Подключение библиотек

Основные уравнения, алгоритмы, зависимости и ф-и

Параметры расчета

## Исходные данные

Коэф. запаса: $safety = 1.3$

Степень двухконтурности: $m2 = 6$

РТ: Воздух

$compressor = \text{"Вл"}$

Число Маха: $M = 0$

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

Массовый расход (кг/с):
$$G = \begin{cases} 35.65 + 213.93 & \text{if } compressor = \text{"Вл"} \\ 35.65 & \text{if } compressor = \text{"КНД"} \\ 34.81 & \text{if } compressor = \text{"КВД"} \end{cases} = 249.58$$

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

Полное давление на входе в К (Па):
$$P^*_{K1} = \begin{cases} 316.2 \cdot 10^3 & \text{if } compressor = \text{"КВД"} \\ 101325 & \text{otherwise} \end{cases} = 101.3 \cdot 10^3$$

Степень повышения давления КВД:
$$\pi^*_K = \begin{cases} 1.6 & \text{if } compressor = \text{"Вл"} \\ \dfrac{3.2}{1.6} & \text{if } compressor = \text{"КНД"} \\ 9 & \text{if } compressor = \text{"КВД"} \end{cases} = 1.600$$

Ожидаемый адиабатический КПД ОК:

$$\eta^*_K = \begin{vmatrix} 0.86 \text{ if } compressor = \text{"Вл"} \\ 0.87 \text{ if } compressor = \text{"КНД"} \\ 0.88 \text{ if } compressor = \text{"КВД"} \end{vmatrix} = 86.00\cdot\%$$

Частота вращения ротора ($с^{-1}$):

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

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

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

$0.3 \le \overline{d}_1 \le 0.6 = 1$

Частота вращения ротора (об/мин):

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

Закон профилирования проточной части (ЗППЧ):

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

Относ. параметры по относительным ступеням:

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

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

[16, с. 60]

[18, с. 24]

Уточнение параметров:

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

увеличение несущественно увеличивает $\pi$

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

понижение существенно увеличивает $\pi$

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

увеличение несущественно увеличивает $\pi$

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

[16, с. 234]

увеличение существенно увеличивает $\pi$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 |
| 2 | 0.990 | 0.980 | 0.970 | 0.960 | 0.950 | 0.950 | 0.950 | 0.950 |
| 3 | 0.860 | 0.870 | 0.885 | 0.890 | 0.890 | 0.885 | 0.870 | 0.860 |
| 4 | 0.335 | 0.325 | 0.315 | 0.305 | 0.295 | 0.285 | 0.275 | 0.265 |
| 5 | 0.265 | 0.305 | 0.335 | 0.345 | 0.365 | 0.335 | 0.305 | 0.285 |

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

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

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

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

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

$$\bar{H}_{Tcp} = \frac{\sum_{i=1}^{\text{rows}(z_\sim)} \bar{H}_{\sim T_i}}{\text{rows}(z_\sim)} = 0.317$$

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

Исходные данные

Распределение основных параметров ОК по ступеням

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

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

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

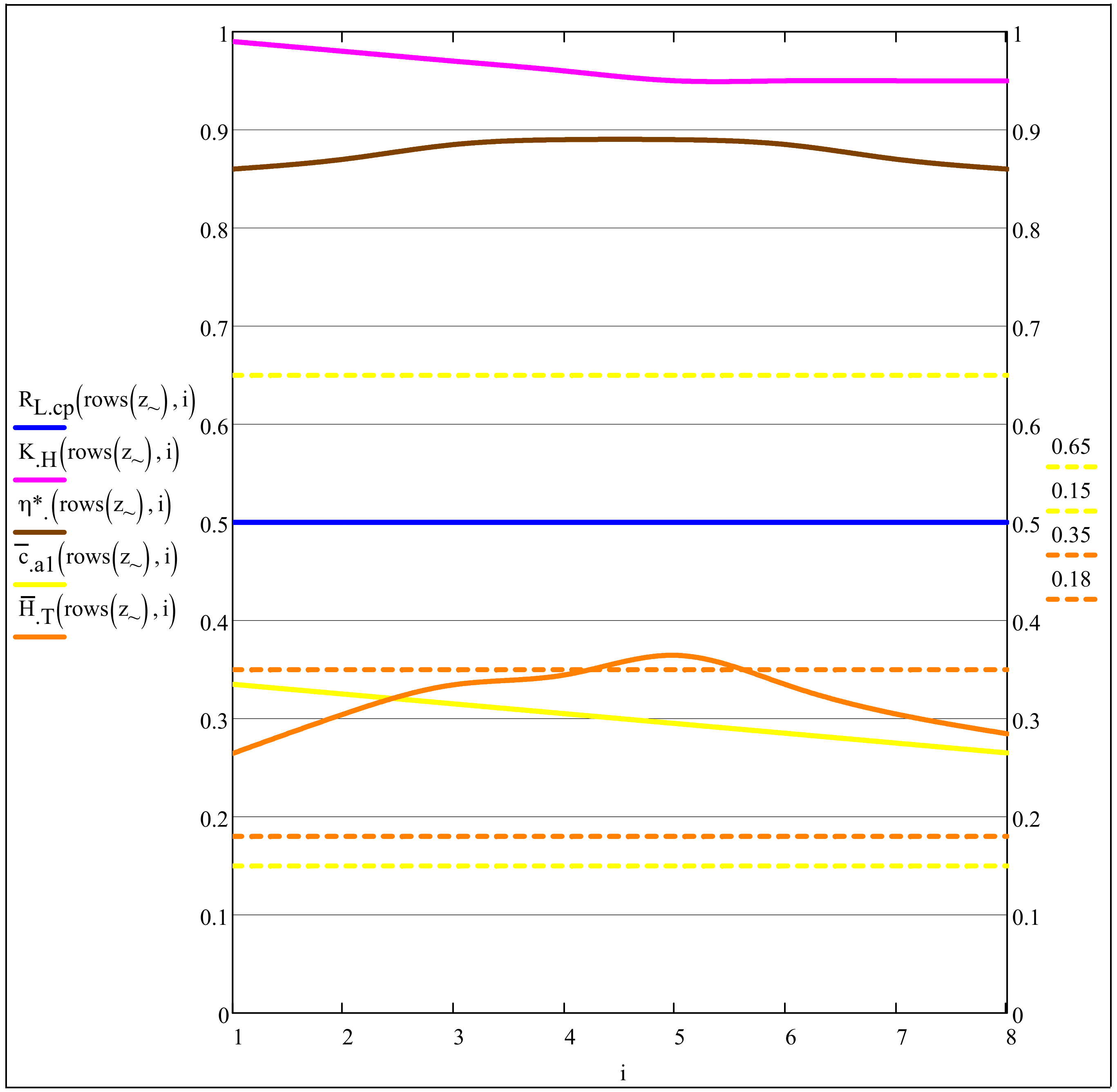
Коэф. расхода: $\bar{c}_{\sim a1}(i) = \mathrm{interp}\left(\mathrm{lspline}\left(\frac{z_{\sim}}{\mathrm{rows}(z_{\sim})}, \bar{c}_{\sim a1}\right), \frac{z_{\sim}}{\mathrm{rows}(z_{\sim})}, \bar{c}_{\sim a1}, i\right)$

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

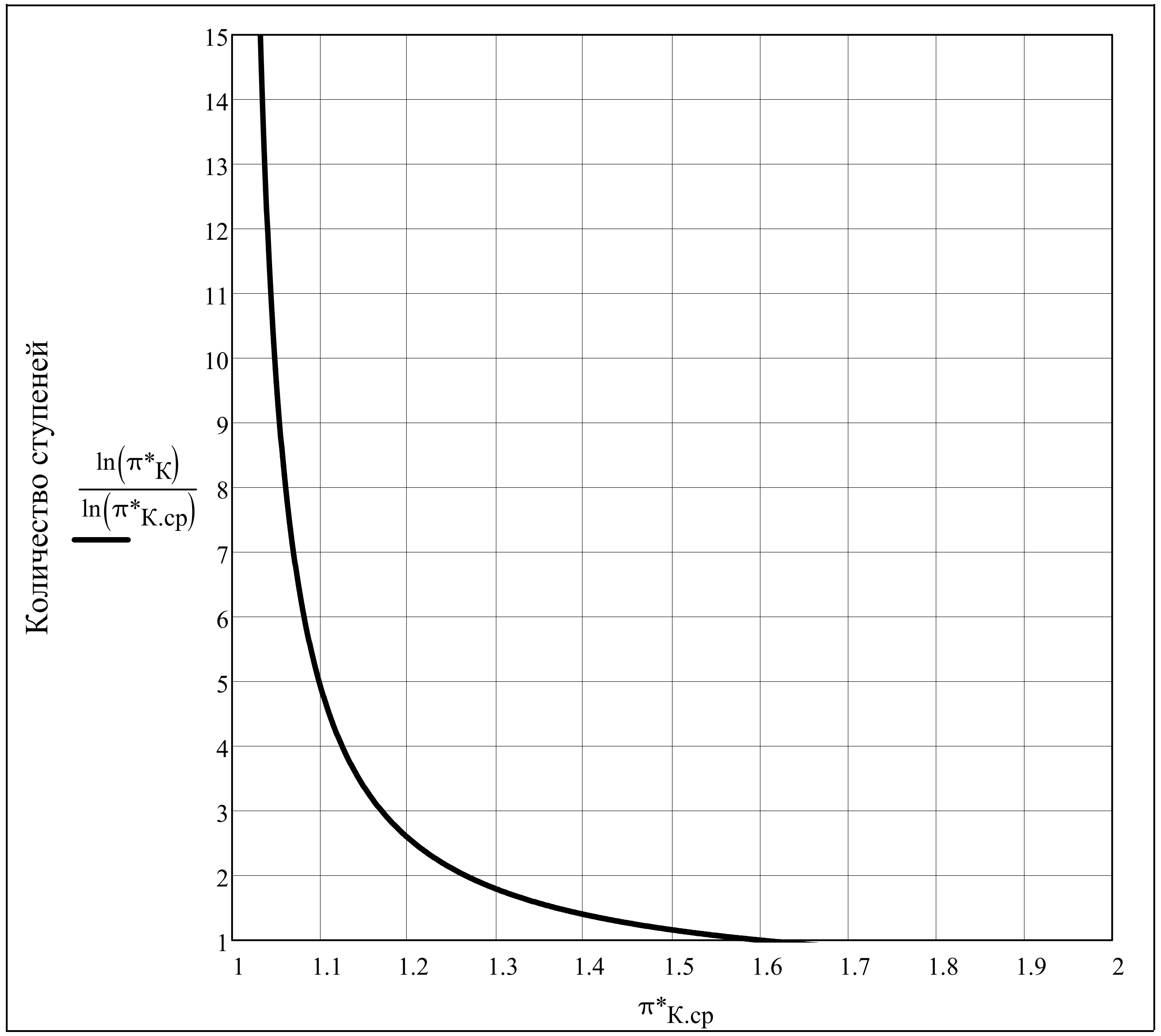
$$\begin{pmatrix} R_{L.cp} \\ K_{.H} \\ \eta^*_{.} \\ \bar{c}_{.a1} \\ \bar{H}_{.T} \end{pmatrix} = \left| \begin{array}{l} R_{L.cp}(Z,i) = \left| \begin{array}{ll} R_{L\sim cp}\left(\dfrac{1}{rows(z_\sim)}\right) & \text{if } i<1 \\ R_{L\sim cp}(1) & \text{if } i>Z \\ R_{L\sim cp}\left(\dfrac{i}{Z}\right)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

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

$$\begin{pmatrix} R_{L.cp}(Z_{temp}, i_{temp}) \\ K_{.H}(Z_{temp}, i_{temp}) \\ \eta^*_{.}(Z_{temp}, i_{temp}) \\ \bar{c}_{.a1}(Z_{temp}, i_{temp}) \\ \bar{H}_{.T}(Z_{temp}, i_{temp}) \end{pmatrix} = \begin{pmatrix} 0.500 \\ 0.950 \\ 0.860 \\ 0.265 \\ 0.285 \end{pmatrix}$$




Распределение основных параметров ОК по ступеням



Количество ступеней
ln(π*К) / ln(π*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
π*К.ср

## Нулевые приближения

Показатель адиаьаты перед К []: $k_{K1} = k_{ад}\left(Cp_{воздух}\left(P^*_{K1}, T^*_{K1}\right), R_в\right) = 1.401$

Полное давление после К [Па]: $P^*_{K3} = \pi^*_K \cdot P^*_{K1} = 162\cdot 10^3$

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

Количество итераций []: $iteration_3 = 1$

Полная температура после К [К]: $T^*_{K3} = 336.5$

Показатель адиаьаты после К []: $k_{K3} = 1.399$

Полная плотность перед и после К [кг/м$^3$]: $\begin{pmatrix} \rho^*_{K1} \\ \rho^*_{K3} \end{pmatrix} = \dfrac{1}{R_в} \cdot \begin{pmatrix} \dfrac{P^*_{K1}}{T^*_{K1}} \\ \dfrac{P^*_{K3}}{T^*_{K3}} \end{pmatrix} = \begin{pmatrix} 1.224 \\ 1.678 \end{pmatrix}$

Критические скорости перед и после К [м/с]: $\begin{pmatrix} a^*_{с.вх} \\ a^*_{с.вых} \end{pmatrix} = \begin{pmatrix} a_{кр}\left(k_{K1}, R_в, T^*_{K1}\right) \\ a_{кр}\left(k_{K3}, R_в, T^*_{K3}\right) \end{pmatrix} = \begin{pmatrix} 310.8 \\ 335.7 \end{pmatrix}$

Ср. показатель адиабаты К []: $k_{ср} = k_{ад}\left(Cp_{воздух.ср}\left(P^*_{K1}, P^*_{K3}, T^*_{K1}, T^*_{K3}\right), R_в\right) = 1.401$

Теоретический напор [Дж/кг]: $H_{TK} = \dfrac{Cp_{воздух.ср}\left(P^*_{K1}, P^*_{K3}, T^*_{K1}, T^*_{K3}\right) \cdot T^*_{K1} \cdot \left(\pi^{*\,\frac{k_{ср}-1}{k_{ср}}}_K - 1\right)}{\eta^*_K} = 48.4\cdot 10^3$

$$\begin{pmatrix} iteration_u \\ u_{1пер} \\ Z_{recomend} \\ c_{вх} \\ \lambda_{вх} \\ \rho_{K1} \end{pmatrix} =$$

```
iteration_u ← 0
ρ_K1 ← ρ*_K1
while 0 < 1
    iteration_u ← iteration_u + 1
    trace(concat("iteration.u = ", num2str(iteration_u)))
    u_1пер ← ∛( π·G·n² / (900·c̄.a1(1,0)·ρ_K1·[1 − (d̄_1)²]) )
    Z_recomend ← max( round( H_TK / (H̄_Tср·u_1пер²) ), 1 )
    c_вх ← c̄.a1(Z_recomend, 0)·u_1пер
    λ_вх ← c_вх / a*_c.вх
    ρ'_K1 ← ρ*_K1·ГДФ("ρ", λ_вх, k_K1)
    if |eps("rel", ρ'_K1, ρ_K1)| ≤ epsilon
        ρ_K1 ← ρ'_K1
        break
    ρ_K1 ← ρ'_K1
(iteration_u, u_1пер, Z_recomend, c_вх, λ_вх, ρ_K1)ᵀ
```

Количество итераций []: $iteration_u = 2$

Окружная скорость на перифкрии перед К [м/с]: $u_{1пер} = 425.9$

Рекомендуемое количество ступеней []: $Z_{recomend} = 1$

Абс. скорость перед К [м/с]: $c_{вх} = 142.7$

Приведенная скорость перед К []: $\lambda_{вх} = 0.4591$

Плотность перед К [кг/м^3]: $\rho_{K1} = 1.120$

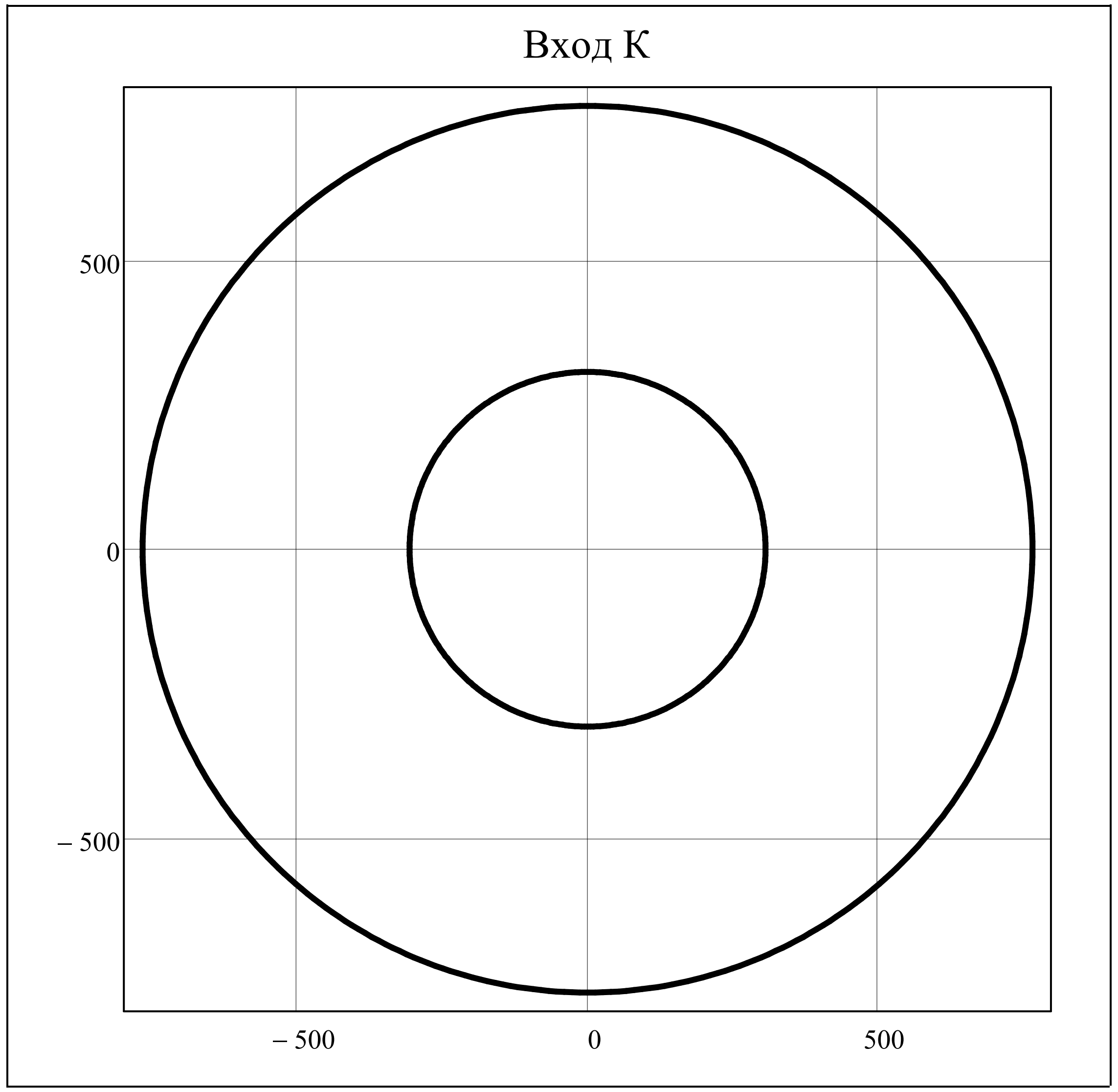
Кольцевая площадь перед К [м²]: $F_{вх} = \dfrac{G\cdot\sqrt{R_в\cdot T^*_{K1}}}{m_q(k_{K1})\cdot P^*_{K1}\cdot ГДФ(\text{"G"}, \lambda_{вх}, k_{K1})} = 1.5621$

$$D'_{пер1} = \frac{2\cdot u_{1пер}}{\omega} = 1534.9\cdot 10^{-3}$$

Диамтеры перед К [м]: $D'_{ср1} = \bar{r}_{ср}(\bar{d}_1)\cdot D'_{пер1} = 1169\cdot 10^{-3}$

$$D'_{кор1} = \bar{d}_1\cdot D'_{пер1} = 614\cdot 10^{-3}$$

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




Рекомендуемое количество ступеней []: $Z_{recomend} = 1$

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

Нулевые приближения

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

Расчет ВНА:

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

$\sigma_{BHA} = 1.0000$

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

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

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

$\begin{pmatrix} \overline{d}_{1BHA} \\ \overline{d}_{3BHA} \end{pmatrix} = \begin{pmatrix} 0.4000 \\ 0.4000 \end{pmatrix}$ $\quad \begin{pmatrix} F_{1BHA} \\ F_{3BHA} \end{pmatrix} = \begin{pmatrix} 1.5621 \\ 1.5621 \end{pmatrix}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\lambda_{c3BHA_r} = \frac{c_{3BHA_r}}{a_{кр3BHA_r}}$$

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

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

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

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

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

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

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

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

$\mathrm{submatrix}\left(a_{кр1BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (310.8)$

$\mathrm{submatrix}\left(a_{кр3BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (310.8)$

$\mathrm{submatrix}\left(\overline{c}_{a1BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.335)$

$\mathrm{submatrix}\left(\overline{c}_{a3BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.335)$

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

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

$\mathrm{submatrix}\left(c_{a1BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (142.7)$

$\mathrm{submatrix}\left(c_{a3BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (142.7)$

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

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

$\mathrm{submatrix}\left(c_{1BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (142.7)$

$\mathrm{submatrix}\left(c_{3BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (142.7)$

$\mathrm{submatrix}\left(\lambda_{c1BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.459)$

$\mathrm{submatrix}\left(\lambda_{c3BHA}, av\left(N_r\right), av\left(N_r\right), 1, 1\right) = (0.459)$

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

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

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

Расчет ВНА:

## Поступенчатый расчет ОК по ср. ЛТ

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

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

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

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

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

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$_{12}$)))

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

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

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

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

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

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

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

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

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

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

break

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

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

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

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

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

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

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

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

$$iteration_3 = 0$$

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

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

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

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

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

while $0 < 1$

$$iteration_3 = iteration_3 + 1$$

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

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

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

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

$$\text{if } ЗППЧ_i = \text{"пер"}$$

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

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

if $ЗППЧ_i$ = "кор"

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

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

if $ЗППЧ_i$ = "ср"

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$iteration_2 = 0$$

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

while $0 < 1$

$$iteration_2 = iteration_2 + 1$$

trace(concat("    iteration.2 = ", num2str($iteration_2$)))

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

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

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

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

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

if $ЗППЧ_i = \text{"пер"}$

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

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

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

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

if $ЗППЧ_i = \text{"кор"}$

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

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

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

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

if $ЗППЧ_i = \text{"ср"}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

for $a \in 1..3$

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

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

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

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

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

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

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

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

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

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

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

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

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

for $radius \in 1..N_r$

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

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

for $i \in 1..Z$

for $a \in 1..3$

for $r \in 1..N_r$

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

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

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

Поступенчатый расчет ОК по ср. ЛТ

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

Расчет CA:

$$\begin{pmatrix} \alpha_{1CA} & \alpha_{3CA} \\ \sigma_{CA} & \sigma_{CA} \\ \bar{d}_{1CA} & \bar{d}_{3CA} \\ T^*_{1CA} & T^*_{3CA} \\ P^*_{1CA} & P^*_{3CA} \\ \rho^*_{1CA} & \rho^*_{3CA} \\ k_{1CA} & k_{3CA} \\ a_{кр1CA} & a_{кр3CA} \\ \bar{c}_{a1CA} & \bar{c}_{a3CA} \\ \bar{c}_{u1CA} & \bar{c}_{u3CA} \\ c_{a1CA} & c_{a3CA} \\ c_{u1CA} & c_{u3CA} \\ c_{1CA} & c_{3CA} \\ \lambda_{1CA} & \lambda_{3CA} \\ F_{1CA} & F_{3CA} \\ \varepsilon_{CA} & \varepsilon_{CA} \end{pmatrix} = \quad \text{for } r \in av(N_r)$$

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

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

$\bar{d}_{1CA} \leftarrow \bar{d}_{st(Z,3)}$

$\bar{d}_{3CA} \leftarrow \bar{d}_{1CA}$

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

$T^*_{3CA_r} \leftarrow T^*_{1CA_r}$

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

$iterarion_{CA} \leftarrow 0$

$\sigma_{CA} \leftarrow 1$

while $0 < 1$

$iterarion_{CA} \leftarrow iterarion_{CA} + 1$

$trace\left(concat\left(\text{"iterarion.CA = "}, num2str\left(iterarion_{CA}\right)\right)\right)$

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

$\begin{pmatrix} \rho^*_{1CA_r} \\ \ldots \end{pmatrix} \leftarrow \ldots \begin{pmatrix} \dfrac{P^*_{1CA_r}}{T^*_{1CA_r}} \\ \ldots \end{pmatrix}$

$\sigma_{CA} = 1.0000$

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

$submatrix\left(\alpha_{1CA}, av(N_r), av(N_r), 1, 1\right) = (51.42)\cdot deg$

$submatrix\left(\alpha_{3CA}, av(N_r), av(N_r), 1, 1\right) = (51.42)\cdot deg$

$\begin{pmatrix} \bar{d}_{1CA} \\ \bar{d}_{3CA} \end{pmatrix} = \begin{pmatrix} 0.4826 \\ 0.4826 \end{pmatrix}$ $\quad \begin{pmatrix} F_{1CA} \\ F_{3CA} \end{pmatrix} = \begin{pmatrix} 1.4194 \\ 1.4195 \end{pmatrix}$

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

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

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

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

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

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

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

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

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

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

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

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

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

$\text{submatrix}\left(T^*_{1CA}, av(N_r), av(N_r), 1, 1\right) = (337.1)$

$\text{submatrix}\left(T^*_{3CA}, av(N_r), av(N_r), 1, 1\right) = (337.1)$

$\text{submatrix}\left(P^*_{1CA}, av(N_r), av(N_r), 1, 1\right) = (163.0)\cdot 10^3$

$\text{submatrix}\left(P^*_{3CA}, av(N_r), av(N_r), 1, 1\right) = (163.0)\cdot 10^3$

$\text{submatrix}\left(\rho^*_{1CA}, av(N_r), av(N_r), 1, 1\right) = (1.684)$

$\text{submatrix}\left(\rho^*_{3CA}, av(N_r), av(N_r), 1, 1\right) = (1.684)$

$\text{submatrix}\left(k_{1CA}, av(N_r), av(N_r), 1, 1\right) = (1.399)$

$\text{submatrix}\left(k_{3CA}, av(N_r), av(N_r), 1, 1\right) = (1.399)$

$\text{submatrix}\left(a_{кр1CA}, av(N_r), av(N_r), 1, 1\right) = (336.0)$

$\text{submatrix}\left(a_{кр3CA}, av(N_r), av(N_r), 1, 1\right) = (336.0)$

$\text{submatrix}\left(\bar{c}_{a1CA}, av(N_r), av(N_r), 1, 1\right) = (0.265)$

$\text{submatrix}\left(\bar{c}_{a3CA}, av(N_r), av(N_r), 1, 1\right) = (0.265)$

$\text{submatrix}\left(\bar{c}_{u1CA}, av(N_r), av(N_r), 1, 1\right) = (0.211)$

$\text{submatrix}\left(\bar{c}_{u3CA}, av(N_r), av(N_r), 1, 1\right) = (0.211)$

$\text{submatrix}\left(c_{a1CA}, av(N_r), av(N_r), 1, 1\right) = (112.9)$

$\text{submatrix}\left(c_{a3CA}, av(N_r), av(N_r), 1, 1\right) = (112.9)$

$\text{submatrix}\left(c_{u1CA}, av(N_r), av(N_r), 1, 1\right) = (90.0)$

$\text{submatrix}\left(c_{u3CA}, av(N_r), av(N_r), 1, 1\right) = (90.0)$

$\text{submatrix}\left(c_{1CA}, av(N_r), av(N_r), 1, 1\right) = (144.4)$

$\text{submatrix}\left(c_{3CA}, av(N_r), av(N_r), 1, 1\right) = (144.4)$

$\text{submatrix}\left(\lambda_{1CA}, av(N_r), av(N_r), 1, 1\right) = (0.430)$

$\text{submatrix}\left(\lambda_{3CA}, av(N_r), av(N_r), 1, 1\right) = (0.430)$

$$1 \quad \text{otherwise}$$

$$\text{break if } \left(\left|eps\left("rel", \sigma'_{CA}, \sigma_{CA}\right)\right| < epsilon\right) \wedge \left(iterarion_{CA} = 0\right)$$

$$iterarion_{CA} = -1 \quad \text{if } \left(\left|eps\left("rel", \sigma'_{CA}, \sigma_{CA}\right)\right| < epsilon\right)$$

$$\sigma_{CA} = \sigma'_{CA}$$

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

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

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

Расчет СА:

Результаты поступенчатого расчета по ср. ЛТ

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

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

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

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

$\cdot\%$

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

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

Количество ступеней ОК: $Z = 1$

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 | 1.609 | | | | | | | | | | | | | | |

[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 | | | | | | | | | | | | | | |

Полученная степень повышения полного давления []: $\prod_{i=1}^{Z} \pi^*_i = 1.609$

Степень повышения давления в ЛА: $\pi^*_{ЛА} = \dfrac{P^*_{3CA_{av(N_r)}}}{P^*_{1BHA_{av(N_r)}}} = 1.609$ $\quad \pi^*_{ЛА} \ge \pi^*_{К} = 1$

$H_T{}^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.62 | | | | | | | | | | | | | | |
| 2 | 51.62 | | | | | | | | | | | | | | |
| 3 | 51.62 | | | | | | | | | | | | | | |

$\cdot 10^3$

Действительная работа К (Дж/кг): $L_K = \sum_{i=1}^{Z} L_i = 49\cdot 10^3$

Адиабатная работа К [Дж/кг]: $L^*_K = \sum_{i=1}^{Z} L^*_i = 42.2\cdot 10^3$

Адиабатная КПД К []: $\eta^*_K = \frac{L^*_K}{L_K} = 86.00\cdot\%$

Мощность К (Вт): $N_K = G\cdot L_K = 12.24\cdot 10^6$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.50 | | | | | | | | | | | | | | |

$K_H{}^T =$

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

$\eta^{*T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 86.00 | | | | | | | | | | | | | | |

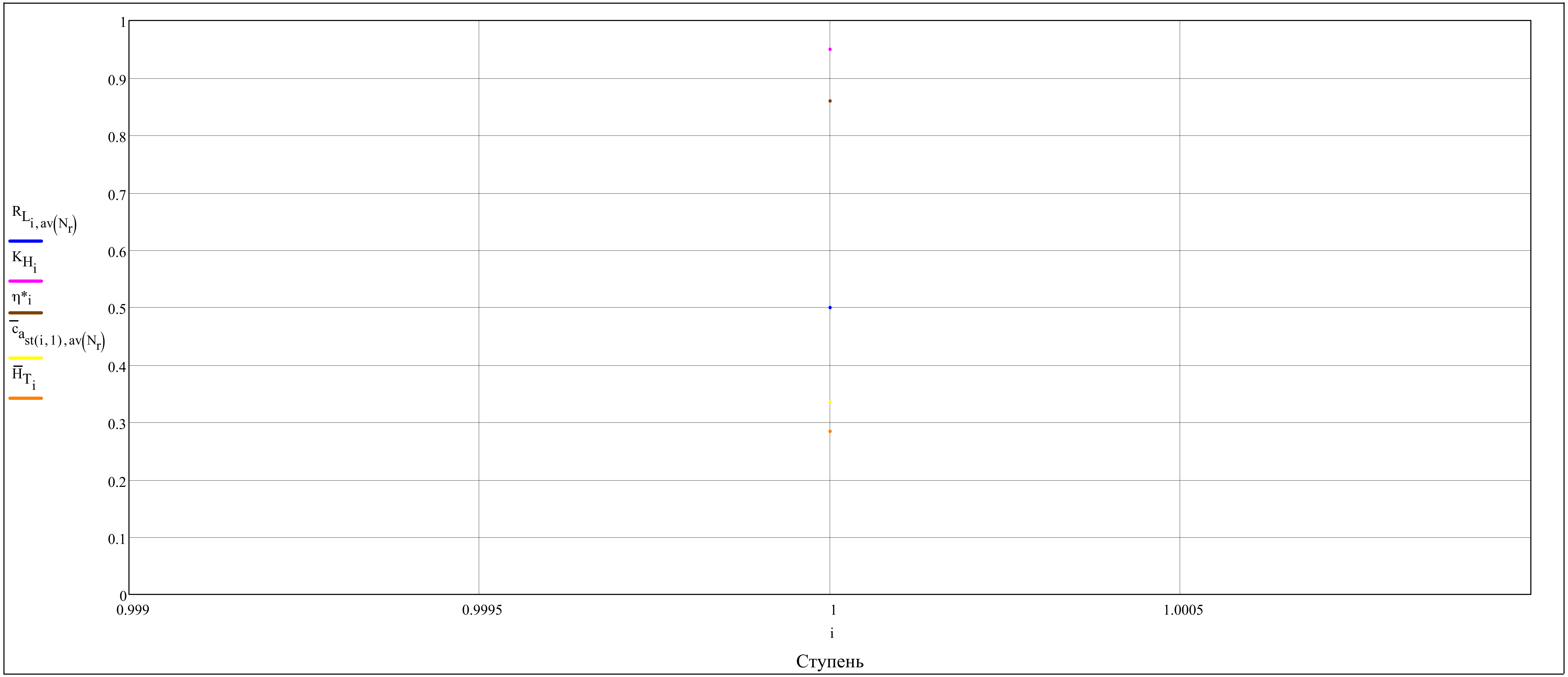
$\cdot\%$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.335 | 0.300 | 0.265 | | | | | | | | | | | | | | | | | |

$\bar{H}_T{}^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.28 | | | | | | | | | | | | | | |



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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1002.6 | 1006.0 | 1006.0 | | | | | | | | | | | | | | | | |

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

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 288.2 | 337.1 | 337.1 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 278 | 316.8 | 326.7 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 101.3 | 163 | 163 | | | | | | | | | | | | | | | |

$\cdot 10^3$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 89.4 | 131.1 | 146.1 | | | | | | | | | | | | | | | |

$\cdot 10^3$

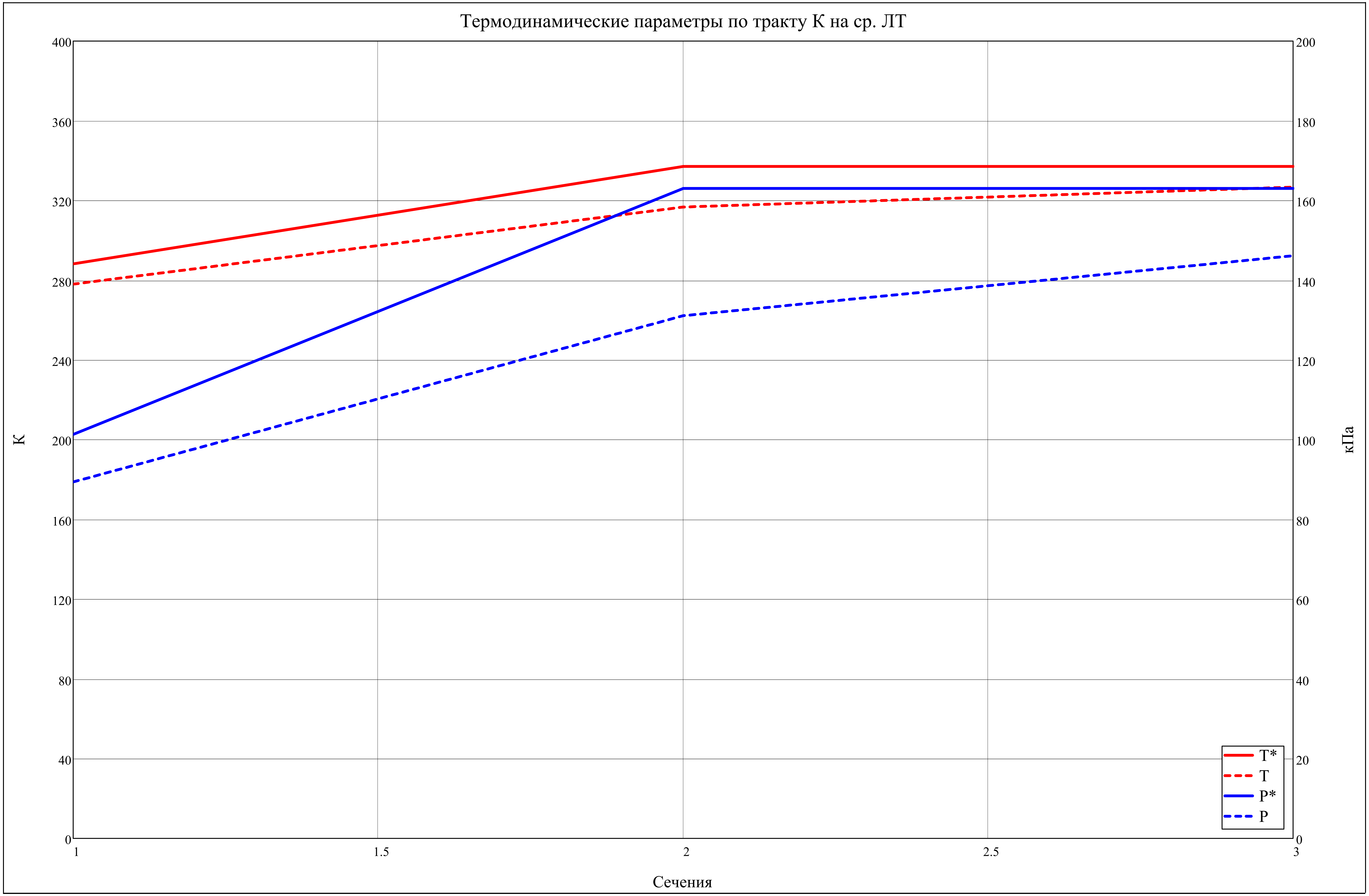
$\mathrm{submatrix}\left(\rho^*, 1, 2Z+1, av\left(N_r\right), av\left(N_r\right)\right)^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.224 | 1.684 | 1.684 | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.12 | 1.441 | 1.558 | | | | | | | | | | | | | | | | |

$$k_{ср} = k_{ад}\left(Cp_{воздух.ср}\left(P^*_{st(1,1), av\left(N_r\right)}, P^*_{st(Z,3), av\left(N_r\right)}, T^*_{st(1,1), av\left(N_r\right)}, T^*_{st(Z,3), av\left(N_r\right)}\right), R_в\right) = 1.401$$



Термодинамические параметры по тракту К на ср. ЛТ
К
кПа
Сечения
0
40
80
120
160
200
240
280
320
360
400
20
60
100
140
180
1
1.5
2
2.5
3
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 | 1.5621 | 1.3551 | 1.4194 | | | | | | | | | | | | | | | | | | |

$\overline{d}^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.3947 | 0.4405 | 0.4826 | | | | | | | | | | | | | | | | | | | | |

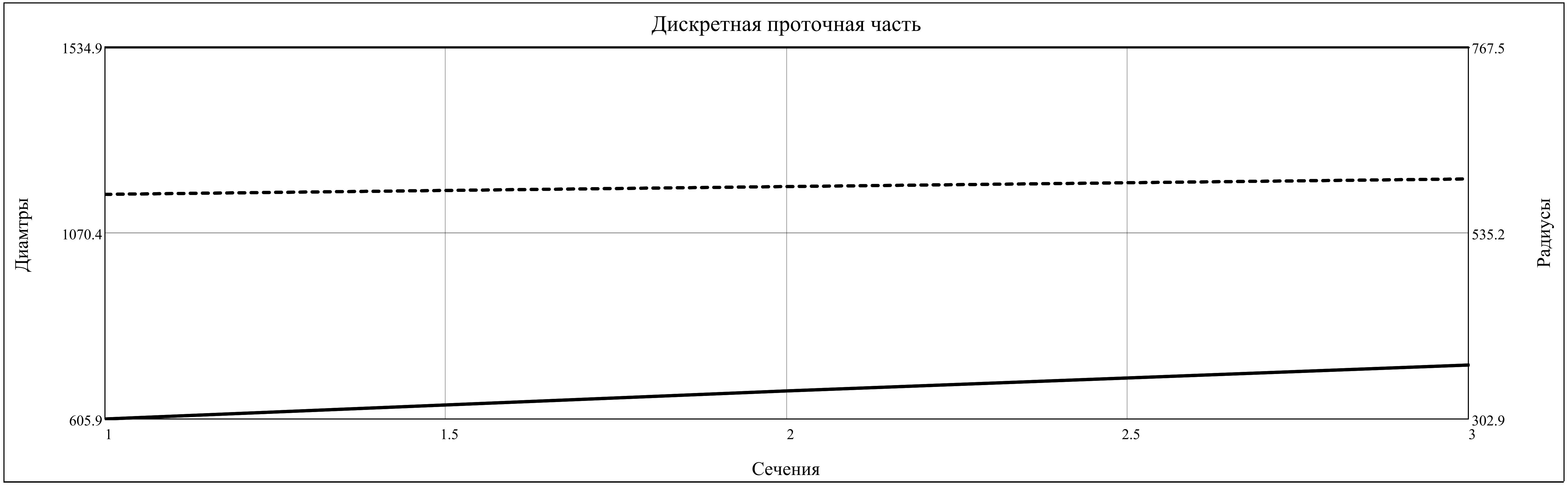
$\overline{d}_{st(Z,3)} = 0.4826$ $\quad$ $\overline{d}_{st(Z,3)} \le 0.9 = 1$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 605.9 | 676.2 | 740.8 | | | | | | | | | | | | | | | | | | |
| 2 | 1166.8 | 1186.0 | 1205.1 | | | | | | | | | | | | | | | | | | |
| 3 | 1534.9 | 1534.9 | 1534.9 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 302.9 | 338.1 | 370.4 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 583.4 | 593.0 | 602.6 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 767.5 | 767.5 | 767.5 | | | | | | | | | | | | | | | | | | | | | | |




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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 464.5 | 429.4 | 397.1 | | | | | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 310.8 | 336.0 | 336.0 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 334.5 | 356.8 | 362.4 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 142.7 | 202.3 | 144.4 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 353.8 | 214.5 | | | | | | | | | | | | | | | | | | | |

$u^T =$

| | 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 | 168.1 | 187.6 | 205.6 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 323.8 | 329.1 | 334.4 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 425.9 | 425.9 | 425.9 | | | | | | | | | | | | | | | | | | | | | | |

$c_{a_{st(Z,3), av(N_r)}} = 112.87$ $\quad c_{a_{st(Z,3), av(N_r)}} \le 130 = 1$ $\quad$ Для КС

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 142.7 | 127.8 | 112.9 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 156.8 | 90 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 323.8 | 172.3 | 244.4 | | | | | | | | | | | | | | | | | | |

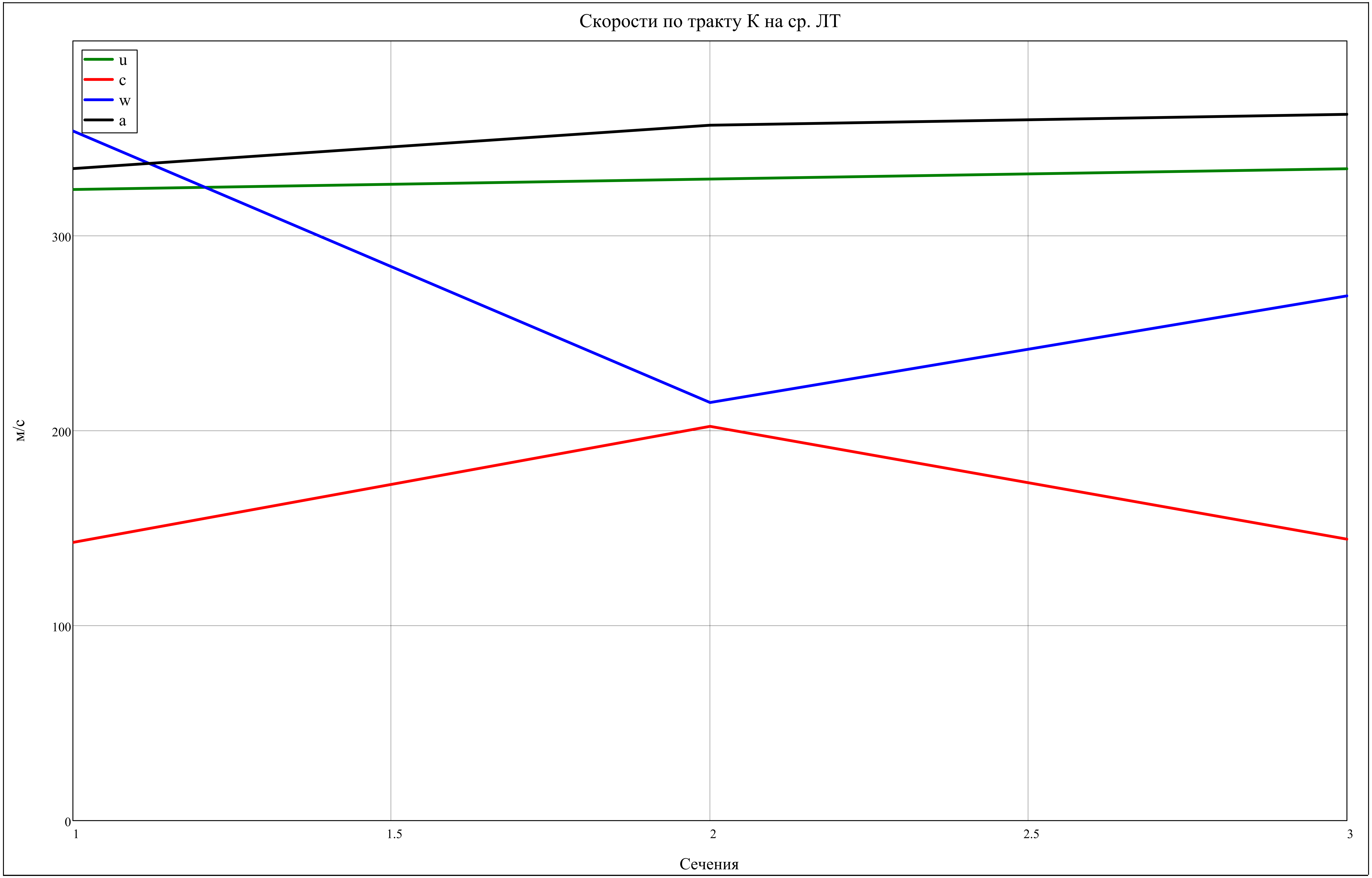
$$\Delta c_{a_{i, av(N_r)}} = \left(c_{a_{st(i,2), av(N_r)}} - c_{a_{st(i,1), av(N_r)}}\right)$$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -14.91 | | | | | | | | | | | |

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

| | 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 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |


Скорости по тракту К на ср. ЛТ
u
c
w
a
м/с
300
200
100
0
1
1.5
2
2.5
3
Сечения

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 90.00 | 39.17 | 51.42 | | | | | | | | | | | | | | | | | | |

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

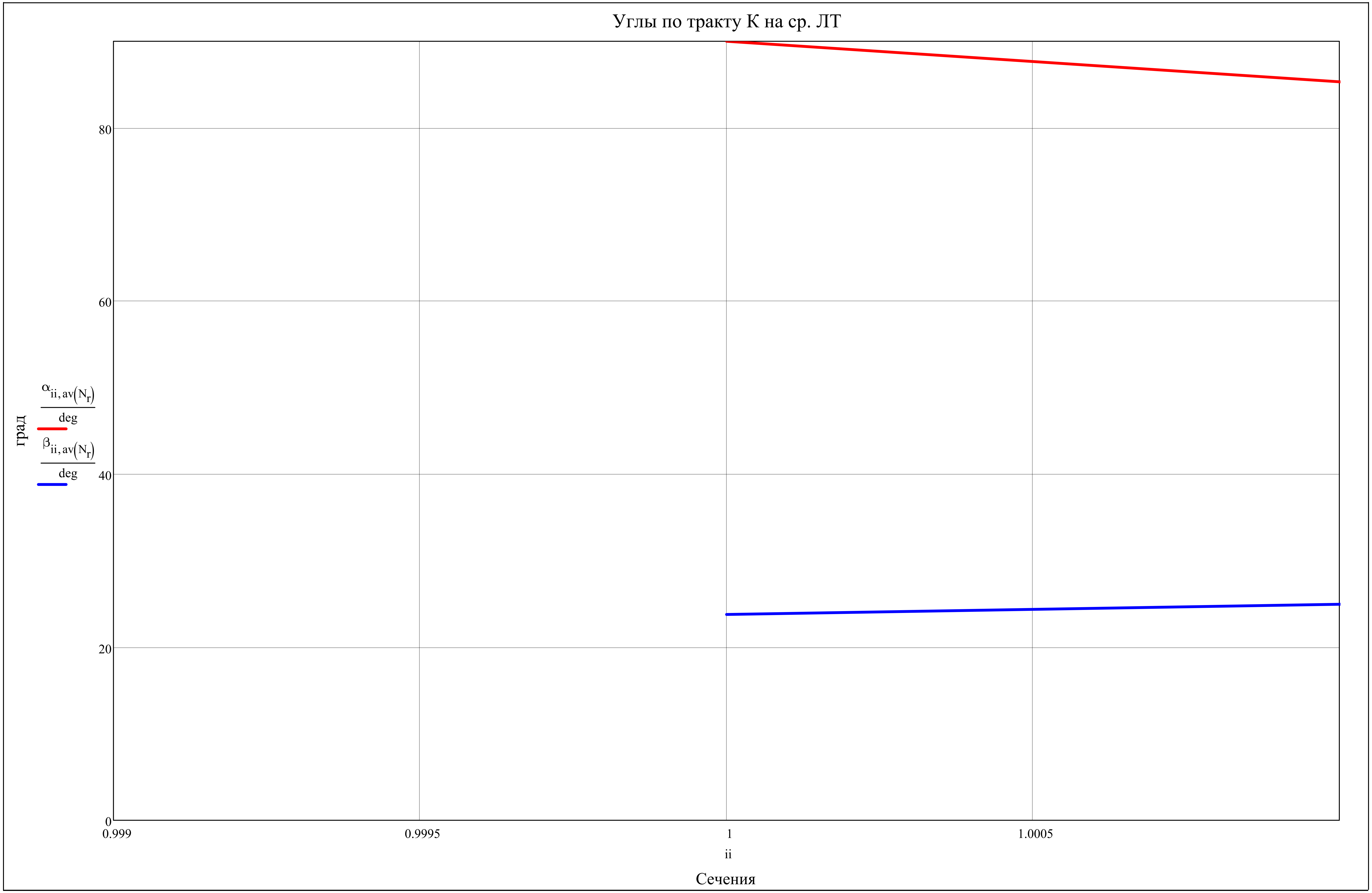
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 23.78 | 36.56 | 24.79 | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12.78 | | | | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12.25 | | | | | | | | | | | | | | | | | | | | |


Углы по тракту К на ср. ЛТ
80
60
40
20
0
град
$\frac{\alpha_{ii,av}(N_r)}{deg}$
$\frac{\beta_{ii,av}(N_r)}{deg}$
0.999
0.9995
1
1.0005
ii
Сечения

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.4591 | 0.6020 | 0.4297 | | | | | | | | | | | | | | | | |

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

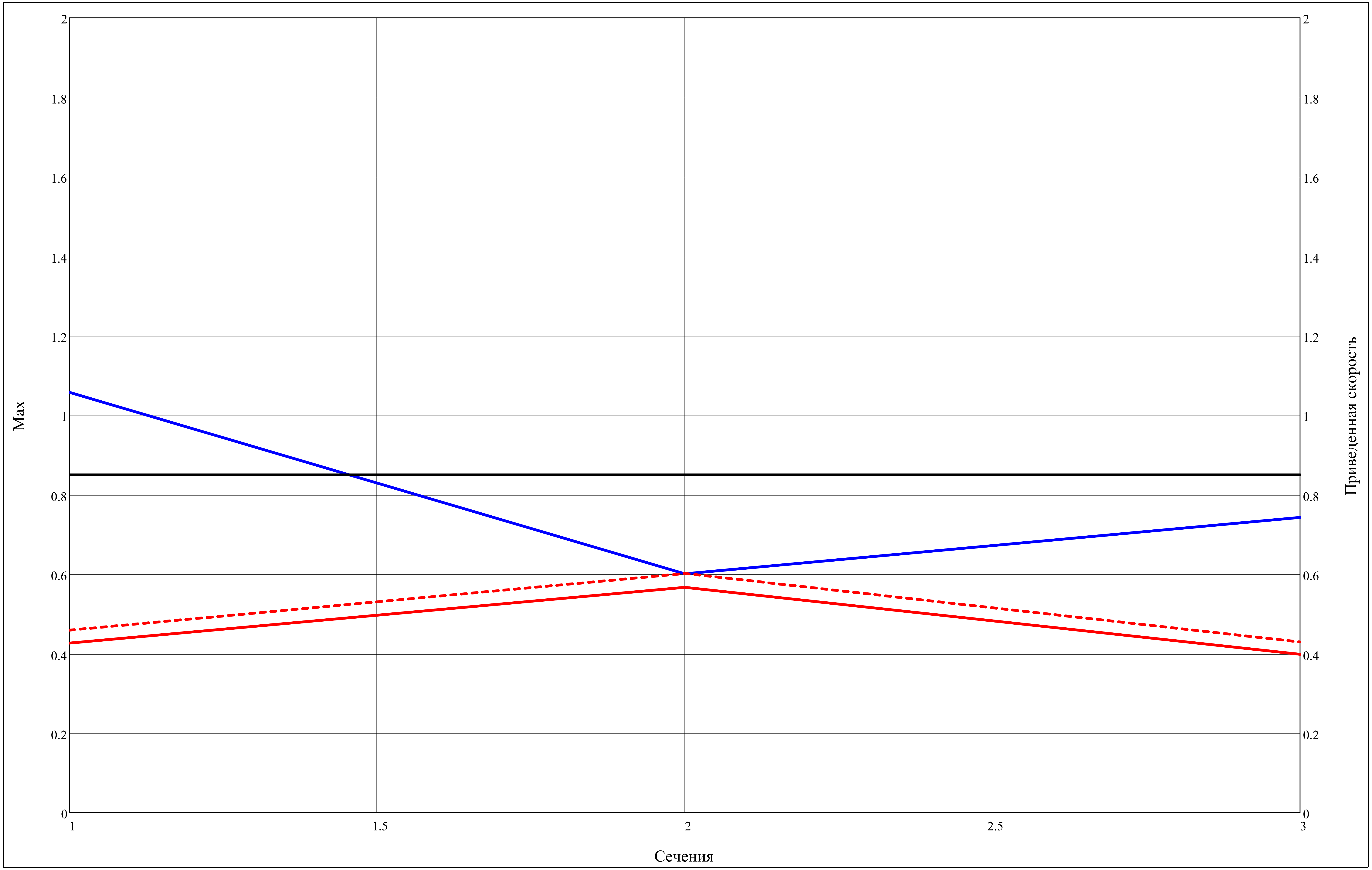
| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 1 | 1 | 1 |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0579 | 0.6012 | | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.4266 | 0.5670 | 0.3985 | | | | | | | | | | | | | | | | |



Max
Приведенная скорость
Сечения
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3

Результаты поступенчатого расчета по ср. ЛТ

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

Расчет параметров потока по высоте Л

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

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

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

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

$m^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.730 | | | | | | | | | | | |

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

for $i \in 1$

for $r \in 1..N_r$

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

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

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

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

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

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

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

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

$$c_{u1BHA_{av(N_r)}}$$

$$\begin{pmatrix} c_{u1BHA_r} \\ c_{u3BHA_r} \end{pmatrix} = \left[ \begin{array}{l} \frac{A}{\left(R_{st(i,1),r}\right)^{m_i}} - \frac{B}{\left(R_{st(i,1),r}\right)} \quad \text{if } BHA = 1 \\ c_{u1BHA_{av(N_r)}} \quad \text{otherwise} \end{array} \right]$$

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

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

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

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

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

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

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

for $i \in 1..Z$

  for $a \in 1..3$

    for $r \in 1..N_r$

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

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

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

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

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

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

if $\Delta H_{Tmax} = 0$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

for $r \in 1..N_r$

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

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

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

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

for $i \in Z$

for $r \in 1..N_r$

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

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

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

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

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

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

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

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

$$
\begin{pmatrix} c_{u1CA_r} \\ c_{u3CA\ldots} \end{pmatrix} = \begin{pmatrix} c_{u_{st(i,3),r}} \\ c_{u3CA_{av(N_r)}} \quad \text{if } CA = 1 \\ \ldots \end{pmatrix}
$$

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

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

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

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

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

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

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

Расчет параметров потока по высоте Л

Результаты расчета параметров потока по высоте Л

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

$$P^*_{1BHA} = \begin{pmatrix} 101.3 \\ 101.3 \\ 101.3 \end{pmatrix}\cdot 10^3 \quad P^*_{3BHA} = \begin{pmatrix} 101.3 \\ 101.3 \\ 101.3 \end{pmatrix}\cdot 10^3 \quad c_{1BHA} = \begin{pmatrix} 142.7 \\ 142.7 \\ 142.7 \end{pmatrix} \quad c_{3BHA} = \begin{pmatrix} 142.7 \\ 142.7 \\ 142.7 \end{pmatrix} \quad \varepsilon_{BHA} = \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \end{pmatrix}\cdot{}^\circ$$

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

$$Cp_{1BHA} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix} \quad Cp_{3BHA} = \begin{pmatrix} 1002.6 \\ 1002.6 \\ 1002.6 \end{pmatrix} \quad c_{a1BHA} = \begin{pmatrix} 142.7 \\ 142.7 \\ 142.7 \end{pmatrix} \quad c_{a3BHA} = \begin{pmatrix} 142.7 \\ 142.7 \\ 142.7 \end{pmatrix} \quad \lambda_{c1BHA} = \begin{pmatrix} 0.459 \\ 0.459 \\ 0.459 \end{pmatrix} \quad \lambda_{c3BHA} = \begin{pmatrix} 0.459 \\ 0.459 \\ 0.459 \end{pmatrix}$$

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

$T^{*T} =$

| | 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 | 337.1 | 337.1 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 288.2 | 337.1 | 337.1 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 288.2 | 337.1 | 337.1 | | | | | | | | | | | | | | | | | | | | | | |

$T^{T} =$

| | 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 | 274.5 | 281.8 | 321.8 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 278.0 | 316.8 | 326.7 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 278.9 | 324.0 | 328.5 | | | | | | | | | | | | | | | | | | | | | | |

$P^{*T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 101.3 | 163.0 | 163.0 | | | | | | | | | | | | | | | | | | |
| 2 | 101.3 | 163.0 | 163.0 | | | | | | | | | | | | | | | | | | |
| 3 | 101.3 | 163.0 | 163.0 | | | | | | | | | | | | | | | | | | |

$\cdot 10^3$

$P^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 85.5 | 87.0 | 138.5 | | | | | | | | | | | | | | | | | | |
| 2 | 89.4 | 131.1 | 146.1 | | | | | | | | | | | | | | | | | | |
| 3 | 90.3 | 141.9 | 148.9 | | | | | | | | | | | | | | | | | | |

$\cdot 10^3$

$\rho^{*T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.224 | 1.684 | 1.684 | | | | | | | | | | | | | | | | | | |
| 2 | 1.224 | 1.684 | 1.684 | | | | | | | | | | | | | | | | | | |
| 3 | 1.224 | 1.684 | 1.684 | | | | | | | | | | | | | | | | | | |

$\rho^{T} =$

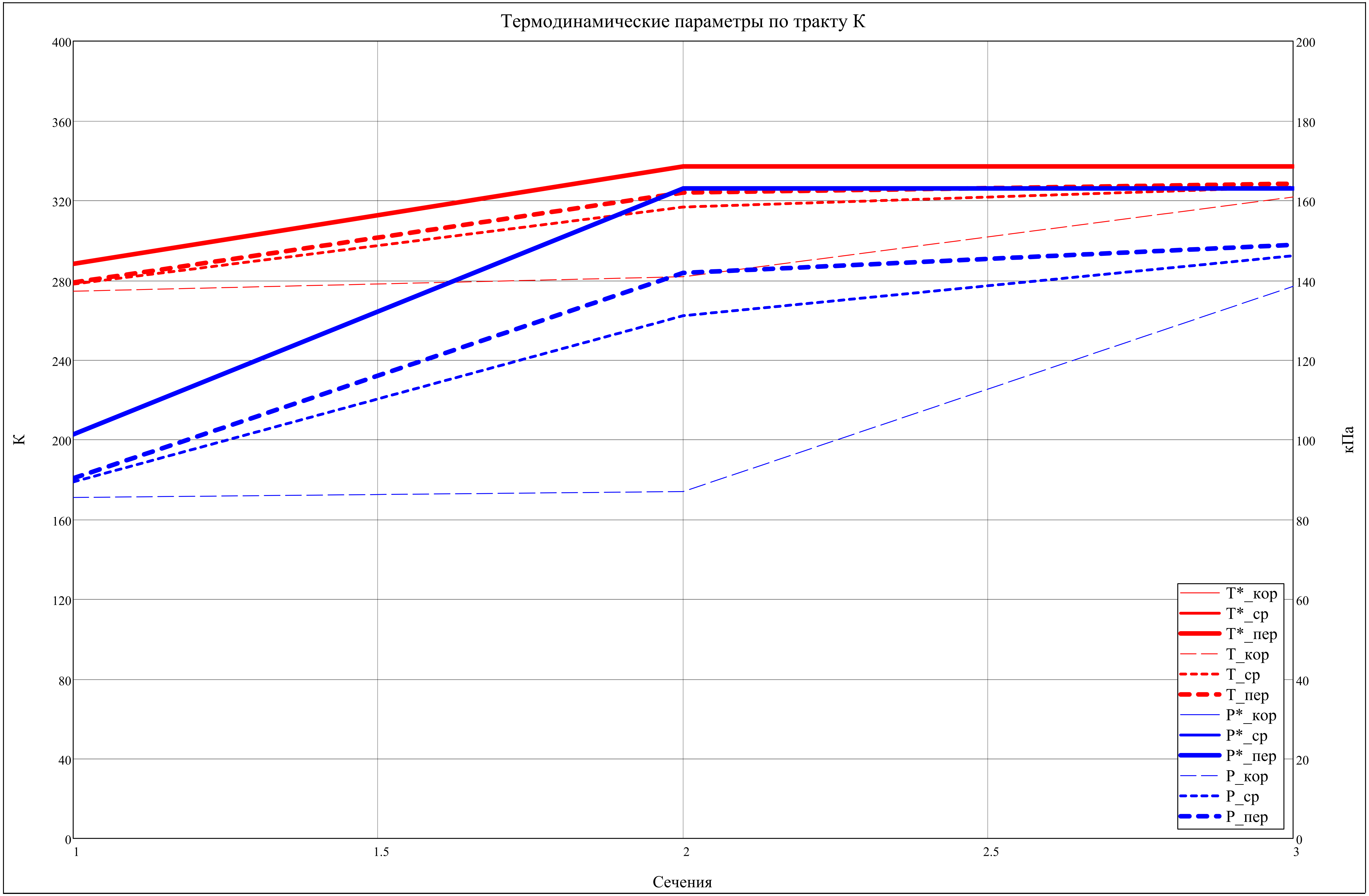
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.085 | 1.075 | 1.499 | | | | | | | | | | | | | | | | | | |
| 2 | 1.120 | 1.441 | 1.558 | | | | | | | | | | | | | | | | | | |
| 3 | 1.128 | 1.525 | 1.578 | | | | | | | | | | | | | | | | | | |

$Cp^{T} =$

| | 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 | 1006 | 1006 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 1003 | 1006 | 1006 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 1003 | 1006 | 1006 | | | | | | | | | | | | | | | | | | | | | | |

$k^{T} =$

| | 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 | 1.399 | 1.399 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 1.401 | 1.399 | 1.399 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 1.401 | 1.399 | 1.399 | | | | | | | | | | | | | | | | | | | | | | |



Термодинамические параметры по тракту К
400
360
320
280
240
200
160
120
80
40
0
200
180
160
140
120
100
80
60
40
20
0
1
1.5
2
2.5
3
K
кПа
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 | 336.0 | 336.0 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 310.8 | 336.0 | 336.0 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 310.8 | 336.0 | 336.0 | | | | | | | | | | | | | | | | | | | | | | |

$a_{зв}{}^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 332.4 | 336.5 | 359.6 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 334.5 | 356.8 | 362.4 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 335.0 | 360.8 | 363.3 | | | | | | | | | | | | | | | | | | | | | | |

$c^T =$

| | 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 | 165.6 | 333.7 | 175.8 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 142.7 | 202.3 | 144.4 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 136.7 | 162.5 | 131.8 | | | | | | | | | | | | | | | | | | | | | | |

$w^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 236.0 | 208.2 | 163.4 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 353.8 | 214.5 | 269.2 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 447.3 | 323.4 | 362.0 | | | | | | | | | | | | | | | | | | | | | | |

$u^T =$

| | 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 | 168.1 | 187.6 | 205.6 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 323.8 | 329.1 | 334.4 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 425.9 | 425.9 | 425.9 | | | | | | | | | | | | | | | | | | | | | | |

$c_a{}^T =$

| | 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 | 165.6 | 188.9 | 134.6 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 142.7 | 127.8 | 112.9 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 136.7 | 108.3 | 105.1 | | | | | | | | | | | | | | | | | | | | | | |

$c_u{}^T =$

| | 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 | 275.1 | 113.0 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 0.0 | 156.8 | 90.0 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 0.0 | 121.2 | 79.6 | | | | | | | | | | | | | | | | | | | | | | |

$w_u{}^T =$

| | 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 | 168.1 | -87.4 | 92.6 | | | | | | | | | | | | | | | | | | | | | |
| 2 | 323.8 | 172.3 | 244.4 | | | | | | | | | | | | | | | | | | | | | |
| 3 | 425.9 | 304.8 | 346.4 | | | | | | | | | | | | | | | | | | | | | |

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

$\Delta c_a{}^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 23.31 | -54.27 | | | | | | | | | | | | | | | | | | |
| 2 | 0.00 | -14.91 | -14.91 | | | | | | | | | | | | | | | | | | |
| 3 | 0.00 | -28.35 | -3.26 | | | | | | | | | | | | | | | | | | |

[16, c. 81]

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

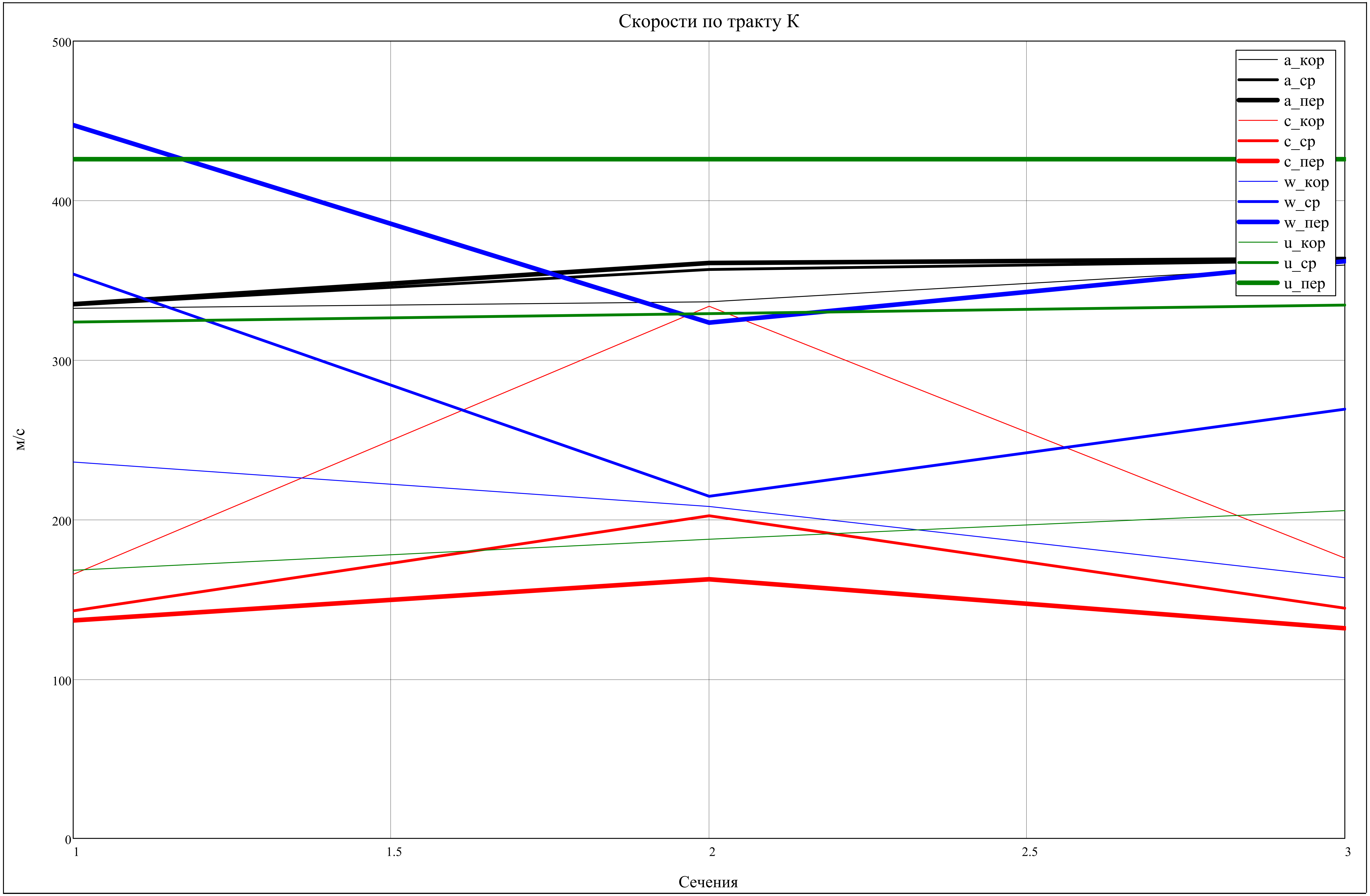
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | |

$R_L{}^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.2268 | | | | | | | | | | | |
| 2 | 0.7598 | | | | | | | | | | | |
| 3 | 0.8578 | | | | | | | | | | | |

$R_L{}^T \geq 0 =$

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


Скорости по тракту К
м/с
Сечения
500
400
300
200
100
0
1
1.5
2
2.5
3
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 | 34.48 | 49.99 | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 90.00 | 39.17 | 51.42 | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 90.00 | 41.80 | 52.87 | | | | | | | | | | | | | | | | | | | | | | |

$\cdot°$

$\beta^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 44.56 | 114.84 | 55.48 | | | | | | | | | | | | | | | | | | |
| 2 | 23.78 | 36.56 | 24.79 | | | | | | | | | | | | | | | | | | |
| 3 | 17.79 | 19.57 | 16.88 | | | | | | | | | | | | | | | | | | |

$\cdot°$

$\beta^T \le 91\cdot° =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | | | |
| 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |
| 3 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |

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

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

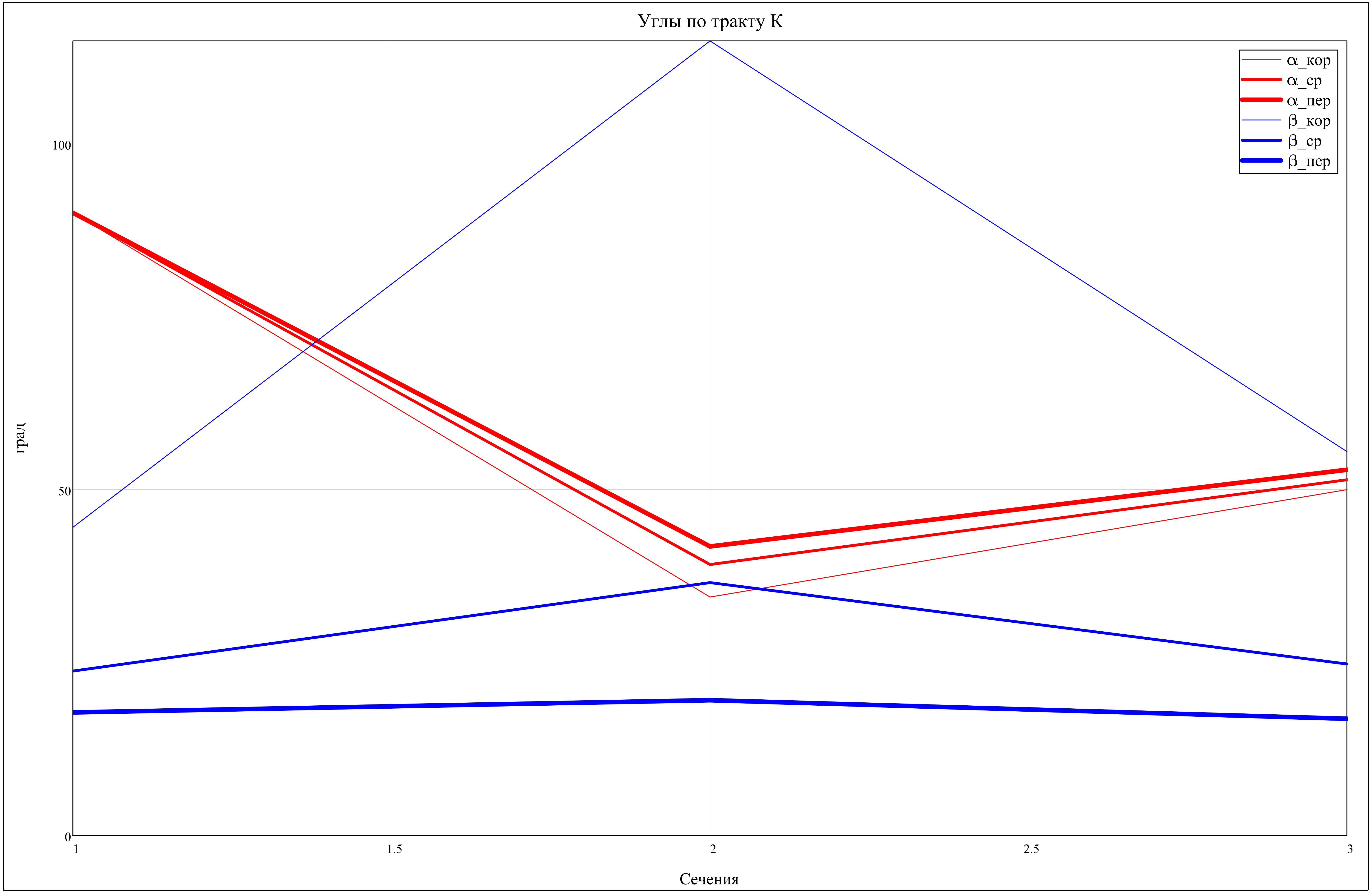
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.28 | | | | | | | | | | | | | | |
| 2 | 12.78 | | | | | | | | | | | | | | |
| 3 | 1.78 | | | | | | | | | | | | | | |

$\cdot°$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15.52 | | | | | | | | | | | | | | |
| 2 | 12.25 | | | | | | | | | | | | | | |
| 3 | 11.07 | | | | | | | | | | | | | | |

$\cdot°$



Углы по тракту К
α_кор
α_ср
α_пер
β_кор
β_ср
β_пер
град
100
50
0
1
1.5
2
2.5
3
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 | 0.5328 | 0.9931 | 0.5231 | | | | | | | | | | | | | | | | | | | | |
| 2 | 0.4591 | 0.6020 | 0.4297 | | | | | | | | | | | | | | | | | | | | |
| 3 | 0.4398 | 0.4837 | 0.3922 | | | | | | | | | | | | | | | | | | | | |

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

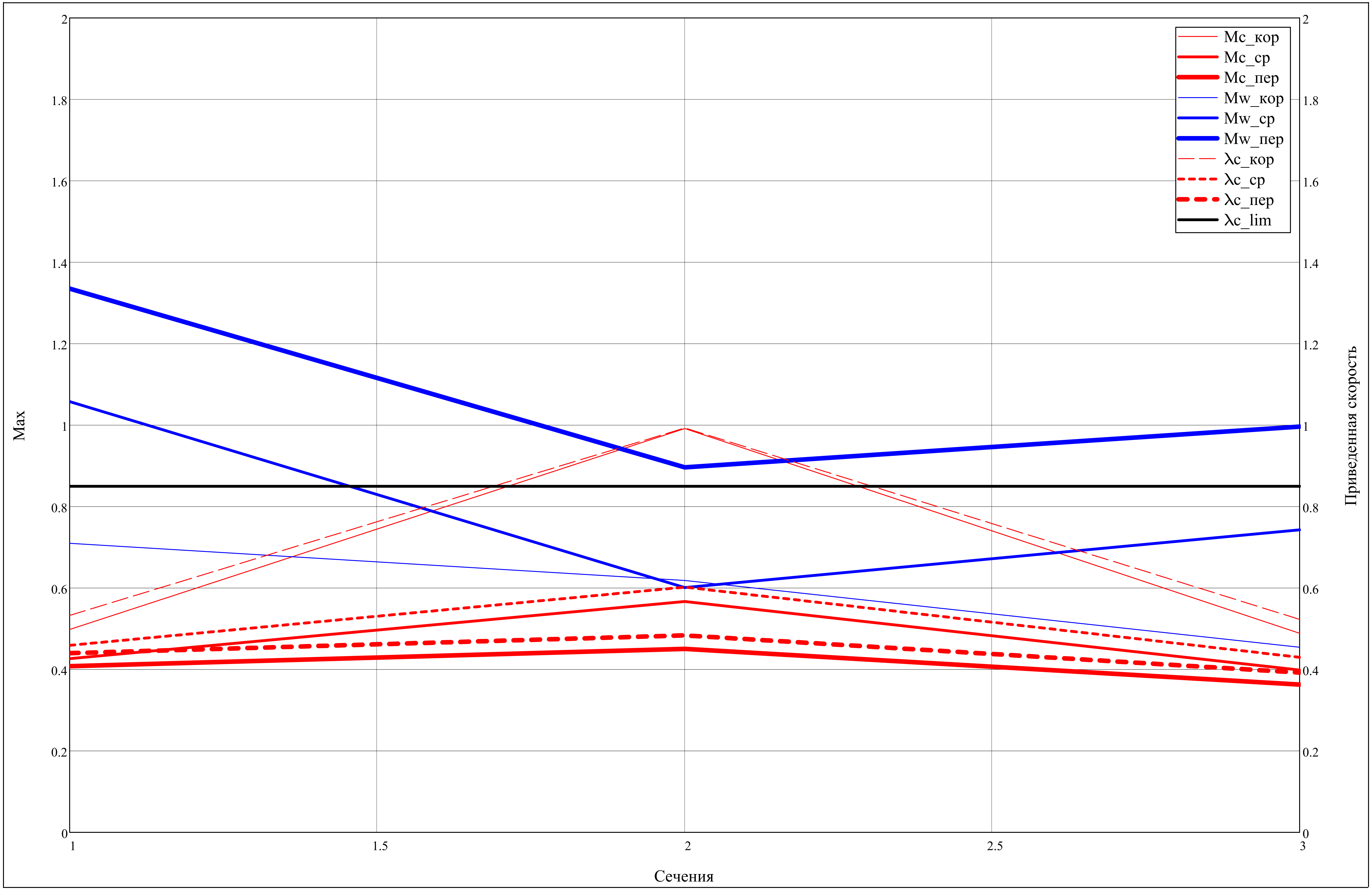
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | | | | | | | | | | | | | | | | |
| 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 3 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |

$M_c^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.4982 | 0.9917 | 0.4888 | | | | | | | | | | | | | | | | | | | | |
| 2 | 0.4266 | 0.5670 | 0.3985 | | | | | | | | | | | | | | | | | | | | |
| 3 | 0.4080 | 0.4505 | 0.3628 | | | | | | | | | | | | | | | | | | | | |

$M_w^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.7100 | 0.6186 | 0.4544 | | | | | | | | | | | | | | | | | | | | |
| 2 | 1.0579 | 0.6012 | 0.7429 | | | | | | | | | | | | | | | | | | | | |
| 3 | 1.3354 | 0.8964 | 0.9963 | | | | | | | | | | | | | | | | | | | | |



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
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1
1.5
2
2.5
3

$$T^*_{1CA} = \begin{pmatrix} 337.1 \\ 337.1 \\ 337.1 \end{pmatrix} \qquad T^*_{3CA} = \begin{pmatrix} 337.1 \\ 337.1 \\ 337.1 \end{pmatrix}$$

$$P^*_{1CA} = \begin{pmatrix} 163.0 \\ 163.0 \\ 163.0 \end{pmatrix} \cdot 10^3 \qquad P^*_{3CA} = \begin{pmatrix} 163.0 \\ 163.0 \\ 163.0 \end{pmatrix} \cdot 10^3$$

$$\rho^*_{1CA} = \begin{pmatrix} 1.684 \\ 1.684 \\ 1.684 \end{pmatrix} \qquad \rho^*_{3CA} = \begin{pmatrix} 1.684 \\ 1.684 \\ 1.684 \end{pmatrix}$$

$$Cp_{1CA} = \begin{pmatrix} 1006.0 \\ 1006.0 \\ 1006.0 \end{pmatrix} \qquad Cp_{3CA} = \begin{pmatrix} 1006.0 \\ 1006.0 \\ 1006.0 \end{pmatrix}$$

$$k_{1CA} = \begin{pmatrix} 1.399 \\ 1.399 \\ 1.399 \end{pmatrix} \qquad k_{3CA} = \begin{pmatrix} 1.399 \\ 1.399 \\ 1.399 \end{pmatrix}$$

$$a^*_{c1CA} = \begin{pmatrix} 336.0 \\ 336.0 \\ 336.0 \end{pmatrix} \qquad a^*_{c3CA} = \begin{pmatrix} 336.0 \\ 336.0 \\ 336.0 \end{pmatrix}$$

$$c_{1CA} = \begin{pmatrix} 175.8 \\ 144.4 \\ 131.8 \end{pmatrix} \qquad c_{3CA} = \begin{pmatrix} 175.8 \\ 144.4 \\ 131.8 \end{pmatrix}$$

$$c_{u1CA} = \begin{pmatrix} 113.0 \\ 90.0 \\ 79.6 \end{pmatrix} \qquad c_{u3CA} = \begin{pmatrix} 113.0 \\ 90.0 \\ 79.6 \end{pmatrix}$$

$$c_{a1CA} = \begin{pmatrix} 134.6 \\ 112.9 \\ 105.1 \end{pmatrix} \qquad c_{a3CA} = \begin{pmatrix} 134.6 \\ 112.9 \\ 105.1 \end{pmatrix}$$

$$\alpha_{1CA} = \begin{pmatrix} 49.99 \\ 51.42 \\ 52.87 \end{pmatrix} \cdot {}^\circ \qquad \alpha_{3CA} = \begin{pmatrix} 49.99 \\ 51.42 \\ 52.87 \end{pmatrix} \cdot {}^\circ$$

$$\varepsilon_{CA} = \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot {}^\circ$$

$$\lambda_{c1CA} = \begin{pmatrix} 0.523 \\ 0.430 \\ 0.392 \end{pmatrix} \qquad \lambda_{c3CA} = \begin{pmatrix} 0.523 \\ 0.430 \\ 0.392 \end{pmatrix}$$

Результаты расчета параметров потока по высоте Л

Вывод результатов расчета параметров потока по высоте Л

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

Построение треугольников скоростей в 3х сечениях

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

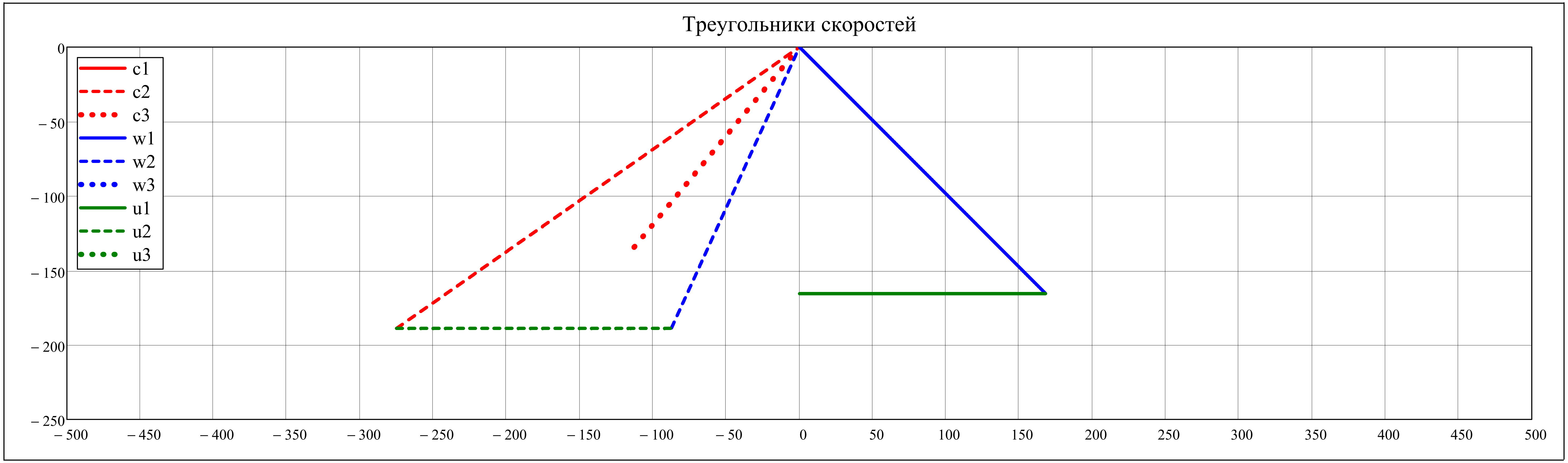
$$\Delta_w(v,i,j,r) = \left| \begin{array}{ll} -\tan\left(\beta_{st(i,j),r}\right)\cdot v & \text{if } \left(-\tan\left(\beta_{st(i,j),r}\right) \ge 0\right) \land \left(-\left|w_{st(i,j),r}\cdot\cos\left(\beta_{st(i,j),r}\right)\right| \le v \le 0\right) \land (j \ne 3) \\ -\tan\left(\beta_{st(i,j),r}\right)\cdot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

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

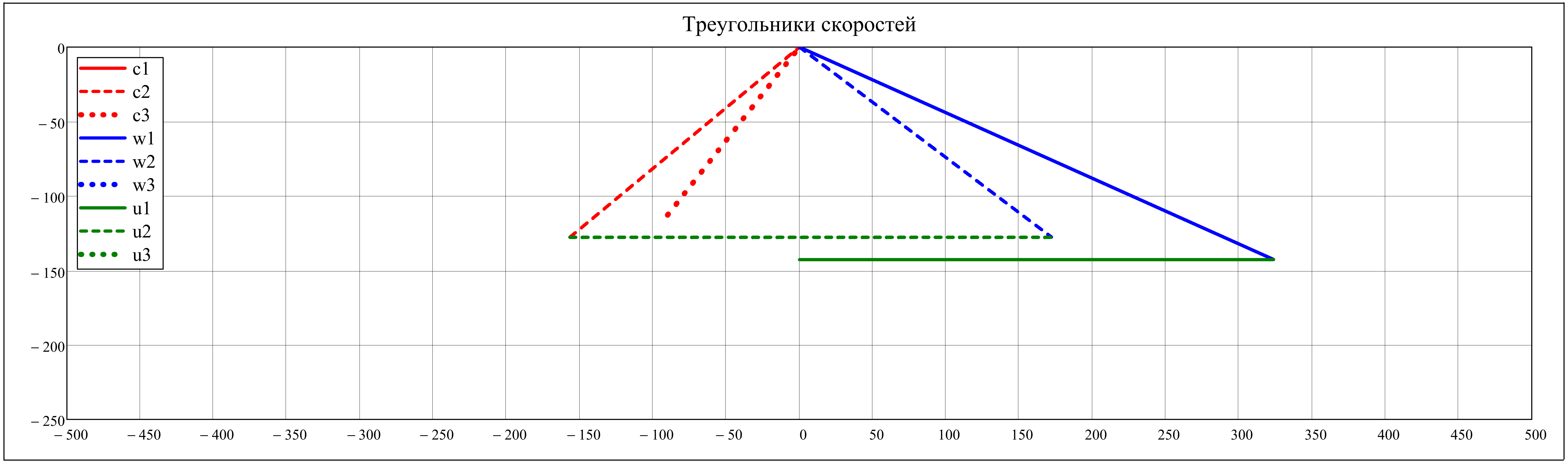
$$v_{lim} = \text{ceil}\left(\frac{\max(c,w,u)}{10^2}\right)\cdot 10^2 = 500$$

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

r = 1

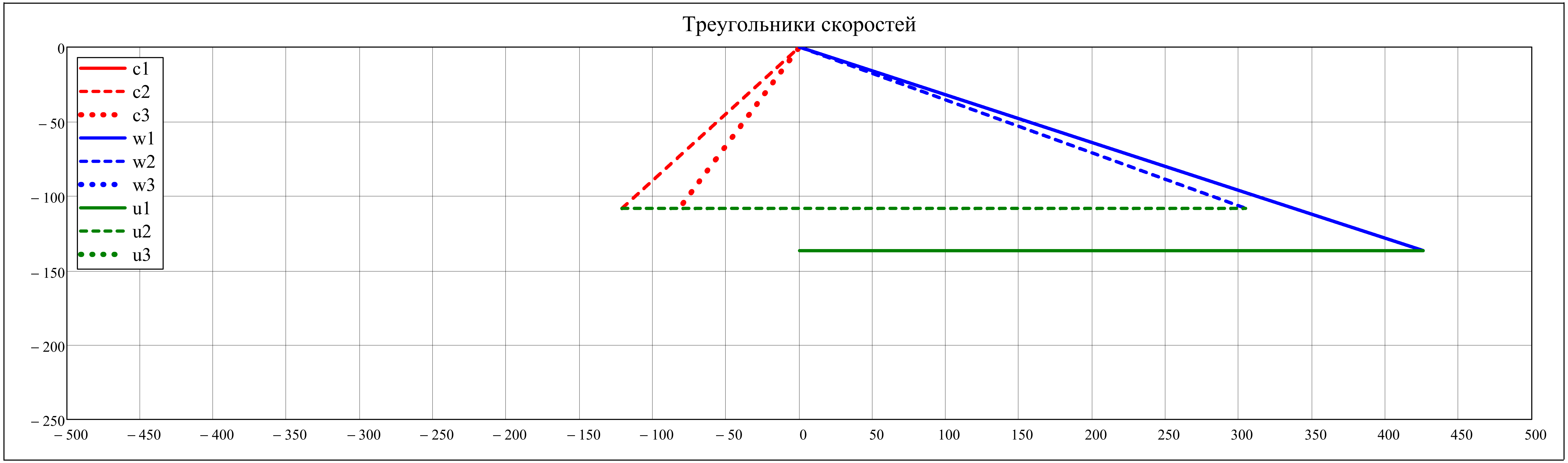

Треугольники скоростей
c1
c2
c3
w1
w2
w3
u1
u2
u3
0
– 50
– 100
– 150
– 200
– 250
– 500
– 450
– 400
– 350
– 300
– 250
– 200
– 150
– 100
– 50
0
50
100
150
200
250
300
350
400
450
500

$r = av(N_r)$



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

$r = N_r$




Построение треугольников скоростей в 3х сечениях

Определение степени повышения полного давлеия по 2ум контурам

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

Кольцевые площади (м^2):

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.2232 | 0.2130 | 0.2028 | | | | | | | | | | | | | | | | |
| 2 | 1.3389 | 1.2783 | 1.2166 | | | | | | | | | | | | | | | | |
| 3 | 1.5621 | 1.3551 | 1.4194 | | | | | | | | | | | | | | | | |

Радиус и диаметр двухконтурности (м):

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 403.5 | 426.7 | 449.2 | | | | | | | | | | | | | | | | |
| 2 | 807.0 | 853.5 | 898.3 | | | | | | | | | | | | | | | | |

$\cdot 10^{-3}$

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.609 | | | | | | | | | | | |
| 2 | 1.609 | | | | | | | | | | | |

$\prod_{i=1}^{Z} \pi^*_{I_i} = 1.609$ $\prod_{i=1}^{Z} \pi^*_{II_i} = 1.609$

Определение степени повышения полного давлеия по 2ум контурам

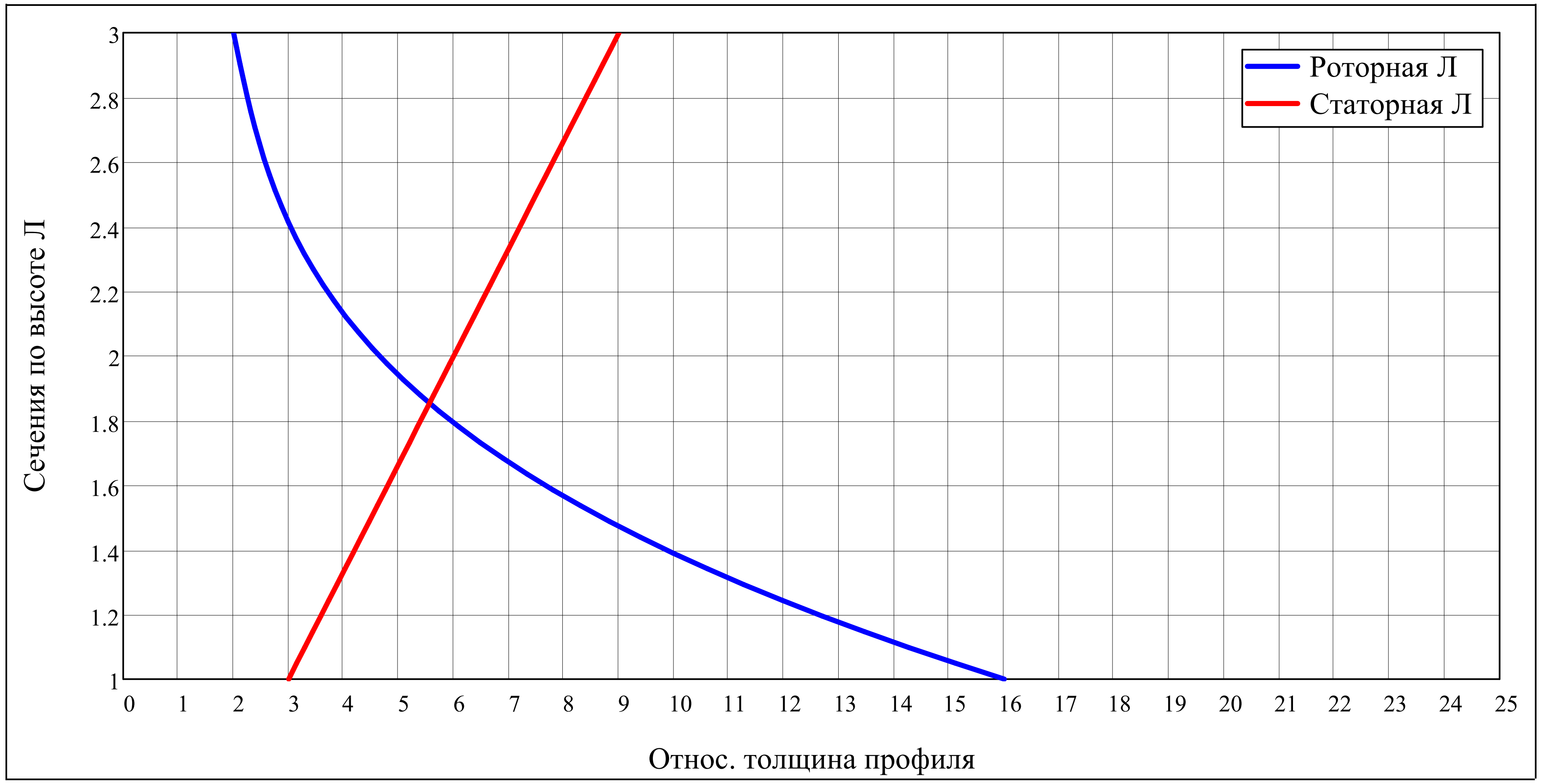
Относ. толщины и радиусы профилей

Относ. толщины Л РК и СА:

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

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

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



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

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

| | 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 |
|---|---|
| 1 | 3.00 |
| 2 | 6.00 |
| 3 | 9.00 |

$\cdot\%$

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

| | 1 |
|---|---|
| 1 | 16.00 |
| 2 | 4.65 |
| 3 | 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 |

$\cdot\%$

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

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

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

$\overline{r\_inlet}_{BHA} = 0.000 \cdot \%$

$\overline{r\_inlet}_{CA} = 0.000 \cdot \%$

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

| | 1 |
|---|---|
| 1 | 0.300 |
| 2 | 0.600 |
| 3 | 0.900 |

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

| | 1 |
|---|---|
| 1 | 1.600 |
| 2 | 0.465 |
| 3 | 0.200 |

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

| | 1 |
|---|---|
| 1 | 0.150 |
| 2 | 0.300 |
| 3 | 0.450 |

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

| | 1 |
|---|---|
| 1 | 0.800 |
| 2 | 0.233 |
| 3 | 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]

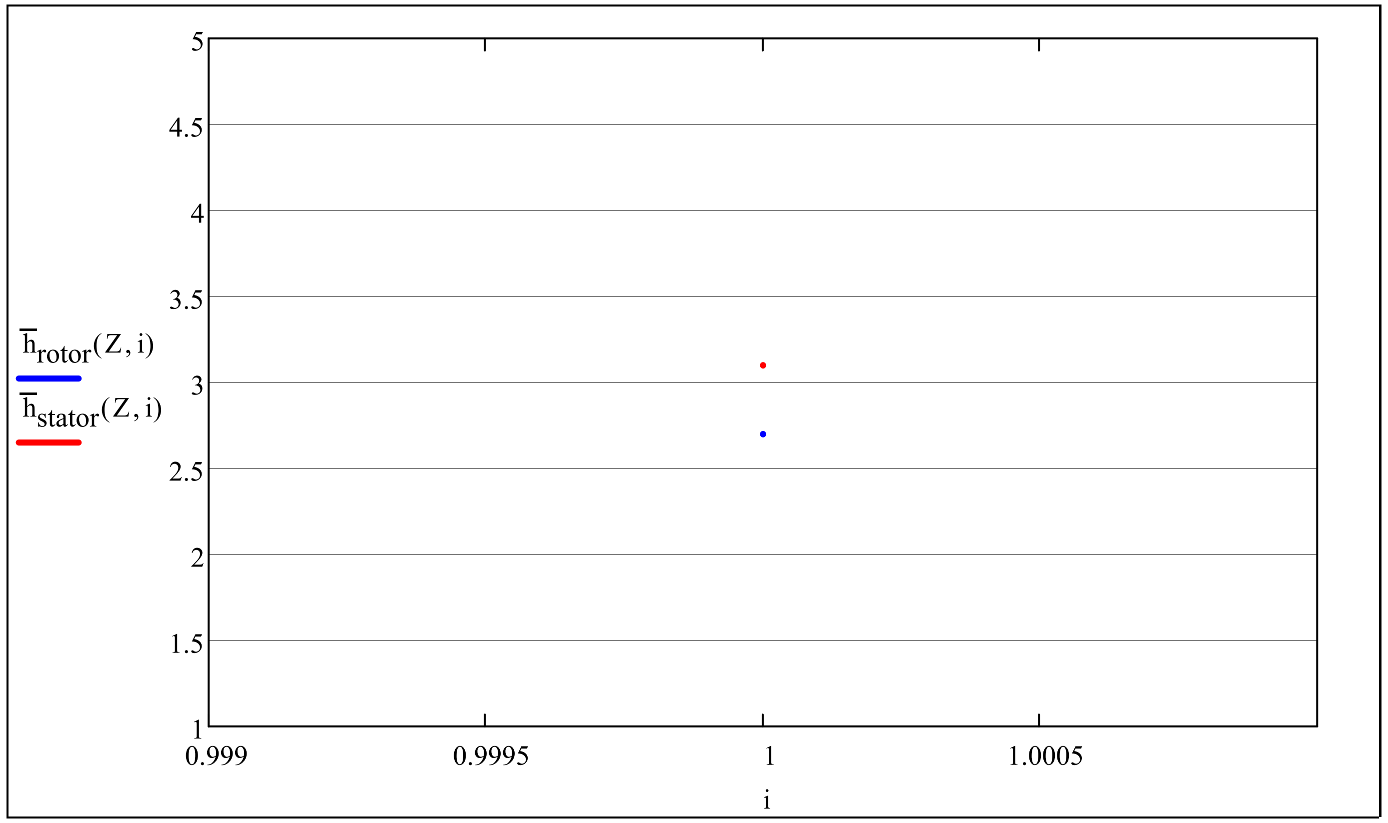
$$\overline{h}_{\sim rotor} = (2\ \ 1.9\ \ 1.85\ \ 1.8\ \ 1.75\ \ 1.7\ \ 1.65\ \ 1.6)^T + \begin{cases} 1.1 & \text{if compressor = "Вл"} \\ -0.1 & \text{if compressor = "КНД"} \\ -0.55 & \text{if compressor = "КВД"} \end{cases}$$

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

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

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

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




Для компрессора газогенератора

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

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

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

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

[16, с. 83-84]

Распределение параметров по высоте Л

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

Расчет длин хорд по высоте Л

$$chord_{BHA} = \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} chordBHA_{av(N_r)} \leftarrow \dfrac{h_{st(i,1)}}{\overline{h}_{stator(Z,0)}} \\ sail \leftarrow \dfrac{R_{st(1,1),N_r} - R_{st(1,1),1}}{R_{st(1,1),av(N_r)} - R_{st(1,1),1}} \\ \text{for } r \in 1..N_r \\ \quad \left| \begin{array}{l} b_{BHAкор} \leftarrow \dfrac{chordBHA_{av(N_r)} \cdot sail}{sail_{stator} - 1 + sail} \\ b_{BHAпер} \leftarrow b_{BHAкор} \cdot sail_{stator} \\ b_{BHA.}(z) \leftarrow interp\left[cspline\left[\begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{BHAкор} \\ chordBHA_{av(N_r)} \\ b_{BHAпер} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{BHAкор} \\ chordBHA_{av(N_r)} \\ b_{BHAпер} \end{pmatrix}, z\right] \\ chordBHA_r \leftarrow b_{BHA.}(R_{st(i,1),r}) \end{array} \right. \end{array} \right. \\ chord_{BHA} \end{array} \right| \quad \text{if } BHA = 1$$

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

$$
\mathrm{chord}_{CA} = \left|
\begin{array}{l}
\text{for } i \in Z \\
\quad \left|
\begin{array}{l}
\mathrm{chord}_{CA_{av(N_r)}} \leftarrow \dfrac{h_{st(i,3)}}{\overline{h}_{stator}(Z, Z+1)} \\
\mathrm{sail} \leftarrow \dfrac{R_{st(1,1),N_r} - R_{st(1,1),1}}{R_{st(1,1),av(N_r)} - R_{st(1,1),1}} \\
\text{for } r \in 1..N_r \\
\quad \left|
\begin{array}{l}
b_{CA\text{кор}} \leftarrow \dfrac{\mathrm{chord}_{CA_{av(N_r)}} \cdot \mathrm{sail}}{\mathrm{sail}_{stator} - 1 + \mathrm{sail}} \\
b_{CA\text{пер}} \leftarrow b_{CA\text{кор}} \cdot \mathrm{sail}_{stator} \\
b_{CA.}(z) \leftarrow \mathrm{interp}\left[\mathrm{cspline}\left[\begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CA\text{кор}} \\ \mathrm{chord}_{CA_{av(N_r)}} \\ b_{CA\text{пер}} \end{pmatrix}\right], \begin{pmatrix} R_{st(i,1),1} \\ R_{st(i,1),av(N_r)} \\ R_{st(i,1),N_r} \end{pmatrix}, \begin{pmatrix} b_{CA\text{кор}} \\ \mathrm{chord}_{CA_{av(N_r)}} \\ b_{CA\text{пер}} \end{pmatrix}, z\right] \\
\mathrm{chord}_{CA_r} \leftarrow b_{CA.}\left(R_{st(i,1),r}\right)
\end{array}
\right.
\end{array}
\right. \\
\mathrm{chord}_{CA}
\end{array}
\right. \quad \text{if } CA = 1
$$

Расчет длин хорд по высоте Л

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

$$\bar{x}_f = 0.5$$

Определение количества Л РК и НА

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

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

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

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

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

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

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

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

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

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

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

for $r \in 1..N_r$

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

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

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

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

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

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

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

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

$$\Bigg( \; chord_{rotor_{i,r}} \; \Bigg.$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Определение количества Л РК и НА

Результаты расчета количества Л и параметров решеток РК и НА

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

Длина хорды Л (м):

$chord_{rotor}^{T} =$ (table) $\cdot 10^{-3}$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 140.51 | | | | | | | | | | | | | | |
| 2 | 165.54 | | | | | | | | | | | | | | |
| 3 | 182.66 | | | | | | | | | | | | | | |

$chord_{stator}^{T} =$ (table) $\cdot 10^{-3}$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 119.15 | | | | | | | | | | | | | | |
| 2 | 133.30 | | | | | | | | | | | | | | |
| 3 | 142.98 | | | | | | | | | | | | | | |

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

Радисы входных и выходных кромок профилей Л (мм):

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

$r\_inlet_{rotor}^{T} =$ (table) $\cdot 10^{-3}$

| | 1 |
|---|---|
| 1 | 2.25 |
| 2 | 0.77 |
| 3 | 0.37 |

$r\_outlet_{rotor}^{T} =$ (table) $\cdot 10^{-3}$

| | 1 |
|---|---|
| 1 | 1.12 |
| 2 | 0.38 |
| 3 | 0.18 |

$r\_inlet_{stator}^{T} =$ (table) $\cdot 10^{-3}$

| | 1 |
|---|---|
| 1 | 0.36 |
| 2 | 0.80 |
| 3 | 1.29 |

$r\_outlet_{stator}^{T} =$ (table) $\cdot 10^{-3}$

| | 1 |
|---|---|
| 1 | 0.18 |
| 2 | 0.40 |
| 3 | 0.64 |

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

Угол поворота потока:

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.86 | | | | | | | | | | | | | | |

$\cdot {}^\circ$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15.65 | | | | | | | | | | | | | | |

$\cdot {}^\circ$

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

Густота решетки:

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.582 | | | | | | | | | | | | | | |
| 2 | 1.657 | | | | | | | | | | | | | | |
| 3 | 1.402 | | | | | | | | | | | | | | |

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

| | 1 |
|---|---|
| 1 | 1.071 |
| 2 | 0.710 |
| 3 | 0.593 |

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

Количество Л:

$Z_{BHA} = 0$

$Z_{rotor}^T =$

| | 1 |
|---|---|
| 1 | 37 |

$Z_{stator}^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 20 | | | | | | | | | | | | | | |

$Z_{CA} = 0$

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 | 54.43 | | | | | | | | | | | | | | |
| 2 | 99.89 | | | | | | | | | | | | | | |
| 3 | 130.33 | | | | | | | | | | | | | | |

$\cdot 10^{-3}$

Шаг решетки (м):

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 111.29 | | | | | | | | | | | | | | |
| 2 | 187.80 | | | | | | | | | | | | | | |
| 3 | 241.10 | | | | | | | | | | | | | | |

$\cdot 10^{-3}$

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

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.954 | | | | | | | | | | | | | | |
| 2 | 1.643 | | | | | | | | | | | | | | |
| 3 | 1.004 | | | | | | | | | | | | | | |

$\cdot {}^{\circ}$

Угол атаки:

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -2.323 | | | | | | | | | | | | | | |
| 2 | -3.226 | | | | | | | | | | | | | | |
| 3 | -3.517 | | | | | | | | | | | | | | |

$\cdot {}^{\circ}$

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

$m_{BHA} = 0.0000$

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 | 0.1803 | | | | | | | | | | | | | | |
| 2 | 0.3369 | | | | | | | | | | | | | | |
| 3 | 0.3709 | | | | | | | | | | | | | | |

$m_{stator}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.3100 | | | | | | | | | | | | | | |
| 2 | 0.3072 | | | | | | | | | | | | | | |
| 3 | 0.3043 | | | | | | | | | | | | | | |

$m_{CA} = 0.0000$

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

Угол изгиба ср. линии профиля:

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 74.71 | | | | | | | | | | | | | | |
| 2 | 15.09 | | | | | | | | | | | | | | |
| 3 | 1.13 | | | | | | | | | | | | | | |

$\cdot {}^{\circ}$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 25.47 | | | | | | | | | | | | | | |
| 2 | 24.35 | | | | | | | | | | | | | | |
| 3 | 24.12 | | | | | | | | | | | | | | |

$\cdot {}^{\circ}$

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

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

Угол отставания:

$\delta_{rotor}{}^T = \begin{array}{c|c} & 1 \\ \hline 1 & 8.384 \\ 2 & 3.948 \\ 3 & 0.353 \end{array} \cdot {}^\circ$

$\delta_{stator}{}^T = \begin{array}{c|c} & 1 \\ \hline 1 & 7.631 \\ 2 & 8.878 \\ 3 & 9.530 \end{array} \cdot {}^\circ$

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

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

Угол установки Л:

$\upsilon_{rotor}{}^T = \begin{array}{c|c} & 1 \\ \hline 1 & 85.87 \\ 2 & 32.97 \\ 3 & 19.36 \end{array} \cdot {}^\circ$

$\upsilon_{stator}{}^T = \begin{array}{c|c} & 1 \\ \hline 1 & 44.89 \\ 2 & 48.12 \\ 3 & 50.34 \end{array} \cdot {}^\circ$

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

$R_{СЛ.ВНА} = 0.00 \cdot 10^{-3}$

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 | 115.79 | | | | | | | | | | | | | | |
| 2 | 630.45 | | | | | | | | | | | | | | |
| 3 | 9298.59 | | | | | | | | | | | | | | |

$\cdot 10^{-3}$

$R_{СЛ.stator}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 270.24 | | | | | | | | | | | | | | |
| 2 | 316.02 | | | | | | | | | | | | | | |
| 3 | 342.17 | | | | | | | | | | | | | | |

$\cdot 10^{-3}$

$R_{СЛ.СА} = 0.00 \cdot 10^{-3}$

$K_{ВНА} = 0.0000$

Фактор диффузорности решетки:

$K_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.1408 | | | | | | | | | | | | | | |
| 2 | 0.8955 | | | | | | | | | | | | | | |
| 3 | 0.7926 | | | | | | | | | | | | | | |

$K_{stator}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.7127 | | | | | | | | | | | | | | |
| 2 | 0.8833 | | | | | | | | | | | | | | |
| 3 | 0.9699 | | | | | | | | | | | | | | |

$K_{СА} = 0.0000$

$D_{BHA} = 0.0000$

Диффузорность решетки:

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.3277 | | | | | | | | | | | | | | |
| 2 | 0.5230 | | | | | | | | | | | | | | |
| 3 | 0.3736 | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.7001 | | | | | | | | | | | | | | |
| 2 | 0.5188 | | | | | | | | | | | | | | |
| 3 | 0.4051 | | | | | | | | | | | | | | |

$D_{CA} = 0.0000$

$D_{BHA} \le 0.6 = 1$

[18, c. 71]

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

| | 1 |
|---|---|
| 1 | 1 |
| 2 | 1 |
| 3 | 1 |

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

| | 1 |
|---|---|
| 1 | 0 |
| 2 | 1 |
| 3 | 1 |

$D_{CA} \le 0.6 = 1$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0604 | | | | | | | | | | | | | | |
| 2 | 0.1180 | | | | | | | | | | | | | | |
| 3 | 0.1038 | | | | | | | | | | | | | | |

Коэф. потерь полного давления:

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.1099 | | | | | | | | | | | | | | |
| 2 | 0.0379 | | | | | | | | | | | | | | |
| 3 | 0.0206 | | | | | | | | | | | | | | |

$quality_{rotor}{}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 25.284 | | | | | | | | | | | | | | |
| 2 | 8.472 | | | | | | | | | | | | | | |
| 3 | 1.765 | | | | | | | | | | | | | | |

Качество профилей решеток РК и НА:

$quality_{stator}{}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.364 | | | | | | | | | | | | | | |
| 2 | 16.506 | | | | | | | | | | | | | | |
| 3 | 28.019 | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 73.49 | | | | | | | | | | | | | | |
| 2 | 79.70 | | | | | | | | | | | | | | |
| 3 | 39.93 | | | | | | | | | | | | | | |

$\cdot\%$

Результаты расчета количества Л и параметров решеток РК и НА

Вывод параметров решеток

Подключение симметричного профиля

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

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

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

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

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

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

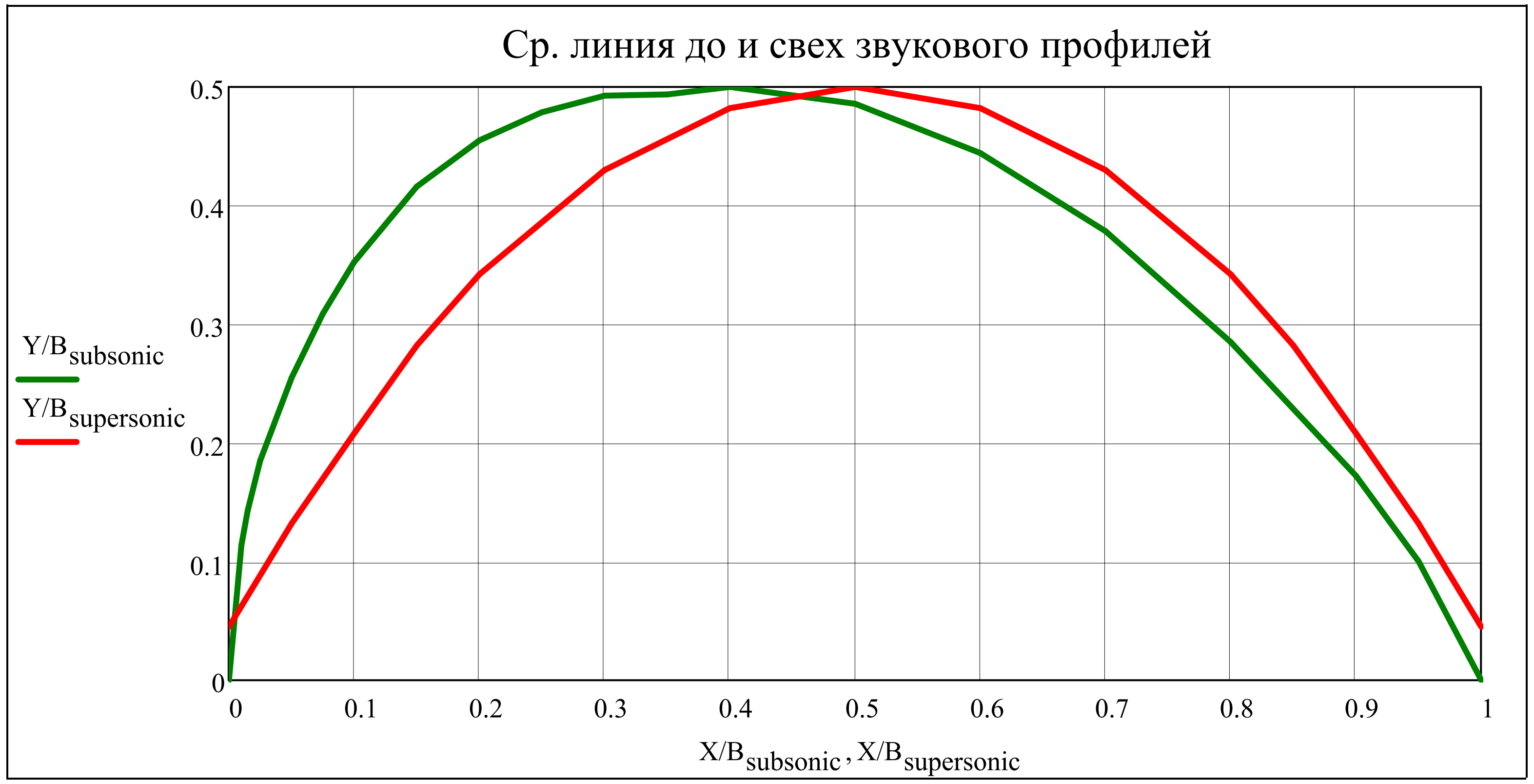
$Y/B_{supersonic} = submatrix\left(EXCEL_{AIRFOIL.supersonic}, 2, rows\left(EXCEL_{AIRFOIL.supersonic}\right), ORIGIN + 1, ORIGIN + 1\right)$

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

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

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

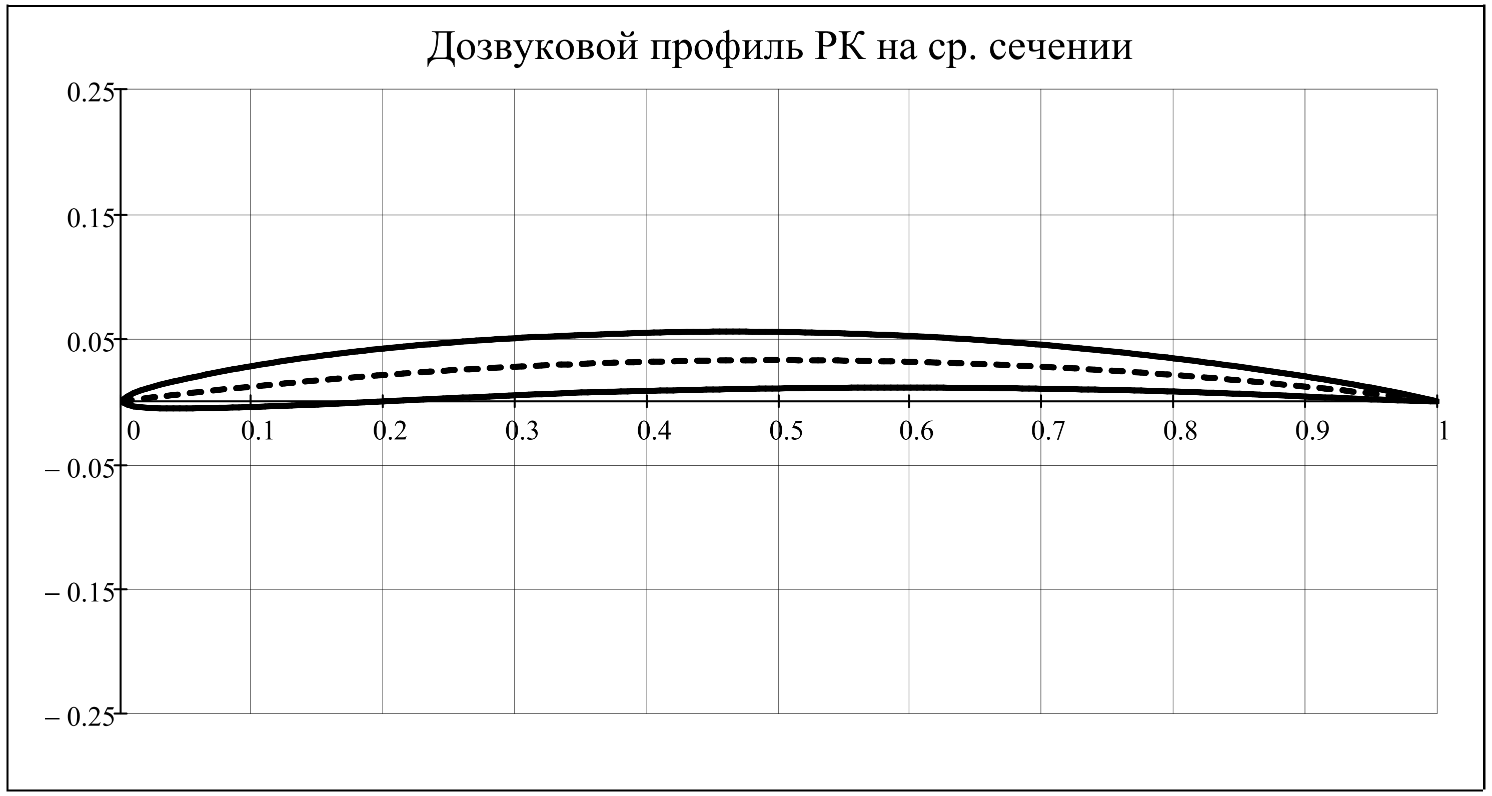
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.000 | 0.050 | 0.100 | 0.150 | 0.200 | 0.300 | 0.400 | 0.500 | 0.600 | 0.700 | 0.800 | 0.850 | 0.900 | 0.950 | 1.000 |
| 2 | 0.045 | 0.132 | 0.208 | 0.282 | 0.342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

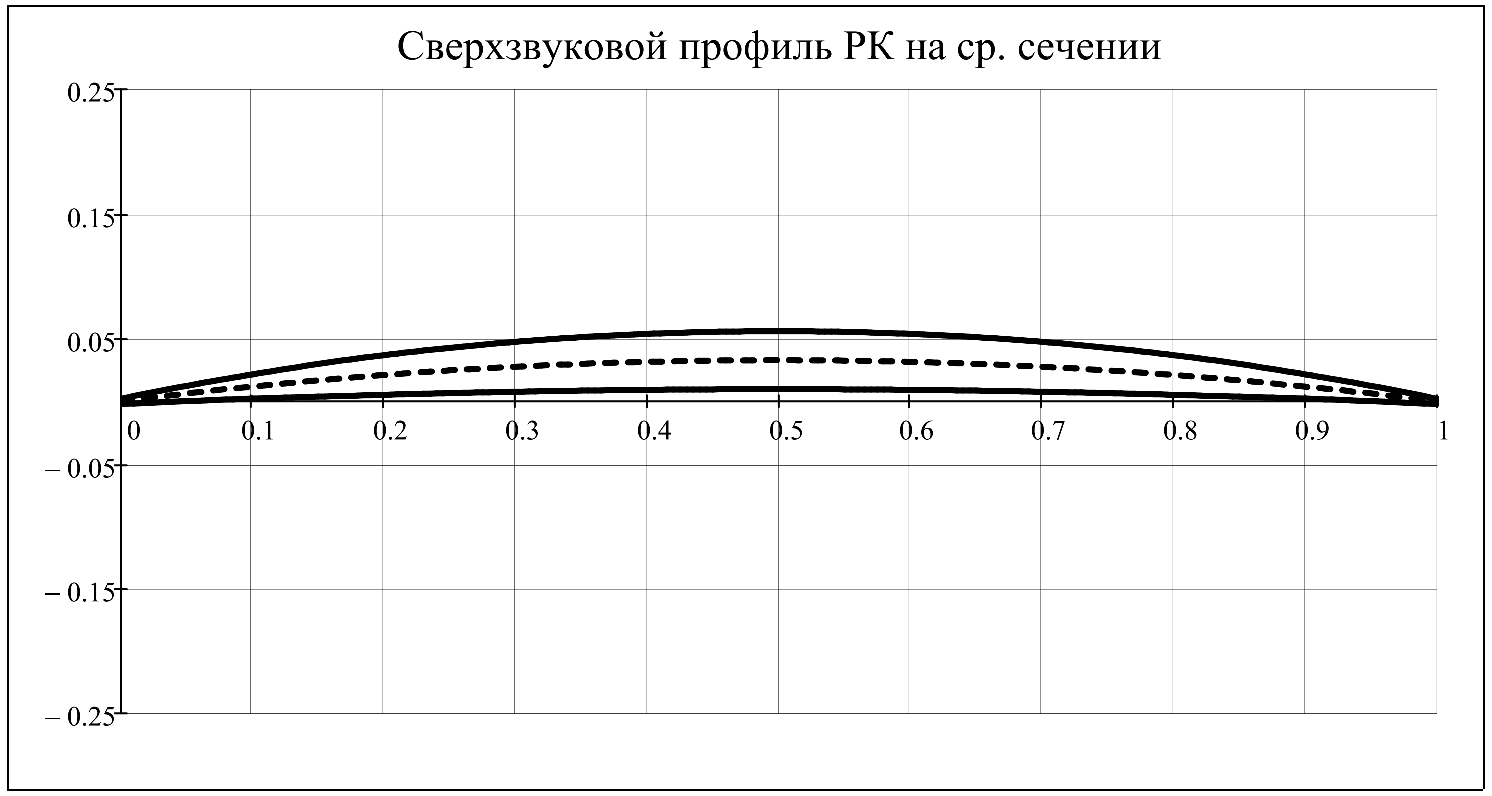


$$AIRFOIL_{subsonic}(x, line, \bar{c}, \theta) = \begin{cases} \text{if } 0 \le x \le 1 \\ \quad interp\left(cspline\left(X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right) + Y/B_{subsonic} \cdot \bar{c}\right), X/B_{subsonic}, y/b_{ср.л}\left(X/B_{subsonic}, \theta\right) + Y/B_{subsonic}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

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

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




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 |
|---|---|
| 1 | 119.87 |
| 2 | 134.75 |
| 3 | 145.45 |

$\cdot 10^{-3}$

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

| | 1 |
|---|---|
| 1 | 119.28 |
| 2 | 133.54 |
| 3 | 143.73 |

$\cdot 10^{-3}$

$area_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 298.38 |
| 2 | 779.71 |
| 3 | 1345.64 |

$\cdot 10^{-6}$

$Sx_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 943.3 |
| 2 | 2120.7 |
| 3 | 3548.4 |

$\cdot 10^{-9}$

$Sy_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 17775.8 |
| 2 | 46938.5 |
| 3 | 86892.0 |

$\cdot 10^{-9}$

$x0_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 59.57 |
| 2 | 60.20 |
| 3 | 64.57 |

$\cdot 10^{-3}$

$y0_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 3.16 |
| 2 | 2.72 |
| 3 | 2.64 |

$\cdot 10^{-3}$

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

| | 1 |
|---|---|
| 1 | 161.30 |
| 2 | 166.60 |
| 3 | 182.75 |

$\cdot 10^{-3}$

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

| | 1 |
|---|---|
| 1 | 143.99 |
| 2 | 165.56 |
| 3 | 182.68 |

$\cdot 10^{-3}$

$area_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2310.37 | | | | | | | | |
| 2 | 892.70 | | | | | | | | |
| 3 | 467.52 | | | | | | | | |

$\cdot 10^{-6}$

$Sx_{rotor}^{T} =$

| | 1 |
|---|---|
| 1 | 39814.7 |
| 2 | 3227.9 |
| 3 | 258.9 |

$\cdot 10^{-9}$

$Sy_{rotor}^{T} =$

| | 1 |
|---|---|
| 1 | 146612.4 |
| 2 | 73887.3 |
| 3 | 42699.6 |

$\cdot 10^{-9}$

$x0_{rotor}^{T} =$

| | 1 |
|---|---|
| 1 | 63.46 |
| 2 | 82.77 |
| 3 | 91.33 |

$\cdot 10^{-3}$

$y0_{rotor}^{T} =$

| | 1 |
|---|---|
| 1 | 17.23 |
| 2 | 3.62 |
| 3 | 0.55 |

$\cdot 10^{-3}$

$Jx_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 3461 |
| 2 | 9375 |
| 3 | 23841 |

$\cdot 10^{-12}$

$Jy_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 1289727 |
| 2 | 3615129 |
| 3 | 7178656 |

$\cdot 10^{-12}$

$Jxy_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 56198 |
| 2 | 132758 |
| 3 | 238268 |

$\cdot 10^{-12}$

$Jx0_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 478.55 |
| 2 | 3606.90 |
| 3 | 14483.55 |

$\cdot 10^{-12}$

$Jy0_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | 230744 |
| 2 | 789412 |
| 3 | 1567759 |

$\cdot 10^{-12}$

$Jxy0_{stator}^{T} =$

| | 1 |
|---|---|
| 1 | -0.16 |
| 2 | 5089.12 |
| 3 | 9135.55 |

$\cdot 10^{-12}$

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

| | 1 |
|---|---|
| 1 | -0.00 |
| 2 | 0.37 |
| 3 | 0.34 |

$\cdot \circ$

$Jx_{rotor}^{T} =$

| | 1 |
|---|---|
| 1 | 819752 |
| 2 | 15738 |
| 3 | 516 |

$\cdot 10^{-12}$

$Jy_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11903414 | | | | | | | | |
| 2 | 7448061 | | | | | | | | |
| 3 | 4749588 | | | | | | | | |

$Jxy_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2623407 | | | | | | | | |
| 2 | 267167 | | | | | | | | |
| 3 | 23649 | | | | | | | | |

$\cdot 10$

$Jx0_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 133622.41 | | | | | | | |
| 2 | 4065.88 | | | | | | | |
| 3 | 372.62 | | | | | | | |

$Jy0_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2599607 | | | | | | | | |
| 2 | 1332528 | | | | | | | | |
| 3 | 849757 | | | | | | | | |

$\cdot 10$

$Jxy0_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 96824.41 | | | | | | | | |
| 2 | -0.77 | | | | | | | | |
| 3 | 0.00 | | | | | | | | |

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

| | 1 |
|---|---|
| 1 | 2.25 |
| 2 | -0.00 |
| 3 | 0.00 |

$\cdot \circ$

$Ju_{stator}^{T} =$ $\cdot 10^{-12}$

| | 1 |
|---|---|
| 1 | 478.55 |
| 2 | 3573.95 |
| 3 | 14429.82 |

$Jv_{stator}^{T} =$ $\cdot 10^{-12}$

| | 1 |
|---|---|
| 1 | 230744 |
| 2 | 789445 |
| 3 | 1567813 |

$Juv_{stator}^{T} =$ $\cdot 10^{-12}$

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

$Jp_{stator}^{T} =$ $\cdot 10^{-12}$

| | 1 |
|---|---|
| 1 | 231223 |
| 2 | 793019 |
| 3 | 1582242 |

$Wp_{stator}^{T} =$ $\cdot 10^{-9}$

| | 1 |
|---|---|
| 1 | 3875.8 |
| 2 | 10841.5 |
| 3 | 20168.9 |

$stiffness_{stator}^{T} =$ $\cdot 10^{-12}$

| | 1 |
|---|---|
| 1 | 880.14 |
| 2 | 12131.62 |
| 3 | 54200.70 |

$Ju_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 129826.54 | | | | | | | | |
| 2 | 4065.88 | | | | | | | | |
| 3 | 372.62 | | | | | | | | |

$Jv_{rotor}^{T} =$ $\cdot 10^{-}$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2603403 | | | | | | | | |
| 2 | 1332528 | | | | | | | | |
| 3 | 849757 | | | | | | | | |

$Juv_{rotor}^{T} =$ $\cdot 10^{-12}$

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

$Jp_{rotor}^{T} =$ $\cdot 10^{-}$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2733229 | | | | | | | | |
| 2 | 1336594 | | | | | | | | |
| 3 | 850130 | | | | | | | | |

$Wp_{rotor}^{T} =$ $\cdot 10^{-9}$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 34617.3 | | | | | | | | |
| 2 | 16133.2 | | | | | | | | |
| 3 | 9308.0 | | | | | | | | |

$stiffness_{rotor}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 284045.72 | | | | | | | |
| 2 | 12211.28 | | | | | | | |
| 3 | 1440.55 | | | | | | | |

$CPx_{stator}{}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 41.702 | | | | | | | | |
| 2 | 46.654 | | | | | | | | |
| 3 | 50.042 | | | | | | | | |

$\cdot 10^{-3}$

$CPx_{rotor}{}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.179 | | | | | | | | |
| 2 | 57.938 | | | | | | | | |
| 3 | 63.932 | | | | | | | | |

$\cdot 10^{-3}$

$CPy_{stator}{}^{T} =$

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

$\cdot 10^{-3}$

$CPy_{rotor}{}^{T} =$

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

$\cdot 10^{-3}$

Результат расчета абсолютных геометрических характеристик сечений Л

Вывод результатов расчета геометрических хар-к сечений Л

Профилирование решеток

Абс. координаты профиля:

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

Профилирование решеток

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

▾ Построение профилей Л РК и НА

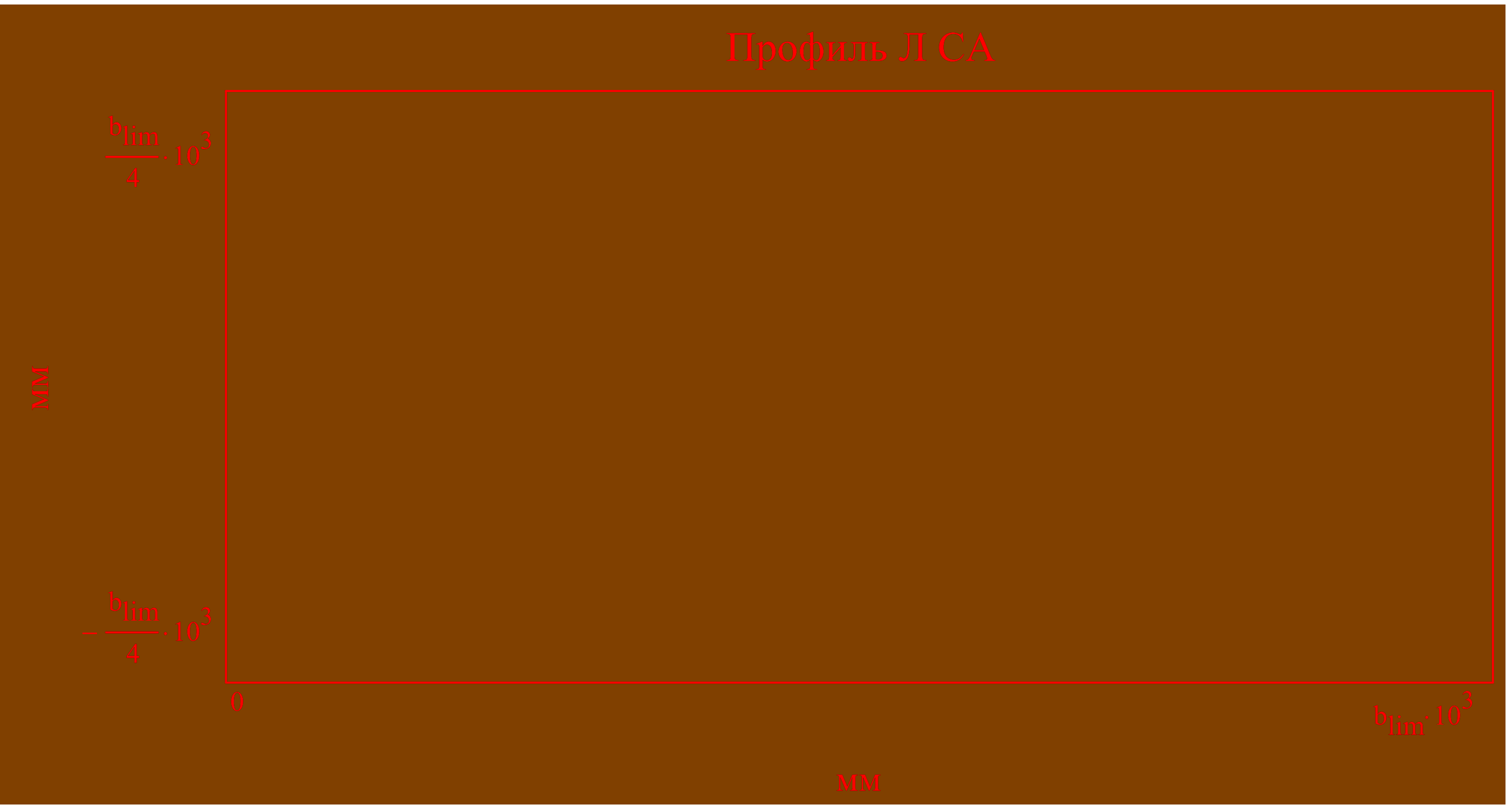
$$\mathrm{AXLE0}(type, x, i, r) = \left| \begin{array}{ll} \dfrac{y0rotor_{i,r}}{chord_{rotor_{i,r}}} + \tan\left(\alpha\_major_{rotor_{i,r}}\right)\cdot\left(x - \dfrac{x0rotor_{i,r}}{chord_{rotor_{i,r}}}\right) & \text{if } type = \text{"rotor"} \\ \dfrac{y0_{stator_{i,r}}}{chord_{stator_{i,r}}} +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

$$b_{lim} = \frac{\mathrm{ceil}\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right)\cdot 10^{2}\right)}{10^{2}} = 190\cdot 10^{-3}$$

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

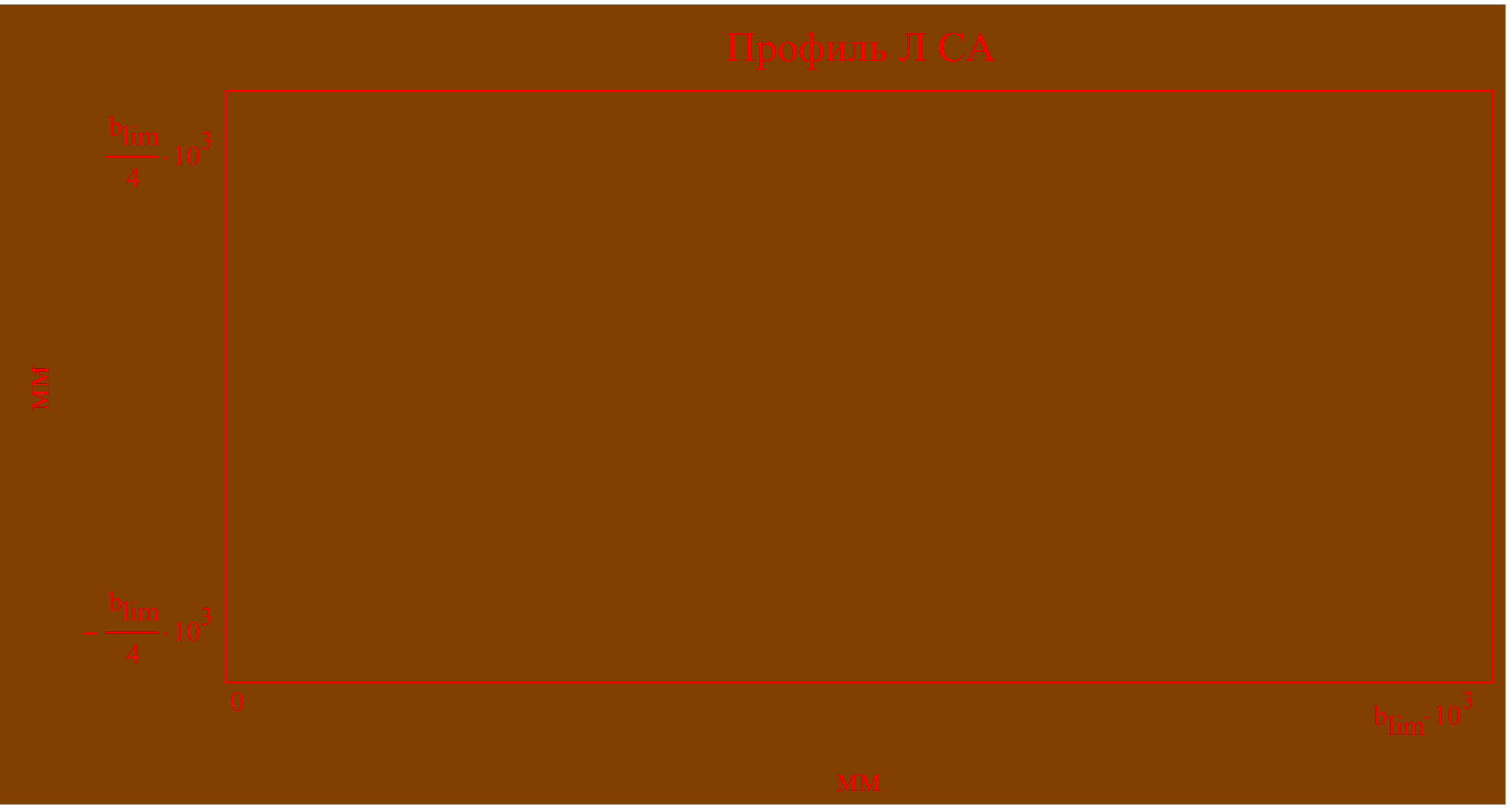
r = 1


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


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

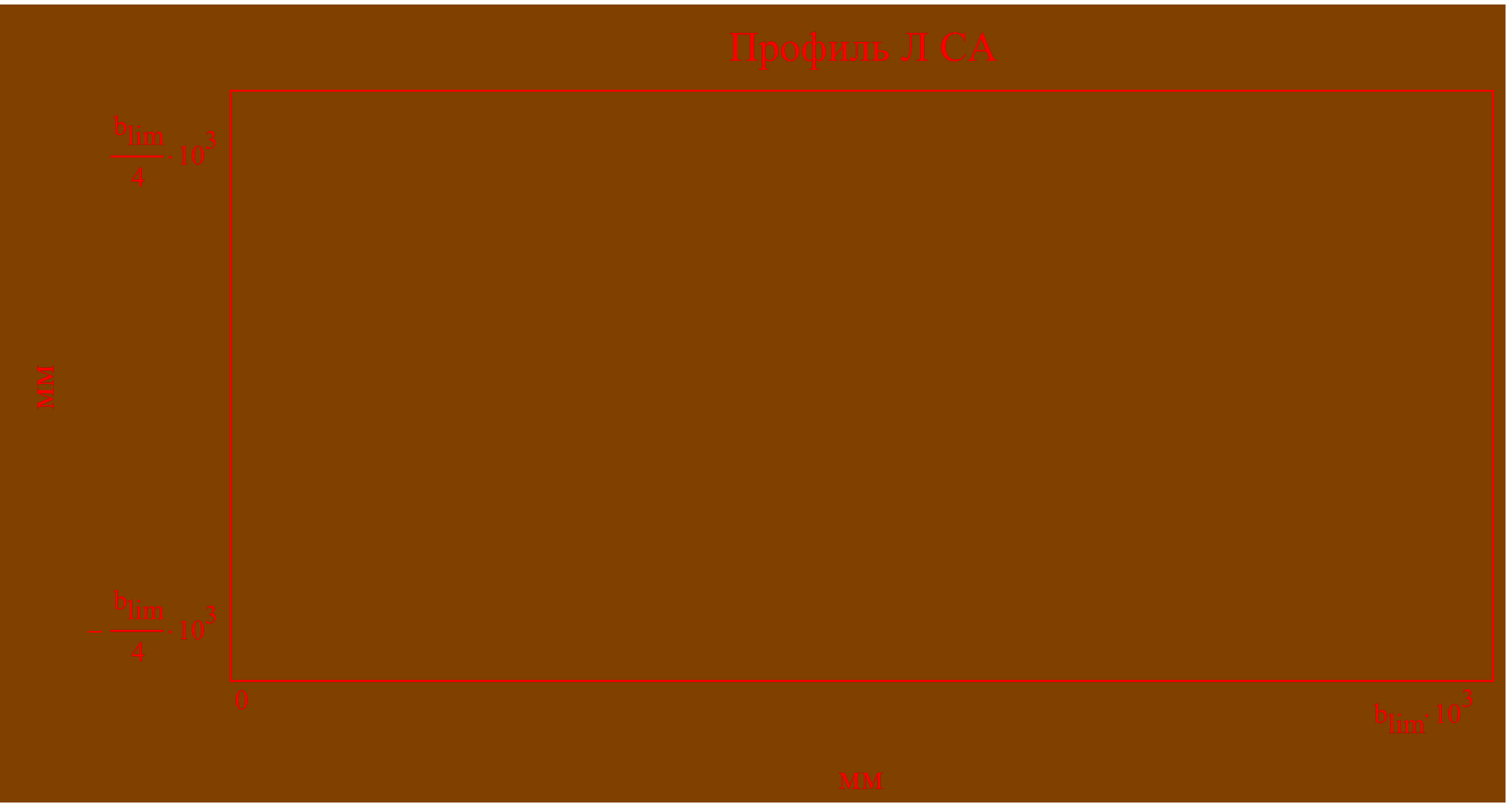
$r = av(N_r)$


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


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

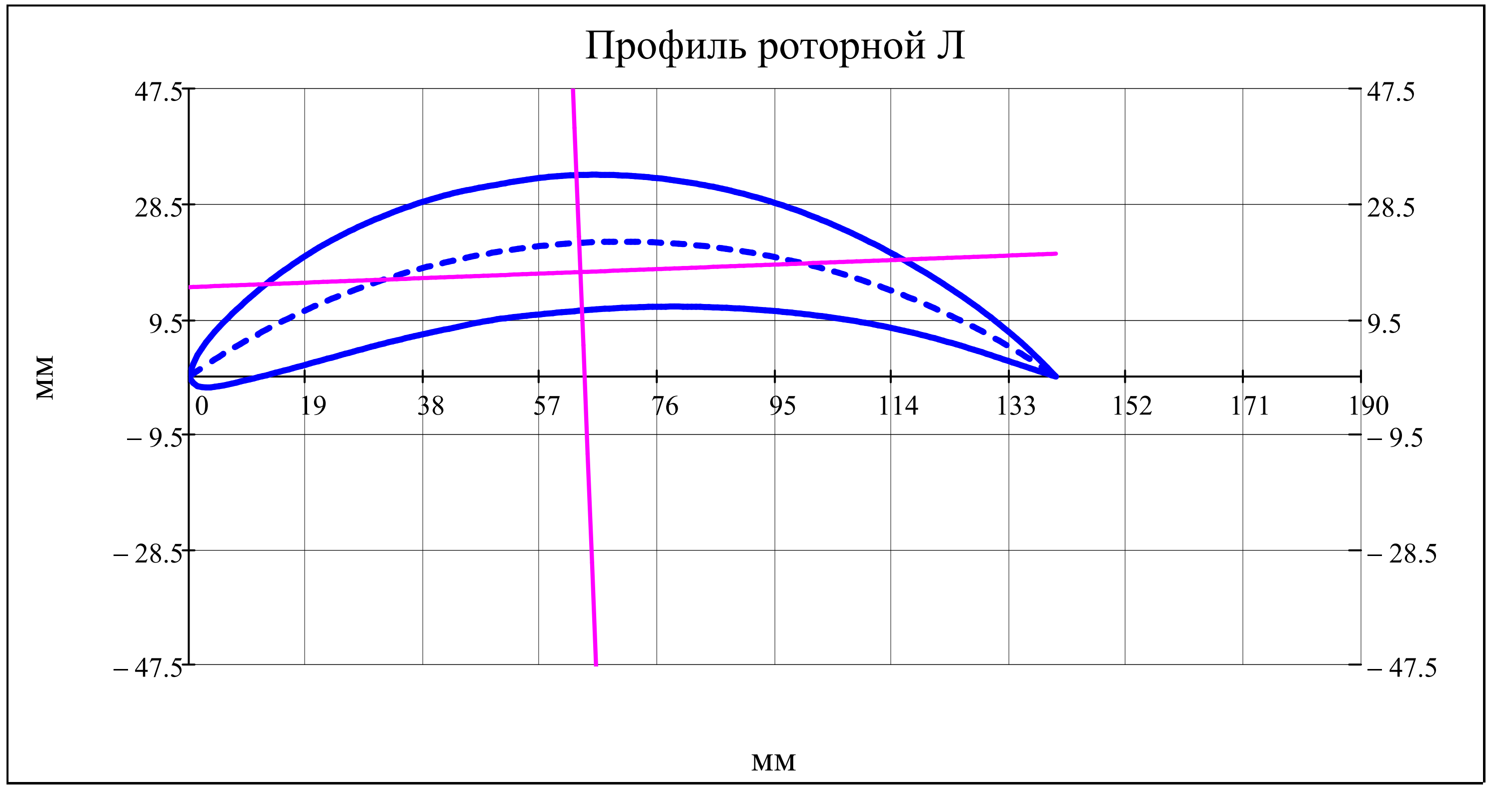
$r = N_r$

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

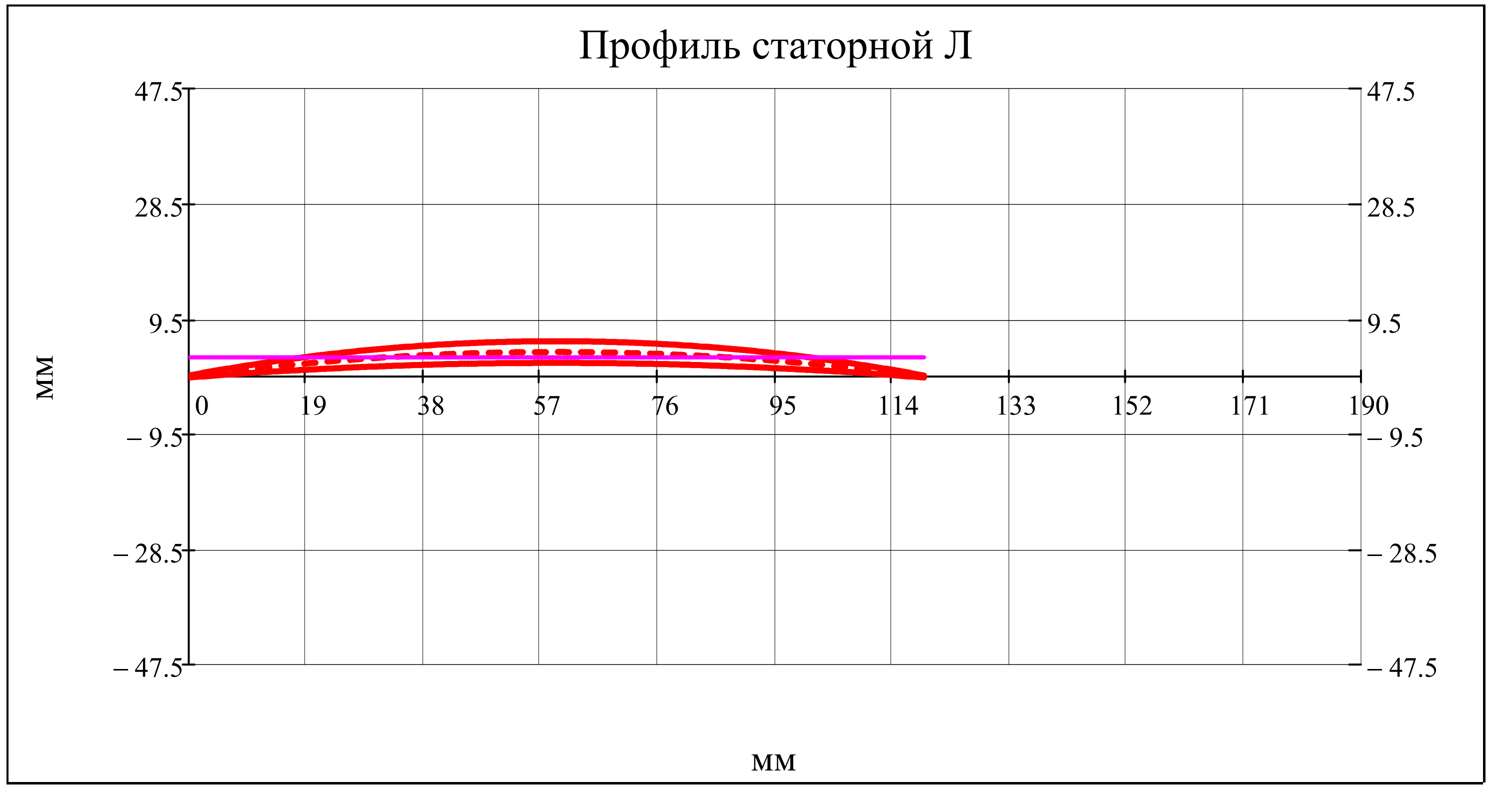



Профиль Л СА
$\frac{b_{lim}}{4} \cdot 10^3$
$-\frac{b_{lim}}{4} \cdot 10^3$
мм
0
$b_{lim} \cdot 10^3$
мм

$r = 1$

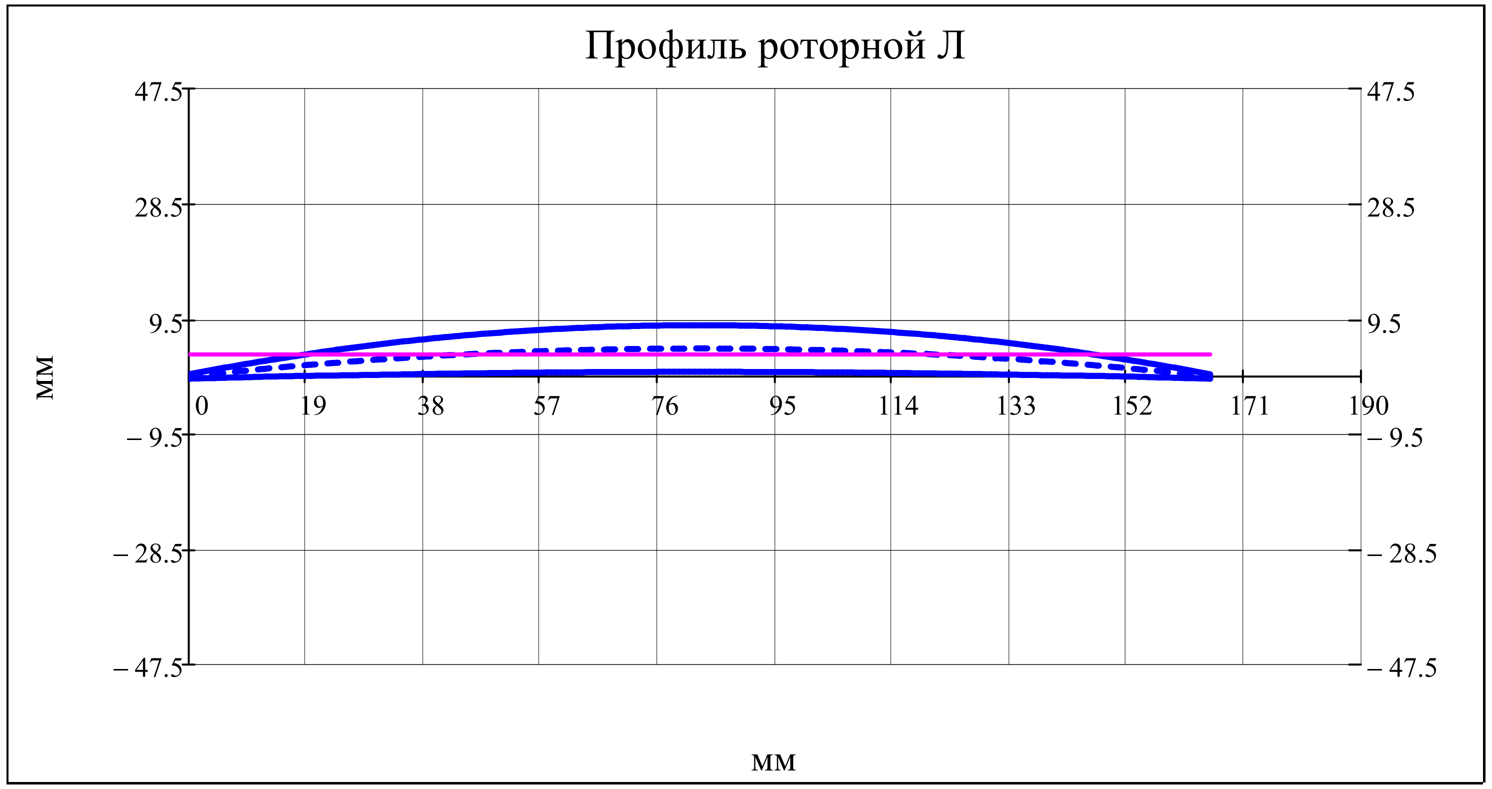


Профиль роторной Л
47.5
28.5
9.5
– 9.5
– 28.5
– 47.5
0
19
38
57
76
95
114
133
152
171
190
мм
мм

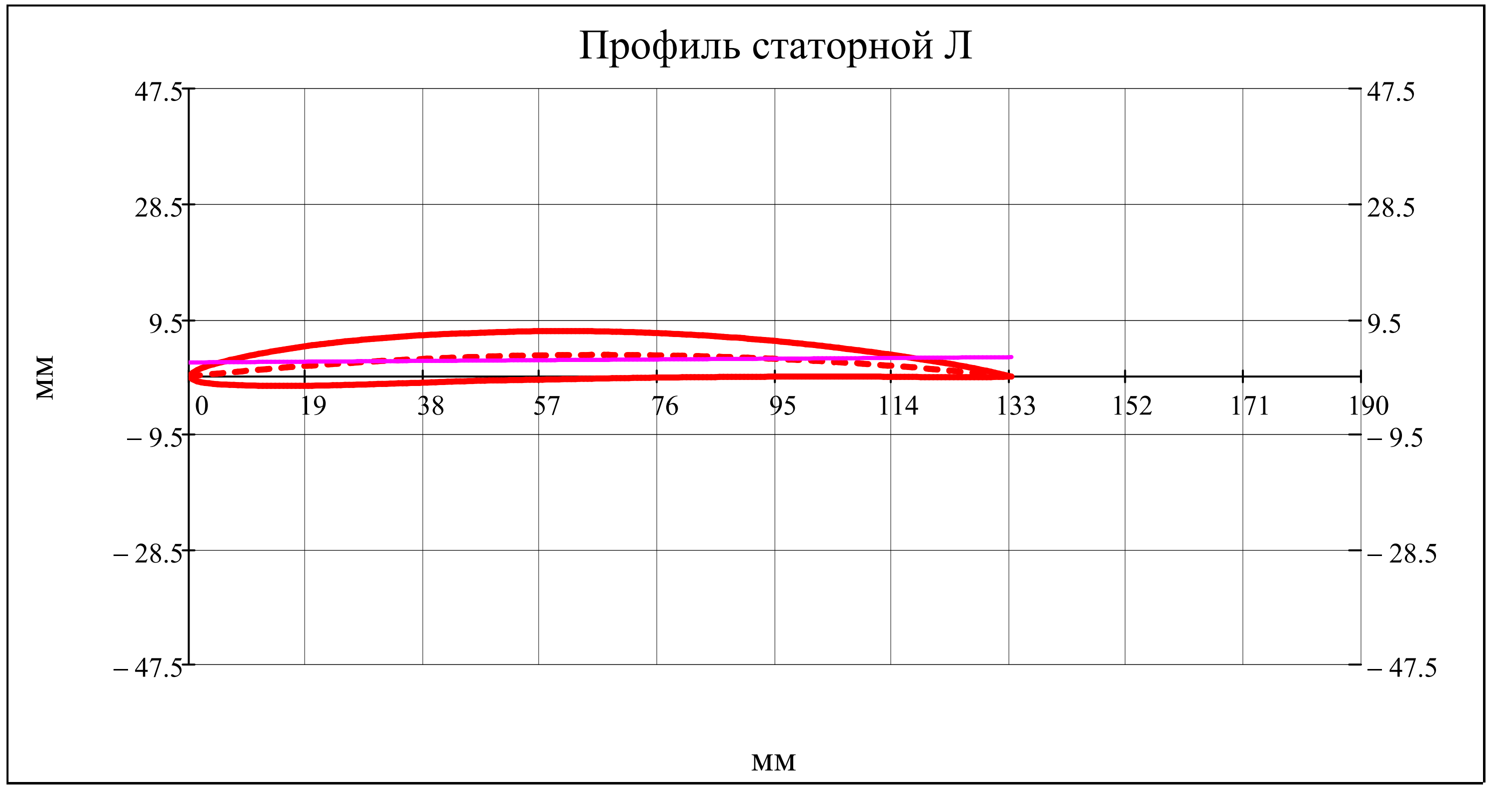



Профиль статорной Л
47.5
28.5
9.5
– 9.5
– 28.5
– 47.5
0
19
38
57
76
95
114
133
152
171
190
мм
мм

$r = av(N_r)$

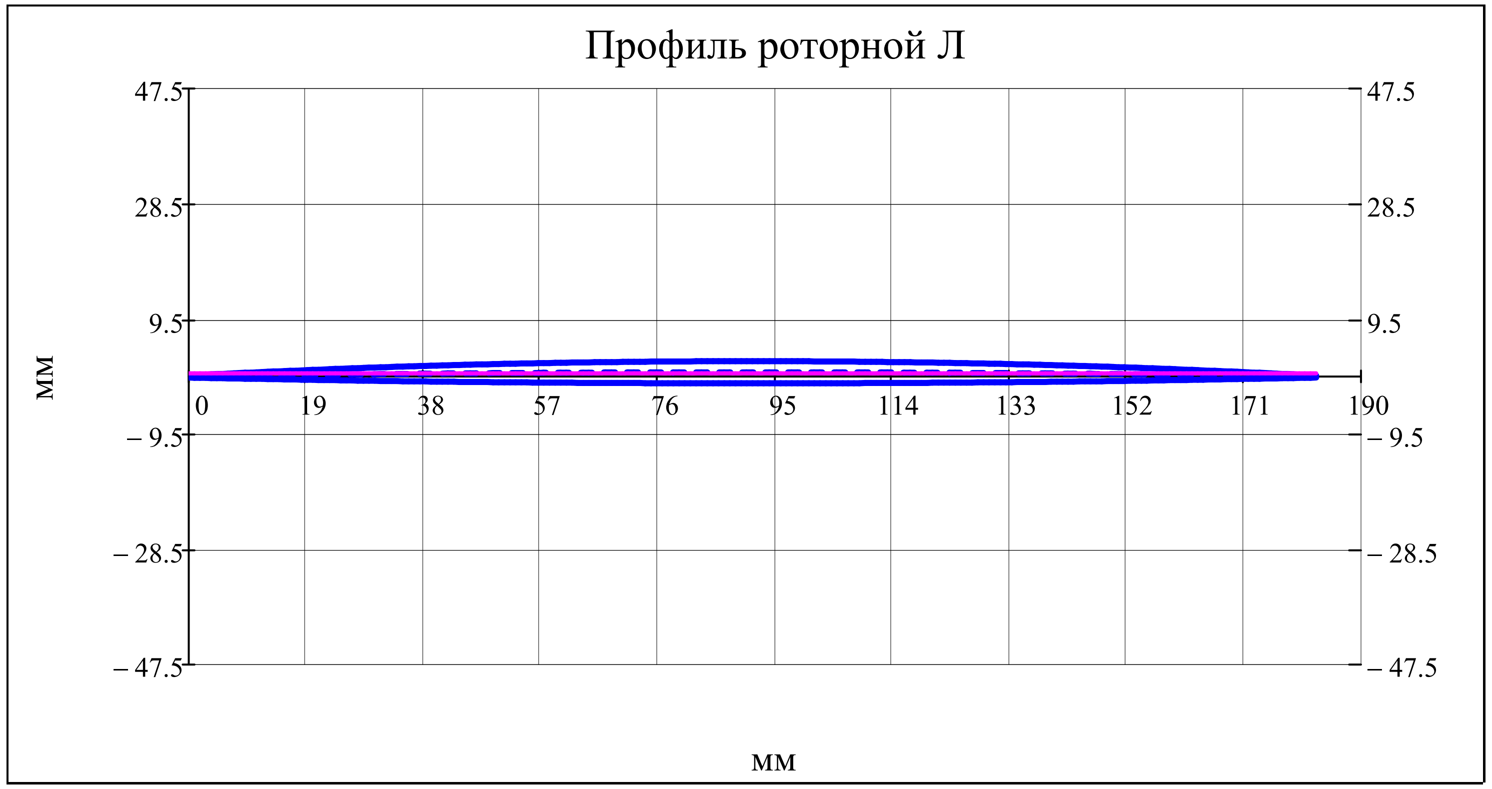


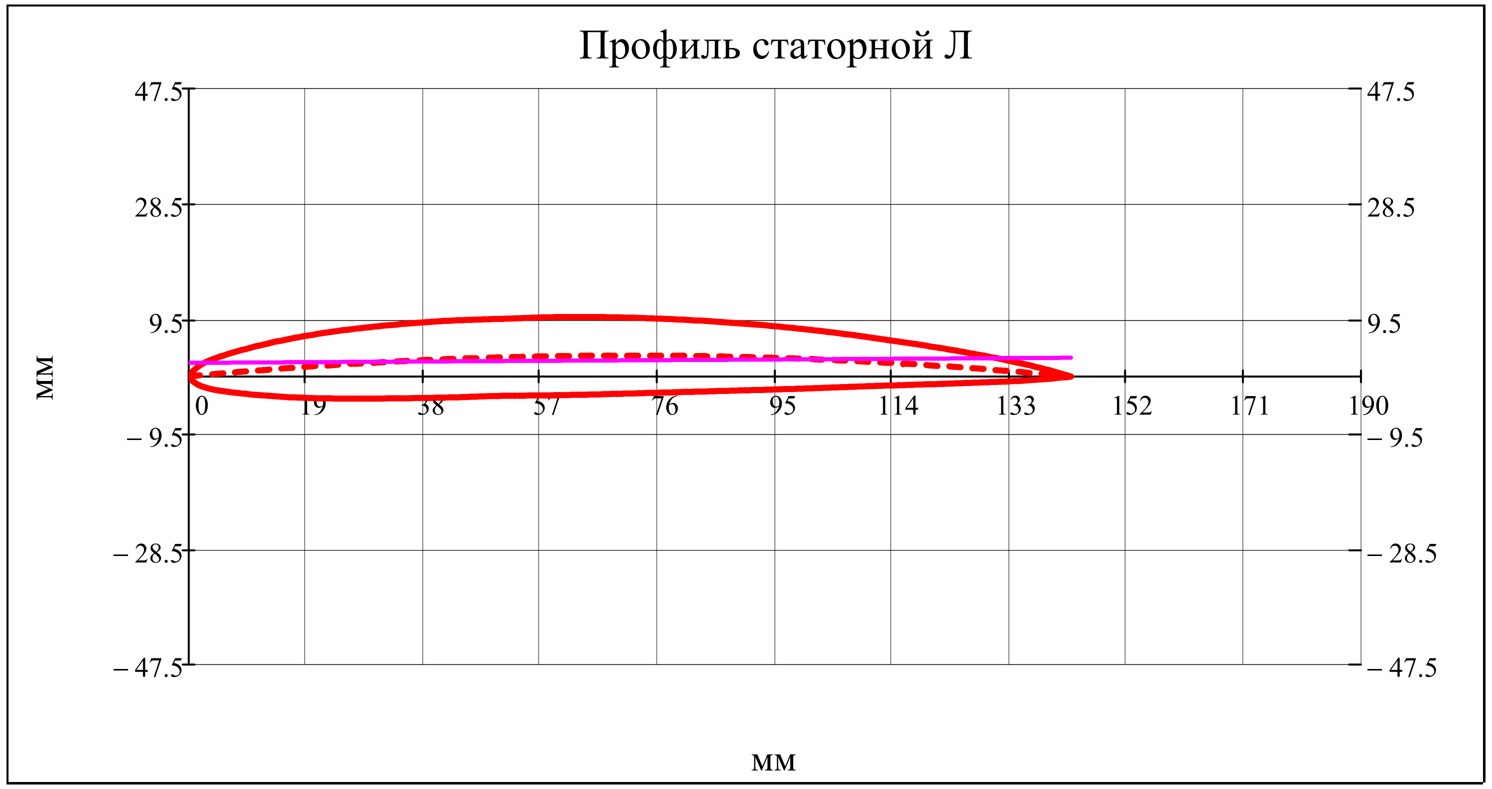
Профиль роторной Л
47.5
28.5
9.5
− 9.5
− 28.5
− 47.5
0
19
38
57
76
95
114
133
152
171
190
мм
мм

Профиль статорной Л
47.5
28.5
9.5
− 9.5
− 28.5
− 47.5
0
19
38
57
76
95
114
133
152
171
190
мм
мм

$r = N_r$




Построение профилей Л РК и НА

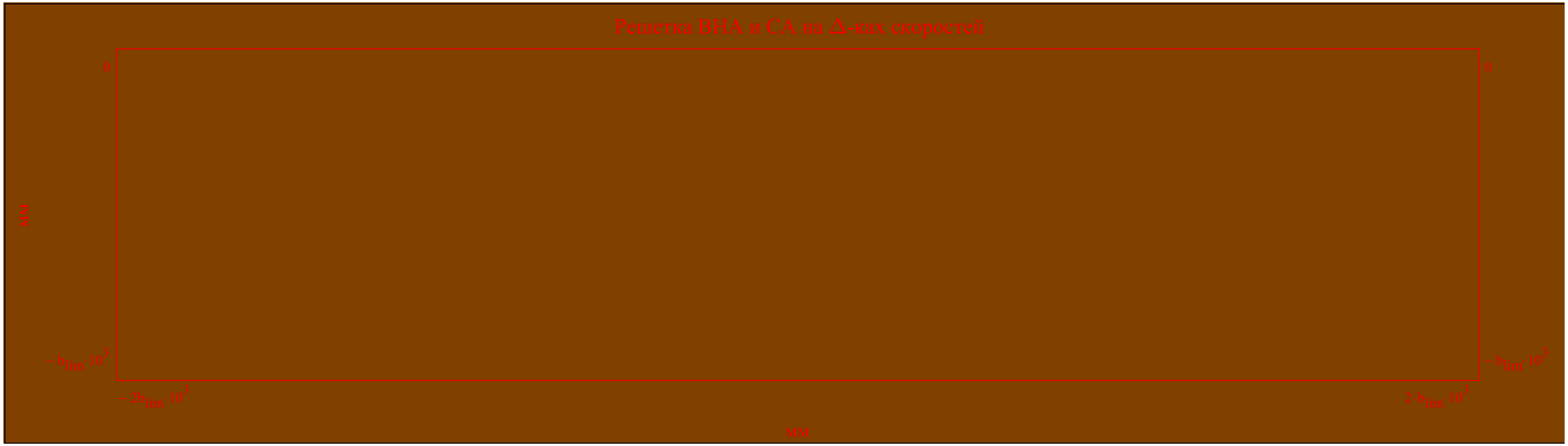
Вывод координат для построения профиля Л

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

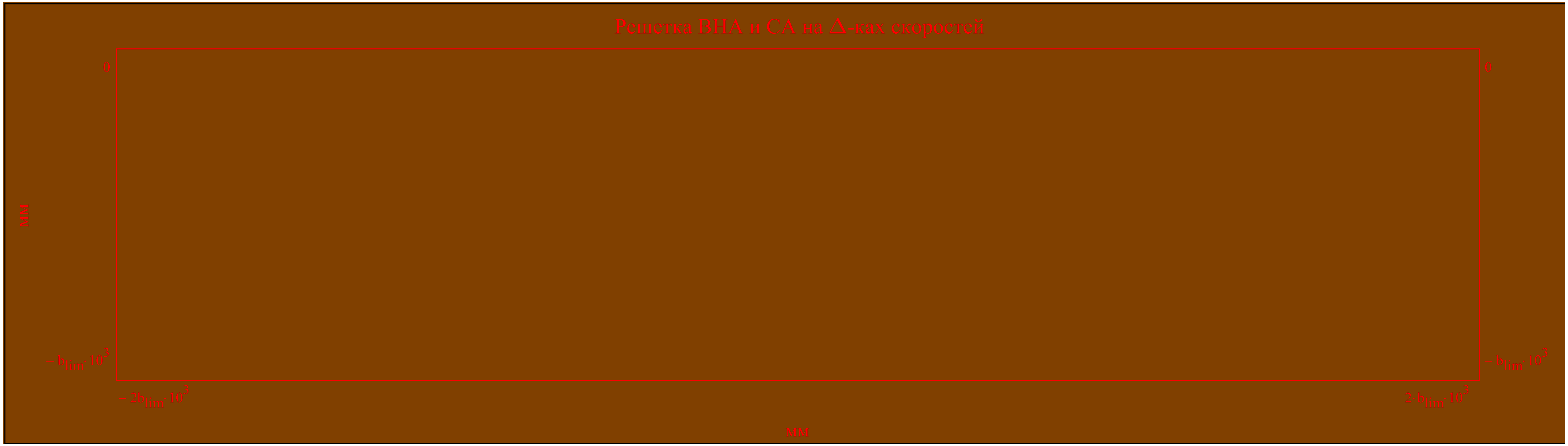
$$b_{lim} = \frac{\mathrm{ceil}\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right)\cdot 10^2\right)}{10^2} = 190\cdot 10^{-3}$$

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

$r = 1$

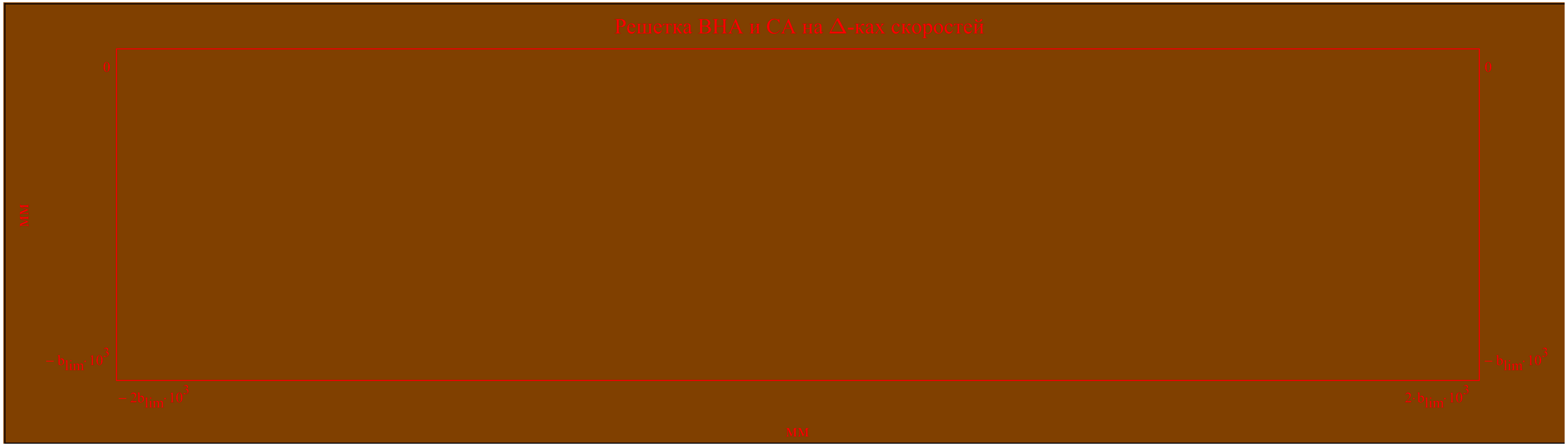


$r = av(N_r)$

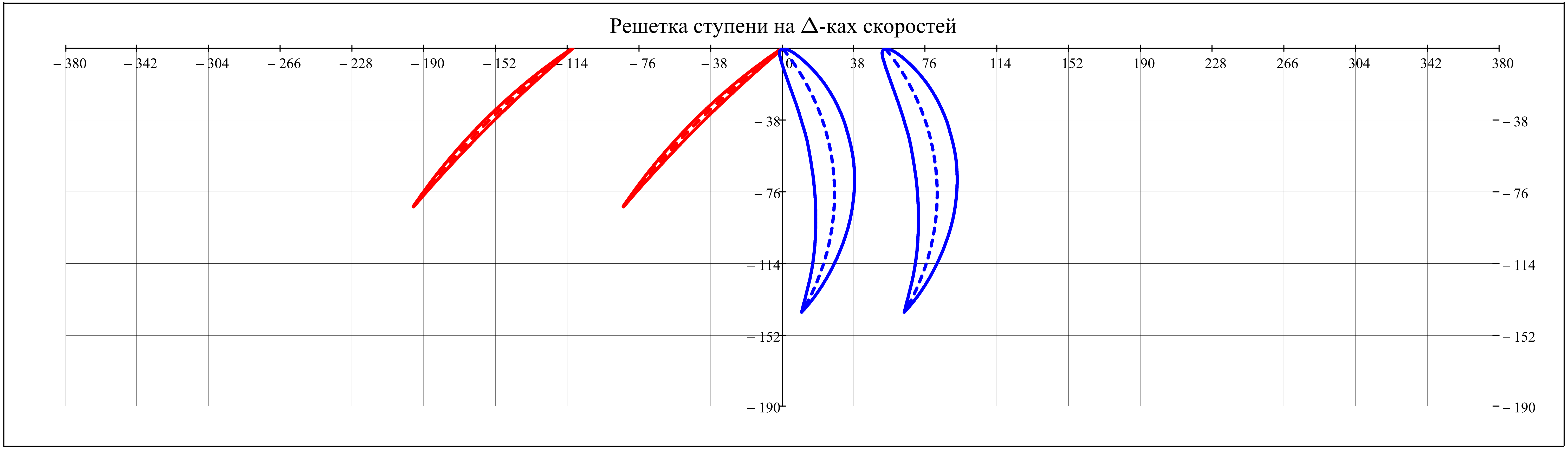


Решетка ВНА и СА на Δ-ках скоростей
0
0
$-b_{lim} \cdot 10^3$
$-b_{lim} \cdot 10^3$
$-2b_{lim} \cdot 10^3$
$2 \cdot b_{lim} \cdot 10^3$
мм
мм

$r = N_r$

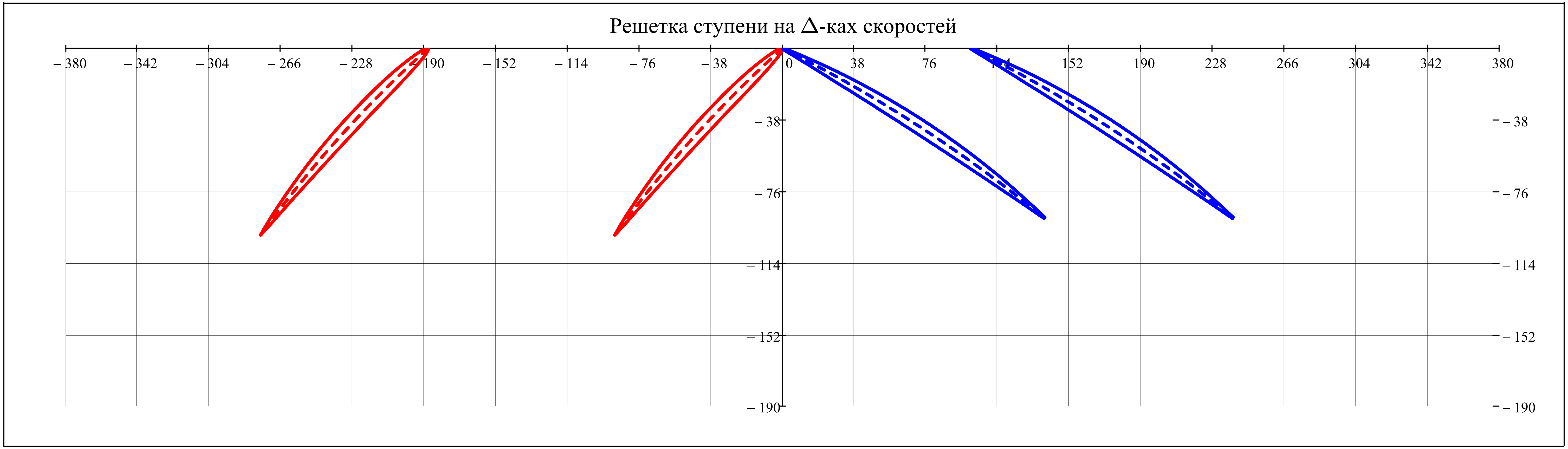

Решетка ВНА и СА на Δ-ках скоростей
0
0
мм
$-b_{lim} \cdot 10^3$
$-b_{lim} \cdot 10^3$
$-2b_{lim} \cdot 10^3$
$2 \cdot b_{lim} \cdot 10^3$
мм

r = 1

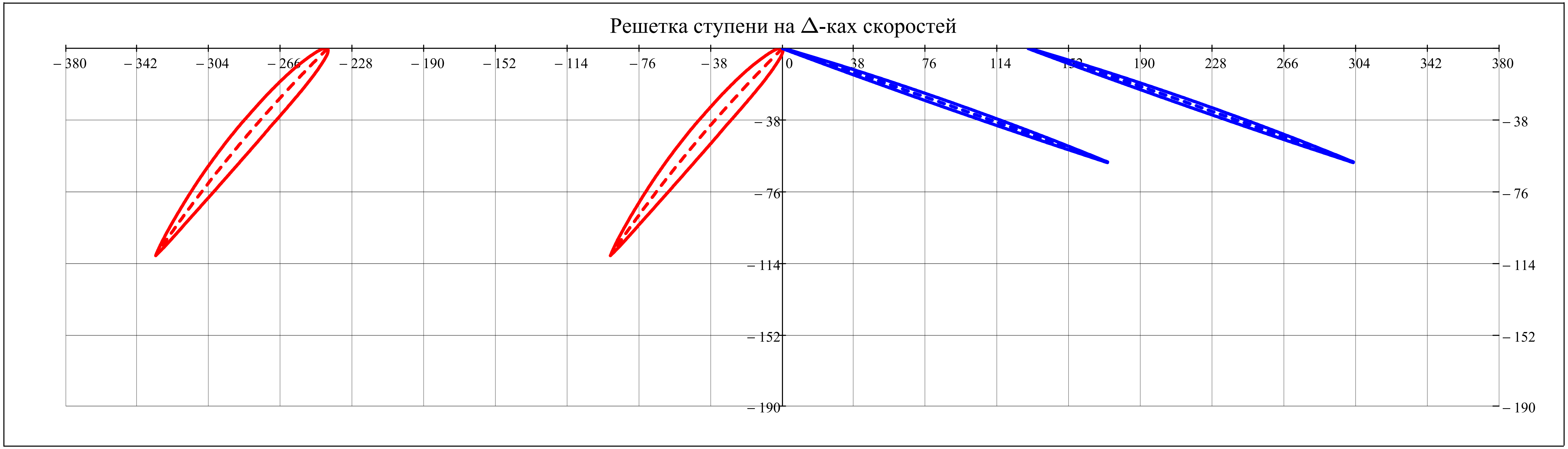


Решетка ступени на Δ-ках скоростей
– 380
– 342
– 304
– 266
– 228
– 190
– 152
– 114
– 76
– 38
0
38
76
114
152
190
228
266
304
342
380
– 38
– 76
– 114
– 152
– 190

$r = av(N_r)$


Решетка ступени на Δ-ках скоростей
– 380
– 342
– 304
– 266
– 228
– 190
– 152
– 114
– 76
– 38
0
38
76
114
152
190
228
266
304
342
380
– 38
– 76
– 114
– 152
– 190

$r = N_r$




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

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

## Радиальные и осевые зазоры и длина К

Радиальный зазор (м) [с.64 казаджан]:

$\overline{\Delta}r = 0.0025$

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

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

$$\Delta_r^T = \begin{array}{c|c} & 1 \\ \hline 1 & 3.84 \end{array} \cdot 10^{-3}$$

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

$\overline{\Delta}a = 0.17$

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

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

$$\Delta a^T = \begin{array}{c|c} & 1 \\ \hline 1 & 28.14 \end{array} \cdot 10^{-3}$$

Односторонний осевой зазор (м):

$$\frac{\Delta a^T}{2} = \begin{array}{c|c} & 1 \\ \hline 1 & 14.07 \end{array} \cdot 10^{-3}$$

Длина ОК (м):

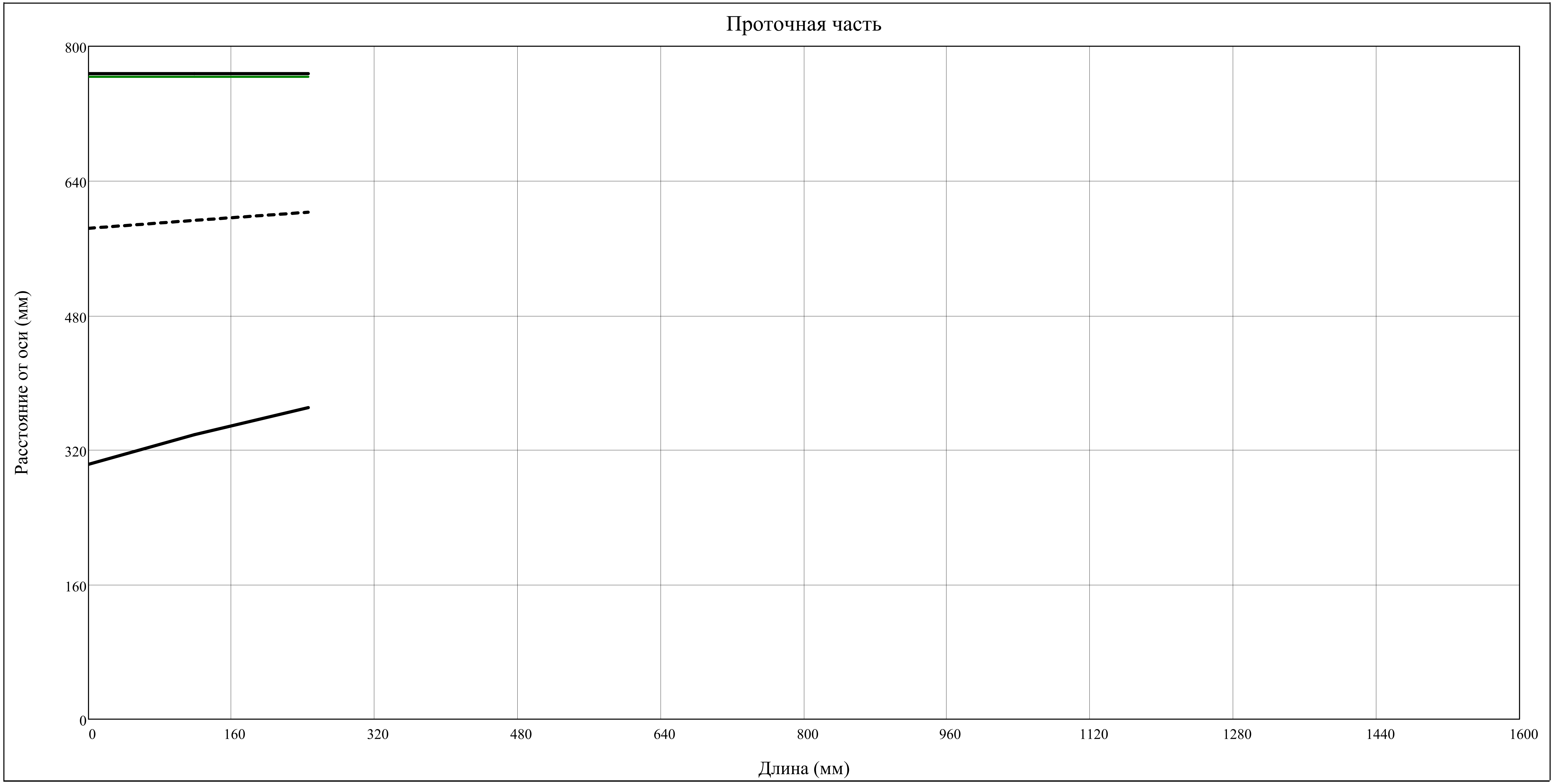
$$Length = \left[ \Delta a_1 + \left| \begin{array}{l} chord_{BHA_{av(N_r)}} \cdot \sin\left(\upsilon_{BHA_{av(N_r)}}\right) \text{ if } BHA = 1 \\ 0 \text{ otherwise} \end{array} \right. \ldots + \sum_{i=1}^{Z} \left(chord_{rotor_{i,av(N_r)}} \cdot \sin\left(\upsilon_{rotor_{i,av(N_r)}}\right)\right) + 2 \cdot \sum_{i=1}^{Z} \Delta a_i + \sum_{i=1}^{Z} \left(chord_{stator_{i,av(N_r)}} \cdot \sin\left(\upsilon_{stator_{i,av(N_r)}}\right)\right) \ldots + \left| \begin{array}{l} chord_{CA_{av(N_r)}} \cdot \sin\left(\upsilon_{CA_{av(N_r)}}\right) \text{ if } CA = 1 \\ 0 \text{ otherwise} \end{array} \right. + \Delta a_Z \right] = 301.9 \cdot 10^{-3}$$

Радиальные и осевые зазоры и длина К

Проточная часть

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

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




Проточная часть

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

Поперечная часть ступени

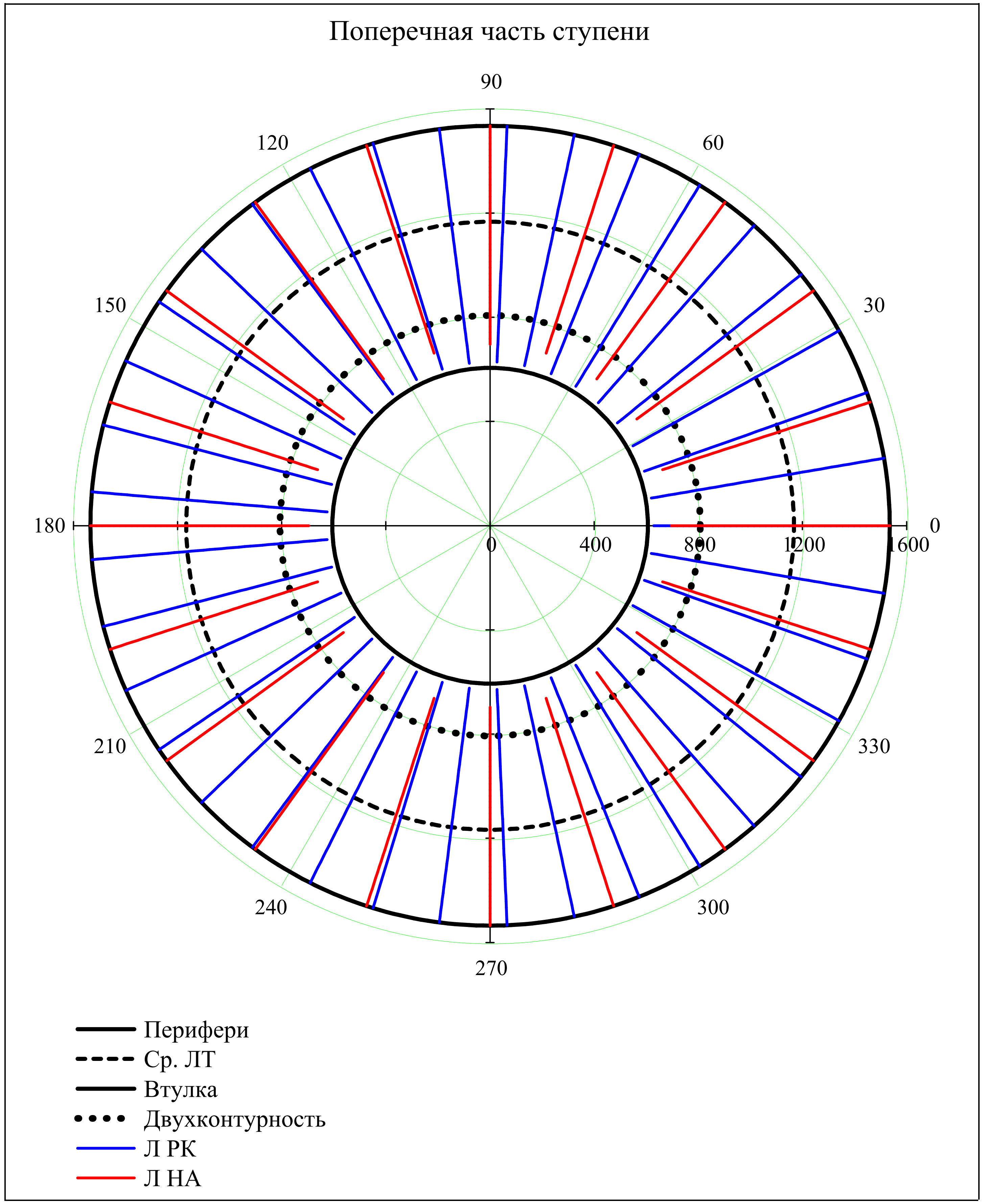
$$r := \min(D), \min(D) + \frac{\max(D) - \min(D)}{N_{dis}} .. \max(D)$$

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

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

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

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




Поперечная часть ступени

Выбор материала Л

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

Выбранный материал Л:

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

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

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 | "ВТ23" | | | | | | | | |

$\rho\_blade^T =$

| | 1 |
|---|---|
| 1 | 4570 |

$\sigma\_blade\_long^T =$

| | 1 |
|---|---|
| 1 | 230.0 |

$\cdot 10^6$

Выбор материала Л

Расчет собственных частот колебаний Л

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

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 315 | 225 | | | | | | | | | | | | | | | | |
| 2 | 944 | 674 | | | | | | | | | | | | | | | | |
| 3 | 1573 | 1124 | | | | | | | | | | | | | | | | |
| 4 | 2202 | 1573 | | | | | | | | | | | | | | | | |
| 5 | 2831 | 2023 | | | | | | | | | | | | | | | | |
| 6 | 3460 | 2472 | | | | | | | | | | | | | | | | |

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 48 | 41 | | | | | | | | | | | | | | | | |
| 2 | 298 | 254 | | | | | | | | | | | | | | | | |
| 3 | 835 | 711 | | | | | | | | | | | | | | | | |
| 4 | 1637 | 1395 | | | | | | | | | | | | | | | | |
| 5 | 2705 | 2305 | | | | | | | | | | | | | | | | |
| 6 | 4039 | 3442 | | | | | | | | | | | | | | | | |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 629 | 450 | | | | | | | | | | | | | | | | |
| 2 | 1258 | 899 | | | | | | | | | | | | | | | | |
| 3 | 1888 | 1349 | | | | | | | | | | | | | | | | |
| 4 | 2517 | 1798 | | | | | | | | | | | | | | | | |
| 5 | 3146 | 2248 | | | | | | | | | | | | | | | | |
| 6 | 3775 | 2697 | | | | | | | | | | | | | | | | |

Расчет собственных частот колебаний Л

Вывод результатов расчета собственных частот колебаний Л

Расчетный узел: $type = "compressor"$

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

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

Расчет Л на прочность

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Расчет Л на прочность

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

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

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 | 7.216 | | | | | | | | |
| 2 | -1.633 | | | | | | | | |
| 3 | -0.389 | | | | | | | | |

$\cdot 10^{-3}$

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

| | 1 |
|---|---|
| 1 | 16.326 |
| 2 | 4.858 |
| 3 | 91.332 |

$\cdot 10^{-3}$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -59.370 | | | | | | | | |
| 2 | 82.748 | | | | | | | | |
| 3 | -0.718 | | | | | | | | |

$\cdot 10^{-3}$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -22.714 | | | | | | | | |
| 2 | -4.352 | | | | | | | | |
| 3 | -91.332 | | | | | | | | |

$\cdot 10^{-3}$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.000 | | | | | | | | |
| 2 | -1.516 | | | | | | | | |
| 3 | -3.040 | | | | | | | | |

$\cdot 10^{-3}$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.665 | | | | | | | | |
| 2 | 4.797 | | | | | | | | |
| 3 | 7.211 | | | | | | | | |

$\cdot 10^{-3}$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 59.574 | | | | | | | | |
| 2 | -42.901 | | | | | | | | |
| 3 | -34.592 | | | | | | | | |

$\cdot 10^{-3}$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -3.335 | | | | | | | | |
| 2 | -3.952 | | | | | | | | |
| 3 | -6.018 | | | | | | | | |

$\cdot 10^{-3}$

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

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 26.78 | | | | | | | | |
| 2 | -59.26 | | | | | | | | |
| 3 | 0.00 | | | | | | | | |

$\cdot 10^{6}$

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

| | 1 |
|---|---|
| 1 | 1 |
| 2 | 1 |
| 3 | 1 |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -45.07 | | | | | | | | |
| 2 | 57.75 | | | | | | | | |
| 3 | 0.00 | | | | | | | | |

$\cdot 10^{6}$

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

| | 1 |
|---|---|
| 1 | 1 |
| 2 | 1 |
| 3 | 1 |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.93 | | | | | | | | |
| 2 | 184.89 | | | | | | | | |
| 3 | 181.78 | | | | | | | | |

$\cdot 10^{6}$

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

| | 1 |
|---|---|
| 1 | 1 |
| 2 | 0 |
| 3 | 0 |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -4.94 | | | | | | | | |
| 2 | -151.32 | | | | | | | | |
| 3 | -150.41 | | | | | | | | |

$\cdot 10^{6}$

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

| | 1 |
|---|---|
| 1 | 1 |
| 2 | 1 |
| 3 | 1 |

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

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

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 178.06 | | | | | | | | |
| 2 | 176.42 | | | | | | | | |
| 3 | 0.00 | | | | | | | | |

$\cdot 10^6$

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.94 | | | | | | | | |
| 2 | 184.89 | | | | | | | | |
| 3 | 181.78 | | | | | | | | |

$\cdot 10^6$

$$\begin{pmatrix} safety_{rotor} \\ safety_{stator} \end{pmatrix} = \left| \begin{array}{l} \text{for } i \in 1..Z \\ \quad \text{for } r \in 1..N_r \\ \quad\quad \left| \begin{array}{l} safety_{rotor_{i,r}} = \left| \begin{array}{ll} \dfrac{\sigma\_blade\_long_i}{\sigma_{rotor_{i,r}}} & \text{if } \sigma_{rotor_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{array} \right. \\ safety_{stator_{i,r}} = \left| \begin{array}{ll} \dfrac{\sigma\_blade\_long_i}{\sigma_{stator_{i,r}}} & \text{if } \sigma_{stator_{i,r}} \neq 0 \\ \infty & \text{otherwise} \end{array} \right. \end{array} \right. \\ \begin{pmatrix} safety_{rotor} \\ safety_{stator} \end{pmatrix} \end{array} \right.$$

$safety_{rotor}{}^{T} =$

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| 1 | 1.29 | | | | | | |
| 2 | 1.30 | | | | | | |
| 3 | )000000000000000000000000000000. | | | | | | |

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

| | 1 |
|---|---|
| 1 | 0 |
| 2 | 1 |
| 3 | 1 |

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

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 58.31 | | | | |
| 2 | 1.24 | | | | |
| 3 | 1.27 | | | | |

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

| | 1 |
|---|---|
| 1 | 1 |
| 2 | 0 |
| 3 | 0 |

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

$$b_{lim} := \frac{\mathrm{ceil}\left(\max\left(chord_{rotor_{j,N_r}}, chord_{stator_{j,N_r}}\right)\cdot 10^2\right)}{10^2} = 190\cdot 10^{-3}$$

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

| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 302.9 | 583.4 | 767.5 |
| 2 | 338.1 | 593.0 | 767.5 |
| 3 | 370.4 | 602.6 | 767.5 |

$\cdot 10^{-3}$

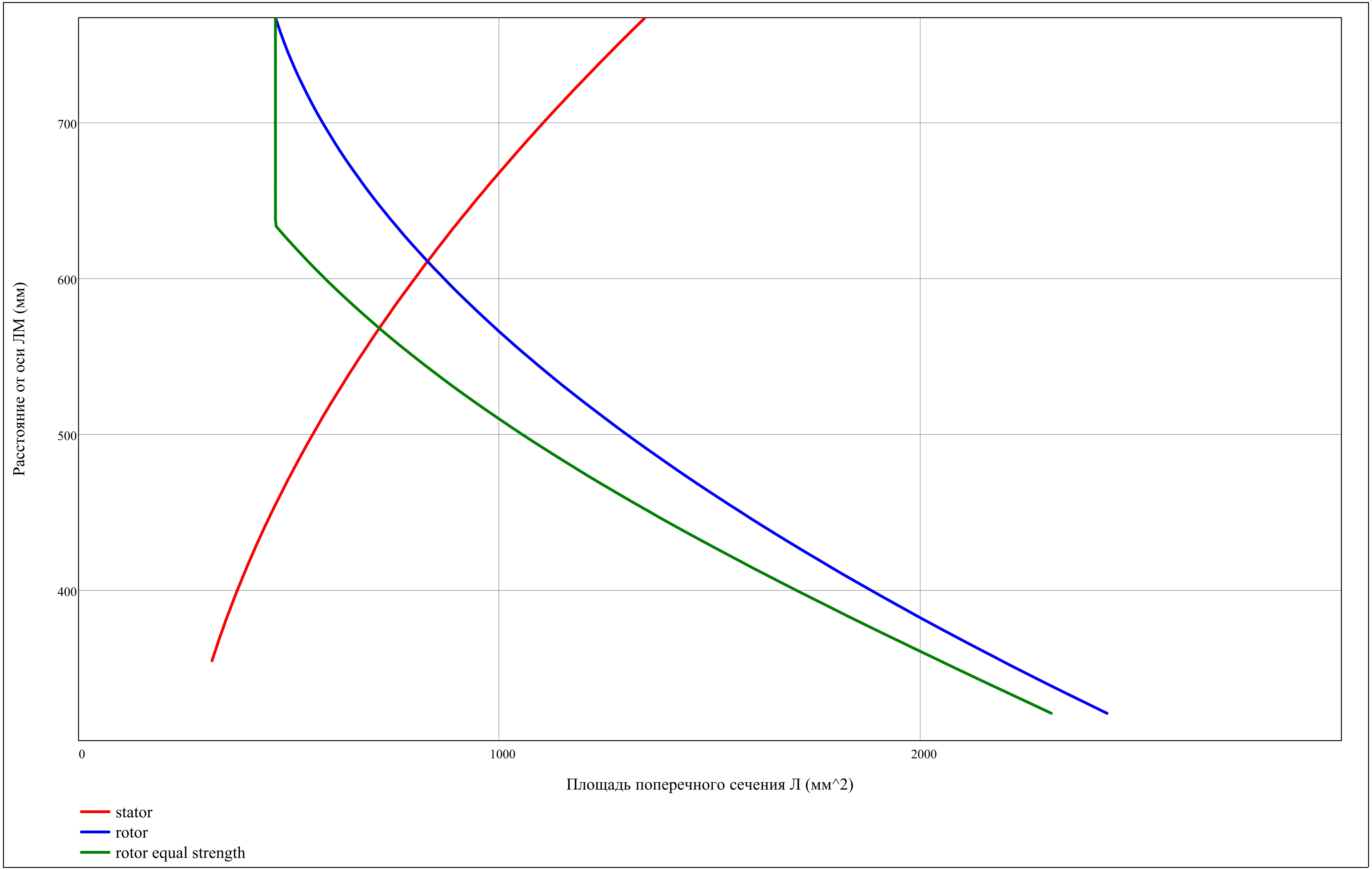
Дискретизация по высоте Л:

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

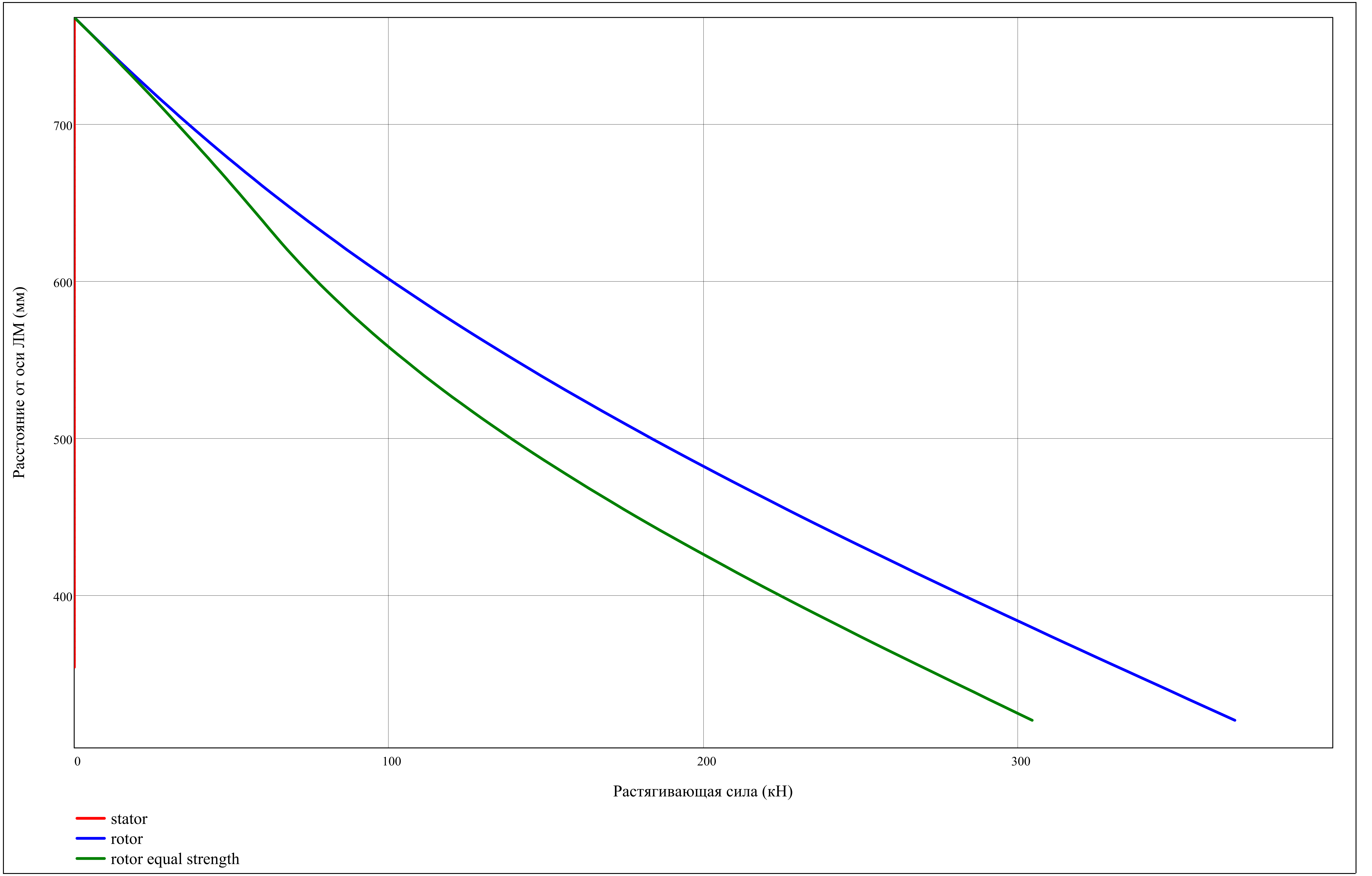
$$z_{rotor} := \left| \begin{array}{ll} \mathrm{mean}(Rj_{1,1}, Rj_{2,1}), \mathrm{mean}(Rj_{1,1}, Rj_{2,1}) + \frac{\mathrm{mean}(Rj_{1,N_r}, Rj_{2,N_r}) - \mathrm{mean}(Rj_{1,1}, Rj_{2,1})}{100} .. \mathrm{mean}(Rj_{1,N_r}, Rj_{2,N_r}) & \text{if } type = \text{"compressor"} \\ \mathrm{mean}(Rj_{2,1},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

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

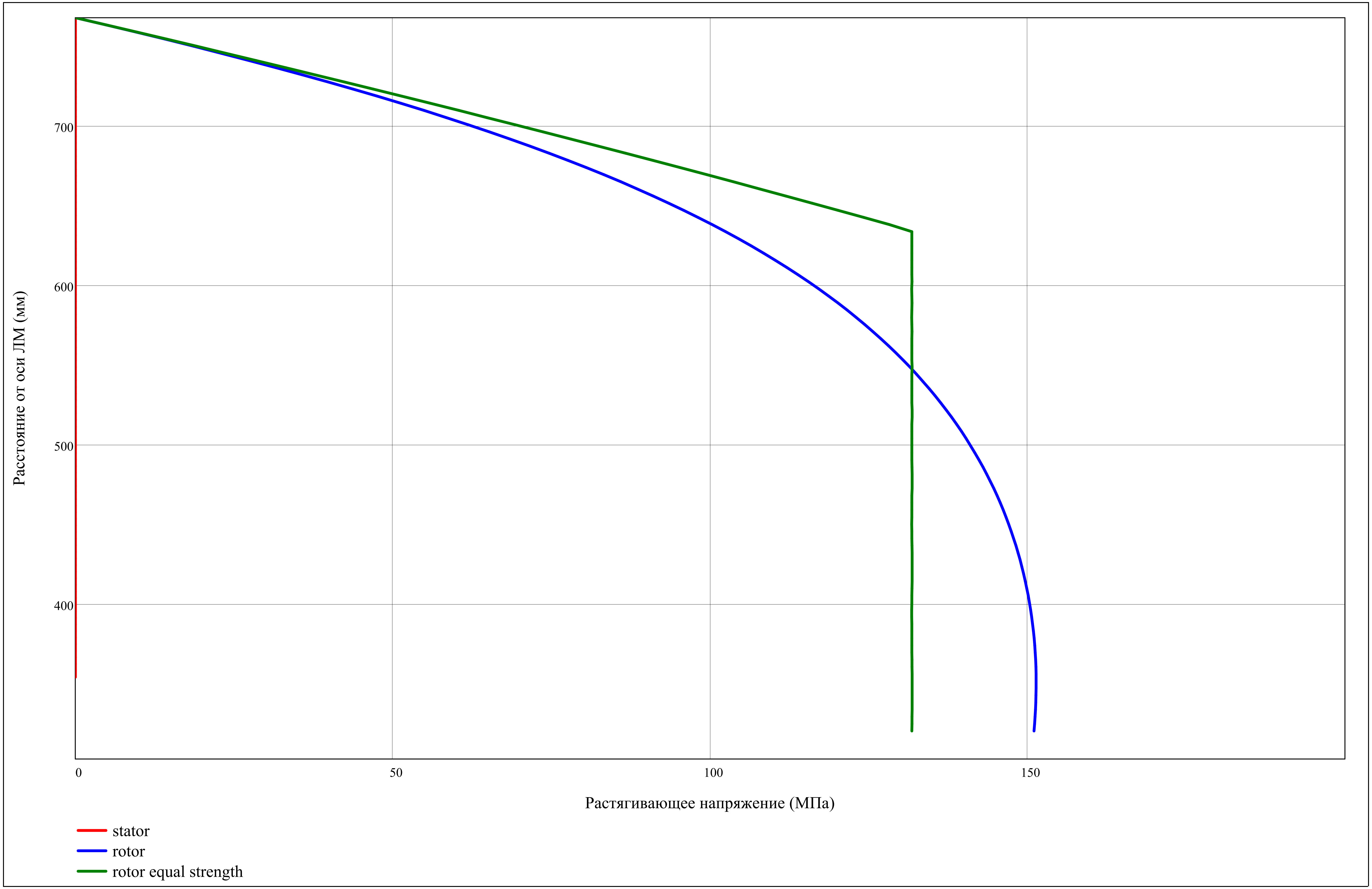
Результаты расчета на прочность Л

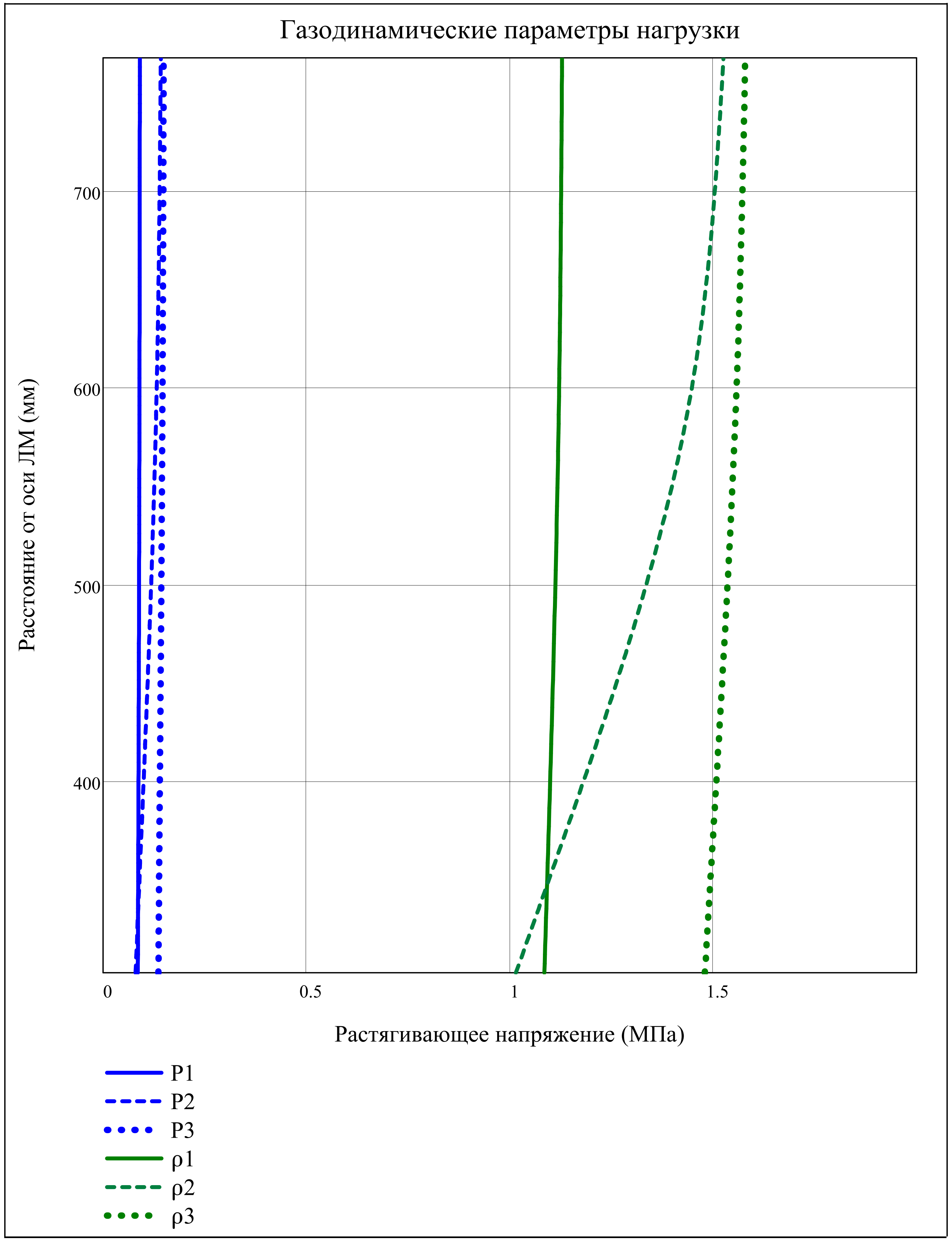


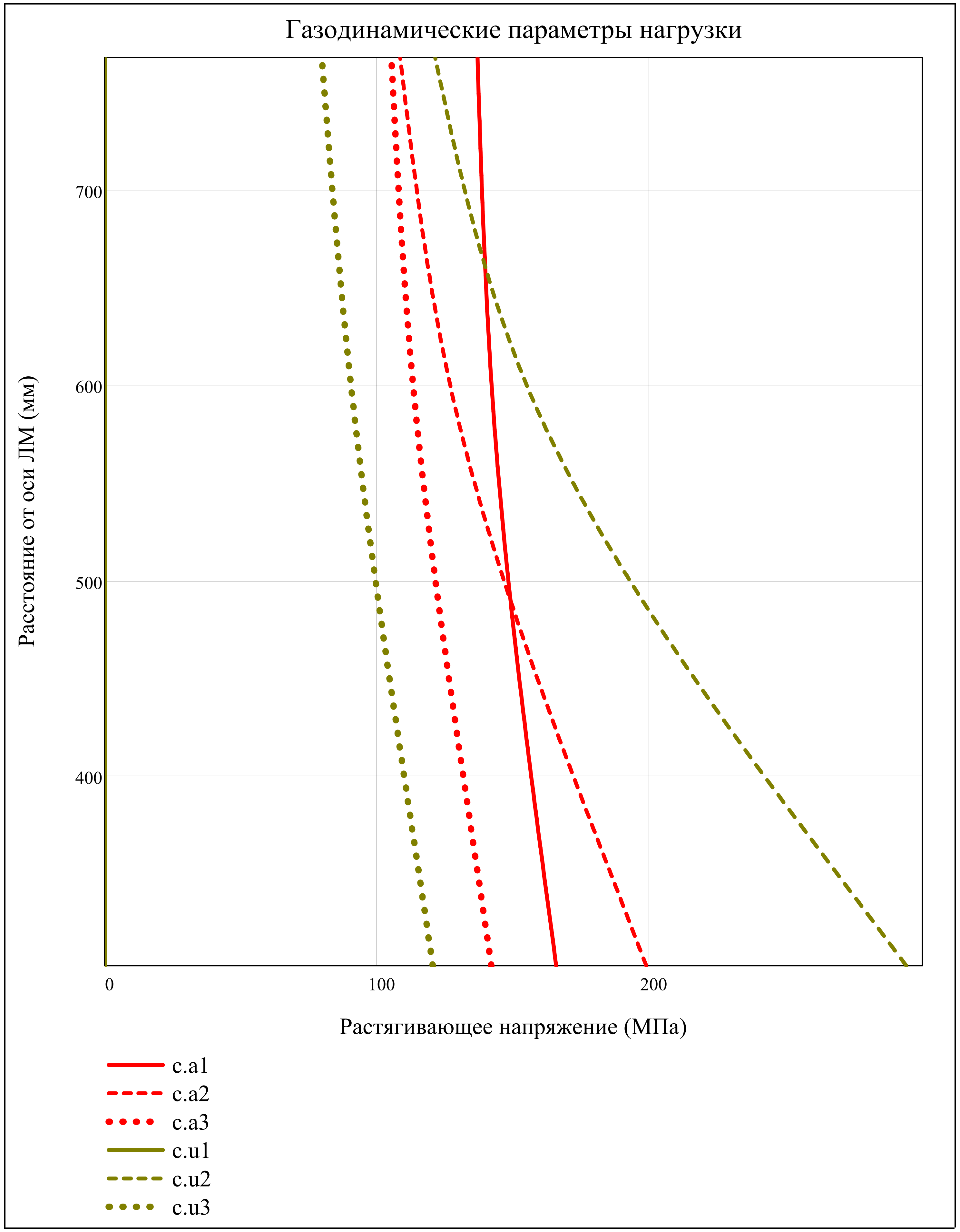
700
600
500
400
0
1000
2000
Расстояние от оси ЛМ (мм)
Площадь поперечного сечения Л (мм^2)
stator
rotor
rotor equal strength

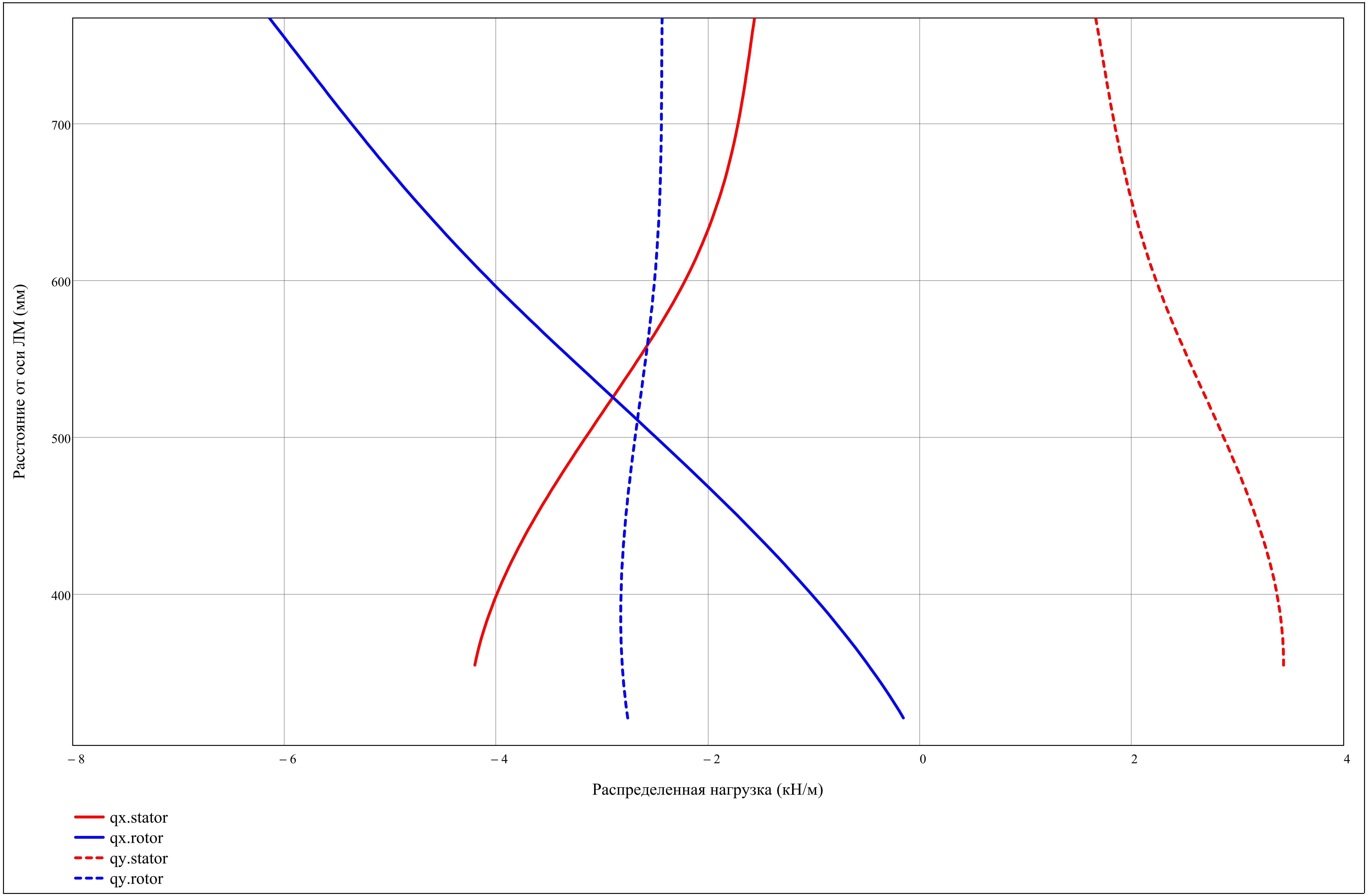


Расстояние от оси ЛМ (мм)
700
600
500
400
0
100
200
300
Растягивающая сила (кН)
stator
rotor
rotor equal strength

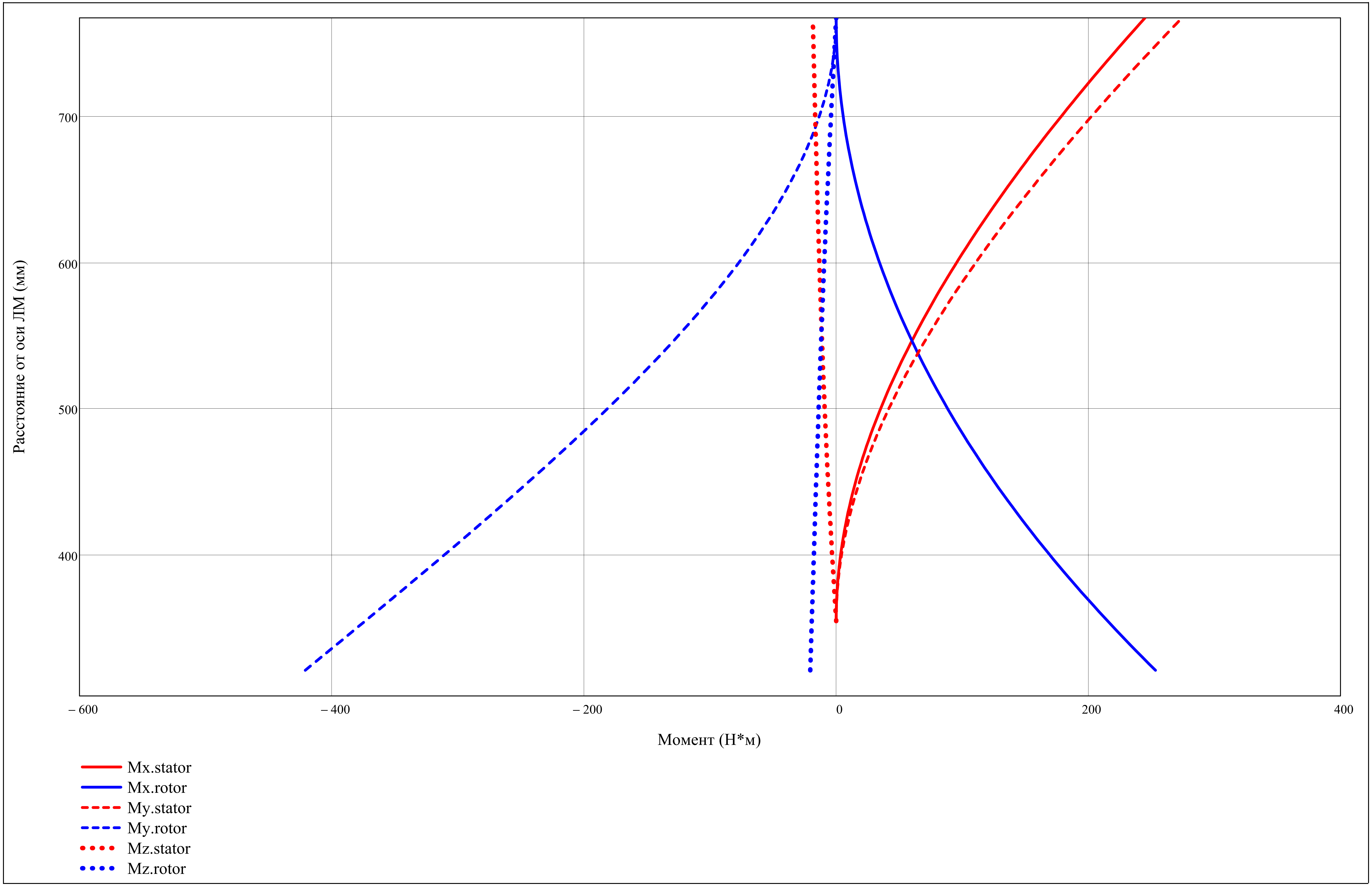

700
600
500
400
Расстояние от оси ЛМ (мм)
0
50
100
150
Растягивающее напряжение (МПа)
stator
rotor
rotor equal strength

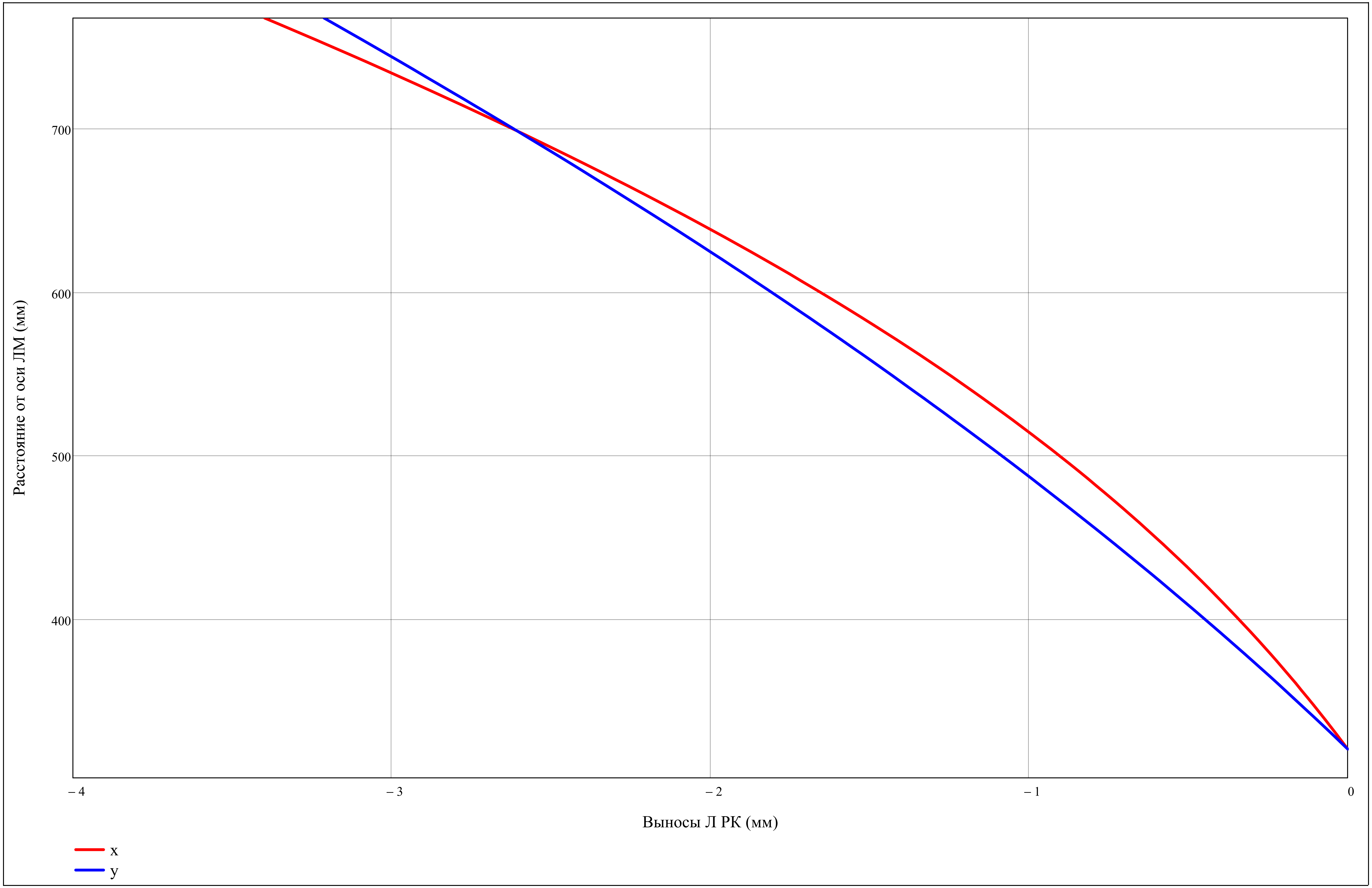

Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
700
600
500
400
0
0.5
1
1.5
Растягивающее напряжение (МПа)
P1
P2
P3
ρ1
ρ2
ρ3


Газодинамические параметры нагрузки
Расстояние от оси ЛМ (мм)
700
600
500
400
0
100
200
Растягивающее напряжение (МПа)
c.a1
c.a2
c.a3
c.u1
c.u2
c.u3

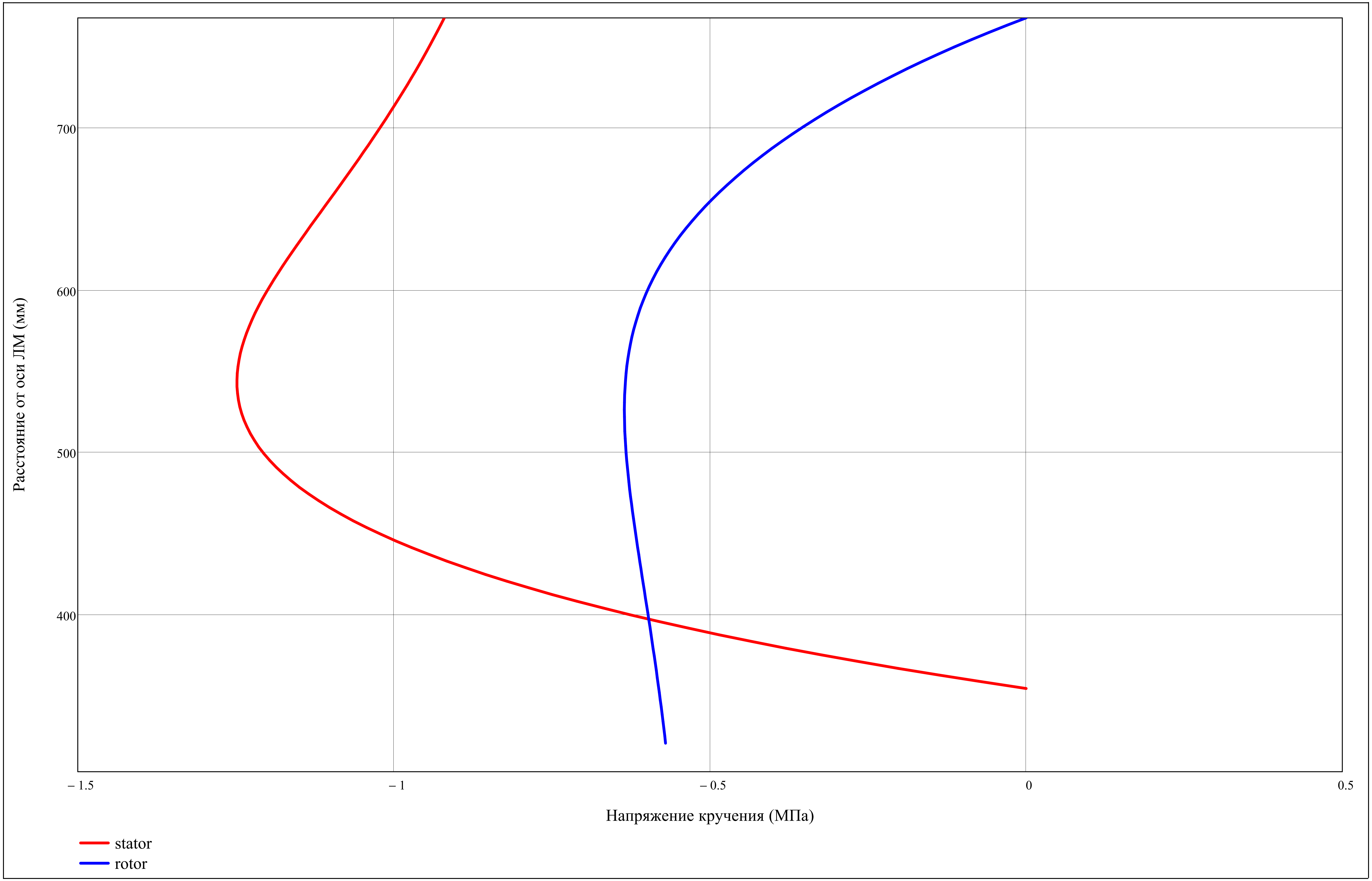


Расстояние от оси ЛМ (мм)
700
600
500
400
– 8
– 6
– 4
– 2
0
2
4
Распределенная нагрузка (кН/м)
qx.stator
qx.rotor
qy.stator
qy.rotor

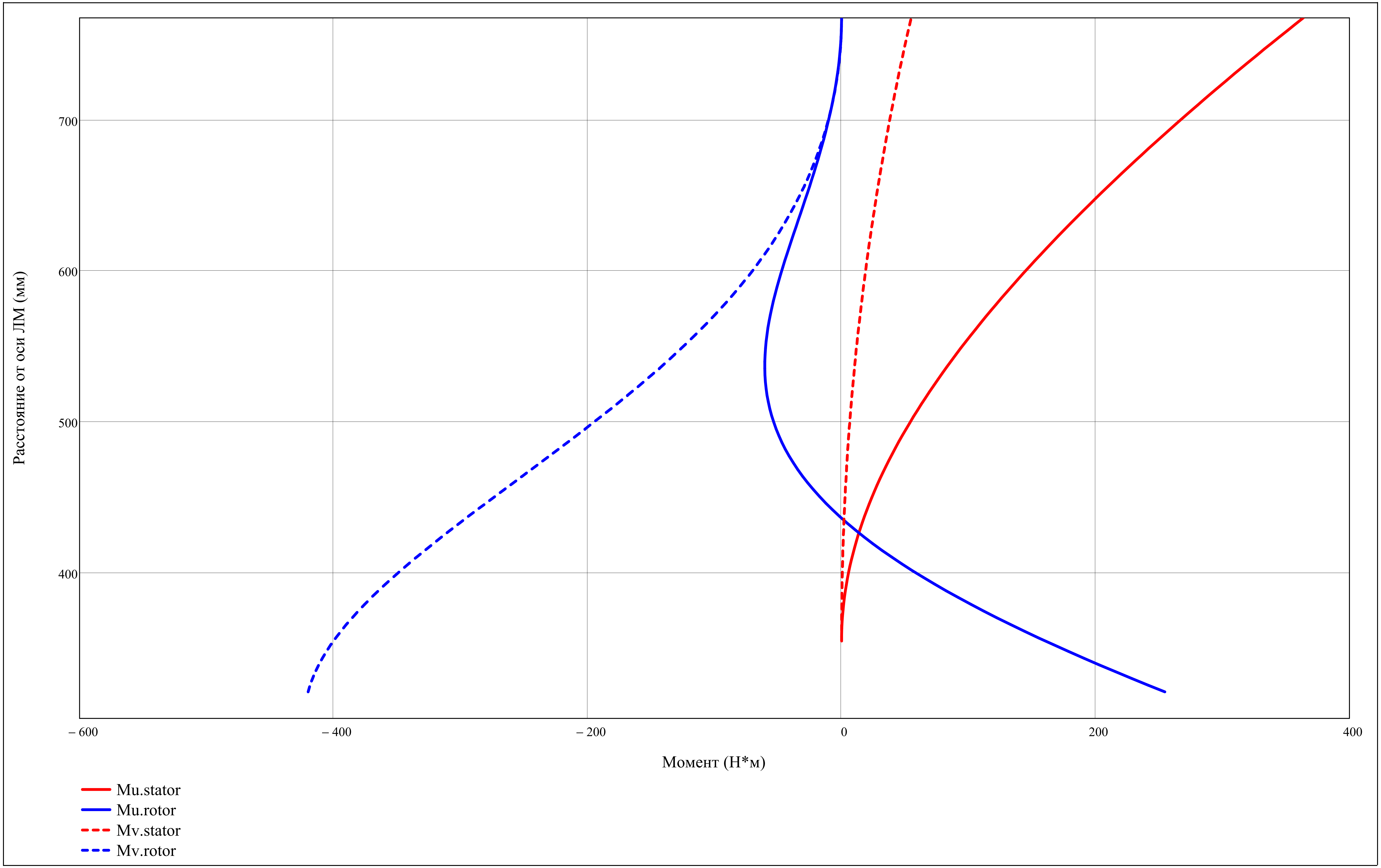

Расстояние от оси ЛМ (мм)
700
600
500
400
– 600
– 400
– 200
0
200
400
Момент (Н*м)
Mx.stator
Mx.rotor
My.stator
My.rotor
Mz.stator
Mz.rotor

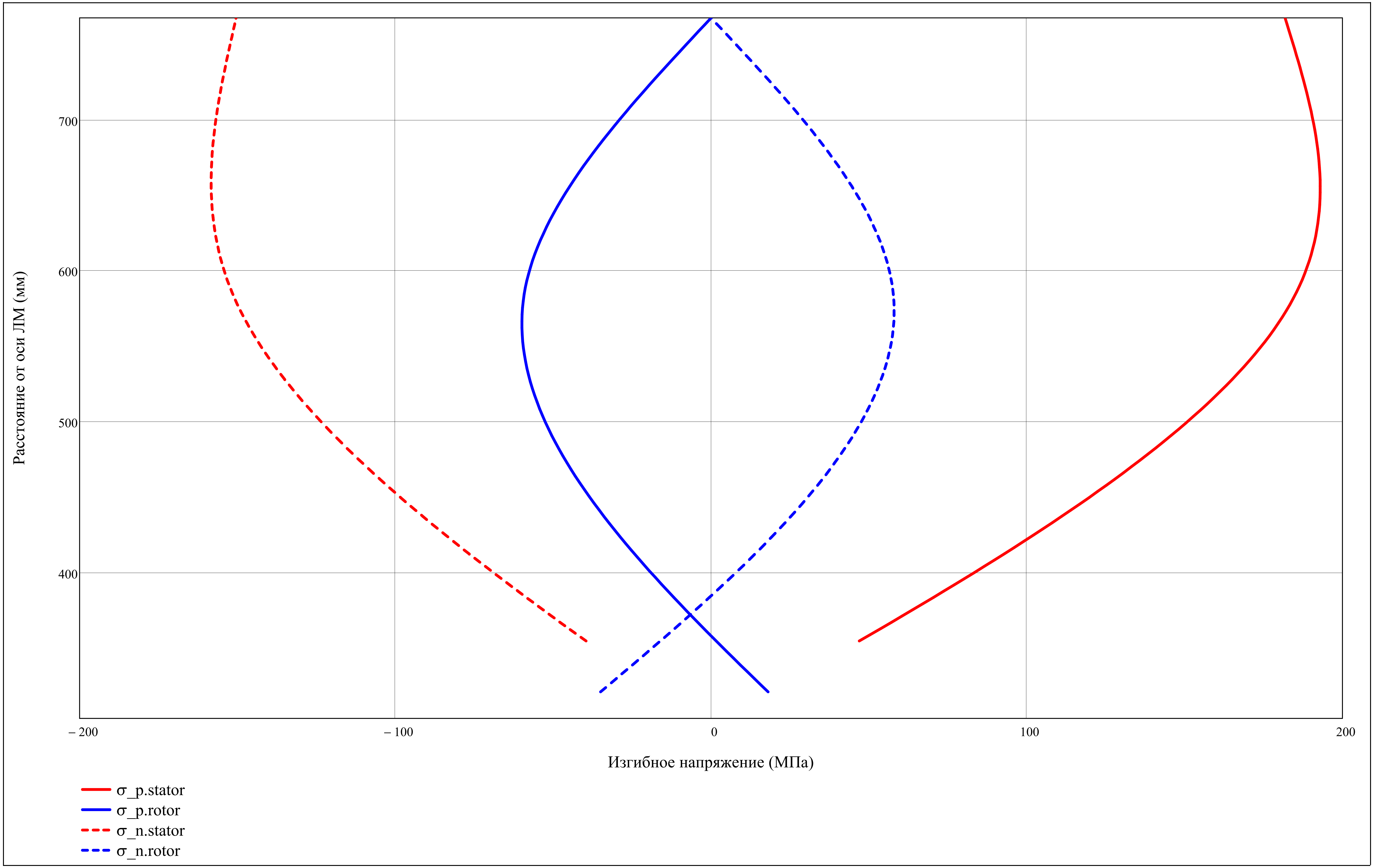


700
600
500
400
Расстояние от оси ЛМ (мм)
– 4
– 3
– 2
– 1
0
Выносы Л РК (мм)
x
y

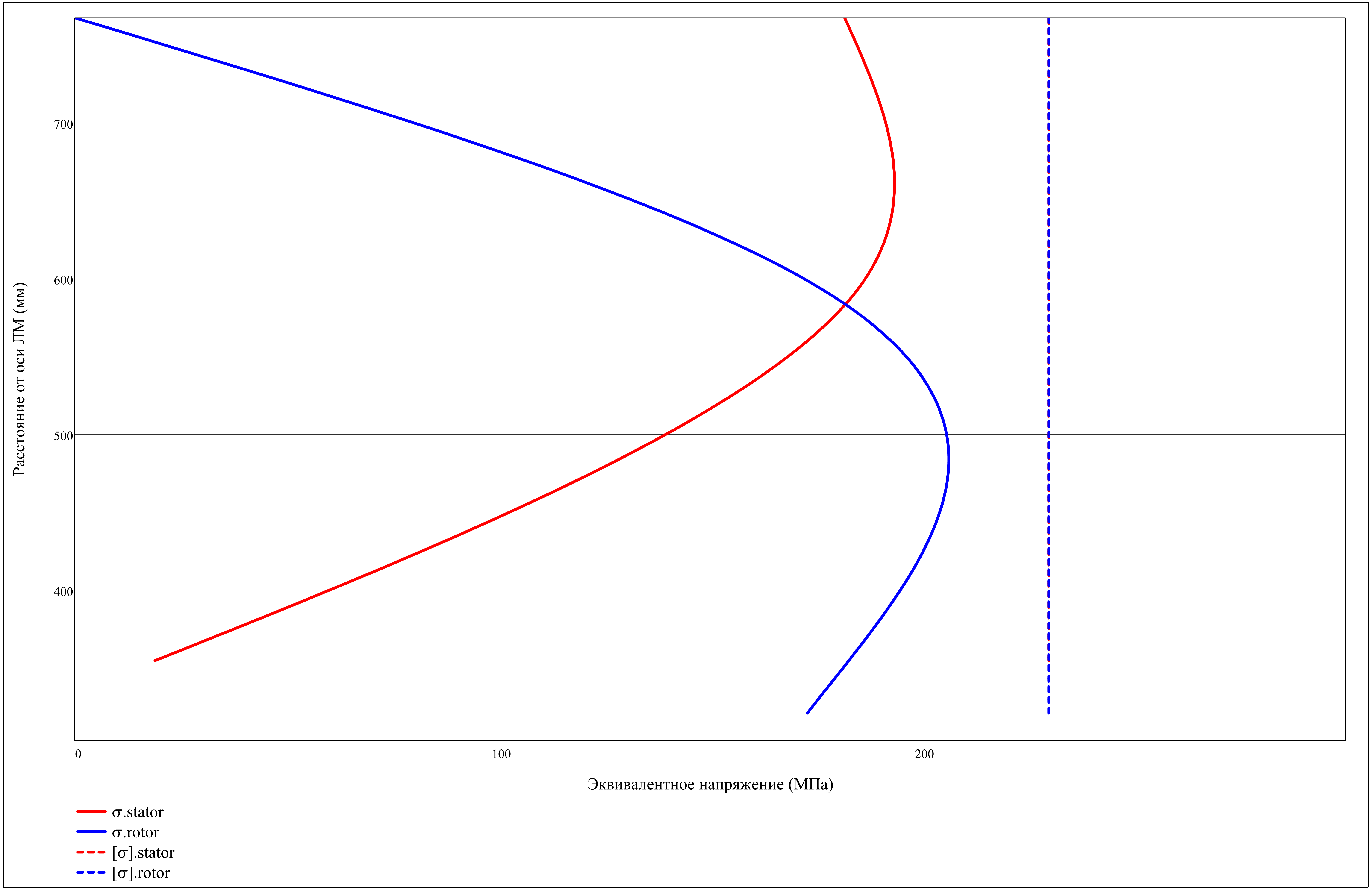


700
600
500
400
– 1.5
– 1
– 0.5
0
0.5
Расстояние от оси ЛМ (мм)
Напряжение кручения (МПа)
stator
rotor


Расстояние от оси ЛМ (мм)
700
600
500
400
– 600
– 400
– 200
0
200
400
Момент (Н*м)
Mu.stator
Mu.rotor
Mv.stator
Mv.rotor



700
600
500
400
Расстояние от оси ЛМ (мм)
– 200
– 100
0
100
200
Изгибное напряжение (МПа)
σ_p.stator
σ_p.rotor
σ_n.stator
σ_n.rotor


700
600
500
400
0
100
200
Расстояние от оси ЛМ (мм)
Эквивалентное напряжение (МПа)
σ.stator
σ.rotor
[σ].stator
[σ].rotor

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

Наиболее удаленные точки от НЛ (мм):

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

| | 1 | 2 |
|---|---|---|
| 1 | 7.22 | 16.33 |
| 2 | -59.37 | -22.71 |
| 3 | 0.00 | 2.67 |
| 4 | 59.57 | -3.33 |

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} 27 & 4 \\ -45 & -5 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 4 \\ 178 \end{pmatrix} \cdot 10^{6}$$

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

| | 1 |
|---|---|
| 1 | 58.312 |
| 2 | 1.292 |

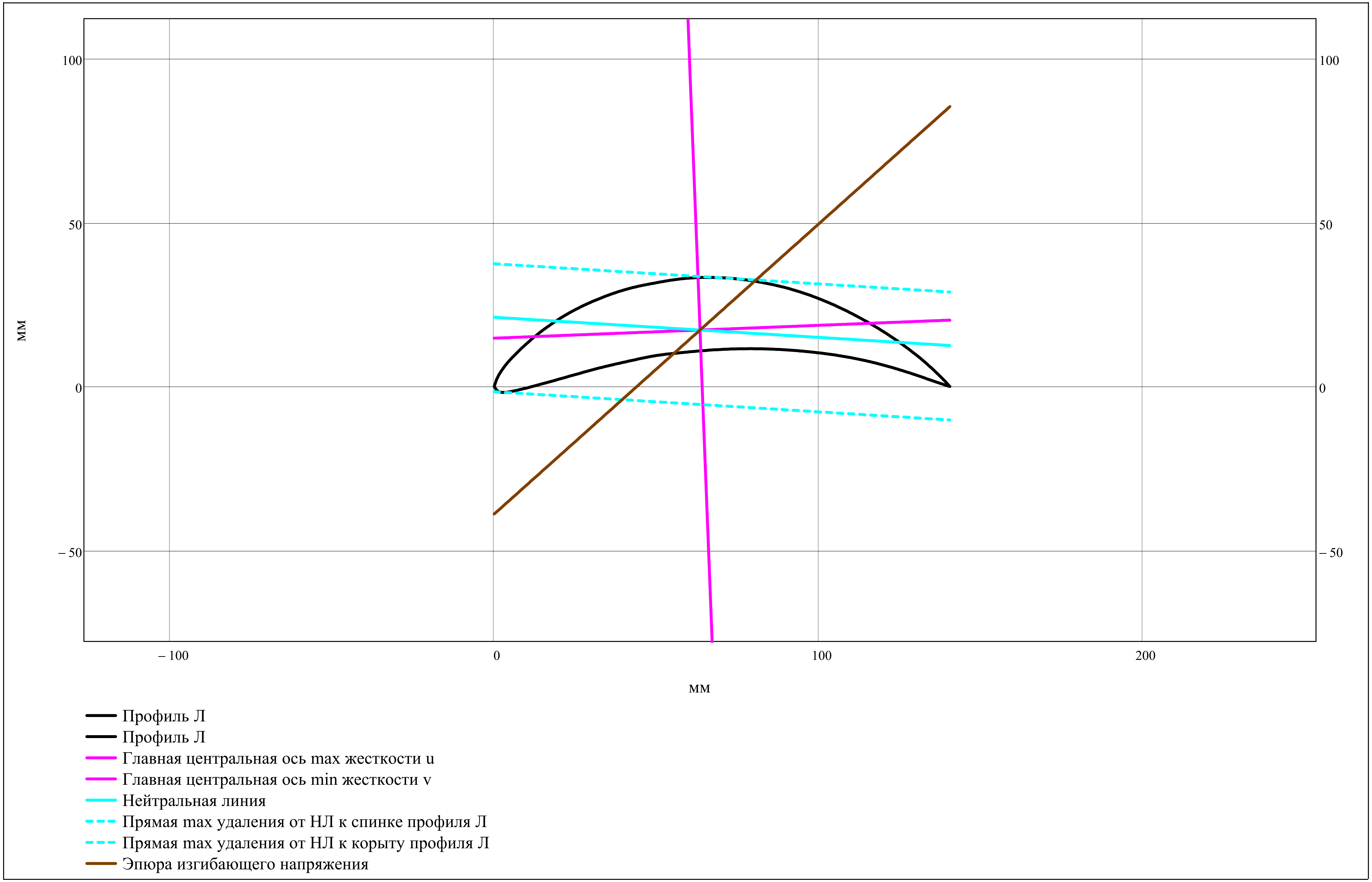
$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if } blade = \text{"rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \cdot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

| | 1 |
|---|---|
| 1 | 16.326 |
| 2 | -22.714 |

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

| | 1 |
|---|---|
| 1 | 63.459 |
| 2 | 17.233 |

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if } blade = \text{"rotor"} \\ chord_{stator_{j,r}} & \text{if } blade = \text{"stator"} \end{array} \right. = 141 \cdot 10^{-3}$$


100
50
0
– 50
– 100
0
100
200
мм
мм
Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

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

| | 1 | 2 |
|---|---|---|
| 1 | -1.63 | 4.86 |
| 2 | 82.75 | -4.35 |
| 3 | -1.52 | 4.80 |
| 4 | -42.90 | -3.95 |

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -59 & 185 \\ 58 & -151 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 185 \\ 176 \end{pmatrix} \cdot 10^{6}$$

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

| | 1 |
|---|---|
| 1 | 1.244 |
| 2 | 1.304 |

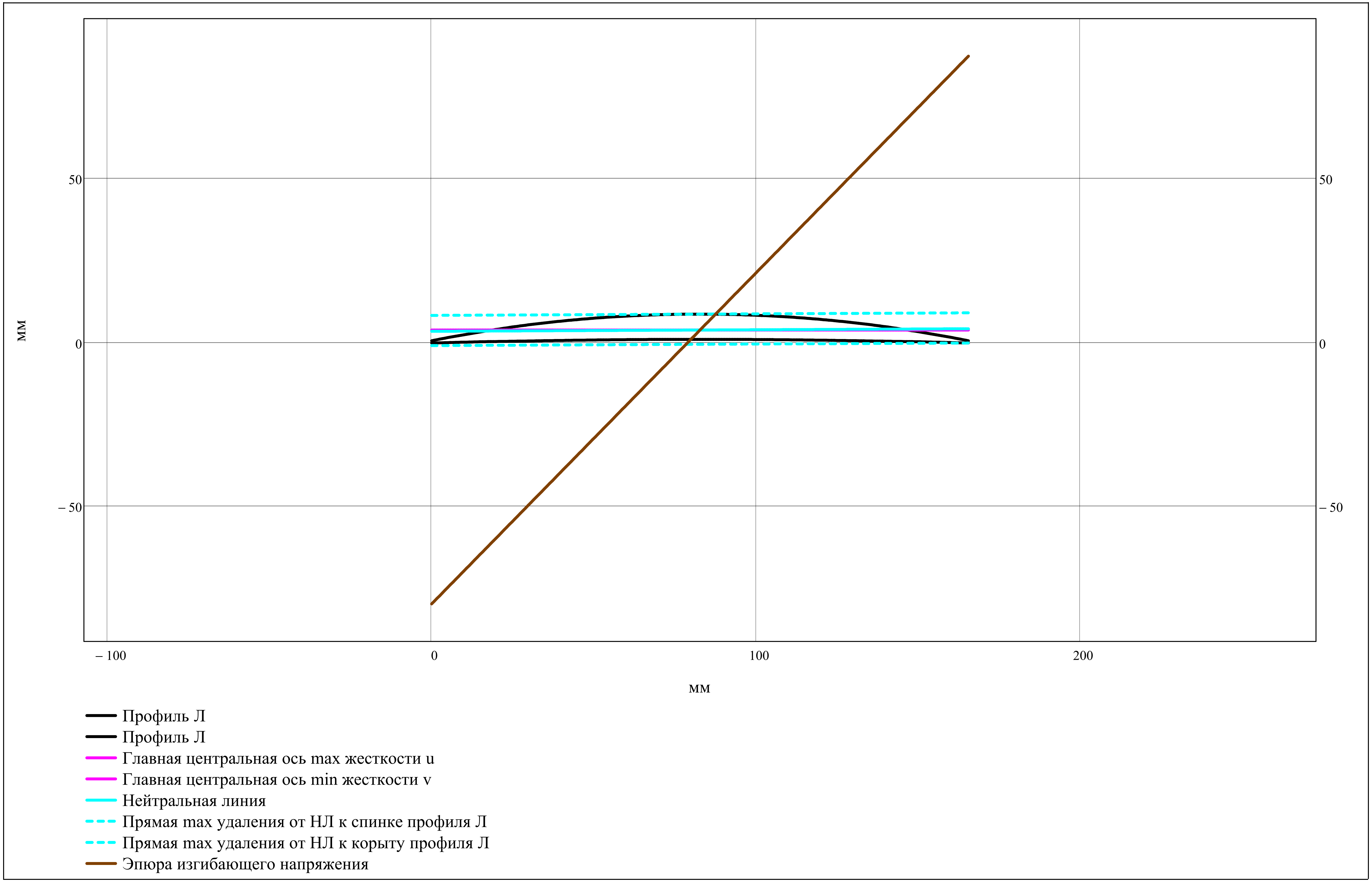
$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \text{(table)}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

| | 1 |
|---|---|
| 1 | 4.858 |
| 2 | -4.352 |

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

| | 1 |
|---|---|
| 1 | 82.768 |
| 2 | 3.616 |

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{array} \right. = 166 \cdot 10^{-3}$$



50
0
– 50
мм
– 100
0
100
200
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

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

Наиболее удаленные точки от НЛ (мм):

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

| | 1 | 2 |
|---|---|---|
| 1 | -1.63 | 4.86 |
| 2 | 82.75 | -4.35 |
| 3 | -1.52 | 4.80 |
| 4 | -42.90 | -3.95 |

$\cdot 10^{-3}$

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} -59 & 185 \\ 58 & -151 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 185 \\ 176 \end{pmatrix} \cdot 10^{6}$$

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

| | 1 |
|---|---|
| 1 | 1.244 |
| 2 | 1.304 |

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

| | 1 |
|---|---|
| 1 | 4.797 |
| 2 | -3.952 |

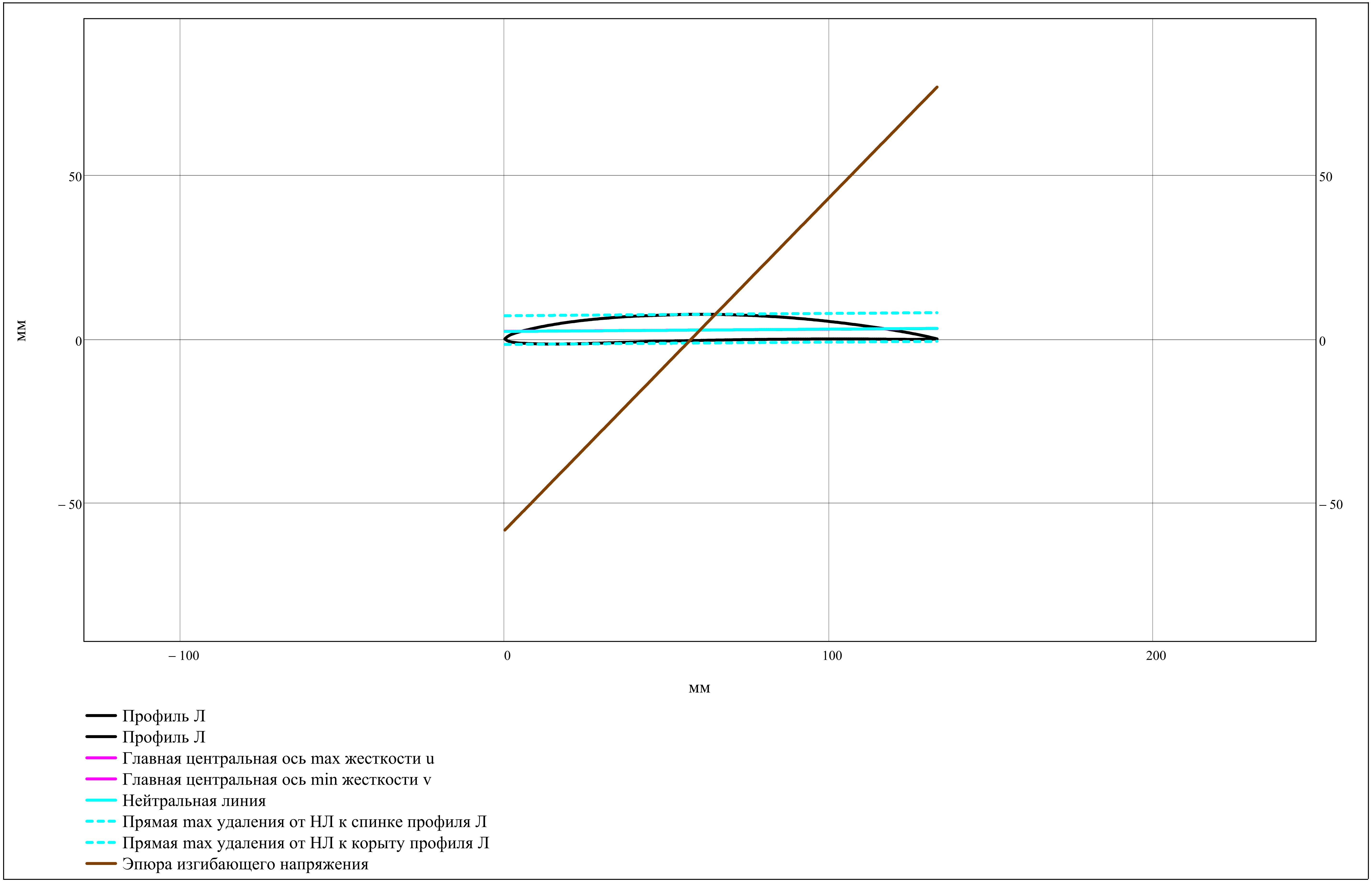
$\cdot 10^{-3}$

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

| | 1 |
|---|---|
| 1 | 60.200 |
| 2 | 2.720 |

$\cdot 10^{-3}$

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if } blade = \text{"rotor"} \\ chord_{stator_{j,r}} & \text{if } blade = \text{"stator"} \end{array} \right. = 133 \cdot 10^{-3}$$


50
0
– 50
– 100
0
100
200
мм
мм
Профиль Л
Профиль Л
Главная центральная ось max жесткости u
Главная центральная ось min жесткости v
Нейтральная линия
Прямая max удаления от НЛ к спинке профиля Л
Прямая max удаления от НЛ к корыту профиля Л
Эпюра изгибающего напряжения

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

Наиболее удаленные точки от НЛ (мм):

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

| | 1 | 2 |
|---|---|---|
| 1 | -0.39 | 91.33 |
| 2 | -0.72 | -91.33 |
| 3 | -3.04 | 7.21 |
| 4 | -34.59 | -6.02 |

Изгибные напряжения (Па):

$$\begin{pmatrix} \sigma\_p_{rotor_{j,r}} & \sigma\_p_{stator_{j,r}} \\ \sigma\_n_{rotor_{j,r}} & \sigma\_n_{stator_{j,r}} \end{pmatrix} = \begin{pmatrix} 0 & 182 \\ 0 & -150 \end{pmatrix} \cdot 10^{6}$$

Эквивалентные напряжения (Па):

$$\begin{pmatrix} \sigma_{stator_{j,r}} \\ \sigma_{rotor_{j,r}} \end{pmatrix} = \begin{pmatrix} 182 \\ 0 \end{pmatrix} \cdot 10^{6}$$

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

| | 1 |
|---|---|
| 1 | 1.265 |
| 2 | )000000000000000000000000000000000.( |

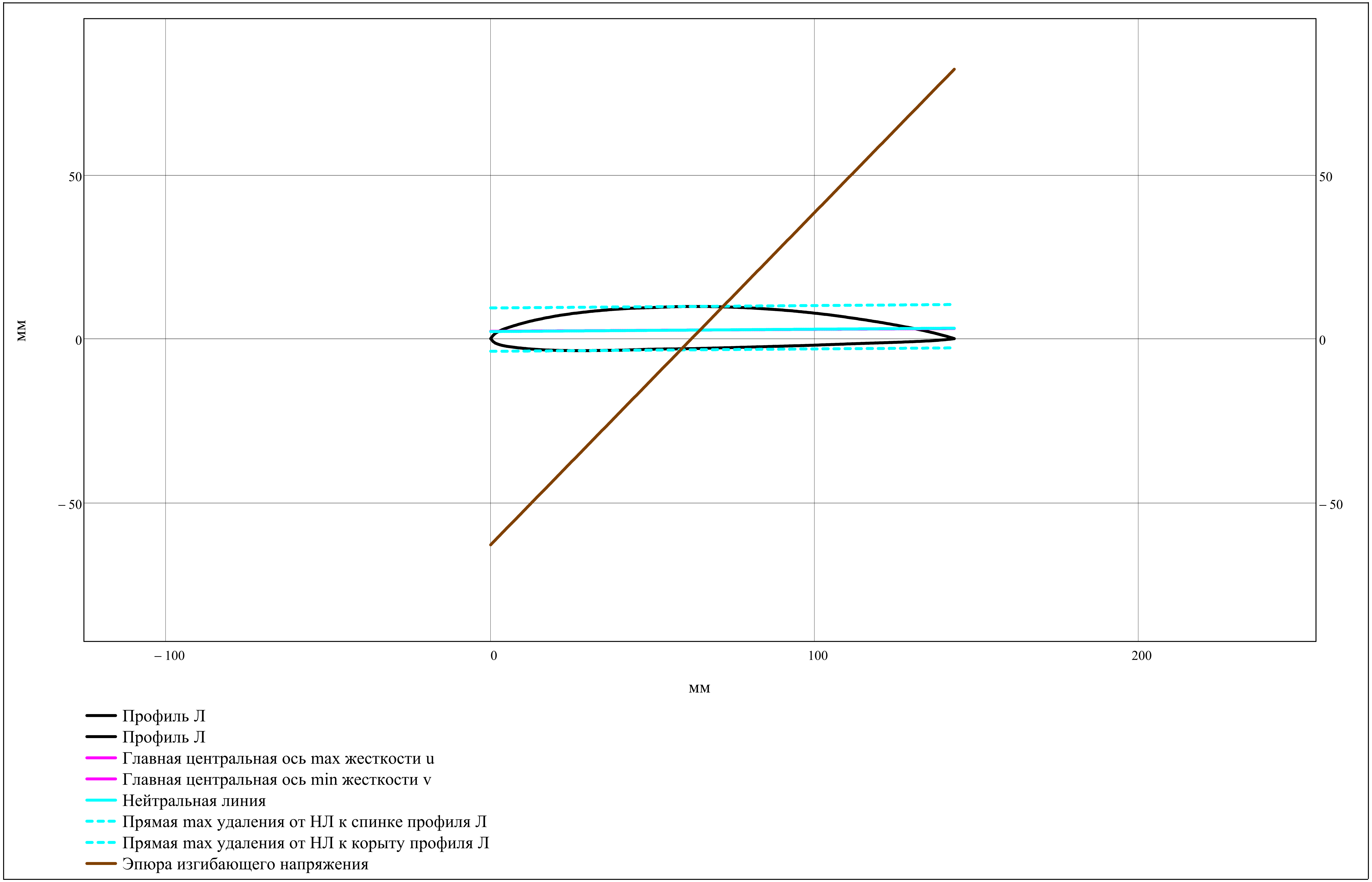
$$\begin{pmatrix} v\_p \\ v\_n \end{pmatrix} = \left| \begin{array}{ll} \begin{pmatrix} v\_u_{rotor_{j,r}} \\ v\_l_{rotor_{j,r}} \end{pmatrix} & \text{if blade = "rotor"} \\ \begin{pmatrix} v\_u_{stator_{j,r}} \\ v\_l_{stator_{j,r}} \end{pmatrix} & \text{otherwise} \end{array} \right. = \cdot 10^{-3}$$

| | 1 |
|---|---|
| 1 | 7.211 |
| 2 | -6.018 |

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

| | 1 |
|---|---|
| 1 | 64.573 |
| 2 | 2.637 |

$$chord = \left| \begin{array}{ll} chord_{rotor_{j,r}} & \text{if blade = "rotor"} \\ chord_{stator_{j,r}} & \text{if blade = "stator"} \end{array} \right. = 143 \cdot 10^{-3}$$




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

Плотность материала Д (кг/м^3):

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

Предел длительной прочности Д (Па):

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

$material\_disk^T =$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | "ВТ23" | | | | | | | | |

$\rho\_disk^T =$

| | 1 |
|---|---|
| 1 | 4570 |

$\sigma\_disk\_long^T =$

| | 1 |
|---|---|
| 1 | 230 |

$\cdot 10^6$

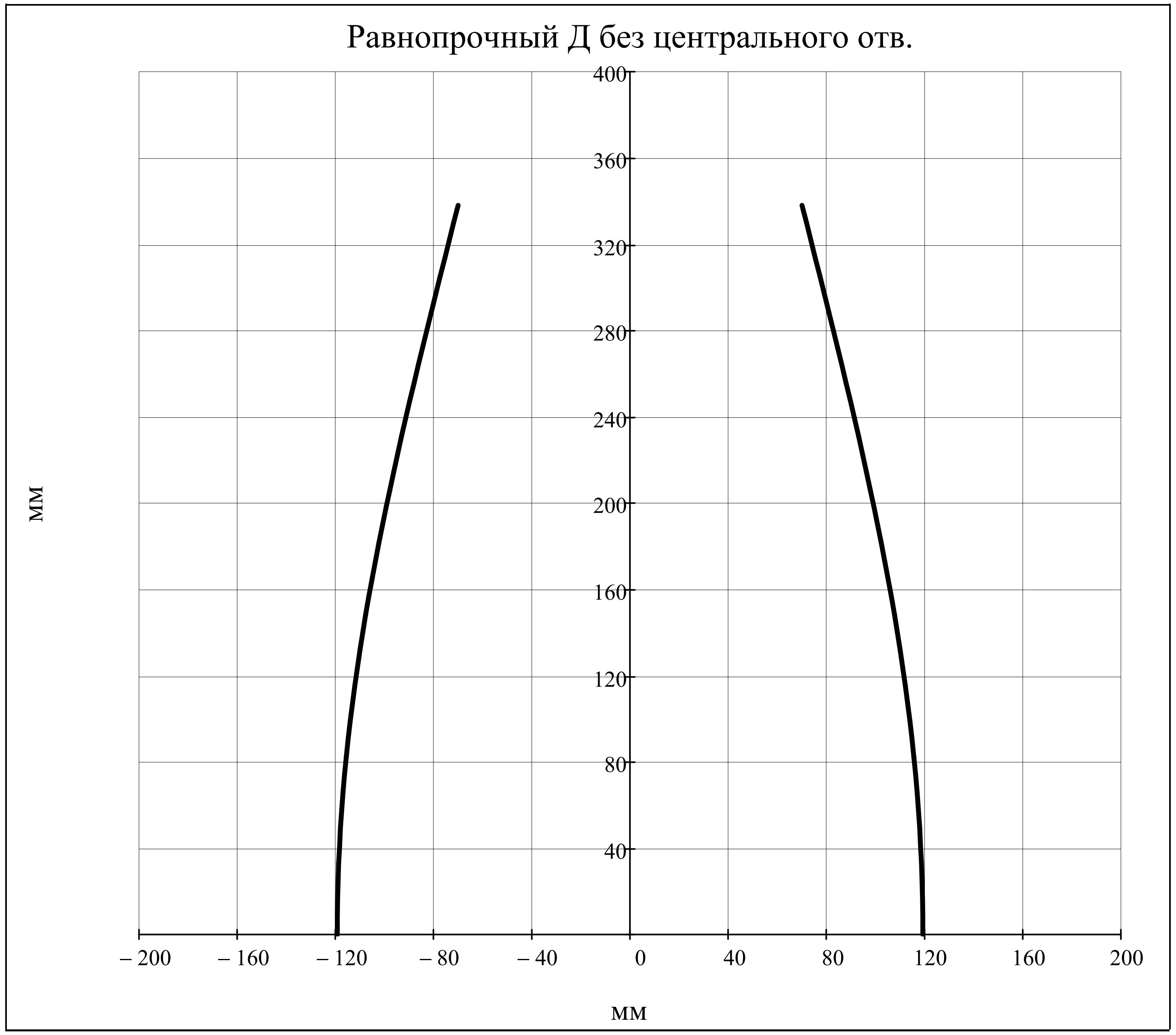
Выбор материала Д

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.

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

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



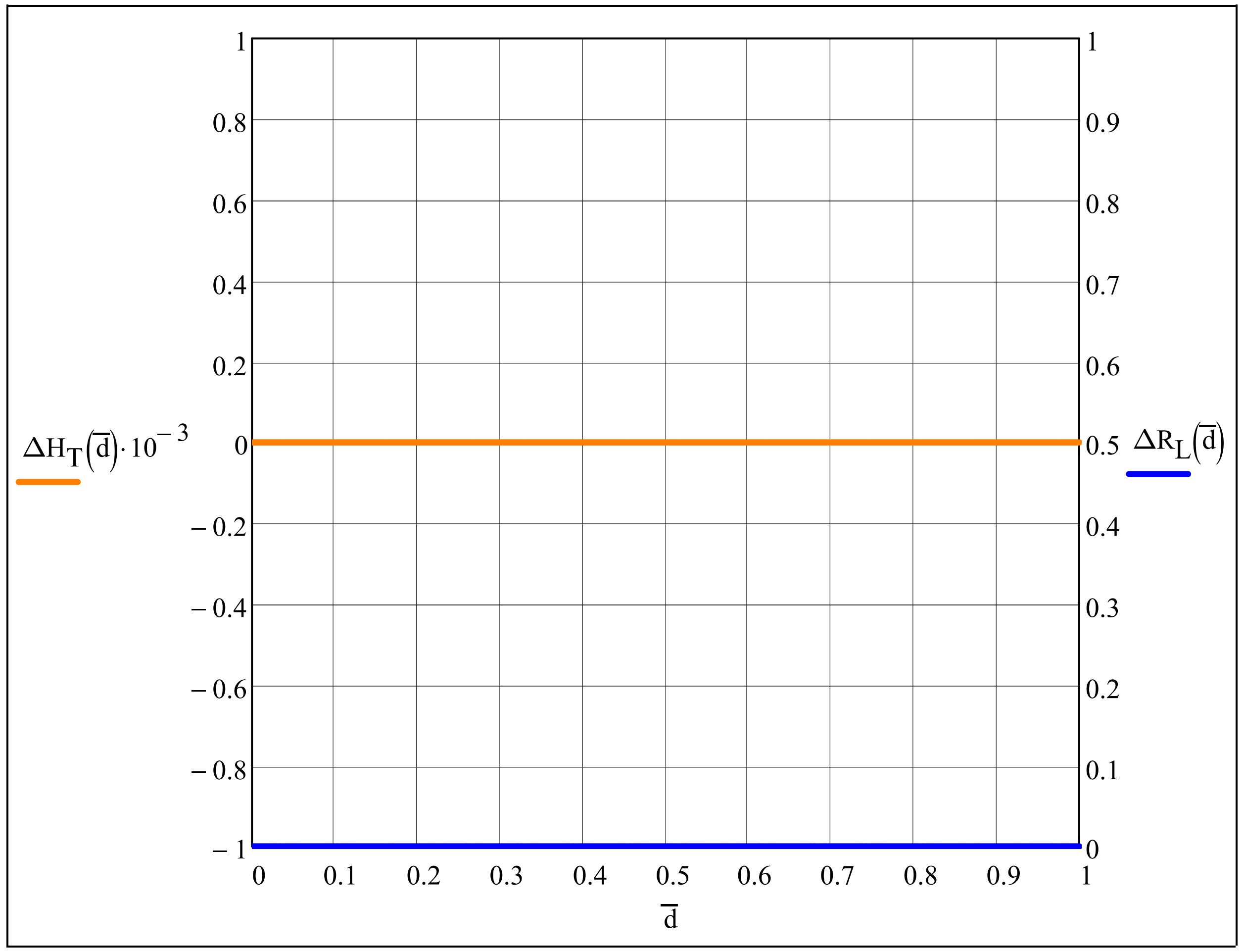

Профилирование равнопрочного Д без центрального отв.

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

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

$\Delta R_{Lmax} = 0.0$

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



$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 165.58 \\ 333.69 \\ 175.76 \end{pmatrix}$$

$$\begin{pmatrix} c_{a_{st(j,1),r}} \\ c_{a_{st(j,2),r}} \\ c_{a_{st(j,3),r}} \end{pmatrix} = \begin{pmatrix} 165.58 \\ 188.89 \\ 134.63 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 235.98 \\ 208.15 \\ 163.39 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 90.00 \\ 34.48 \\ 49.99 \end{pmatrix} \cdot {}^\circ$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 168.13 \\ 187.64 \\ 205.57 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 44.56 \\ 114.84 \\ 55.48 \end{pmatrix} \cdot {}^\circ$$

$$\varepsilon_{stator_{j,r}} = 15.52 \cdot {}^\circ$$

$$\varepsilon_{rotor_{j,r}} = 70.28 \cdot {}^\circ$$

$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 142.69 \\ 202.3 \\ 144.39 \end{pmatrix}$$

$$\begin{pmatrix} c_{a_{st(j,1),r}} \\ c_{a_{st(j,2),r}} \\ c_{a_{st(j,3),r}} \end{pmatrix} = \begin{pmatrix} 142.69 \\ 127.78 \\ 112.87 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 353.85 \\ 214.5 \\ 269.19 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 90 \\ 39.17 \\ 51.42 \end{pmatrix} \cdot {}^\circ$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 323.8 \\ 329.11 \\ 334.43 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 23.78 \\ 36.56 \\ 24.79 \end{pmatrix} \cdot {}^\circ$$

$$\varepsilon_{stator_{j,r}} = 12.25 \cdot {}^\circ$$

$$\varepsilon_{rotor_{j,r}} = 12.78 \cdot {}^\circ$$

$$\begin{pmatrix} c_{st(j,1),r} \\ c_{st(j,2),r} \\ c_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 136.69 \\ 162.54 \\ 131.80 \end{pmatrix}$$

$$\begin{pmatrix} c_{a_{st(j,1),r}} \\ c_{a_{st(j,2),r}} \\ c_{a_{st(j,3),r}} \end{pmatrix} = \begin{pmatrix} 136.69 \\ 108.33 \\ 105.08 \end{pmatrix}$$

$$\begin{pmatrix} w_{st(j,1),r} \\ w_{st(j,2),r} \\ w_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 447.33 \\ 323.44 \\ 361.97 \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{st(j,1),r} \\ \alpha_{st(j,2),r} \\ \alpha_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 90 \\ 41.8 \\ 52.87 \end{pmatrix} \cdot ^\circ$$

$$\begin{pmatrix} u_{st(j,1),r} \\ u_{st(j,2),r} \\ u_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 425.94 \\ 425.94 \\ 425.94 \end{pmatrix}$$

$$\begin{pmatrix} \beta_{st(j,1),r} \\ \beta_{st(j,2),r} \\ \beta_{st(j,3),r} \end{pmatrix} = \begin{pmatrix} 17.79 \\ 19.57 \\ 16.88 \end{pmatrix} \cdot ^\circ$$

$$\varepsilon_{stator_{j,r}} = 11.07 \cdot ^\circ$$

$$\varepsilon_{rotor_{j,r}} = 1.78 \cdot ^\circ$$

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