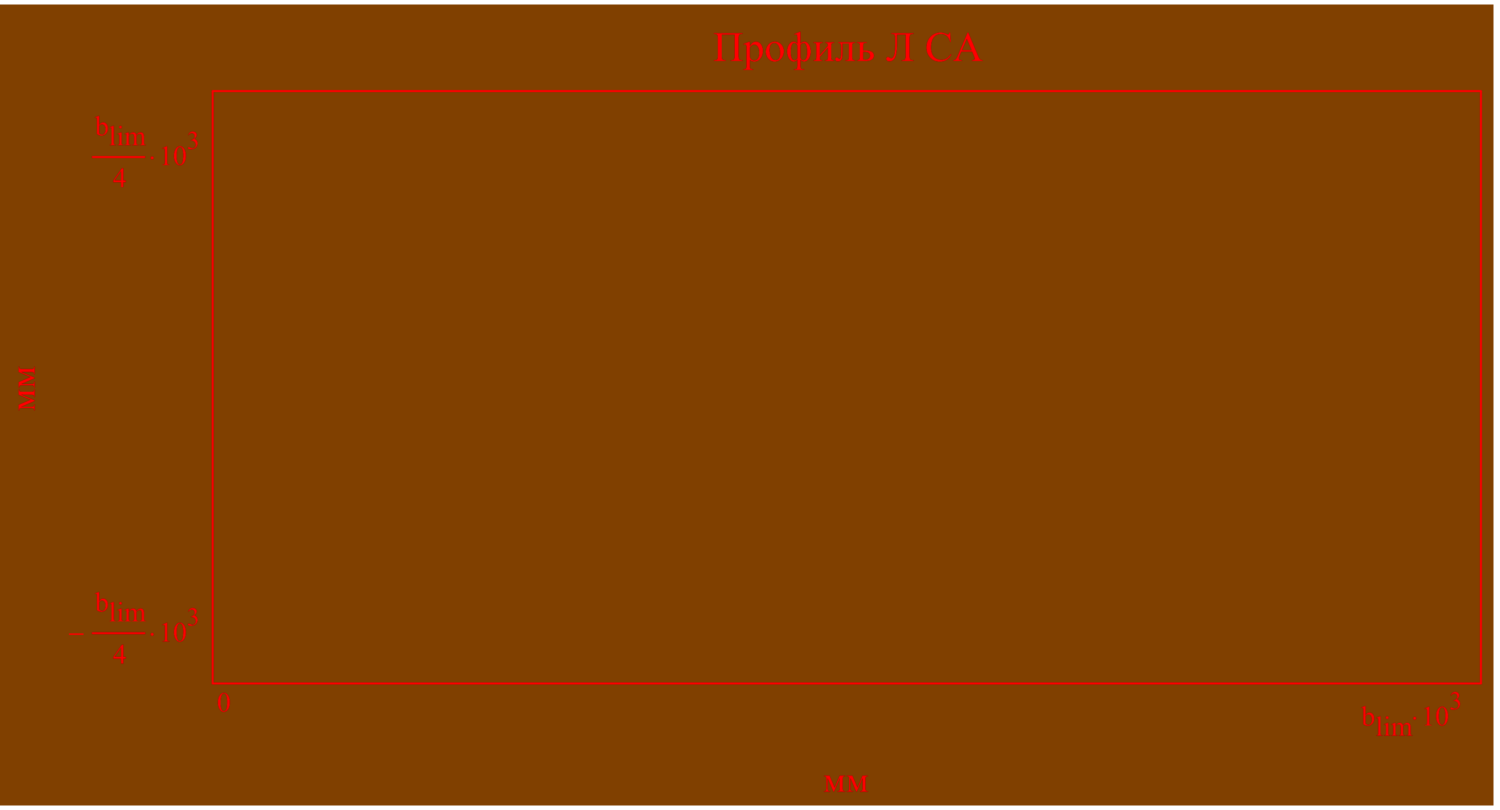

Профиль Л ВНА


Профиль Л СА

$r = N_r$

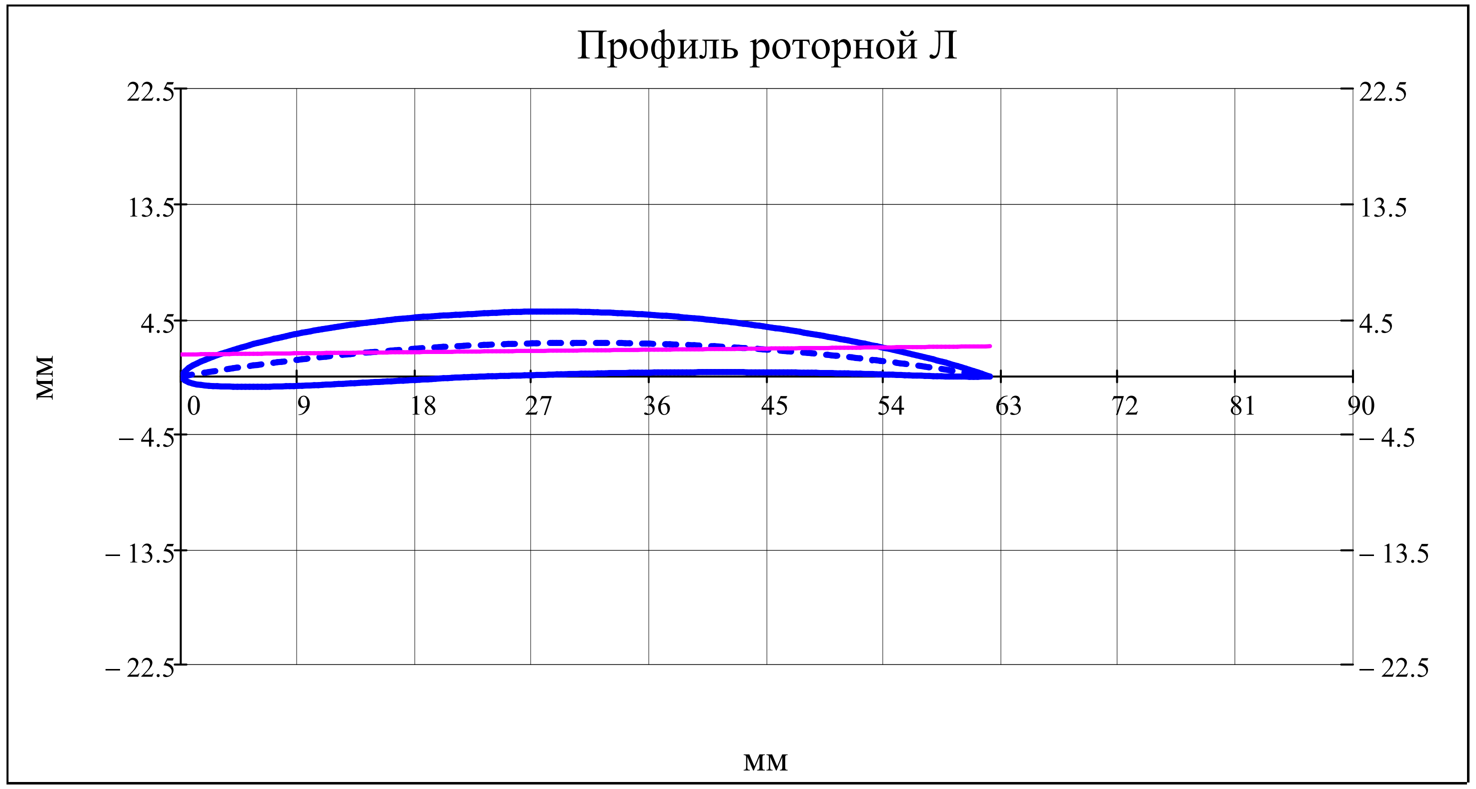


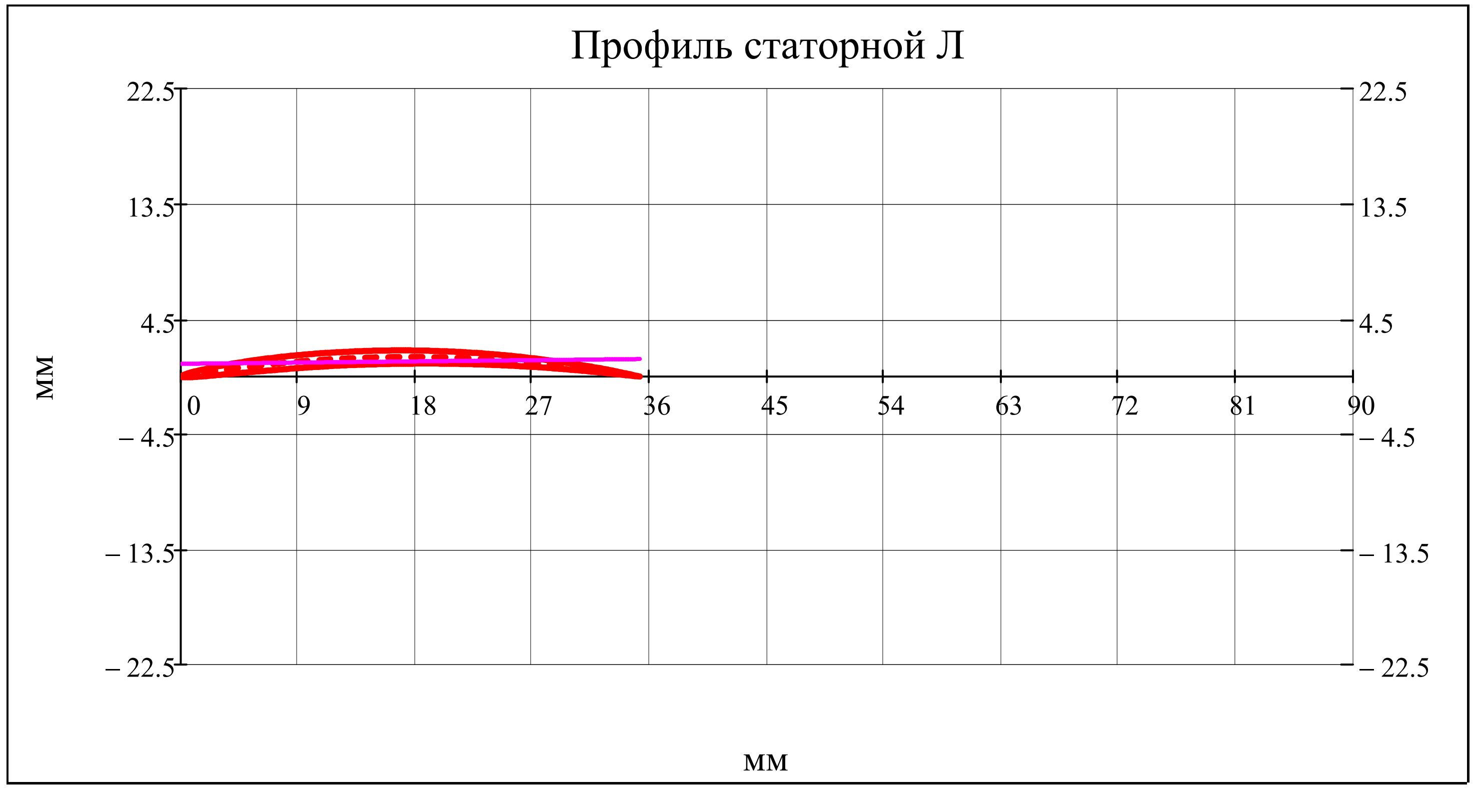
Профиль Л ВНА



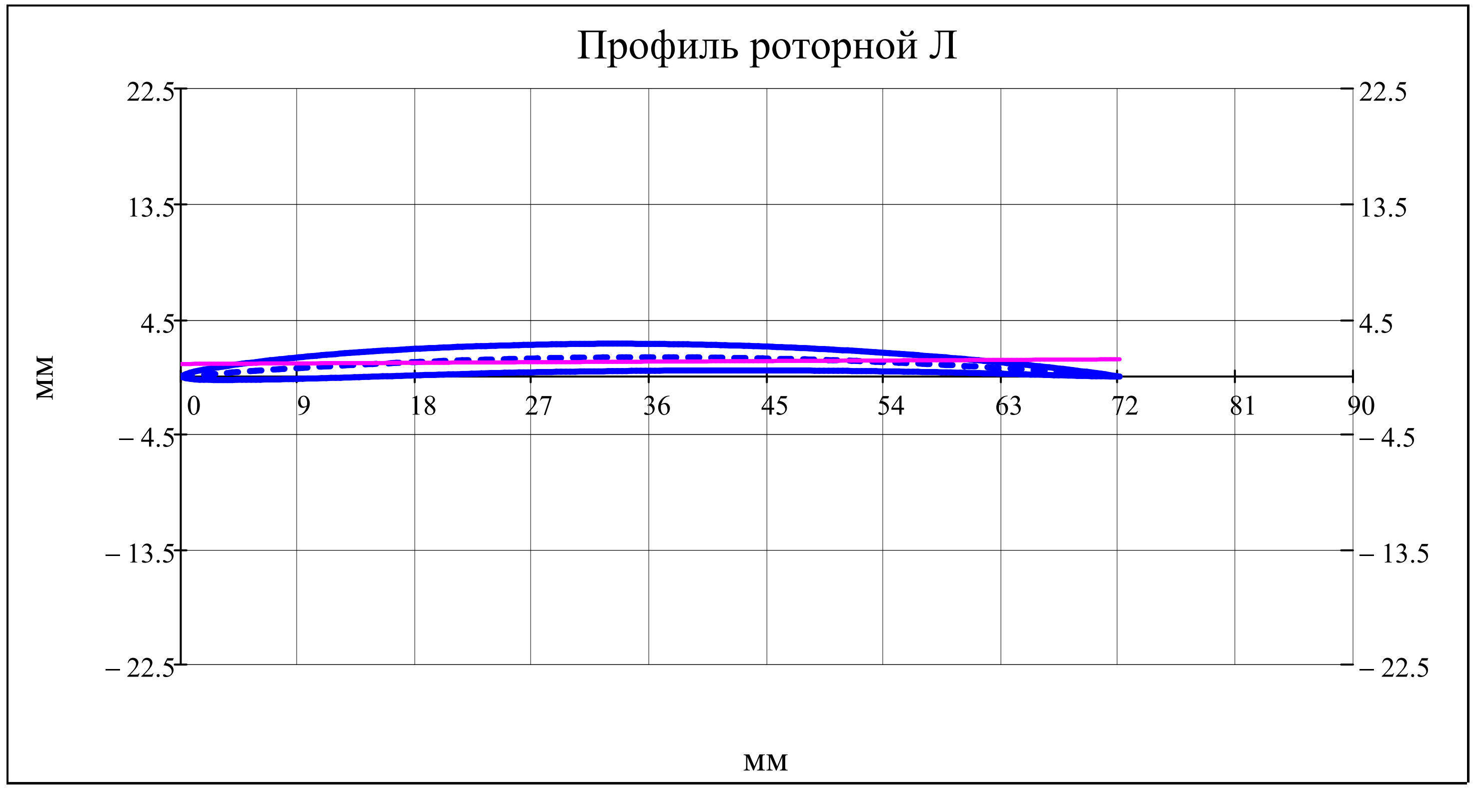
Профиль Л СА

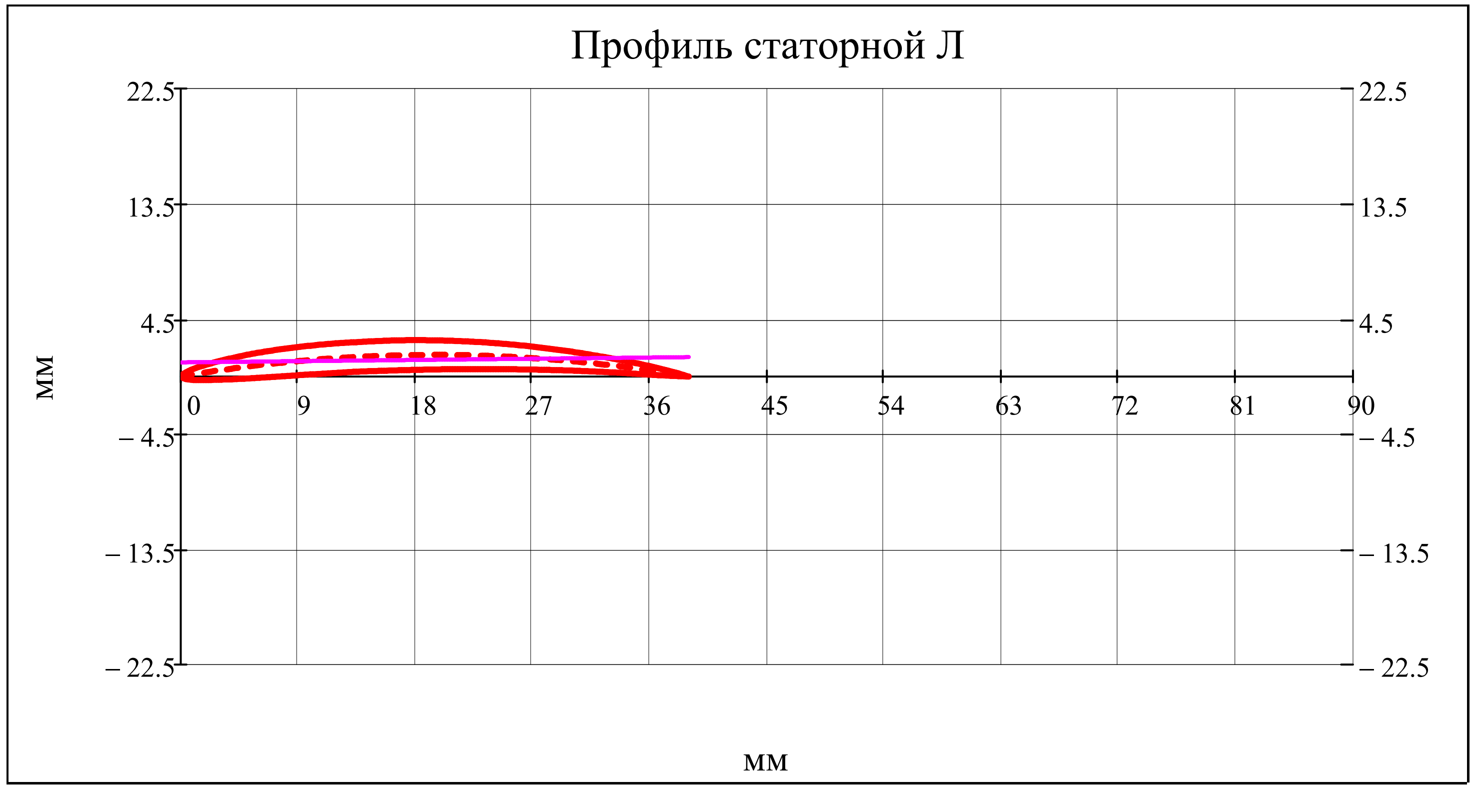
r = 1


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

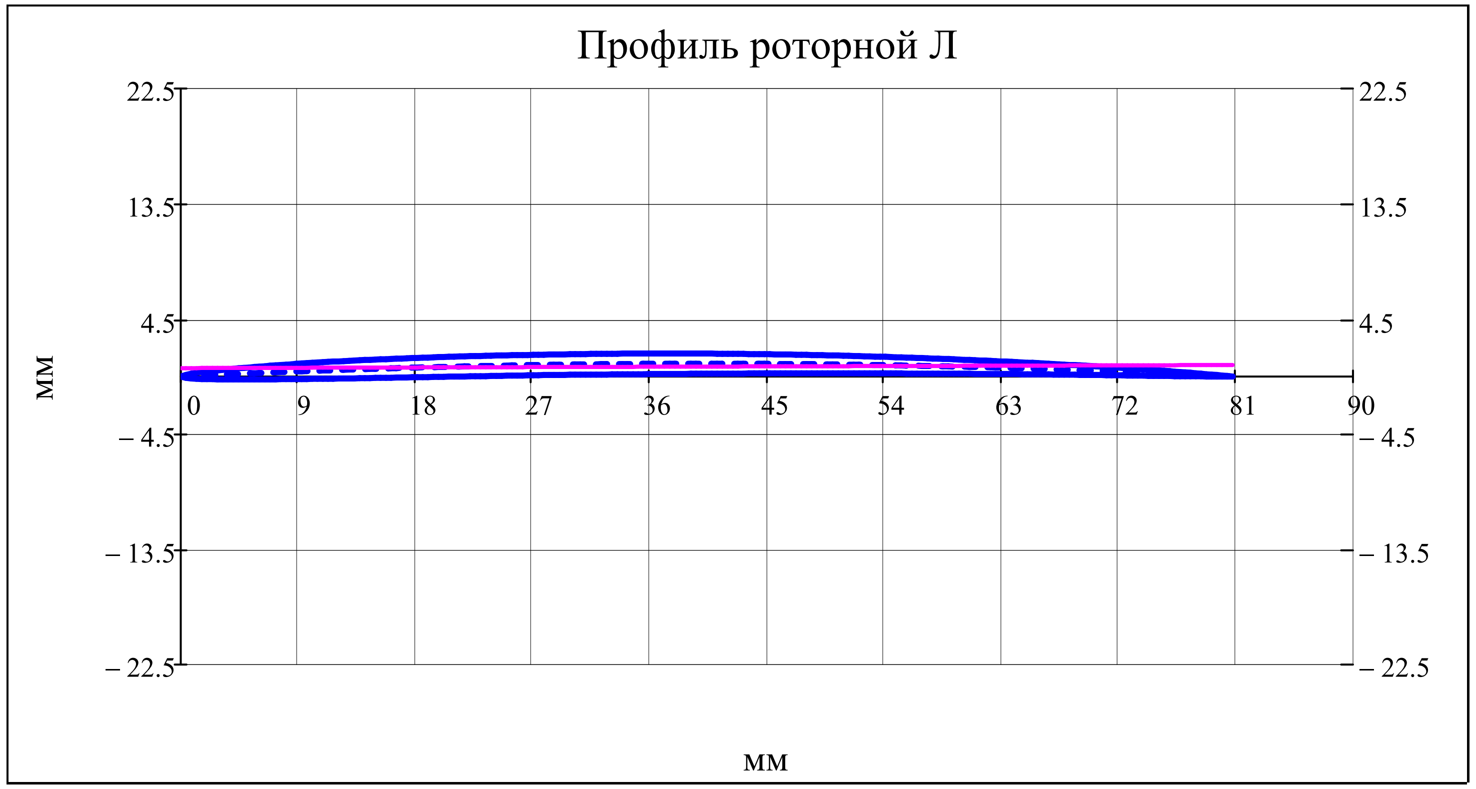

Профиль статорной Л
22.5
13.5
4.5
− 4.5
− 13.5
− 22.5
0
9
18
27
36
45
54
63
72
81
90
мм
мм

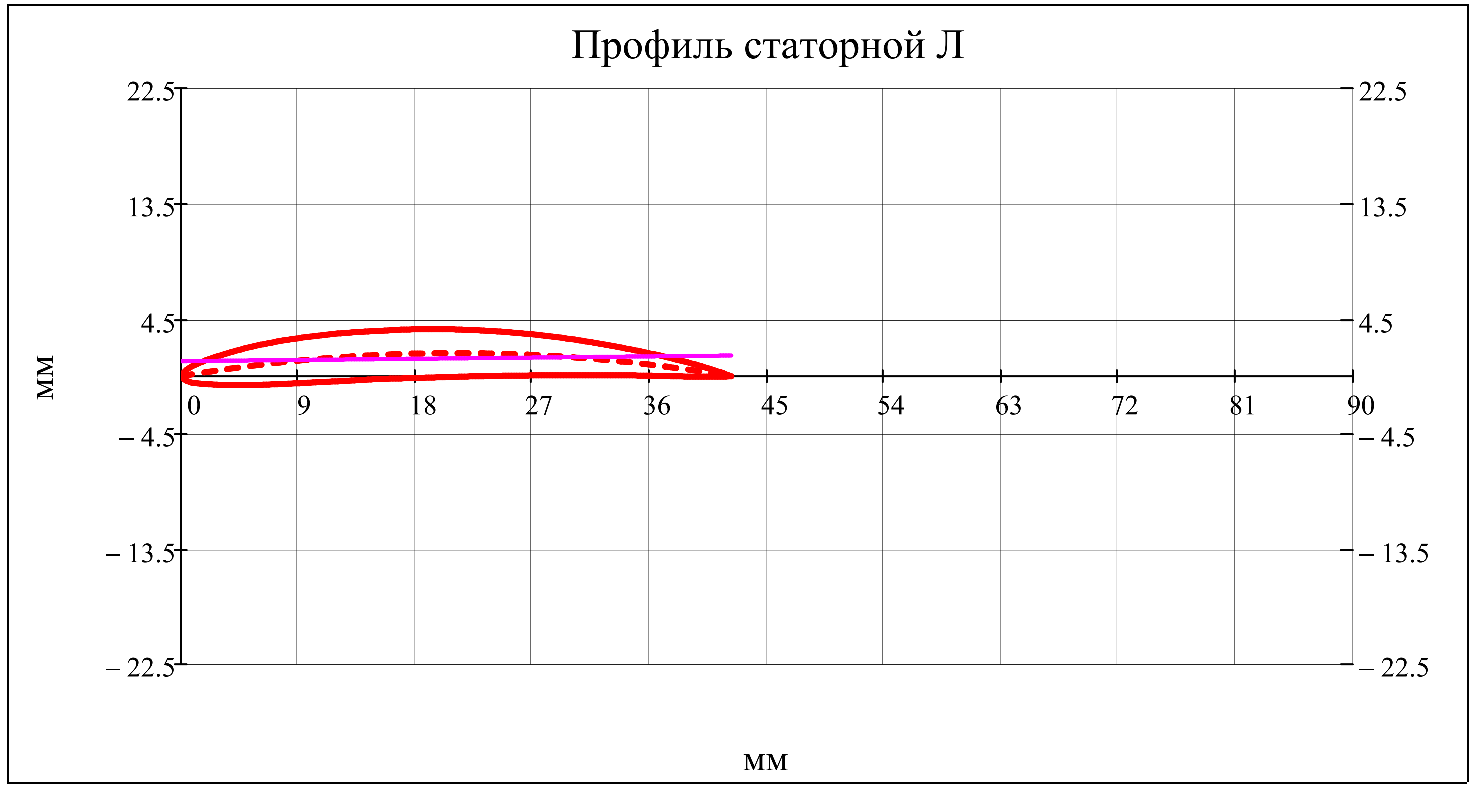
$r = av(N_r)$


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

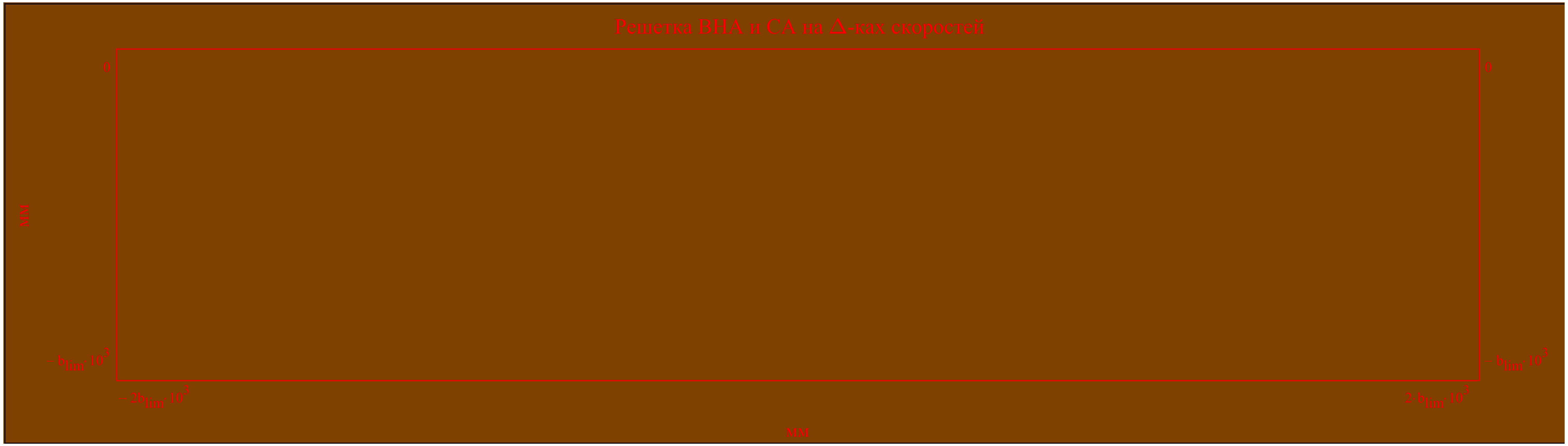

Вывод координат для построения профиля Л

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

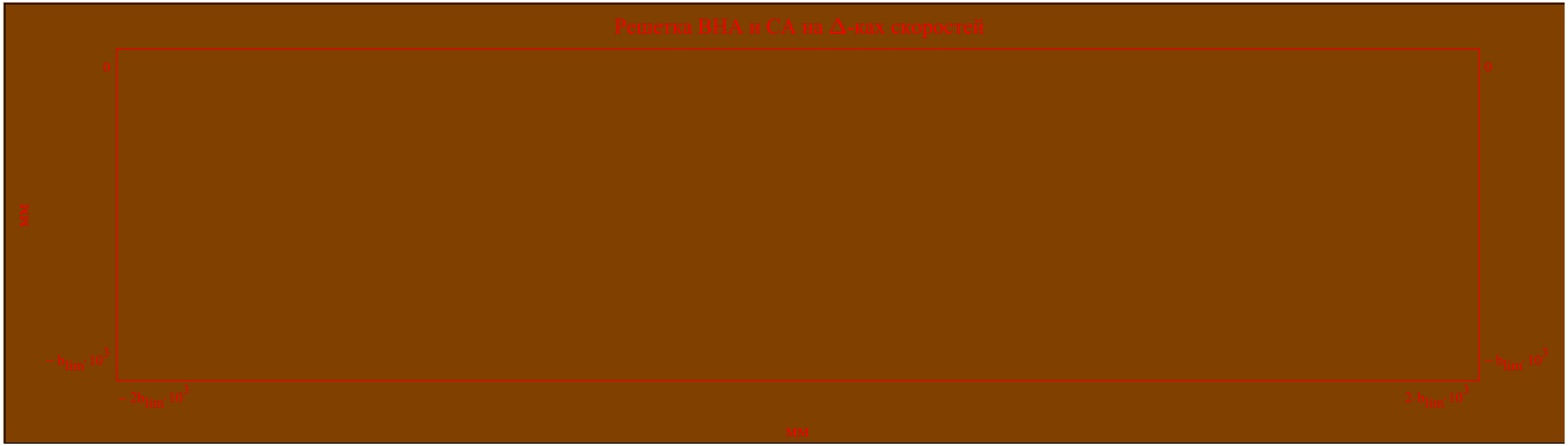
$$b_{lim} := \frac{\mathrm{ceil}\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right)\cdot 10^2\right)}{10^2} = 90\cdot 10^{-3}$$

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

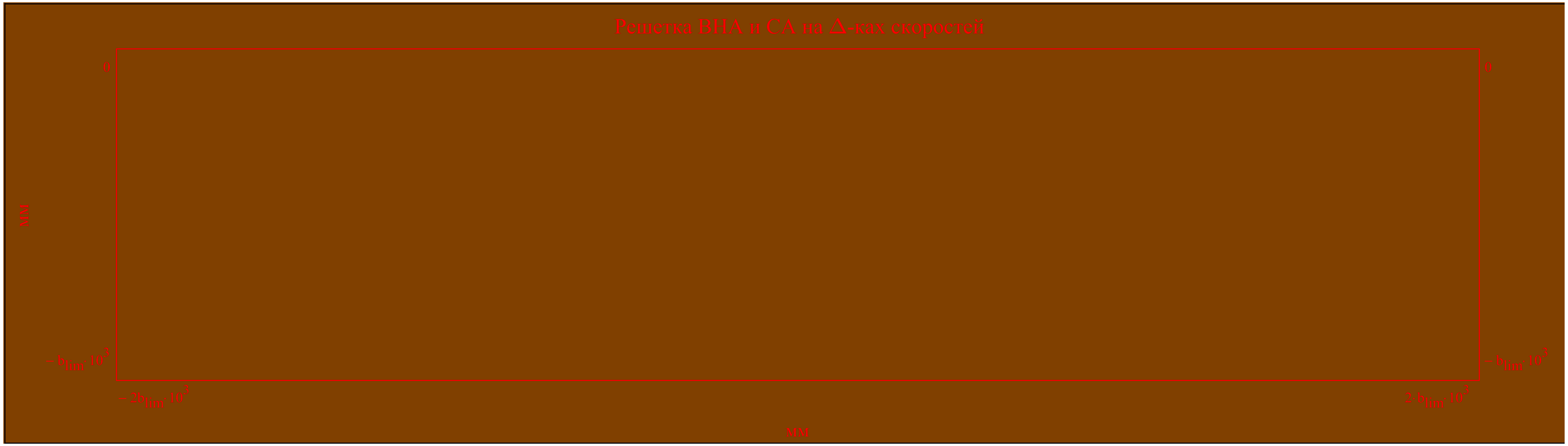
$r := 1$



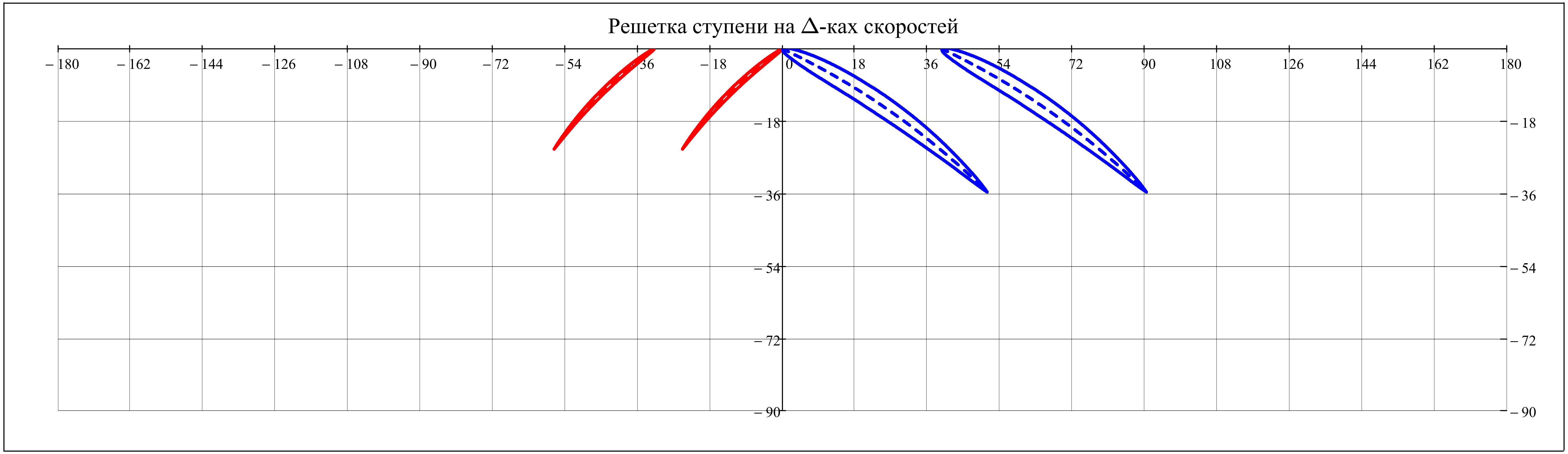
$r = av(N_r)$


Решетка ВНА и СА на Δ-ках скоростей
0
0
мм
$-b_{lim} \cdot 10^3$
$-b_{lim} \cdot 10^3$
$-2b_{lim} \cdot 10^3$
$2 \cdot b_{lim} \cdot 10^3$
мм

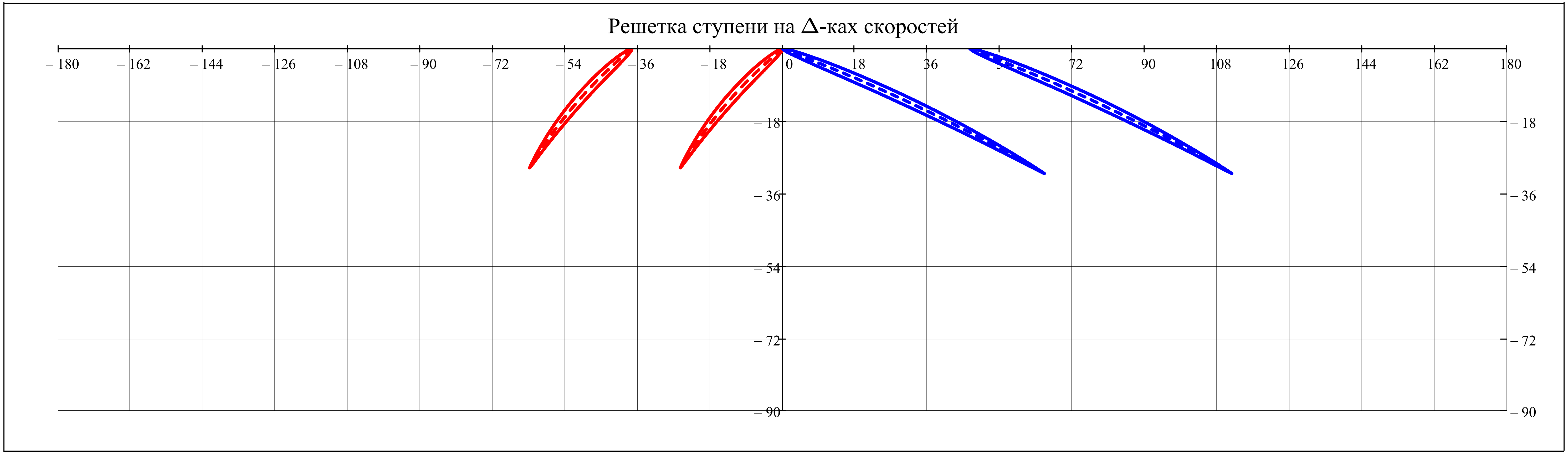
$r = N_r$


Решетка ВНА и СА на Δ-ках скоростей
0
0
мм
$-b_{lim} \cdot 10^3$
$-b_{lim} \cdot 10^3$
$-2b_{lim} \cdot 10^3$
$2 \cdot b_{lim} \cdot 10^3$
мм

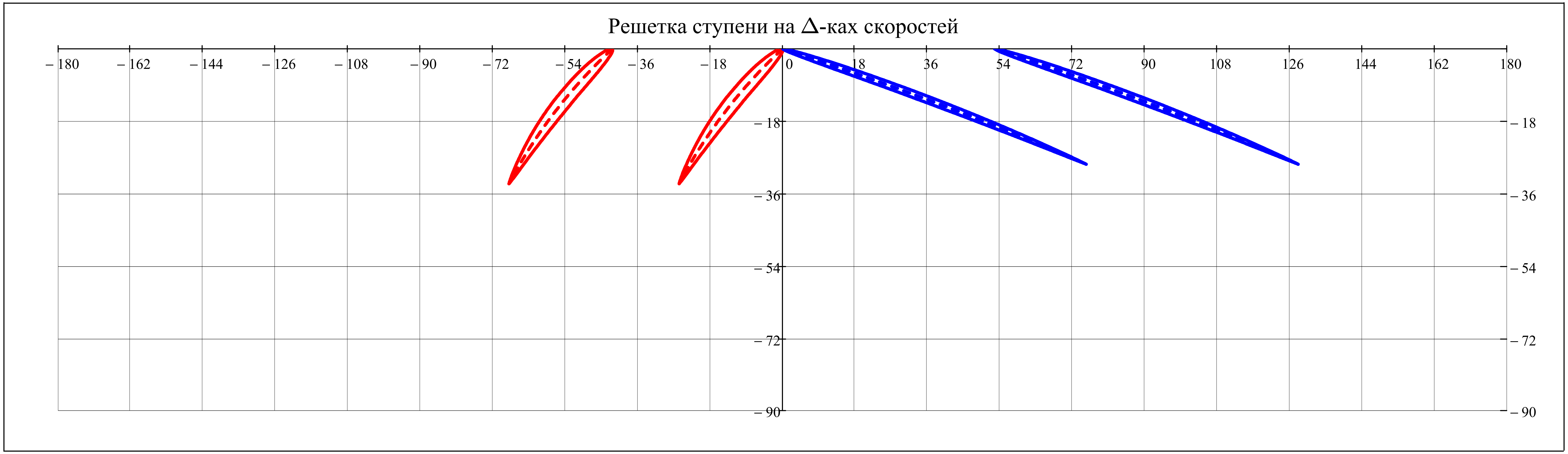
r = 1


Решетка ступени на Δ-ках скоростей
– 180
– 162
– 144
– 126
– 108
– 90
– 72
– 54
– 36
– 18
0
18
36
54
72
90
108
126
144
162
180
– 18
– 36
– 54
– 72
– 90

$r = av(N_r)$


Решетка ступени на Δ-ках скоростей
– 180
– 162
– 144
– 126
– 108
– 90
– 72
– 54
– 36
– 18
0
18
36
54
72
90
108
126
144
162
180
– 18
– 36
– 54
– 72
– 90

$r = N_r$



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

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

Радиальные и осевые зазоры и длина К

Радиальный зазор (м)
[с.64 казаджан]:

$\overline{\Delta}r = 0.0025$

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

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

$\Delta_r^T =$

	1	2	3
1	2.56	2.51	2.36

$\cdot 10^{-3}$

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

$\overline{\Delta}a = 0.17$

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

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

$\Delta a^T =$

	1	2	3
1	12.25	13.09	14.79

$\cdot 10^{-3}$

Односторонний осевой зазор (м):

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

	1	2	3
1	6.13	6.55	7.40

$\cdot 10^{-3}$

Длина ОК (м):

$$Length = \left[\Delta a_1 + \left|\begin{array}{l} chord_{BHA_{av(N_r)}} \cdot \sin\left(\upsilon_{BHA_{av(N_r)}}\right) \ \text{ if } BHA = 1 \\ 0 \ \text{ otherwise} \end{array}\right. \ldots \\ + \sum_{i=1}^{Z} \left(chord_{rotor_{i,av(N_r)}} \cdot \sin\left(\upsilon_{rotor_{i,av(N_r)}}\right)\right) + 2 \cdot \sum_{i=1}^{Z} \Delta a_i + \sum_{i=1}^{Z} \left(chord_{stator_{i,av(N_r)}} \cdot \sin\left(\upsilon_{stator_{i,av(N_r)}}\right)\right) \ldots \\ + \left|\begin{array}{l} chord_{CA_{av(N_r)}} \cdot \sin\left(\upsilon_{CA_{av(N_r)}}\right) \ \text{ if } CA = 1 \\ 0 \ \text{ otherwise} \end{array}\right. + \Delta a_Z \right] = 346.4 \cdot 10^{-3}$$

Радиальные и осевые зазоры и длина К

Проточная часть

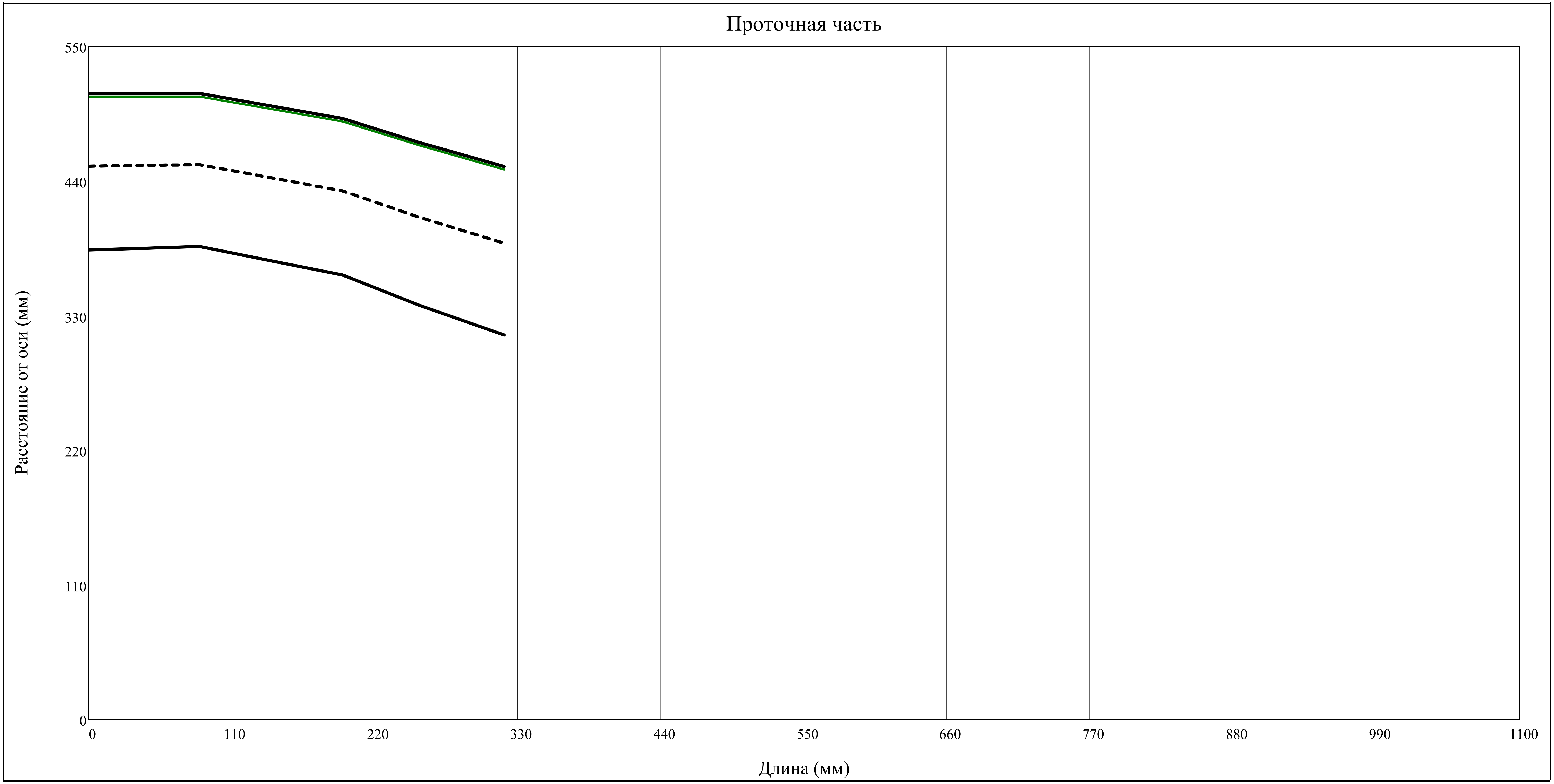
```
$\begin{pmatrix} x_{\text{ПЧ}} \\ y_{\text{ПЧпер}} \\ y_{\text{ПЧср}} \\ y_{\text{ПЧкор}} \\ y_{\text{Лпер}} \end{pmatrix} =$
    $c = 1$
    $x_{\text{ПЧ}_c} =$
        $chord_{BHA_{av(N_r)}} \cdot \sin\left(\upsilon_{BHA_{av(N_r)}}\right)$  if  $BHA = 1$
        $0$  otherwise
    $y_{\text{ПЧпер}_c}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

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

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

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

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


Проточная часть
550
440
330
220
110
0
0
110
220
330
440
550
660
770
880
990
1100
Расстояние от оси (мм)
Длина (мм)

Проточная часть

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

Поперечная часть ступени

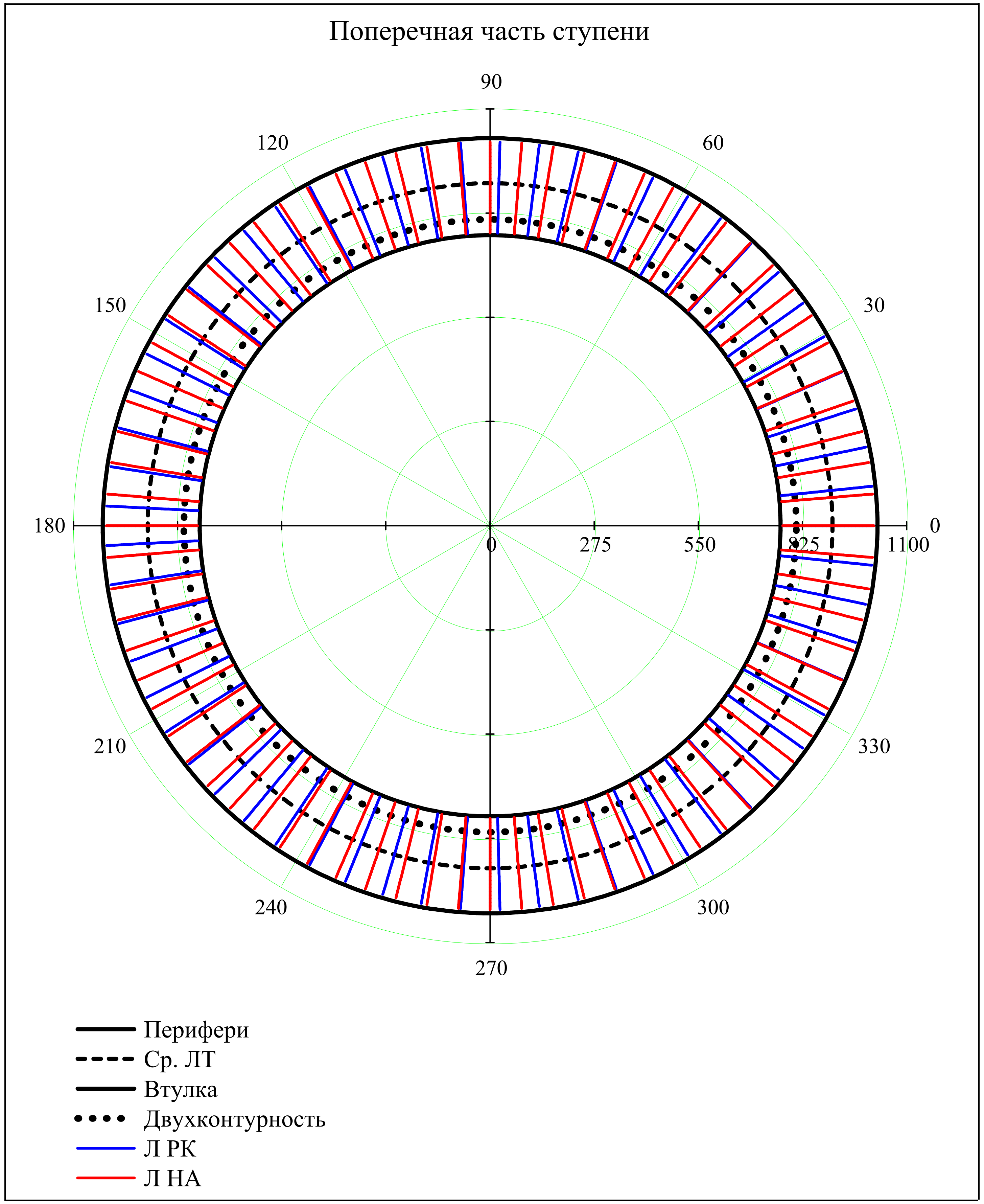
$$r := \min(D), \min(D) + \frac{\max(D) - \min(D)}{N_{dis}} .. \max(D)$$

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

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

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

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



Поперечная часть ступени

▼ Выбор материала Л

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

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

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

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

Коэф. формы: $k_n = 6.8$

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

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

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

$material\_blade^T =$

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

$\rho\_blade^T =$

	1	2	3
1	4430	4430	4430

$\sigma\_blade\_long^T =$

	1	2	3
1	210.0	210.0	210.0

$\cdot 10^6$

▲ Выбор материала Л

Расчет собственных частот колебаний Л

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

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

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

$\mathrm{stack}\left(\nu0_{\text{угл.stator}}, \nu0_{\text{угл.rotor}}\right)^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1049	1034	973	520	525	506												
2	3148	3103	2919	1559	1576	1519												
3	5246	5171	4865	2599	2626	2531												
4	7345	7240	6811	3638	3677	3544												
5	9443	9308	8757	4678	4727	4557												
6	11542	11377	10703	5718	5778	5569												

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

$\mathrm{stack}\left(\nu0_{\text{изг.stator}}, \nu0_{\text{изг.rotor}}\right)^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	170	286	343	152	228	221												
2	1067	1795	2148	953	1429	1382												
3	2989	5026	6015	2669	4003	3871												
4	5861	9855	11796	5233	7849	7591												
5	9685	16285	19492	8648	12970	12544												
6	14465	24321	29110	12915	19370	18734												

$\mathrm{stack}\left(\nu0_{\text{угл.stator\_bondage}}, \nu0_{\text{угл.rotor\_bondage}}\right)^{T} =$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	2099	2069	1946	1040	1051	1013												
2	4197	4137	3892	2079	2101	2025												
3	6296	6206	5838	3119	3152	3038												
4	8394	8274	7784	4158	4202	4050												
5	10493	10343	9730	5198	5253	5063												
6	12591	12411	11676	6237	6303	6075												

▲ 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

$$\begin{pmatrix} R0_{rotor} & area0_{rotor} \\ N0_{rotor} & \sigma0\_z_{rotor} \\ area_{rotor.} & area_{stator.} \\ N_{rotor} & \sigma\_z_{rotor} \\ P_1 & \rho_1 \\ P_2 & \rho_2 \\ P_3 & \rho_3 \\ c_{a1} & c_{u1} \\ c_{a2} & c_{u2} \\ c_{a3} & c_{u3} \\ qx_{rotor} & qx_{stator} \\ qy_{rotor} & qy_{stator} \\ Mx_{rotor} & Mx_{stator} \\ My_{rotor} & My_{stator} \\ shift\_x_{rotor} & shift\_y_{rotor} \\ x0_{rotor.} & x0_{stator.} \\ y0_{rotor.} & y0_{stator.} \\ \alpha\_major_{rotor.} & \alpha\_major_{stator.} \\ Ju_{rotor.} & Ju_{stator.} \\ Jv_{rotor.} & Jv_{stator.} \\ CPx_{rotor.} & CPx_{stator.} \\ CPy_{rotor.} & CPy_{stator.} \\ CPx_{rotor.axis} & CPx_{stator.axis} \\ CPy_{rotor.axis} & CPy_{stator.axis} \end{pmatrix} = \left| \begin{aligned} & \chi_{rotor}(i,z) = \frac{area_{rotor_{i,N_r}}}{area_{rotor_{i,1}}} \\ & R0_{rotor}(i,z) = \frac{1}{\sqrt{1-\ln\left(\chi_{rotor}(i,z)\right)}} \cdot \left| \begin{array}{l} \sqrt{mean\left(R_{st(i,1),1}, R_{st(i,2),1}\right)^2 - mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)^2 \cdot \ln\left(\chi_{rotor}(i,z)\right)} \ \text{ if type = "compressor"} \\ \sqrt{mean\left(R_{st(i,2),1}, R_{st(i,3),1}\right)^2 - mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)^2 \cdot \ln\left(\chi_{rotor}(i,z)\right)} \ \text{ if type = "turbine"} \end{array} \right. \\ & \sigma0_{rotor.max}(i,z) = \frac{\rho\_blade_i \cdot \omega^2}{2} \cdot \left| \begin{array}{l} \left[mean\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)^2 - \left(R0_{rotor}(i,z)\right)^2 \right] \ \text{ if type = "compressor"} \\ \left[mean\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)^2 - \left(R0_{rotor}(i,z)\right)^2 \right] \ \text{ if type = "turbine"} \end{array} \right. \\ & \qquad \left| \left(\rho\_blade_i \cdot \omega^2 \int^{R0_{rotor}(i,z)} \right) \right. \end{aligned} \right.$$

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

$$\text{area0}_{\text{rotor}}(i,z) = \text{area}_{\text{rotor}_{i,N_r}} \cdot \left| \begin{array}{ll} e^{\left(\frac{}{\sigma 0_{\text{rotor.max}}(i,z)} \cdot \int_z z\,dz\right)} & \text{if } z \le R0_{\text{rotor}}(i,z) \\ 1 \ \ \text{otherwise} & \end{array} \right.$$

$$N0_{\text{rotor}}(i,z) = \rho\_\text{blade}_i \cdot \omega^2 \cdot \left| \begin{array}{ll} \left(\int_z^{\text{mean}\left(R_{st(i,1),N_r}, R_{st(i,2),N_r}\right)} \text{area0}_{\text{rotor}}(i,z) \cdot z\,dz + V_{\text{бп}} \cdot R_{\text{бп}} \right) & \text{if type = "compressor"} \\ \left(\int_z^{\text{mean}\left(R_{st(i,2),N_r}, R_{st(i,3),N_r}\right)} \text{area0}_{\text{rotor}}(i,z) \cdot z\,dz + V_{\text{бп}} \cdot R_{\text{бп}} \right) & \text{if type = "turbine"} \end{array} \right.$$

$$\sigma 0\_z_{\text{rotor}}(i,z) = \frac{N0_{\text{rotor}}(i,z)}{\text{area0}_{\text{rotor}}(i,z)}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$CPx_{rotor.axis}(i,z) = \mathrm{axis}_{x}\left(CPx_{rotor.}(i,z),CPy_{rotor.}(i,z),x0_{rotor.}(i,z),y0_{rotor.}(i,z),\alpha\_\mathrm{major}_{rotor.}(i,z),1\right)$$

$$CPx_{stator.axis}(i,z) = \mathrm{axis}_{x}\left(CPx_{stator.}(i,z),CPy_{stator.}(i,z),x0_{stator.}(i,z),y0_{stator.}(i,z),\alpha\_\mathrm{major}_{stator.}(i,z),1\right)$$

$$CPy_{rotor.axis}(i,z) = \mathrm{axis}_{y}\left(CPx_{rotor.}(i,z),CPy_{rotor.}(i,z),x0_{rotor.}(i,z),y0_{rotor.}(i,z),\alpha\_\mathrm{major}_{rotor.}(i,z),1\right)$$

$$CPy_{stator.axis}(i,z) = \mathrm{axis}_{y}\left(CPx_{stator.}(i,z),CPy_{stator.}(i,z),x0_{stator.}(i,z),y0_{stator.}(i,z),\alpha\_\mathrm{major}_{stator.}(i,z),1\right)$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\begin{pmatrix} R0_{rotor} & area0_{rotor} \\ N0_{rotor} & \sigma0\_z_{rotor} \\ area_{rotor.} & area_{stator.} \\ N_{rotor} & \sigma\_z_{rotor} \end{pmatrix}$$

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

▲ Расчет Л на прочность

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

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

▶ Определение координат точек профиля Л, наиболее удаленных от НЛ

Наиболее удаленные точки от НЛ (мм):

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

	1	2	3	4	5	6	7	8	9
1	-1.888	-10.435	-8.761						
2	-0.829	-0.813	-0.818						
3	-0.658	-0.124	-0.126						

$\cdot 10^{-3}$

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

	1	2	3
1	3.091	5.012	4.562
2	1.420	1.754	1.667
3	36.463	1.193	1.131

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	33.995	32.065	32.633						
2	39.513	39.485	39.495						
3	-0.901	44.262	44.265						

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	-2.853	-12.645	-11.080						
2	-1.407	-2.843	-2.453						
3	-44.269	-1.572	-1.317						

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	-0.048	-0.031	0.314						
2	-0.436	-0.014	-0.026						
3	-0.464	-0.412	-0.430						

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	0.872	1.159	1.080						
2	1.549	1.891	1.824						
3	2.307	2.694	2.631						

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	19.302	19.261	19.278						
2	21.367	21.311	21.331						
3	-14.041	23.088	23.114						

$\cdot 10^{-3}$

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

	1	2	3	4	5	6	7	8	9
1	-1.370	-2.599	-2.226						
2	-1.531	-3.031	-2.686						
3	-1.896	-3.403	-3.046						

$\cdot 10^{-3}$

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

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

$$\sigma\_p_{rotor}{}^{T} = \begin{array}{c|ccccccccc} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & -35.55 & -2.18 & -1.74 & & & & & & \\ 2 & -44.51 & -7.98 & -7.67 & & & & & & \\ 3 & 0.00 & -0.14 & -0.39 & & & & & & \end{array} \cdot 10^{6}$$

$$\sigma\_p_{stator}{}^{T} = \begin{array}{c|ccccccccc} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 0.02 & 0.04 & 0.25 & & & & & & \\ 2 & 38.44 & 2.31 & 4.02 & & & & & & \\ 3 & 51.60 & 3.35 & 5.20 & & & & & & \end{array} \cdot 10^{6}$$

$$\sigma\_p_{rotor}{}^{T} \le 70 \cdot 10^{6} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1 & 1 & 1 \\ 2 & 1 & 1 & 1 \\ 3 & 1 & 1 & 1 \end{array}$$

$$\sigma\_p_{stator}{}^{T} \le 70 \cdot 10^{6} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1 & 1 & 1 \\ 2 & 1 & 1 & 1 \\ 3 & 1 & 1 & 1 \end{array}$$

$$\sigma\_n_{rotor}{}^{T} = \begin{array}{c|ccccccccc} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & 38.12 & 5.84 & 4.72 & & & & & & \\ 2 & 45.98 & 13.70 & 11.84 & & & & & & \\ 3 & 0.00 & 0.19 & 0.46 & & & & & & \end{array} \cdot 10^{6}$$

$$\sigma\_n_{stator}{}^{T} = \begin{array}{c|ccccccccc} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ \hline 1 & -0.03 & -0.09 & -0.53 & & & & & & \\ 2 & -38.36 & -3.85 & -6.05 & & & & & & \\ 3 & -41.88 & -4.48 & -6.22 & & & & & & \end{array} \cdot 10^{6}$$

$$\sigma\_n_{rotor}{}^{T} \le 70 \cdot 10^{6} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1 & 1 & 1 \\ 2 & 1 & 1 & 1 \\ 3 & 1 & 1 & 1 \end{array}$$

$$\sigma\_n_{stator}{}^{T} \le 70 \cdot 10^{6} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1 & 1 & 1 \\ 2 & 1 & 1 & 1 \\ 3 & 1 & 1 & 1 \end{array}$$

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

```
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	82.45	50.69	49.65						
2	79.36	49.31	49.03						
3	0.00	3.74	6.95						

$\cdot 10^6$

$\sigma_{stator}^T =$

	1	2	3	4	5	6	7	8	9
1	0.02	0.04	0.26						
2	38.44	2.31	4.02						
3	51.60	3.35	5.20						

$\cdot 10^6$

```
$\begin{pmatrix} safety_{rotor} \\ safety_{stator} \end{pmatrix} =$ for $i \in 1..Z$
    for $r \in 1..N_r$
        $safety_{rotor_{i,r}} = \frac{\sigma\_blade\_long_i}{\sigma_{rotor_{i,r}}}$ if $\sigma_{rotor_{i,r}} \neq 0$
                                $\infty$ otherwise
        $safety_{stator_{i,r}} = \frac{\sigma\_blade\_long_i}{\sigma_{stator_{i,r}}}$ 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	2.55	4.14	4.23				
2	2.65	4.26	4.28				
3	00000000000000000000000000000000.	56.22	30.22				

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

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

$safety_{stator}{}^{T} =$

	1	2	3	4	5
1	11543.03	4999.05	814.47		
2	5.46	91.01	52.18		
3	4.07	62.74	40.4		

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

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

Рассматриваемая ступень:

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

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

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

$\cdot 10^{-3}$

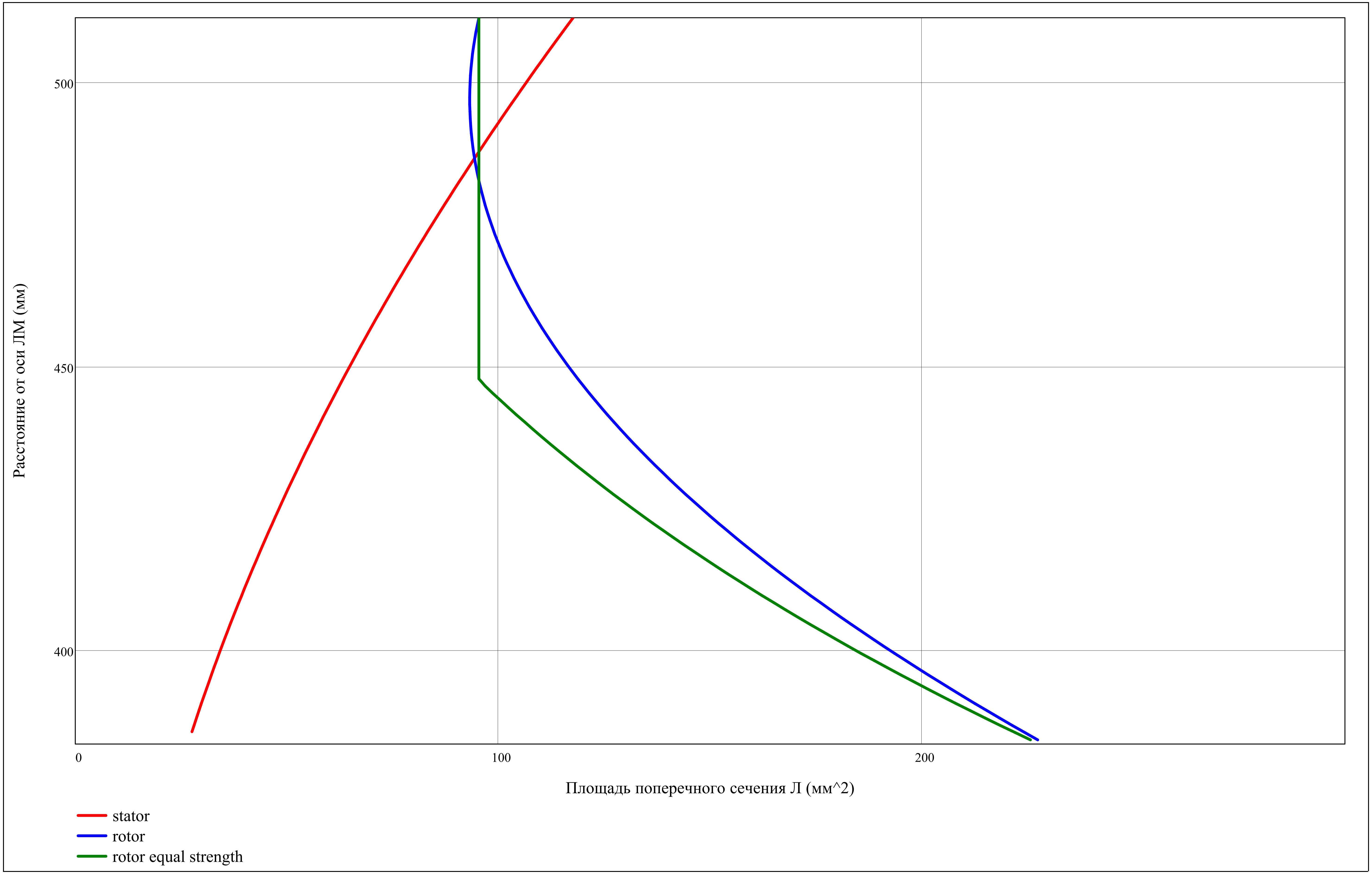
Дискретизация по высоте Л:

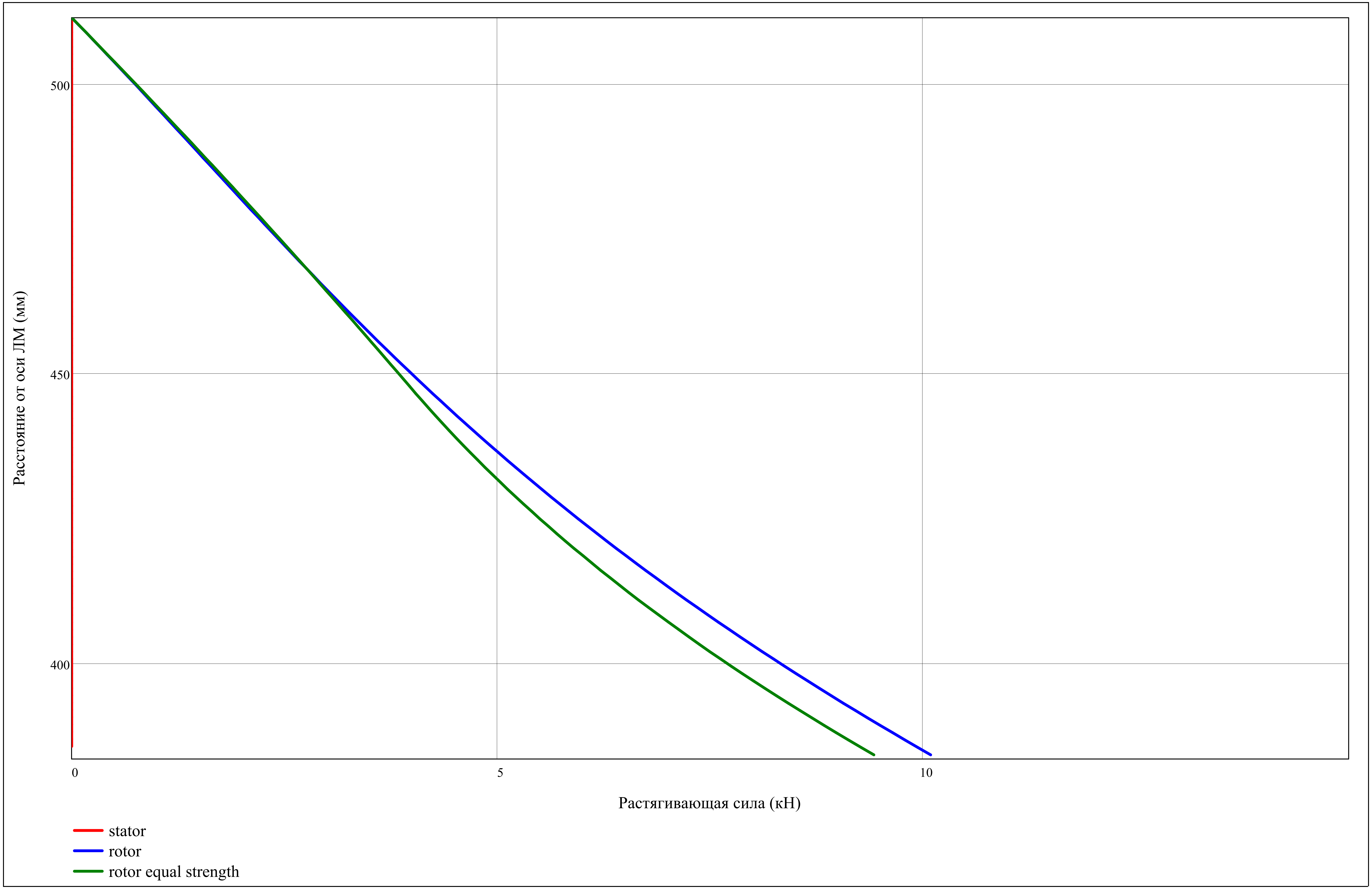
$$z = \min(Rj), \min(Rj) + \frac{\max(Rj) - \min(Rj)}{100} .. \max(Rj)$$

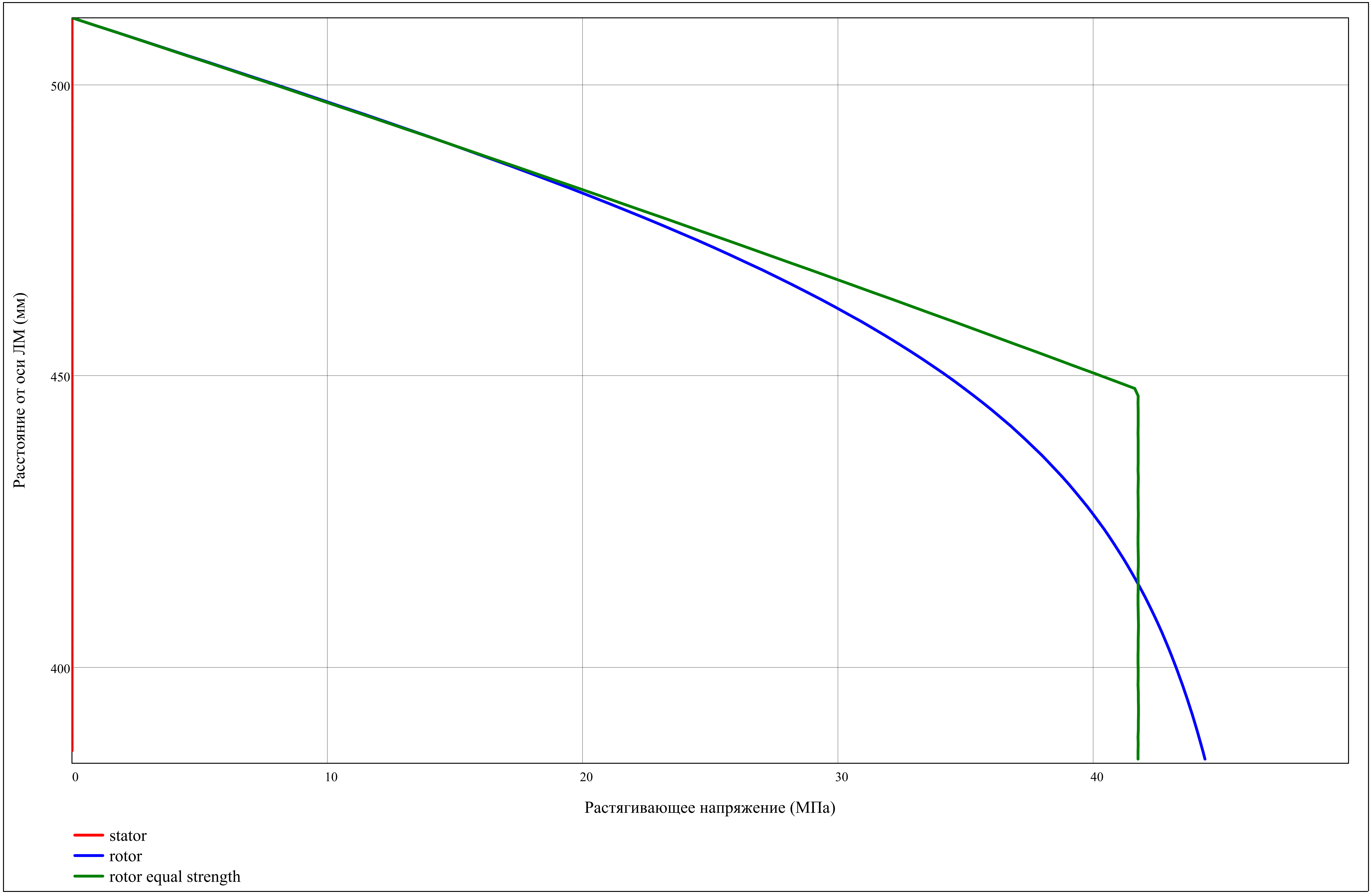
$$z_{rotor} = \left| \begin{array}{ll} \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right), \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) - \mathrm{mean}\left(Rj_{1,1}, Rj_{2,1}\right)}{100} .. \mathrm{mean}\left(Rj_{1,N_r}, Rj_{2,N_r}\right) & \text{if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

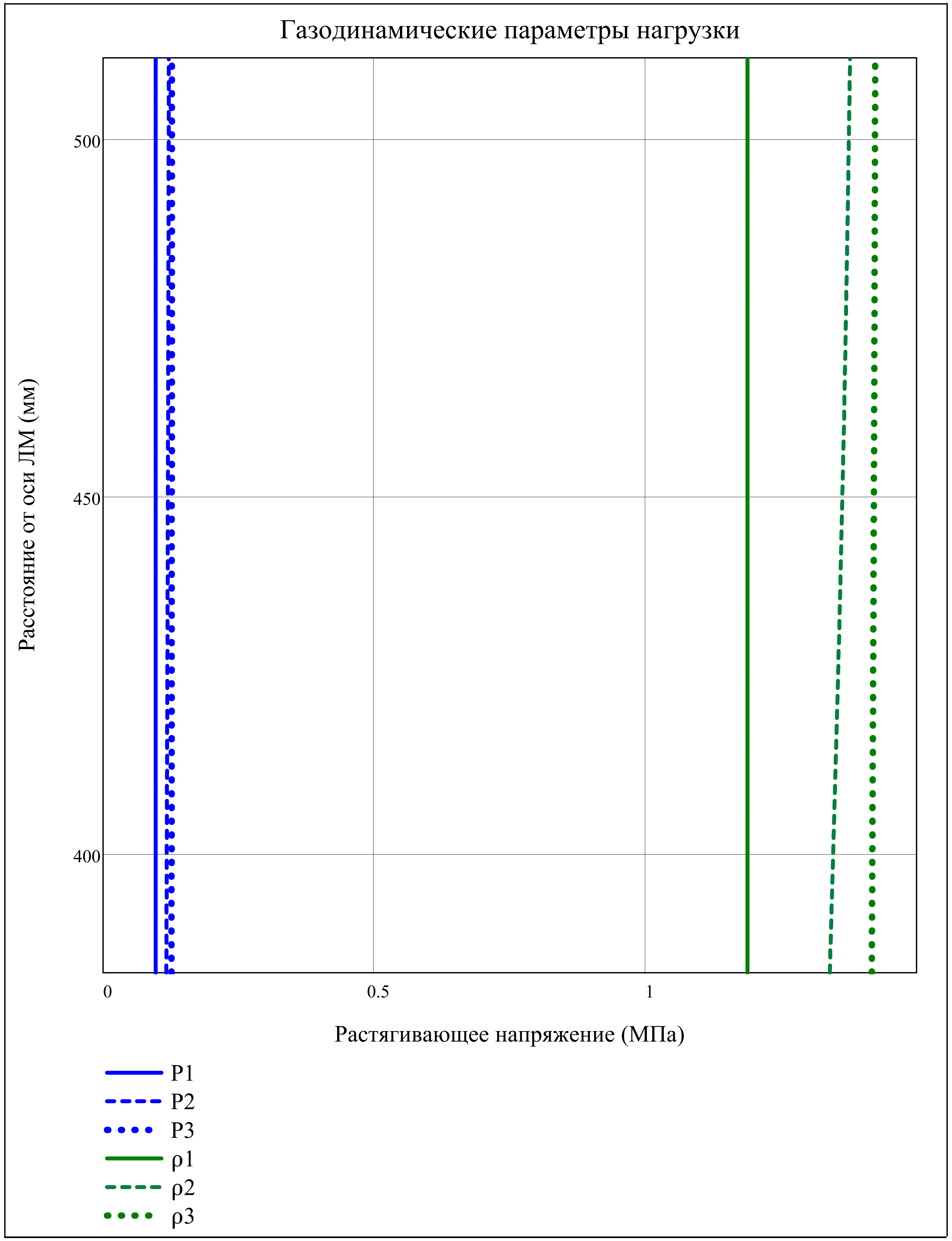
$$z_{stator} = \left| \begin{array}{ll} \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right), \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right) + \dfrac{\mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) - \mathrm{mean}\left(Rj_{2,1}, Rj_{3,1}\right)}{100} .. \mathrm{mean}\left(Rj_{2,N_r}, Rj_{3,N_r}\right) & \text{if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

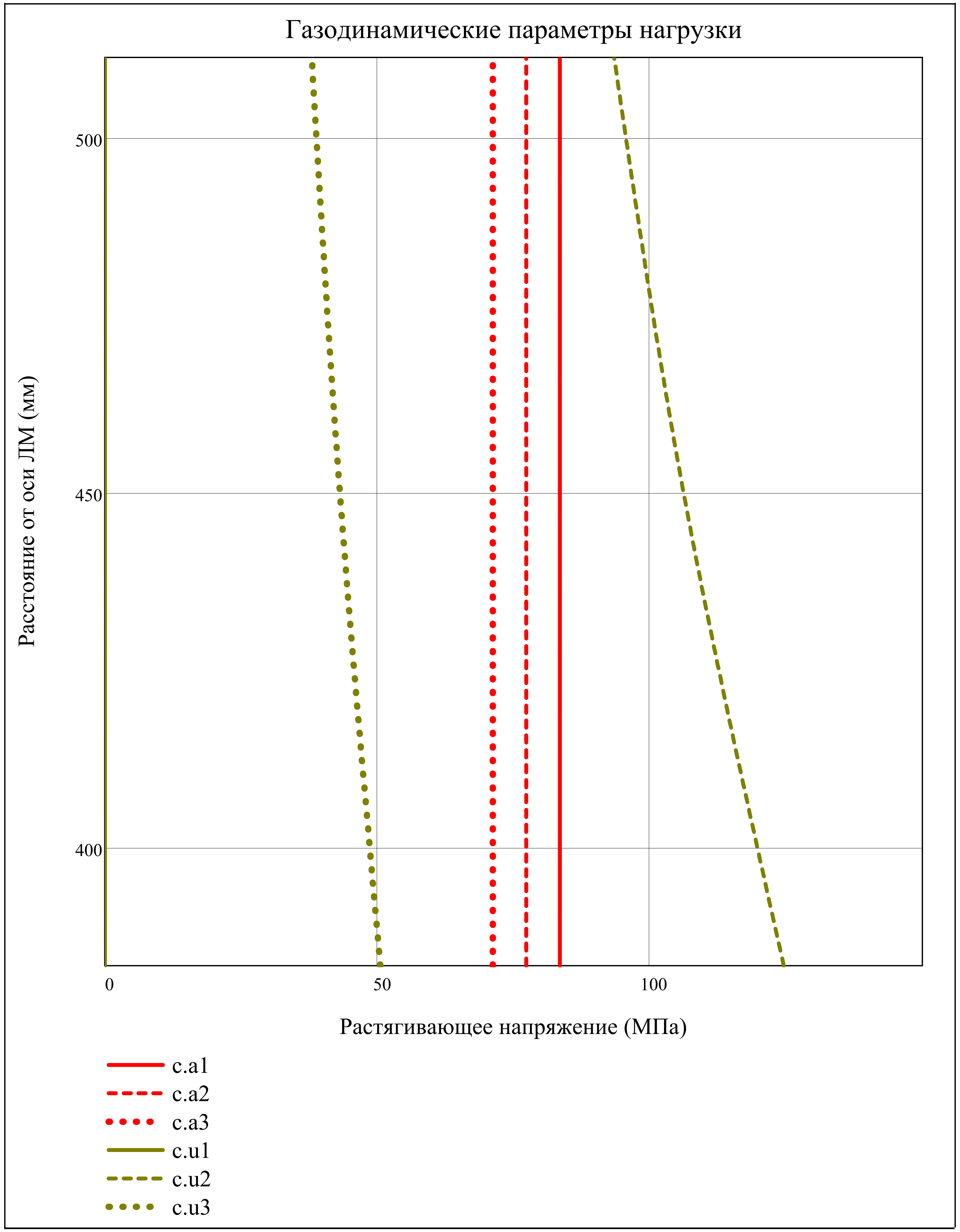
▾ Результаты расчета на прочность Л

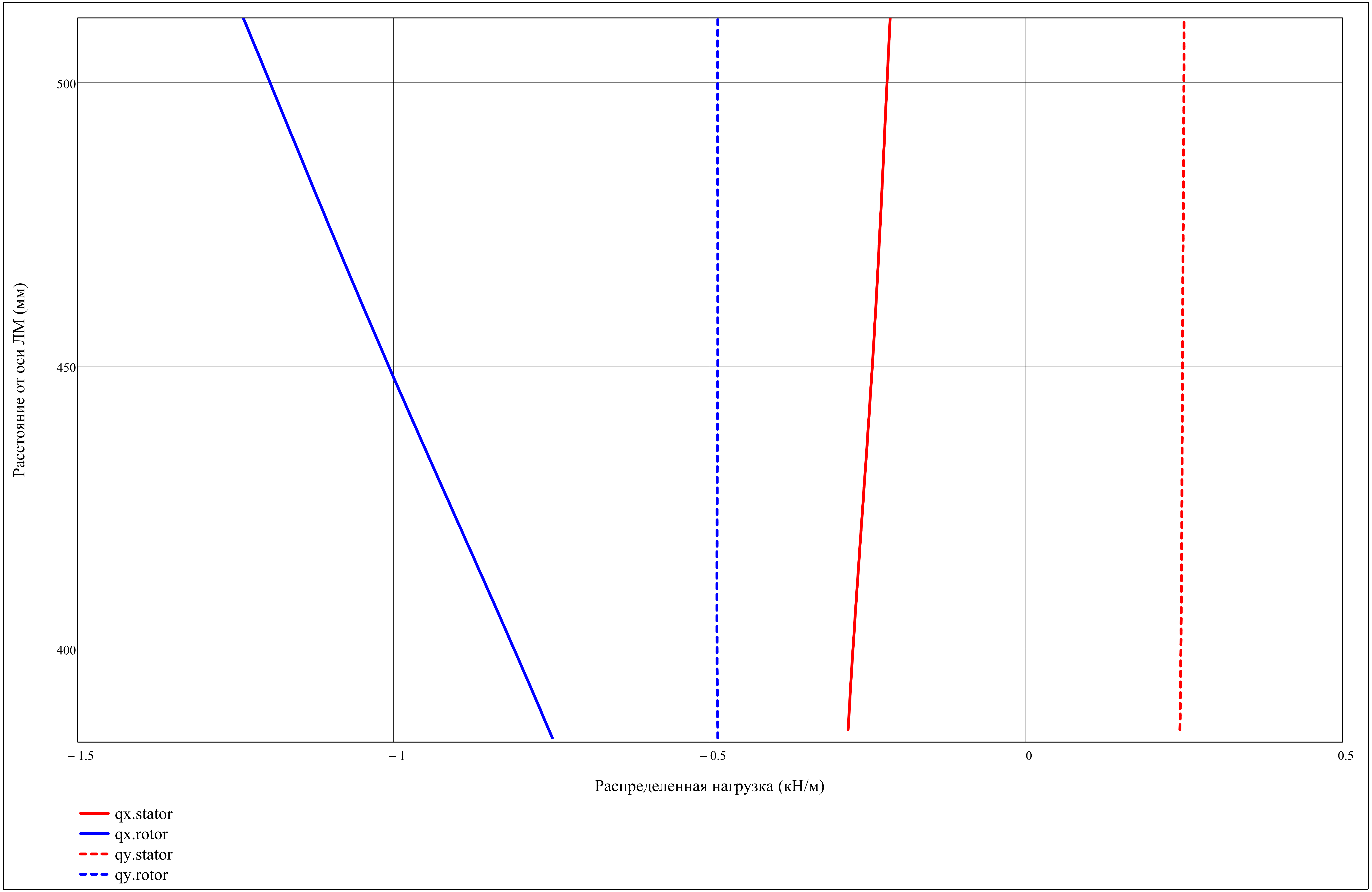

Расстояние от оси ЛМ (мм)
500
450
400
0
100
200
Площадь поперечного сечения Л (мм^2)
stator
rotor
rotor equal strength

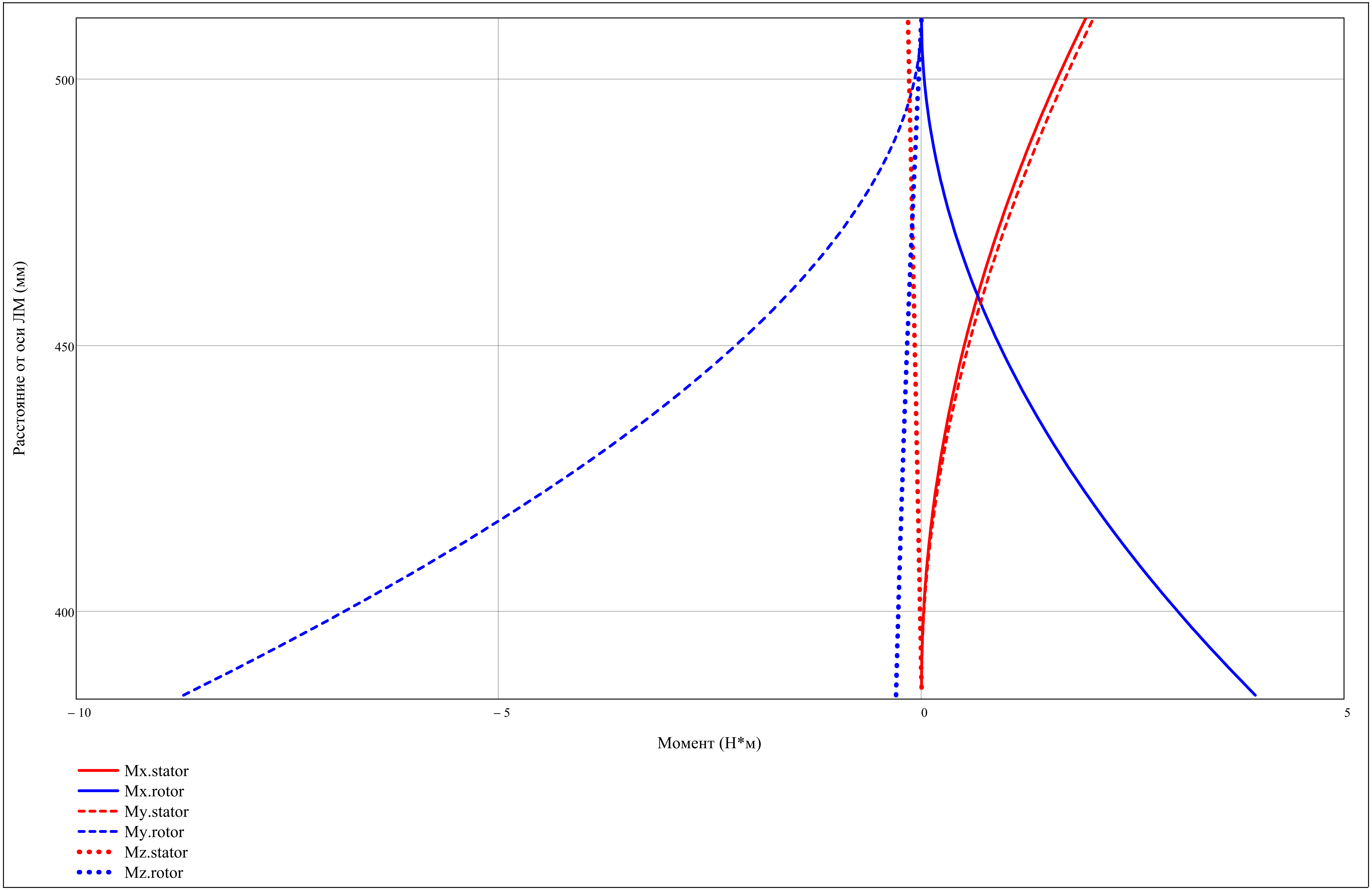

500
450
400
0
5
10
Расстояние от оси ЛМ (мм)
Растягивающая сила (кН)
stator
rotor
rotor equal strength

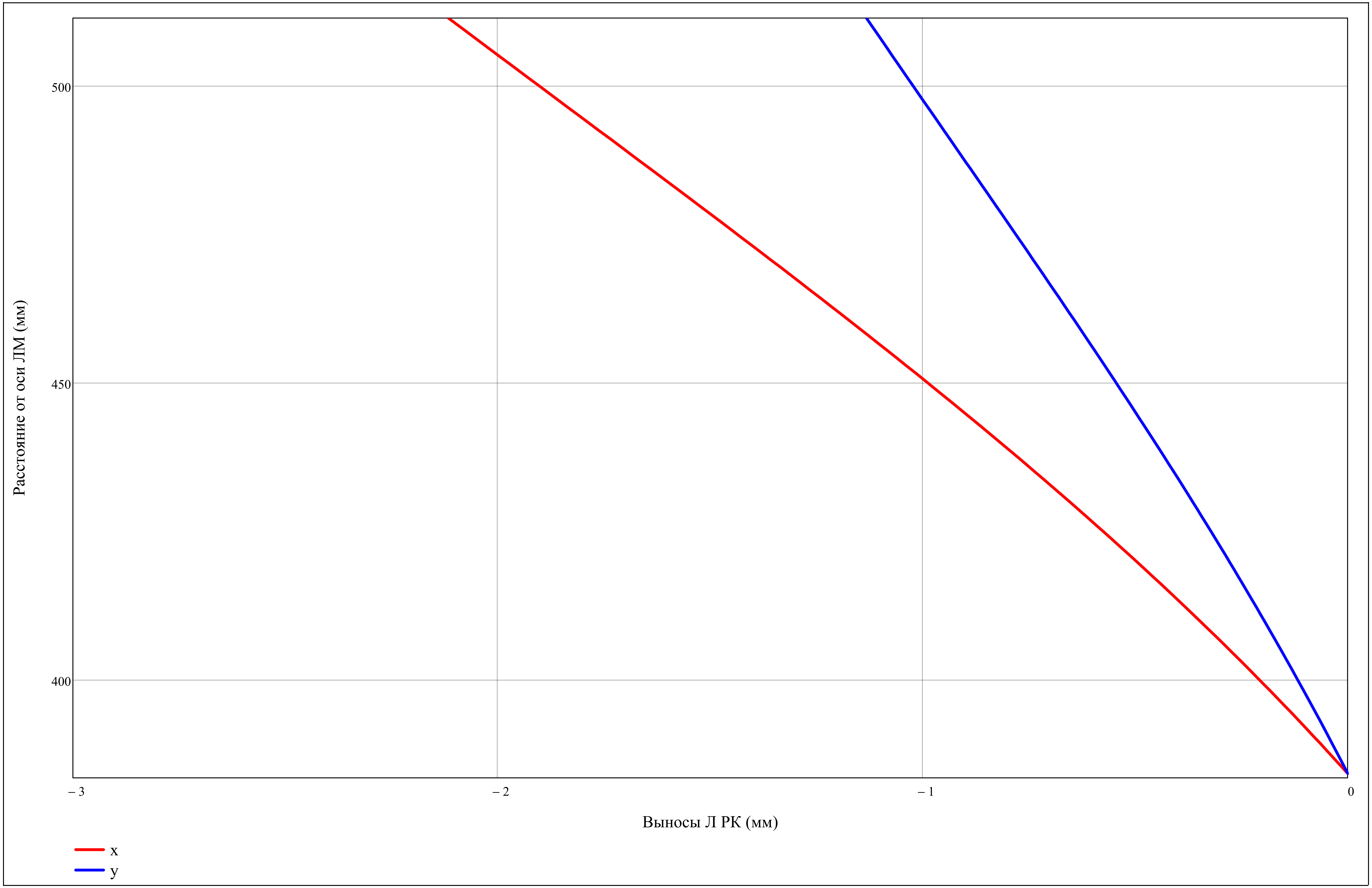

500
450
400
0
10
20
30
40
Расстояние от оси ЛМ (мм)
Растягивающее напряжение (МПа)
stator
rotor
rotor equal strength

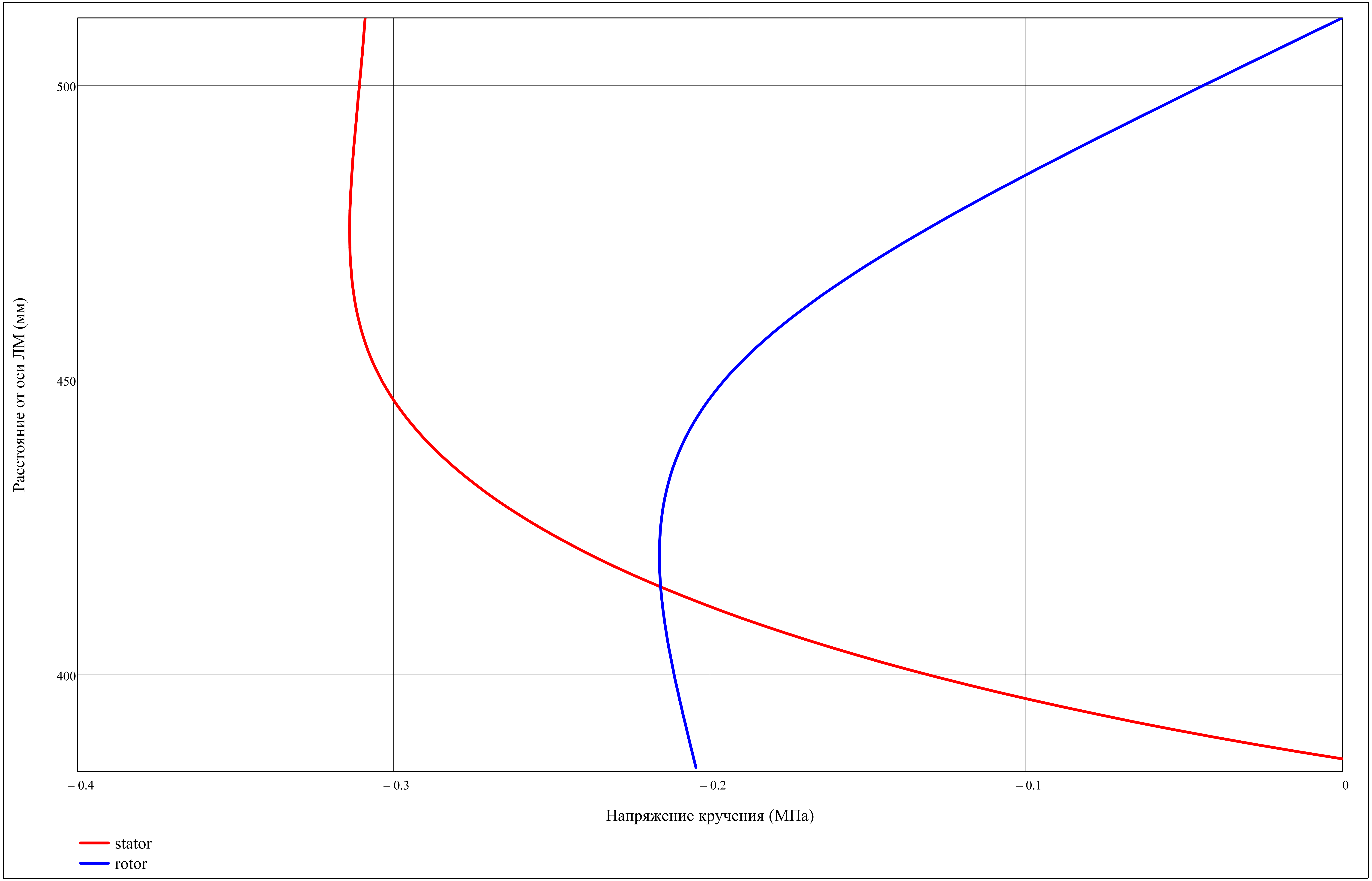

Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
500
450
400
0
0.5
1
Растягивающее напряжение (МПа)
P1
P2
P3
ρ1
ρ2
ρ3

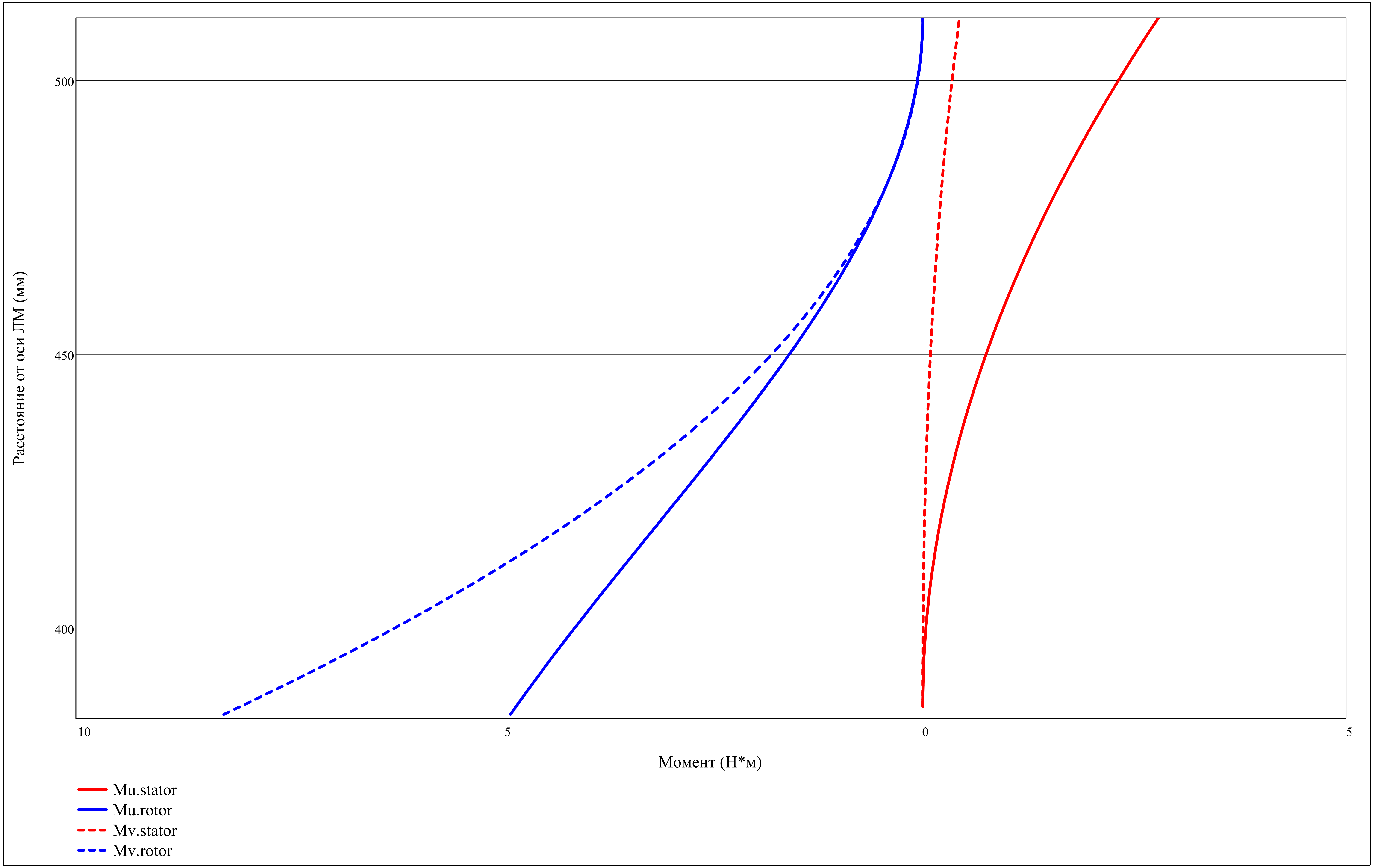

Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
500
450
400
0
50
100
Растягивающее напряжение (МПа)
c.a1
c.a2
c.a3
c.u1
c.u2
c.u3


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

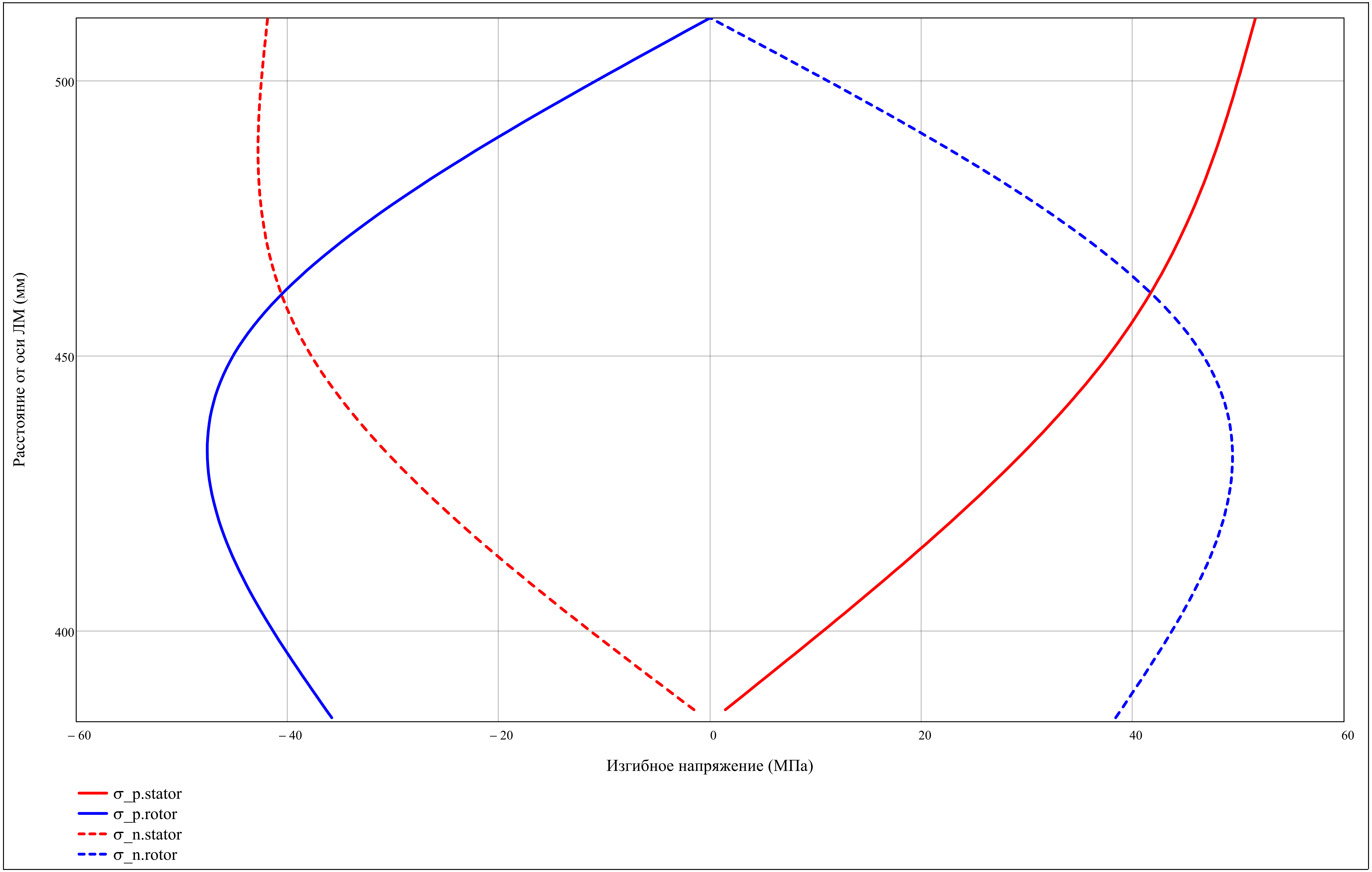

Расстояние от оси ЛМ (мм)
500
450
400
– 10
– 5
0
5
Момент (Н*м)
Mx.stator
Mx.rotor
My.stator
My.rotor
Mz.stator
Mz.rotor

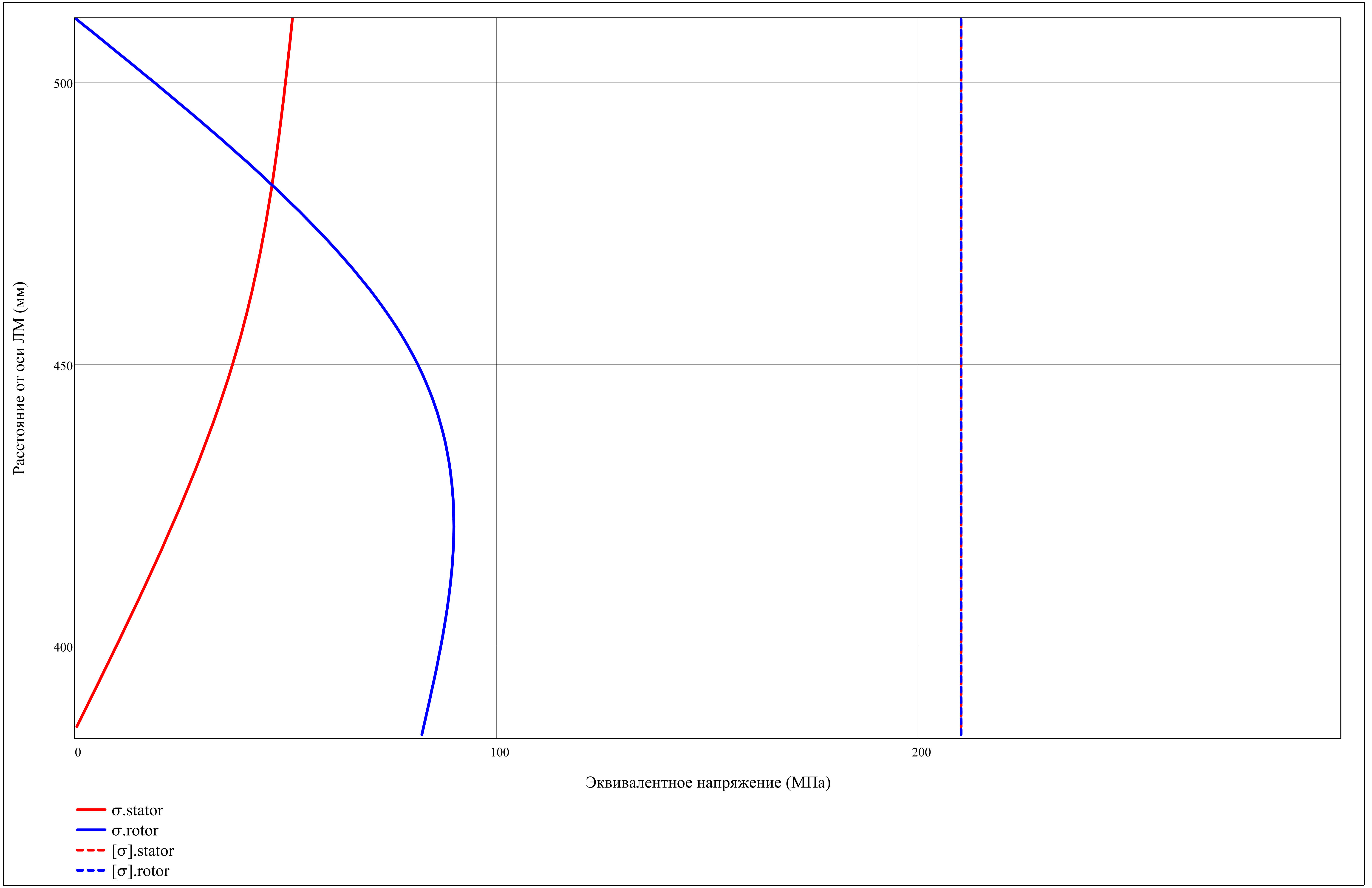

500
450
400
Расстояние от оси ЛМ (мм)
− 3
− 2
− 1
0
Выносы Л РК (мм)
x
y


Расстояние от оси ЛМ (мм)
500
450
400
– 0.4
– 0.3
– 0.2
– 0.1
0
Напряжение кручения (МПа)
stator
rotor



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


500
450
400
Расстояние от оси ЛМ (мм)
– 60
– 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

$$\begin{pmatrix} \text{blade} \\ r \end{pmatrix} = \begin{pmatrix} \text{"rotor"} \\ 1 \end{pmatrix}$$

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} =$$

	1	2
1	-1.89	3.09
2	33.99	-2.85
3	-0.05	0.87
4	19.30	-1.37

$\cdot 10^{-3}$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -36 & 0 \\ 38 & -0 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 0 \\ 82 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса: $\begin{pmatrix} safety_{stator_{j,r}} \\ safety_{rotor_{j,r}} \end{pmatrix} =$

	1
1	11543.032
2	2.547

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

	1
1	3.091
2	-2.853

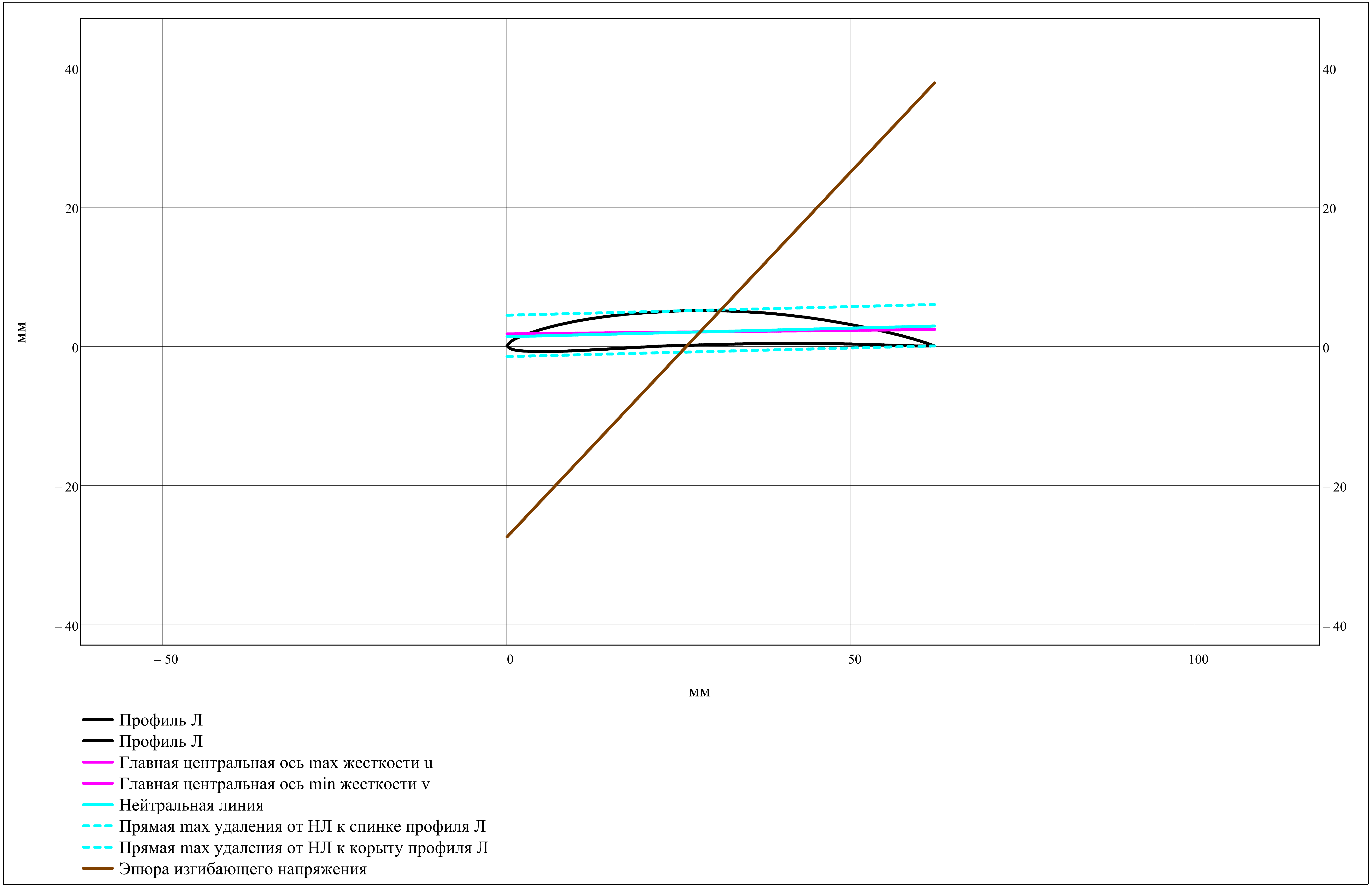
$\cdot 10^{-3}$

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

	1
1	28.047
2	2.012

$\cdot 10^{-3}$

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{array} \right. = 62 \cdot 10^{-3}$$


мм
40
20
0
– 20
– 40
– 50
0
50
100
мм
Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} = \begin{array}{|c|c|c|} \hline & 1 & 2 \\ \hline 1 & -0.83 & 1.42 \\ \hline 2 & 39.51 & -1.41 \\ \hline 3 & -0.44 & 1.55 \\ \hline 4 & 21.37 & -1.53 \\ \hline \end{array} \cdot 10^{-3}$$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -45 & 38 \\ 46 & -38 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

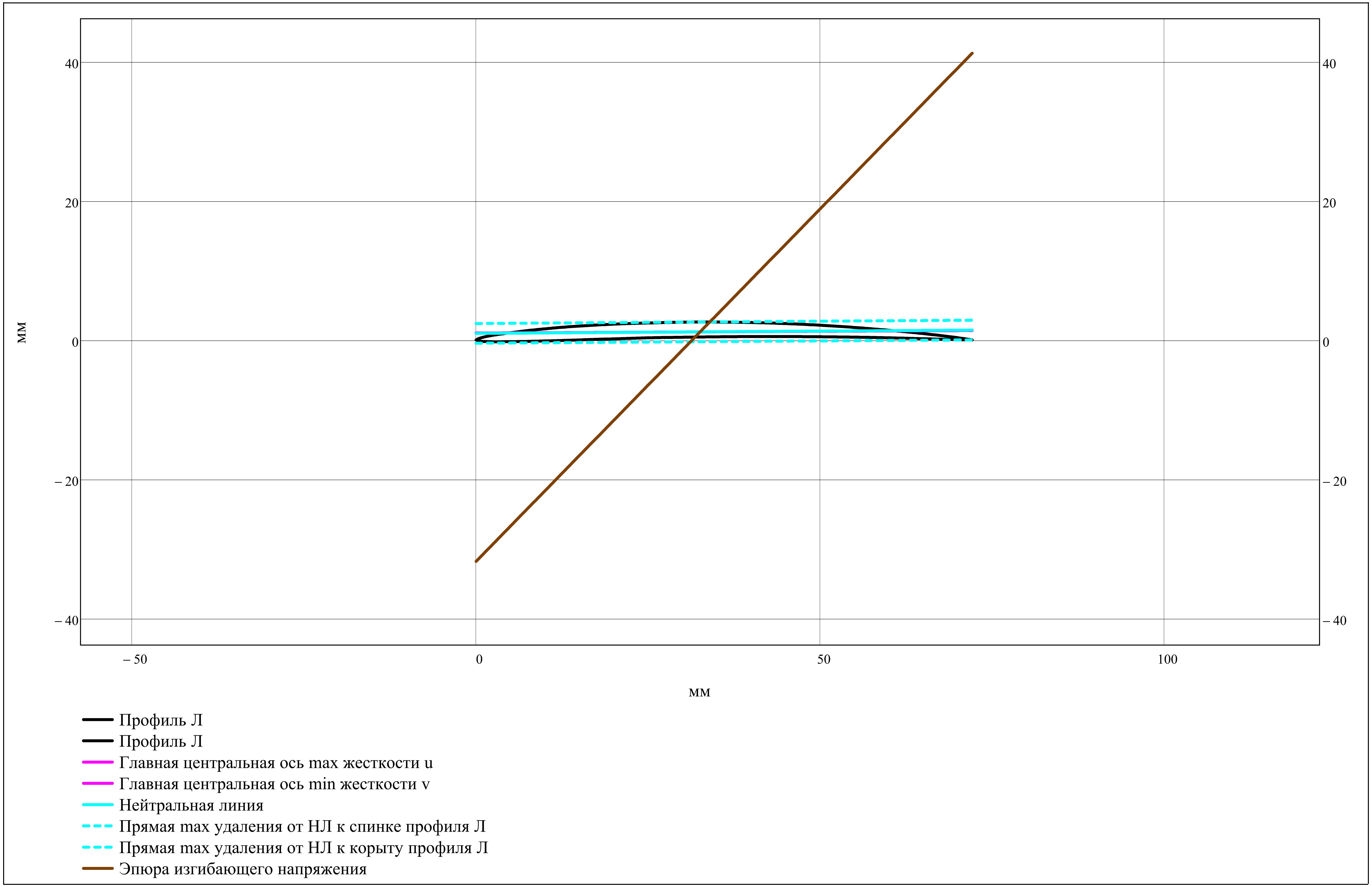
$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 38 \\ 79 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса: $\begin{pmatrix} safety_{stator_{j,r}} \\ safety_{rotor_{j,r}} \end{pmatrix} = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 5.462 \\ \hline 2 & 2.646 \\ \hline \end{array}$

$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if } blade = \text{"rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \begin{array}{|c|c|} \hline & 1 \\ \hline 1 & 1.420 \\ \hline 2 & -1.407 \\ \hline \end{array} \cdot 10^{-3}$$

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

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


40
20
0
– 20
– 40
40
20
0
– 20
– 40
мм
– 50
0
50
100
мм
Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} = \cdot 10^{-3}$$

	1	2
1	-0.83	1.42
2	39.51	-1.41
3	-0.44	1.55
4	21.37	-1.53

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -45 & 38 \\ 46 & -38 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 38 \\ 79 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса:

$$\begin{pmatrix} \text{safety}_{stator_{j,r}} \\ \text{safety}_{rotor_{j,r}} \end{pmatrix} =$$

	1
1	5.462
2	2.646

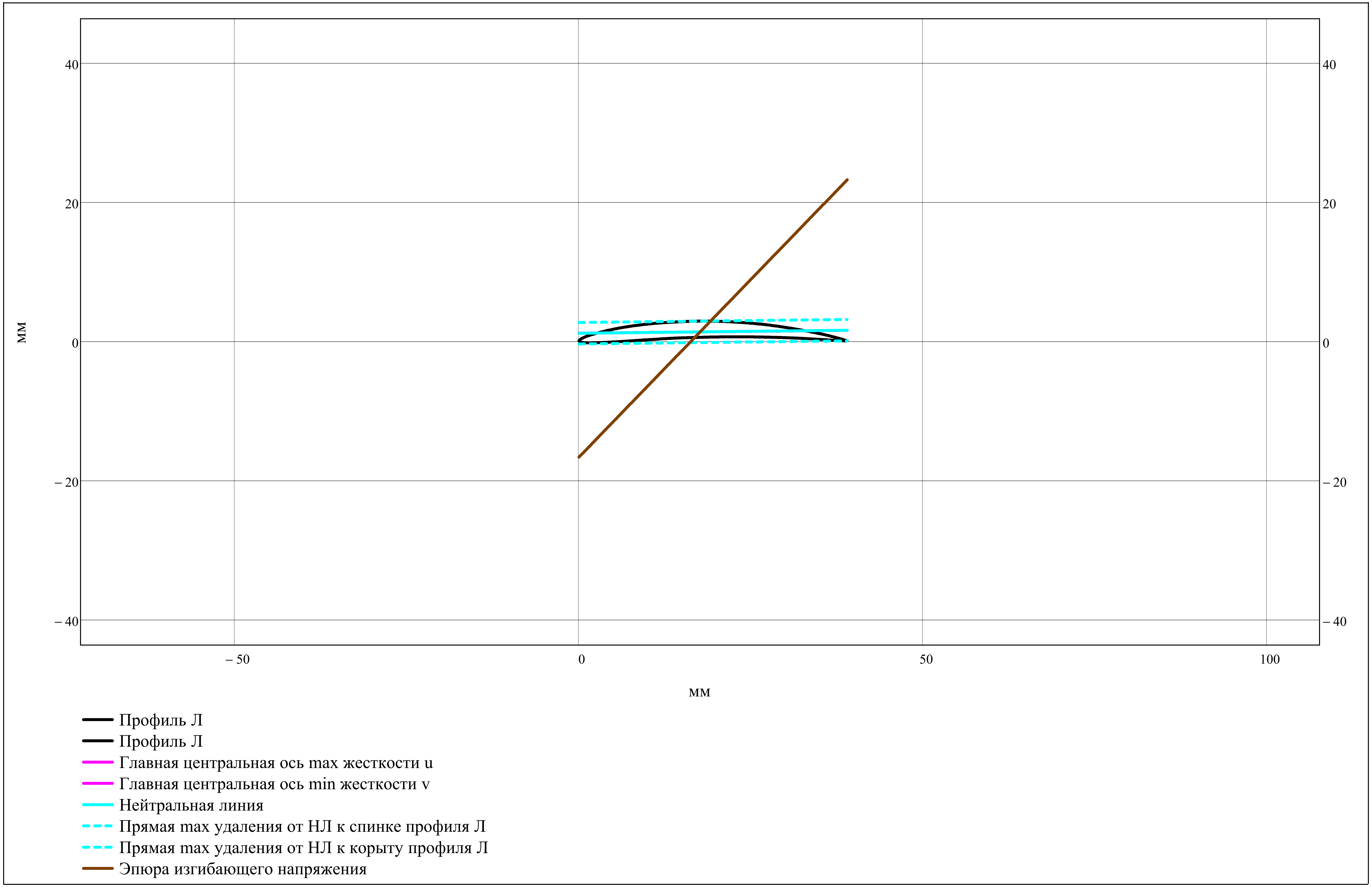
$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} := \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade} = \text{"rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \cdot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

	1
1	1.549
2	-1.531

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

	1
1	17.610
2	1.292

$$\text{chord} := \left| \begin{array}{ll} \text{chord}_{rotor_{j,r}} & \text{if blade} = \text{"rotor"} \\ \text{chord}_{stator_{j,r}} & \text{if blade} = \text{"stator"} \end{array} \right. = 39 \cdot 10^{-3}$$


40
20
0
– 20
– 40
мм
– 50
0
50
100
мм
Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

$$\begin{pmatrix} u\_u_{rotor_{j,r}} & v\_u_{rotor_{j,r}} \\ u\_l_{rotor_{j,r}} & v\_l_{rotor_{j,r}} \\ u\_u_{stator_{j,r}} & v\_u_{stator_{j,r}} \\ u\_l_{stator_{j,r}} & v\_l_{stator_{j,r}} \end{pmatrix} =$$

	1	2
1	-0.66	36.46
2	-0.90	-44.27
3	-0.46	2.31
4	-14.04	-1.90

$\cdot 10^{-3}$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} 0 & 52 \\ 0 & -42 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 52 \\ 0 \end{pmatrix} \cdot 10^{6}$$

Коэф. запаса: $\begin{pmatrix} safety_{stator_{j,r}} \\ safety_{rotor_{j,r}} \end{pmatrix} =$

	1
1	4.070
2	00000000000000000000000000000.

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

	1
1	2.307
2	-1.896

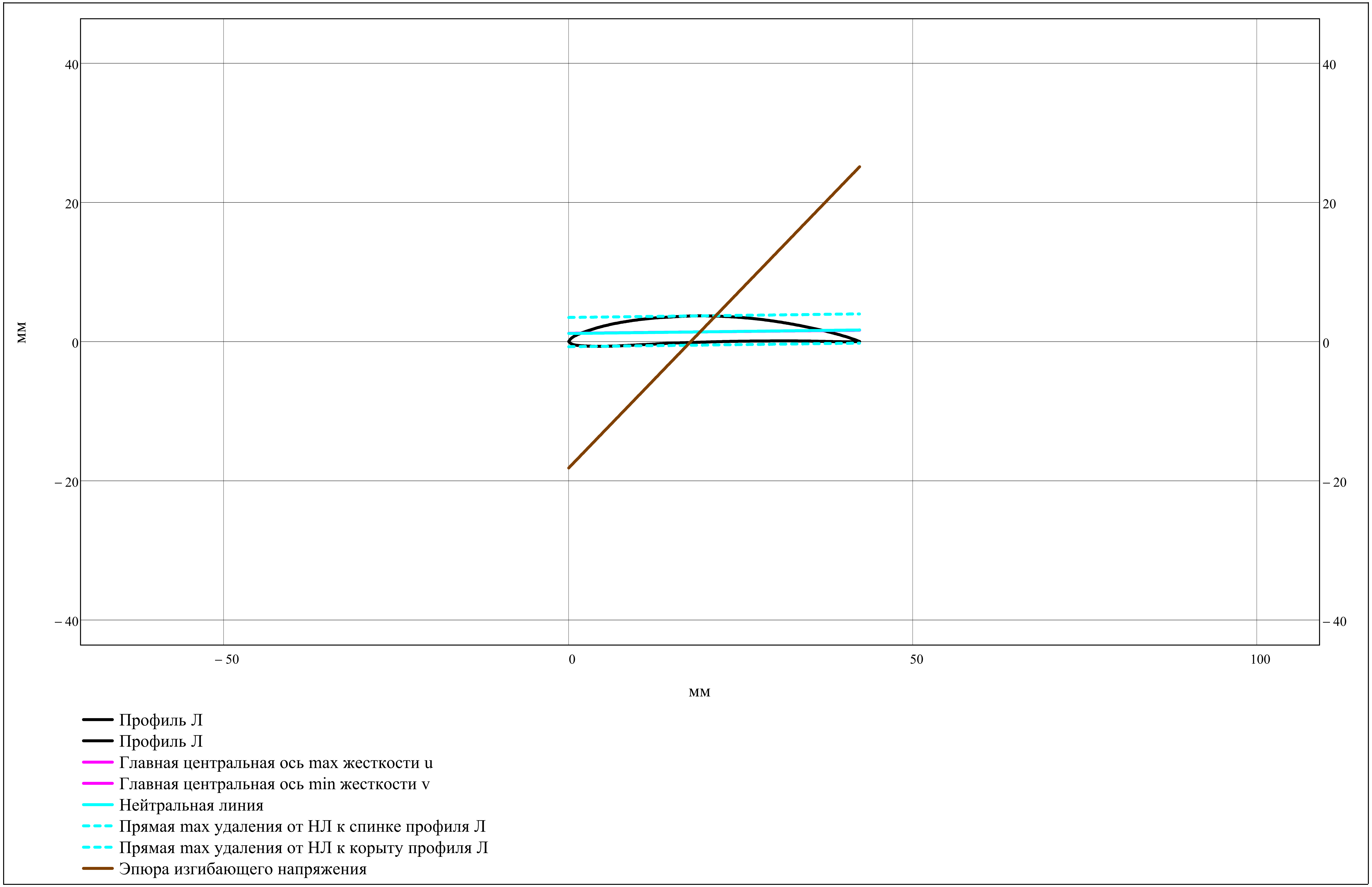
$\cdot 10^{-3}$

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

	1
1	19.089
2	1.381

$\cdot 10^{-3}$

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{array} \right. = 42 \cdot 10^{-3}$$



▲ Результаты расчета на прочность Л

Вывод результатов расчета Л на прочность

▾ Выбор материала Д

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

Выбранный материал Д:
$$material\_disk_i = \begin{cases} \text{"ВТ23"} & \text{if } compressor = \text{"Вл"} \\ \text{"ВТ6"} & \text{if } compressor = \text{"КНД"} \\ \text{"ВТ9"} & \text{if } compressor = \text{"КВД"} \end{cases}$$

Плотность материала Д (кг/м^3):
$$\rho\_disk_i = \begin{cases} 8266 & \text{if } material\_disk_i = \text{"ВЖ175"} \\ 8320 & \text{if } material\_disk_i = \text{"ЭП742"} \\ 8393 & \text{if } material\_disk_i = \text{"ЖС-6К"} \\ 7900 & \text{if } material\_disk_i = \text{"ВТ41"} \\ 4500 & \text{if } material\_disk_i = \text{"ВТ25"} \\ 4570 & \text{if } material\_disk_i = \text{"ВТ23"} \\ 4510 & \text{if } material\_disk_i = \text{"ВТ9"} \\ 4430 & \text{if } material\_disk_i = \text{"ВТ6"} \\ NaN & \text{otherwise} \end{cases}$$

Предел длительной прочности Д (Па):
$$\sigma\_disk\_long_i = 10^6 \cdot \begin{cases} 620 & \text{if } material\_disk_i = \text{"ВЖ175"} \\ 680 & \text{if } material\_disk_i = \text{"ЭП742"} \\ 125 & \text{if } material\_disk_i = \text{"ЖС-6К"} \\ 123 & \text{if } material\_disk_i = \text{"ВТ41"} \\ 150 & \text{if } material\_disk_i = \text{"ВТ25"} \\ 230 & \text{if } material\_disk_i = \text{"ВТ23"} \\ 200 & \text{if } material\_disk_i = \text{"ВТ9"} \\ 210 & \text{if } material\_disk_i = \text{"ВТ6"} \\ NaN & \text{otherwise} \end{cases}$$

$material\_disk^T =$

	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

$\cdot 10^6$

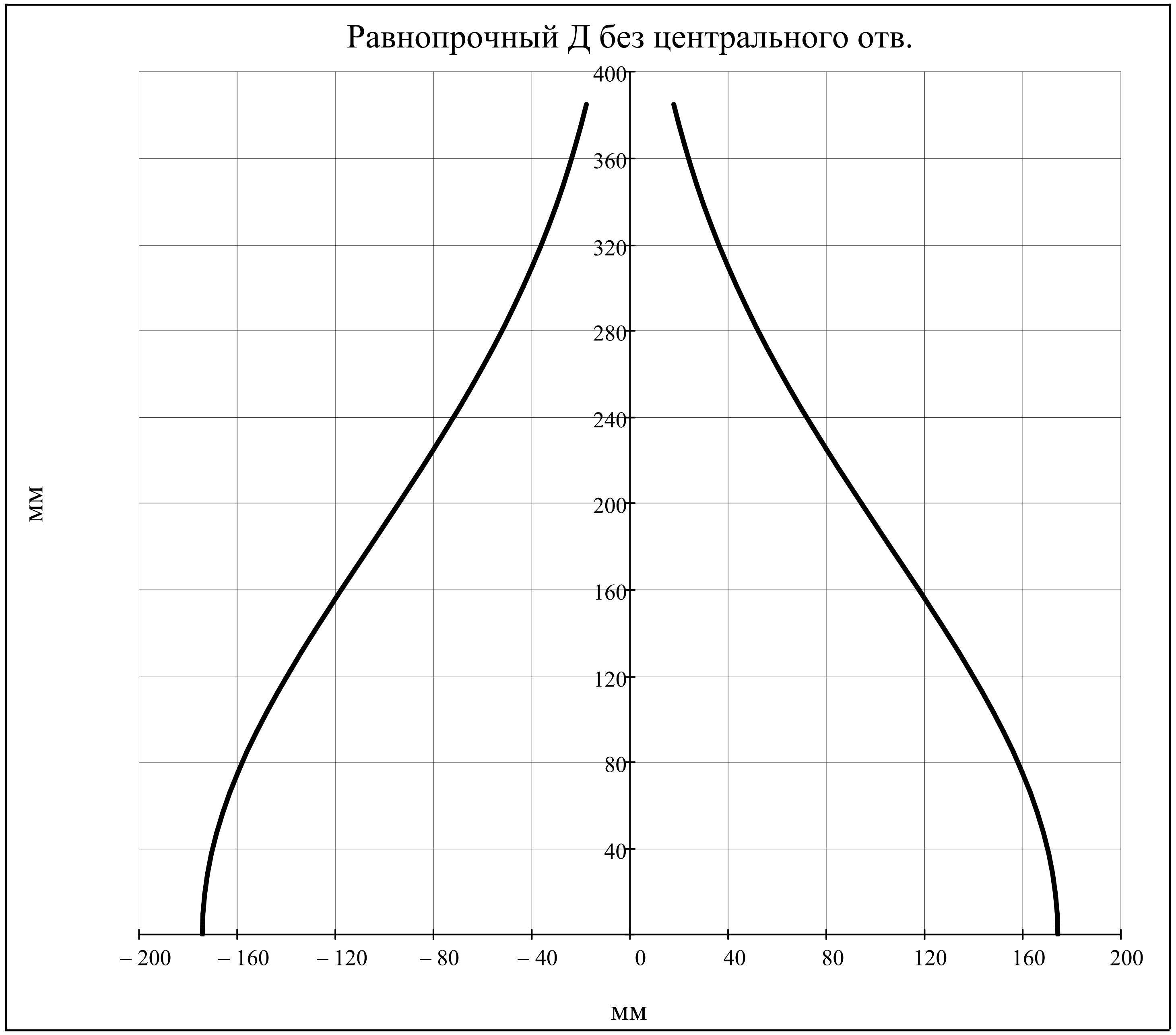
▴ Выбор материала Д

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.

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

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



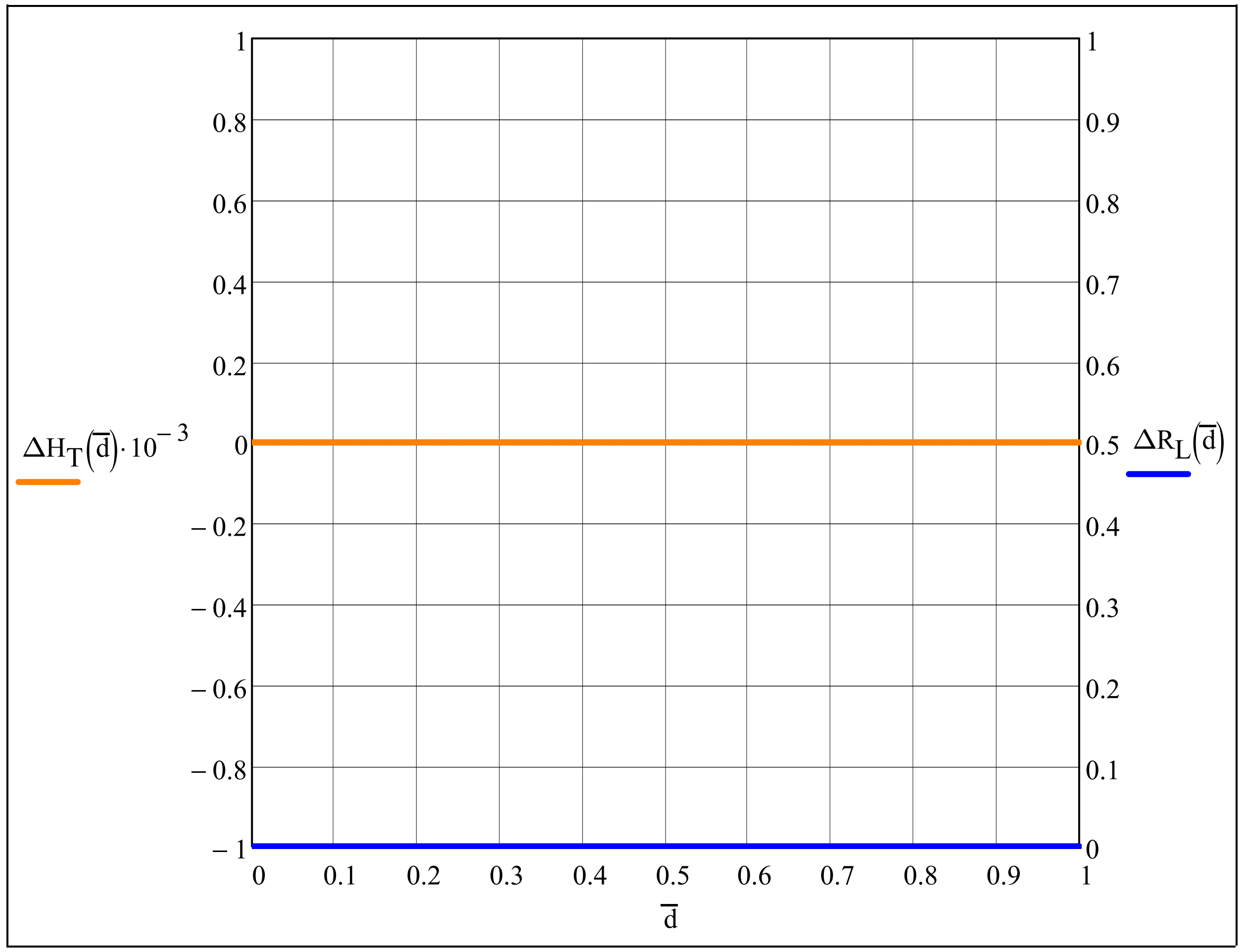
▲ Профилирование равнопрочного Д без центрального отв.

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

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

$\Delta R_{Lmax} = 0.0$

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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