Отчет по курсовой работе по дисциплине «Математические модели»

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1 Задание

Для **МОДЕЛИ 3** в плоскости параметров (**p4, p6**) построить бифуркационные диаграммы точек поворота (**p4, p6** > 0). При построении диаграммы целесообразно использовать логарифмический масштаб ($\log$(**p4,p6**)) по обеим осям. Убедиться, что это точки поворота, а не ветвления. Проиллюстрировать количество решений в каждой области.
($p1 = 8.4e\text{-}6$, $p2 = 6.6667e\text{-}4$, $p3 = 1.7778e\text{-}5$, $p5 = 2$).

$$\frac{dx_1}{dt} = (p_1 x_2 - x_1 x_2 + x_1 - x_1^2)/p_2 - p_4 x_1;$$
$$\frac{dx_2}{dt} = (-p_1 x_2 - x_1 x_2 + p_5 x_3)/p_3 + p_4(p_6 - x_2);$$
$$\frac{dx_1}{dt} = x_1 - x_3 - p_4 x_3;$$

2 Блок аналитических преобразований

Будем решать систему, в качестве ε варьируя p_4

$$\begin{cases} det(J_N) = 0 \\ f(x, \varepsilon) = 0 \end{cases} \tag{1}$$

Посчитаем матрицу Якоби:

$$J_N = \begin{pmatrix} -\frac{x_2}{p_2} + \frac{1}{p_2} - \frac{2x_1}{p_2 - p_4} & \frac{p_1}{p_2} - \frac{x_1}{p_2} & 0 \\ -\frac{x_2}{p_3} & -\frac{p_1}{p_3} - \frac{x_1}{p_3 - p_4} & \frac{p_5}{p_3} \\ 1 & 0 & -1 - p_4 \end{pmatrix}$$

Запишем систему $f(x, p_4) = 0$:

$$\begin{cases} (p_1 x_2 - x_1 x_2 + x_1 - x_1^2)/p_2 - p_4 x_1 = 0; \\ (-p_1 x_2 - x_1 x_2 + p_5 x_3)/p_3 + p_4(p_6 - x_2) = 0; \\ x_1 - x_3 - p_4 x_3 = 0; \end{cases} \tag{2}$$

Из первого уравнения выразим x_3 через x_3, из третьего уравнения выразим x_3 через x_1:

$$x_2 = \frac{x_1^2 + p_2 p_4 x_1 - x_1}{p_1 - x_1}$$
$$x_3 = \frac{x_1}{1 + p_4}$$

Подставим их в уравнение $det(J_N) = 0$ и получим кубическое уравнение относительно x_1. Находим корни, подставляем их в выражения для x_2 и x_3.

p_6 можем найти из второго уравнения:

$$p_6 = \frac{p_1 x_2 + x_1 x_2 - p_5 x_3}{p_3 p_4}$$

3 Блок проверки

4 Результаты работы программы

```
p4 = 1.000000e+00
x11 = 1.670455e-04  x12 = 1.670455e-04

p4 = 1.100000e+00
x11 = -7.218337e-05  x12 = 8.926165e-05
x22 = 1.102973e+00  x32 = 4.250555e-05  p6 = 2.507956e+00, cond = 0.000000
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x23 = 9.761923e-01 x33 = 1.115448e-02 p6 = 3.599497e+01 cond = 0.000000


p4 = 1.200000e+00
x11 = -5.117704e-05 x12 = 6.805597e-05
x22 = 1.139817e+00 x32 = 3.093453e-05 p6 = 2.845977e+00, cond = 0.000000
x23 = 9.543426e-01 x33 = 2.047064e-02 p6 = 1.390539e+02 cond = 0.000000


p4 = 1.300000e+00
x11 = -4.243626e-05 x12 = 5.927620e-05
x22 = 1.164028e+00 x32 = 2.577226e-05 p6 = 3.155377e+00, cond = 0.000000
x23 = 9.344905e-01 x33 = 2.815829e-02 p6 = 3.089823e+02 cond = 0.000000


p4 = 1.400000e+00
x11 = -3.754076e-05 x12 = 5.436625e-05
x22 = 1.181575e+00 x32 = 2.265260e-05 p6 = 3.454098e+00, cond = 0.000000
x23 = 9.163138e-01 x33 = 3.451908e-02 p6 = 5.428889e+02 cond = 0.000000


p4 = 1.500000e+00
x11 = -3.441010e-05 x12 = 5.122853e-05
x22 = 1.194874e+00 x32 = 2.049141e-05 p6 = 3.748512e+00, cond = 0.000000
x23 = 8.995977e-01 x33 = 3.979130e-02 p6 = 8.374978e+02 cond = 0.000000


p4 = 1.600000e+00
x11 = -3.225269e-05 x12 = 4.906709e-05
x22 = 1.205209e+00 x32 = 1.887196e-05 p6 = 4.041608e+00, cond = 0.000000
x23 = 8.841694e-01 x33 = 4.416486e-02 p6 = 1.189380e+03 cond = 0.000000


p4 = 1.700000e+00
x11 = -3.069462e-05 x12 = 4.750647e-05
x22 = 1.213364e+00 x32 = 1.759499e-05 p6 = 4.334994e+00, cond = 0.000000
x23 = 8.698839e-01 x33 = 4.779238e-02 p6 = 1.595097e+03 cond = 0.000000


p4 = 1.800000e+00
x11 = -2.953402e-05 x12 = 4.634414e-05
x22 = 1.219856e+00 x32 = 1.655148e-05 p6 = 4.629609e+00, cond = 0.000000
x23 = 8.566179e-01 x33 = 5.079740e-02 p6 = 2.051294e+03 cond = 0.000000


p4 = 1.900000e+00
x11 = -2.865147e-05 x12 = 4.546035e-05
x22 = 1.225048e+00 x32 = 1.567598e-05 p6 = 4.926033e+00, cond = 0.000000
x23 = 8.442654e-01 x33 = 5.328061e-02 p6 = 2.554752e+03 cond = 0.000000


p4 = 2.000000e+00
x11 = -2.797139e-05 x12 = 4.477937e-05
x22 = 1.229204e+00 x32 = 1.492646e-05 p6 = 5.224633e+00, cond = 0.000000
x23 = 8.327350e-01 x33 = 5.532460e-02 p6 = 3.102418e+03 cond = 0.000000


p4 = 2.000000e+00
x11 = -2.797139e-05 x12 = 4.477937e-05
x22 = 1.229204e+00 x32 = 1.492646e-05 p6 = 5.224633e+00, cond = 0.000000
x23 = 8.327350e-01 x33 = 5.532460e-02 p6 = 3.102418e+03 cond = 0.000000


p4 = 3.000000e+00
x11 = -2.596059e-05 x12 = 4.276534e-05
x22 = 1.241890e+00 x32 = 1.069133e-05 p6 = 8.356144e+00, cond = 0.000000
x23 = 7.490603e-01 x33 = 6.224123e-02 p6 = 1.046541e+04 cond = 0.000000


p4 = 4.000000e+00
x11 = -2.671448e-05 x12 = 4.351861e-05
x22 = 1.235831e+00 x32 = 8.703722e-06 p6 = 1.175562e+01, cond = 0.000000
x23 = 6.987303e-01 x33 = 5.972454e-02 p6 = 2.007349e+04 cond = 0.000000


p4 = 5.000000e+00
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x11 = -2.812414e-05 x12 = 4.492816e-05
x22 = 1.225804e+00 x32 = 7.488027e-06 p6 = 1.539890e+01, cond = 0.000000
x23 = 6.650697e-01 x33 = 5.526897e-02 p6 = 3.094170e+04 cond = 0.000000


p4 = 6.000000e+00
x11 = -2.973710e-05 x12 = 4.654120e-05
x22 = 1.215297e+00 x32 = 6.648743e-06 p6 = 1.926199e+01, cond = 0.000000
x23 = 6.409340e-01 x33 = 5.072587e-02 p6 = 4.257142e+04 cond = 0.000000


p4 = 7.000000e+00
x11 = -3.140684e-05 x12 = 4.821110e-05
x22 = 1.205287e+00 x32 = 6.026387e-06 p6 = 2.332582e+01, cond = 0.000000
x23 = 6.227513e-01 x33 = 4.657450e-02 p6 = 5.468823e+04 cond = 0.000000


p4 = 8.000000e+00
x11 = -3.307634e-05 x12 = 4.988079e-05
x22 = 1.196030e+00 x32 = 5.542310e-06 p6 = 2.757513e+01, cond = 0.000000
x23 = 6.085372e-01 x33 = 4.290474e-02 p6 = 6.712978e+04 cond = 0.000000


p4 = 9.000000e+00
x11 = -3.472148e-05 x12 = 5.152617e-05
x22 = 1.187547e+00 x32 = 5.152617e-06 p6 = 3.199749e+01, cond = 0.000000
x23 = 5.971010e-01 x33 = 3.969116e-02 p6 = 7.979422e+04 cond = 0.000000


p4 = 1.000000e+01
x11 = -3.633204e-05 x12 = 5.313697e-05
x22 = 1.179783e+00 x32 = 4.830634e-06 p6 = 3.658252e+01, cond = 0.000000
x23 = 5.876852e-01 x33 = 3.687821e-02 p6 = 9.261453e+04 cond = 0.000000


p4 = 1.000000e+01
x11 = -3.633204e-05 x12 = 5.313697e-05
x22 = 1.179783e+00 x32 = 4.830634e-06 p6 = 3.658252e+01, cond = 0.000000
x23 = 5.876852e-01 x33 = 3.687821e-02 p6 = 9.261453e+04 cond = 0.000000


p4 = 2.000000e+01
x11 = -5.044742e-05 x12 = 6.725519e-05
x22 = 1.127410e+00 x32 = 3.202628e-06 p6 = 8.987660e+01, cond = 0.000000
x23 = 5.411487e-01 x33 = 2.121562e-02 p6 = 2.235018e+05 cond = 0.000000


p4 = 3.000000e+01
x11 = -6.194986e-05 x12 = 7.876068e-05
x22 = 1.096909e+00 x32 = 2.540667e-06 p6 = 1.538576e+02, cond = 0.000000
x23 = 5.225427e-01 x33 = 1.475699e-02 p6 = 3.535887e+05 cond = 0.000000


p4 = 4.000000e+01
x11 = -7.185679e-05 x12 = 8.867074e-05
x22 = 1.075091e+00 x32 = 2.162701e-06 p6 = 2.261497e+02, cond = 0.000000
x23 = 5.114301e-01 x33 = 1.126616e-02 p6 = 4.808373e+05 cond = 0.000000


p4 = 5.000000e+01
x11 = -8.068348e-05 x12 = 9.750061e-05
x22 = 1.057693e+00 x32 = 1.911777e-06 p6 = 3.053291e+02, cond = 0.000000
x23 = 5.034031e-01 x33 = 9.083775e-03 p6 = 6.048197e+05 cond = 0.000000


p4 = 6.000000e+01
x11 = -8.871947e-05 x12 = 1.055398e-04
x22 = 1.042899e+00 x32 = 1.730161e-06 p6 = 3.904033e+02, cond = 0.000000
x23 = 4.969441e-01 x33 = 7.591225e-03 p6 = 7.254106e+05 cond = 0.000000


p4 = 7.000000e+01
x11 = -9.614519e-05 x12 = 1.129689e-04
x22 = 1.029792e+00 x32 = 1.591111e-06 p6 = 4.806210e+02, cond = 0.000000
x23 = 4.913906e-01 x33 = 6.506358e-03 p6 = 8.425756e+05 cond = 0.000000
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p4 = 8.000000e+01
x11 = -1.030817e-04 x12 = 1.199087e-04
x22 = 1.017850e+00 x32 = 1.480355e-06 p6 = 5.753832e+02, cond = 0.000000
x23 = 4.864073e-01 x33 = 5.682321e-03 p6 = 9.563157e+05 cond = 0.000000


p4 = 9.000000e+01
x11 = -1.096149e-04 x12 = 1.264453e-04
x22 = 1.006754e+00 x32 = 1.389509e-06 p6 = 6.741943e+02, cond = 0.000000
x23 = 4.818061e-01 x33 = 5.035191e-03 p6 = 1.066648e+06 cond = 0.000000


p4 = 1.000000e+02
x11 = -1.158081e-04 x12 = 1.326420e-04
x22 = 9.962940e-01 x32 = 1.313287e-06 p6 = 7.766331e+02, cond = 0.000000
x23 = 4.774736e-01 x33 = 4.513546e-03 p6 = 1.173597e+06 cond = 0.000000


p4 = 1.000000e+02
x11 = -1.158081e-04 x12 = 1.326420e-04
x22 = 9.962940e-01 x32 = 1.313287e-06 p6 = 7.766331e+02, cond = 0.000000
x23 = 4.774736e-01 x33 = 4.513546e-03 p6 = 1.173597e+06 cond = 0.000000


p4 = 2.000000e+02
x11 = -1.661613e-04 x12 = 1.830327e-04
x22 = 9.081616e-01 x32 = 9.106106e-07 p6 = 1.936229e+03, cond = 0.000000
x23 = 4.401031e-01 x33 = 2.122247e-03 p6 = 2.064290e+06 cond = 0.000000


p4 = 3.000000e+02
x11 = -2.051452e-04 x12 = 2.220610e-04
x22 = 8.312199e-01 x32 = 7.377441e-07 p6 = 3.208531e+03, cond = 0.000000
x23 = 4.060056e-01 x33 = 1.308977e-03 p6 = 2.655291e+06 cond = 0.000000


p4 = 4.000000e+02
x11 = -2.382579e-04 x12 = 2.552268e-04
x22 = 7.580248e-01 x32 = 6.364757e-07 p6 = 4.468362e+03, cond = 0.000000
x23 = 3.727326e-01 x33 = 8.992720e-04 p6 = 2.983800e+06 cond = 0.000000


p4 = 5.000000e+02
x11 = -2.676819e-04 x12 = 2.847153e-04
x22 = 6.866383e-01 x32 = 5.682939e-07 p6 = 5.629204e+03, cond = 0.000000
x23 = 3.397904e-01 x33 = 6.524618e-04 p6 = 3.087236e+06 cond = 0.000000


p4 = 6.000000e+02
x11 = -2.945760e-04 x12 = 3.116897e-04
x22 = 6.162954e-01 x32 = 5.186184e-07 p6 = 6.623382e+03, cond = 0.000000
x23 = 3.070138e-01 x33 = 4.875091e-04 p6 = 3.003053e+06 cond = 0.000000


p4 = 7.000000e+02
x11 = -3.196790e-04 x12 = 3.368951e-04
x22 = 5.466234e-01 x32 = 4.805921e-07 p6 = 7.394496e+03, cond = 0.000000
x23 = 2.743320e-01 x33 = 3.694834e-04 p6 = 2.768717e+06 cond = 0.000000


p4 = 8.000000e+02
x11 = -3.435475e-04 x12 = 3.608990e-04
x22 = 4.774150e-01 x32 = 4.505605e-07 p6 = 7.893728e+03, cond = 0.000000
x23 = 2.417096e-01 x33 = 2.808532e-04 p6 = 2.421696e+06 cond = 0.000000


p4 = 9.000000e+02
x11 = -3.666956e-04 x12 = 3.842341e-04
x22 = 4.085442e-01 x32 = 4.264530e-07 p6 = 8.077805e+03, cond = 0.000000
x23 = 2.091268e-01 x33 = 2.118528e-04 p6 = 1.999463e+06 cond = 0.000000


p4 = 1.000000e+03
x11 = -3.897385e-04 x12 = 4.075523e-04
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x22 = 3.399287e-01 x32 = 4.071452e-07 p6 = 7.907856e+03, cond = 0.000000
x23 = 1.765719e-01 x33 = 1.566110e-04 p6 = 1.539488e+06 cond = 0.000000


p4 = 1.100000e+03
x11 = -4.136672e-04 x12 = 4.319249e-04
x22 = 2.715114e-01 x32 = 3.923024e-07 p6 = 7.348988e+03, cond = 0.000000
x23 = 1.440374e-01 x33 = 1.113855e-04 p6 = 1.079243e+06 cond = 0.000000


p4 = 1.200000e+03
x11 = -4.406586e-04 x12 = 4.597494e-04
x22 = 2.032498e-01 x32 = 3.828055e-07 p6 = 6.371155e+03, cond = 0.000000
x23 = 1.115187e-01 x33 = 7.367849e-05 p6 = 6.562022e+05 cond = 0.000000


p4 = 1.300000e+03
x11 = -4.776898e-04 x12 = 4.988790e-04
x22 = 1.351050e-01 x32 = 3.834581e-07 p6 = 4.955681e+03, cond = 0.000000
x23 = 7.901385e-02 x33 = 4.175816e-05 p6 = 3.078351e+05 cond = 0.000000


p4 = 1.400000e+03
x11 = -5.714680e-04 x12 = 6.054597e-04
x22 = 6.698589e-02 x32 = 4.321625e-07 p6 = 3.170157e+03, cond = 0.000000
x23 = 4.653437e-02 x33 = 1.438047e-05 p6 = 7.159545e+04 cond = 0.000000


p4 = 1.500000e+03
x11 = -1.953864e-06 x12 = 1.874622e-05
x22 = -4.302556e-05 x32 = 1.248916e-08 p6 = -2.206109e+00, cond = 0.000000


p4 = 1.600000e+03
x11 = -3.999931e-04 x12 = 4.133617e-04
x22 = -6.847689e-02 x32 = 2.581897e-07 p6 = -2.645793e+03, cond = 0.000000


p4 = 1.700000e+03
x11 = -4.462527e-04 x12 = 4.605574e-04
x22 = -1.362852e-01 x32 = 2.707568e-07 p6 = -6.163423e+03, cond = 0.000000


p4 = 1.800000e+03
x11 = -4.729292e-04 x12 = 4.877500e-04
x22 = -2.040071e-01 x32 = 2.708218e-07 p6 = -1.030325e+04, cond = 0.000000


p4 = 1.900000e+03
x11 = -4.934987e-04 x12 = 5.086335e-04
x22 = -2.716682e-01 x32 = 2.675610e-07 p6 = -1.506910e+04, cond = 0.000000


p4 = 2.000000e+03
x11 = -5.112363e-04 x12 = 5.265806e-04
x22 = -3.392787e-01 x32 = 2.631587e-07 p6 = -2.047889e+04, cond = 0.000000


p4 = 2.100000e+03
x11 = -5.273467e-04 x12 = 5.428402e-04
x22 = -4.068454e-01 x32 = 2.583723e-07 p6 = -2.655296e+04, cond = 0.000000


p4 = 2.200000e+03
x11 = -5.423843e-04 x12 = 5.579896e-04
x22 = -4.743732e-01 x32 = 2.535164e-07 p6 = -3.331196e+04, cond = 0.000000


p4 = 2.300000e+03
x11 = -5.566450e-04 x12 = 5.723369e-04
x22 = -5.418661e-01 x32 = 2.487340e-07 p6 = -4.077633e+04, cond = 0.000000


p4 = 2.400000e+03
x11 = -5.703037e-04 x12 = 5.860648e-04
x22 = -6.093275e-01 x32 = 2.440920e-07 p6 = -4.896611e+04, cond = 0.000000
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p4 = 2.500000e+03
x11 = -5.834731e-04  x12 = 5.992906e-04
x22 = -6.767601e-01  x32 = 2.396204e-07  p6 = -5.790089e+04, cond = 0.000000


p4 = 2.600000e+03
x11 = -5.962299e-04  x12 = 6.120945e-04
x22 = -7.441666e-01  x32 = 2.353304e-07  p6 = -6.759985e+04, cond = 0.000000


p4 = 2.700000e+03
x11 = -6.086298e-04  x12 = 6.245340e-04
x22 = -8.115489e-01  x32 = 2.312232e-07  p6 = -7.808170e+04, cond = 0.000000


p4 = 2.800000e+03
x11 = -6.207142e-04  x12 = 6.366523e-04
x22 = -8.789090e-01  x32 = 2.272946e-07  p6 = -8.936477e+04, cond = 0.000000


p4 = 2.900000e+03
x11 = -6.325155e-04  x12 = 6.484831e-04
x22 = -9.462485e-01  x32 = 2.235378e-07  p6 = -1.014670e+05, cond = 0.000000


p4 = 3.000000e+03
x11 = -6.440597e-04  x12 = 6.600530e-04
x22 = -1.013569e+00  x32 = 2.199443e-07  p6 = -1.144059e+05, cond = 0.000000


p4 = 3.100000e+03
x11 = -6.553682e-04  x12 = 6.713840e-04
x22 = -1.080872e+00  x32 = 2.165057e-07  p6 = -1.281986e+05, cond = 0.000000


p4 = 3.200000e+03
x11 = -6.664585e-04  x12 = 6.824945e-04
x22 = -1.148158e+00  x32 = 2.132129e-07  p6 = -1.428622e+05, cond = 0.000000


p4 = 3.300000e+03
x11 = -6.773460e-04  x12 = 6.934000e-04
x22 = -1.215428e+00  x32 = 2.100576e-07  p6 = -1.584131e+05, cond = 0.000000


p4 = 3.400000e+03
x11 = -6.880438e-04  x12 = 7.041139e-04
x22 = -1.282684e+00  x32 = 2.070314e-07  p6 = -1.748675e+05, cond = 0.000000


p4 = 3.500000e+03
x11 = -6.985632e-04  x12 = 7.146480e-04
x22 = -1.349927e+00  x32 = 2.041268e-07  p6 = -1.922415e+05, cond = 0.000000


p4 = 3.600000e+03
x11 = -7.089144e-04  x12 = 7.250124e-04
x22 = -1.417156e+00  x32 = 2.013364e-07  p6 = -2.105507e+05, cond = 0.000000


p4 = 3.700000e+03
x11 = -7.191064e-04  x12 = 7.352166e-04
x22 = -1.484373e+00  x32 = 1.986535e-07  p6 = -2.298107e+05, cond = 0.000000


p4 = 3.800000e+03
x11 = -7.291474e-04  x12 = 7.452686e-04
x22 = -1.551579e+00  x32 = 1.960717e-07  p6 = -2.500365e+05, cond = 0.000000


p4 = 3.900000e+03
x11 = -7.390446e-04  x12 = 7.551761e-04
x22 = -1.618774e+00  x32 = 1.935853e-07  p6 = -2.712432e+05, cond = 0.000000


p4 = 4.000000e+03
x11 = -7.488047e-04  x12 = 7.649456e-04
x22 = -1.685959e+00  x32 = 1.911886e-07  p6 = -2.934455e+05, cond = 0.000000
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```
p4 = 4.100000e+03
x11 = -7.584338e-04 x12 = 7.745835e-04
x22 = -1.753134e+00 x32 = 1.888767e-07 p6 = -3.166580e+05, cond = 0.000000


p4 = 4.200000e+03
x11 = -7.679376e-04 x12 = 7.840953e-04
x22 = -1.820299e+00 x32 = 1.866449e-07 p6 = -3.408949e+05, cond = 0.000000


p4 = 4.300000e+03
x11 = -7.773212e-04 x12 = 7.934864e-04
x22 = -1.887455e+00 x32 = 1.844888e-07 p6 = -3.661704e+05, cond = 0.000000


p4 = 4.400000e+03
x11 = -7.865893e-04 x12 = 8.027616e-04
x22 = -1.954603e+00 x32 = 1.824044e-07 p6 = -3.924984e+05, cond = 0.000000


p4 = 4.500000e+03
x11 = -7.957465e-04 x12 = 8.119254e-04
x22 = -2.021743e+00 x32 = 1.803878e-07 p6 = -4.198927e+05, cond = 0.000000


p4 = 4.600000e+03
x11 = -8.047969e-04 x12 = 8.209819e-04
x22 = -2.088876e+00 x32 = 1.784355e-07 p6 = -4.483669e+05, cond = 0.000000


p4 = 4.700000e+03
x11 = -8.137442e-04 x12 = 8.299350e-04
x22 = -2.156000e+00 x32 = 1.765444e-07 p6 = -4.779343e+05, cond = 0.000000


p4 = 4.800000e+03
x11 = -8.225923e-04 x12 = 8.387885e-04
x22 = -2.223118e+00 x32 = 1.747112e-07 p6 = -5.086082e+05, cond = 0.000000


p4 = 4.900000e+03
x11 = -8.313444e-04 x12 = 8.475457e-04
x22 = -2.290229e+00 x32 = 1.729332e-07 p6 = -5.404018e+05, cond = 0.000000


p4 = 5.000000e+03
x11 = -8.400037e-04 x12 = 8.562099e-04
x22 = -2.357333e+00 x32 = 1.712077e-07 p6 = -5.733278e+05, cond = 0.000000


p4 = 5.100000e+03
x11 = -8.485733e-04 x12 = 8.647841e-04
x22 = -2.424431e+00 x32 = 1.695323e-07 p6 = -6.073993e+05, cond = 0.000000


p4 = 5.200000e+03
x11 = -8.570560e-04 x12 = 8.732711e-04
x22 = -2.491523e+00 x32 = 1.679045e-07 p6 = -6.426286e+05, cond = 0.000000


p4 = 5.300000e+03
x11 = -8.654545e-04 x12 = 8.816738e-04
x22 = -2.558609e+00 x32 = 1.663222e-07 p6 = -6.790285e+05, cond = 0.000000


p4 = 5.400000e+03
x11 = -8.737714e-04 x12 = 8.899945e-04
x22 = -2.625690e+00 x32 = 1.647833e-07 p6 = -7.166113e+05, cond = 0.000000


p4 = 5.500000e+03
x11 = -8.820090e-04 x12 = 8.982358e-04
x22 = -2.692765e+00 x32 = 1.632859e-07 p6 = -7.553892e+05, cond = 0.000000


p4 = 5.600000e+03
x11 = -8.901696e-04 x12 = 9.064000e-04
```

```
x22 = -2.759835e+00  x32 = 1.618283e-07  p6 = -7.953744e+05 , cond = 0.000000


p4 =  5.700000e+03
x11 = -8.982555e-04  x12 =  9.144893e-04
x22 = -2.826900e+00  x32 = 1.604086e-07  p6 = -8.365788e+05 , cond = 0.000000


p4 =  5.800000e+03
x11 = -9.062687e-04  x12 =  9.225057e-04
x22 = -2.893960e+00  x32 = 1.590253e-07  p6 = -8.790143e+05 , cond = 0.000000


p4 =  5.900000e+03
x11 = -9.142111e-04  x12 =  9.304512e-04
x22 = -2.961015e+00  x32 = 1.576769e-07  p6 = -9.226928e+05 , cond = 0.000000


p4 =  6.000000e+03
x11 = -9.220847e-04  x12 =  9.383277e-04
x22 = -3.028066e+00  x32 = 1.563619e-07  p6 = -9.676259e+05 , cond = 0.000000


p4 =  6.100000e+03
x11 = -9.298913e-04  x12 =  9.461371e-04
x22 = -3.095112e+00  x32 = 1.550790e-07  p6 = -1.013825e+06 , cond = 0.000000


p4 =  6.200000e+03
x11 = -9.376325e-04  x12 =  9.538810e-04
x22 = -3.162154e+00  x32 = 1.538270e-07  p6 = -1.061302e+06 , cond = 0.000000


p4 =  6.300000e+03
x11 = -9.453100e-04  x12 =  9.615612e-04
x22 = -3.229192e+00  x32 = 1.526045e-07  p6 = -1.110068e+06 , cond = 0.000000


p4 =  6.400000e+03
x11 = -9.529255e-04  x12 =  9.691791e-04
x22 = -3.296226e+00  x32 = 1.514106e-07  p6 = -1.160134e+06 , cond = 0.000000


p4 =  6.500000e+03
x11 = -9.604804e-04  x12 =  9.767364e-04
x22 = -3.363256e+00  x32 = 1.502440e-07  p6 = -1.211511e+06 , cond = 0.000000


p4 =  6.600000e+03
x11 = -9.679761e-04  x12 =  9.842344e-04
x22 = -3.430282e+00  x32 = 1.491038e-07  p6 = -1.264211e+06 , cond = 0.000000


p4 =  6.700000e+03
x11 = -9.754141e-04  x12 =  9.916746e-04
x22 = -3.497305e+00  x32 = 1.479890e-07  p6 = -1.318244e+06 , cond = 0.000000


p4 =  6.800000e+03
x11 = -9.827956e-04  x12 =  9.990583e-04
x22 = -3.564324e+00  x32 = 1.468987e-07  p6 = -1.373621e+06 , cond = 0.000000


p4 =  6.900000e+03
x11 = -9.901221e-04  x12 =  1.006387e-03
x22 = -3.631339e+00  x32 = 1.458320e-07  p6 = -1.430353e+06 , cond = 0.000000


p4 =  7.000000e+03
x11 = -9.973946e-04  x12 =  1.013661e-03
x22 = -3.698351e+00  x32 = 1.447881e-07  p6 = -1.488451e+06 , cond = 0.000000


p4 =  7.100000e+03
x11 = -1.004614e-03  x12 =  1.020883e-03
x22 = -3.765360e+00  x32 = 1.437661e-07  p6 = -1.547925e+06 , cond = 0.000000


p4 =  7.200000e+03
```

```
x11 = -1.011783e-03 x12 =  1.028053e-03
x22 = -3.832365e+00 x32 =  1.427653e-07 p6 = -1.608786e+06, cond = 0.000000


p4 = 7.300000e+03
x11 = -1.018900e-03 x12 =  1.035173e-03
x22 = -3.899368e+00 x32 =  1.417850e-07 p6 = -1.671045e+06, cond = 0.000000


p4 = 7.400000e+03
x11 = -1.025969e-03 x12 =  1.042243e-03
x22 = -3.966367e+00 x32 =  1.408246e-07 p6 = -1.734711e+06, cond = 0.000000


p4 = 7.500000e+03
x11 = -1.032989e-03 x12 =  1.049264e-03
x22 = -4.033364e+00 x32 =  1.398833e-07 p6 = -1.799795e+06, cond = 0.000000


p4 = 7.600000e+03
x11 = -1.039962e-03 x12 =  1.056239e-03
x22 = -4.100357e+00 x32 =  1.389605e-07 p6 = -1.866308e+06, cond = 0.000000


p4 = 7.700000e+03
x11 = -1.046888e-03 x12 =  1.063166e-03
x22 = -4.167348e+00 x32 =  1.380556e-07 p6 = -1.934258e+06, cond = 0.000000


p4 = 7.800000e+03
x11 = -1.053769e-03 x12 =  1.070049e-03
x22 = -4.234336e+00 x32 =  1.371681e-07 p6 = -2.003658e+06, cond = 0.000000


p4 = 7.900000e+03
x11 = -1.060605e-03 x12 =  1.076886e-03
x22 = -4.301321e+00 x32 =  1.362975e-07 p6 = -2.074515e+06, cond = 0.000000


p4 = 8.000000e+03
x11 = -1.067397e-03 x12 =  1.083680e-03
x22 = -4.368304e+00 x32 =  1.354431e-07 p6 = -2.146842e+06, cond = 0.000000


p4 = 8.100000e+03
x11 = -1.074147e-03 x12 =  1.090431e-03
x22 = -4.435284e+00 x32 =  1.346045e-07 p6 = -2.220646e+06, cond = 0.000000


p4 = 8.200000e+03
x11 = -1.080854e-03 x12 =  1.097140e-03
x22 = -4.502262e+00 x32 =  1.337812e-07 p6 = -2.295938e+06, cond = 0.000000


p4 = 8.300000e+03
x11 = -1.087520e-03 x12 =  1.103807e-03
x22 = -4.569237e+00 x32 =  1.329728e-07 p6 = -2.372729e+06, cond = 0.000000


p4 = 8.400000e+03
x11 = -1.094146e-03 x12 =  1.110434e-03
x22 = -4.636210e+00 x32 =  1.321788e-07 p6 = -2.451026e+06, cond = 0.000000


p4 = 8.500000e+03
x11 = -1.100731e-03 x12 =  1.117021e-03
x22 = -4.703180e+00 x32 =  1.313988e-07 p6 = -2.530841e+06, cond = 0.000000


p4 = 8.600000e+03
x11 = -1.107278e-03 x12 =  1.123569e-03
x22 = -4.770148e+00 x32 =  1.306323e-07 p6 = -2.612183e+06, cond = 0.000000


p4 = 8.700000e+03
x11 = -1.113786e-03 x12 =  1.130078e-03
x22 = -4.837114e+00 x32 =  1.298791e-07 p6 = -2.695061e+06, cond = 0.000000
```

```
p4 = 8.800000e+03
x11 = -1.120257e-03 x12 = 1.136550e-03
x22 = -4.904078e+00 x32 = 1.291387e-07 p6 = -2.779484e+06, cond = 0.000000


p4 = 8.900000e+03
x11 = -1.126690e-03 x12 = 1.142984e-03
x22 = -4.971039e+00 x32 = 1.284108e-07 p6 = -2.865463e+06, cond = 0.000000


p4 = 9.000000e+03
x11 = -1.133087e-03 x12 = 1.149382e-03
x22 = -5.037998e+00 x32 = 1.276949e-07 p6 = -2.953005e+06, cond = 0.000000


p4 = 9.100000e+03
x11 = -1.139448e-03 x12 = 1.155744e-03
x22 = -5.104956e+00 x32 = 1.269909e-07 p6 = -3.042122e+06, cond = 0.000000


p4 = 9.200000e+03
x11 = -1.145774e-03 x12 = 1.162071e-03
x22 = -5.171911e+00 x32 = 1.262984e-07 p6 = -3.132821e+06, cond = 0.000000


p4 = 9.300000e+03
x11 = -1.152065e-03 x12 = 1.168364e-03
x22 = -5.238864e+00 x32 = 1.256170e-07 p6 = -3.225112e+06, cond = 0.000000


p4 = 9.400000e+03
x11 = -1.158322e-03 x12 = 1.174622e-03
x22 = -5.305816e+00 x32 = 1.249465e-07 p6 = -3.319004e+06, cond = 0.000000


p4 = 9.500000e+03
x11 = -1.164546e-03 x12 = 1.180846e-03
x22 = -5.372765e+00 x32 = 1.242865e-07 p6 = -3.414506e+06, cond = 0.000000


p4 = 9.600000e+03
x11 = -1.170737e-03 x12 = 1.187038e-03
x22 = -5.439713e+00 x32 = 1.236369e-07 p6 = -3.511628e+06, cond = 0.000000


p4 = 9.700000e+03
x11 = -1.176895e-03 x12 = 1.193197e-03
x22 = -5.506659e+00 x32 = 1.229973e-07 p6 = -3.610377e+06, cond = 0.000000


p4 = 9.800000e+03
x11 = -1.183021e-03 x12 = 1.199324e-03
x22 = -5.573603e+00 x32 = 1.223675e-07 p6 = -3.710764e+06, cond = 0.000000


p4 = 9.900000e+03
x11 = -1.189116e-03 x12 = 1.205420e-03
x22 = -5.640545e+00 x32 = 1.217473e-07 p6 = -3.812796e+06, cond = 0.000000


p4 = 1.000000e+04
x11 = -1.195180e-03 x12 = 1.211484e-03
x22 = -5.707485e+00 x32 = 1.211363e-07 p6 = -3.916483e+06, cond = 0.000000
```
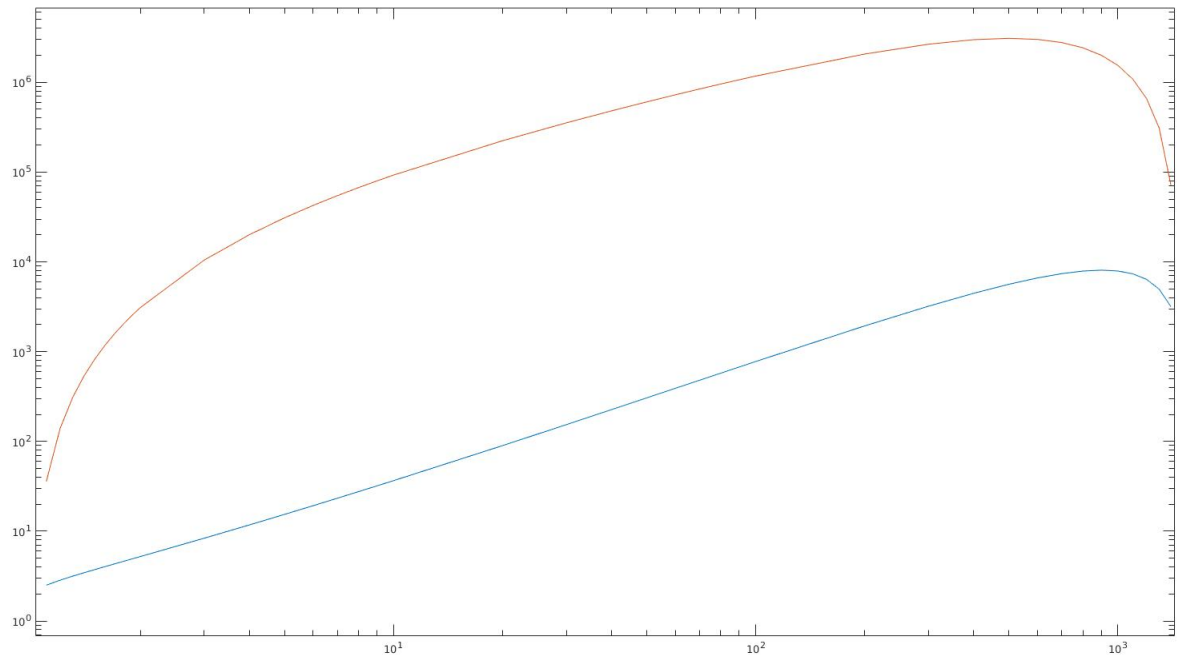
5 Выводы

6 Приложение

6.1 Исходный код

```matlab
syms x1 x2 x3 p4 p6 k
%p1 p2 p3 p4 p6 x2val x3val eq matrix

p1 = 8.4e-6;
p2 = 6.6667e-4;
p3 = 1.7778e-5;
p5 = 2;

x2val = (x1 * x1 + p2 * p4 * x1 - x1) / (p1 - x1);
x3val = x1 / (1 + p4);
p6 = (p1 * x2 + x1 * x2 - p5 * x3) / p3 * p4 + x2;

det11 = -x2/p2 + 1/p2 - 2*x1/p2 - p4;
det12 = p1 / p2 - x1 / p2;
det13 = 0;
det21 = -x2/p3;
det22 = - p1 / p3 - x1 / p3 - p4;
det23 = p5/p3;
det31 = 1;
det32 = 0;
det33 = - 1 - p4;

det11 = subs(det11, x2, x2val);
det21 = subs(det21, x2, x2val);

res = det ( [det11 det12 det13; det21 det22 det23; det31 det32 det33] );
res2 = det ( [det11 det12 det13; det21 det22 det23; det31 det32 det33] );
matrix = [det11 det12 det13; det21 det22 det23; det31 det32 det33];
```

```matlab
29
30 eq = res2 == 0;
31
32 fileID = fopen('resulst.txt', 'w');
33 fileIDcheck = fopen('check.txt', 'w');
34 fileIDplot1 = fopen('forplot1.txt', 'w');
35 fileIDplot2 = fopen('forplot2.txt', 'w');
36 fileIDplot3 = fopen('forplot3.txt', 'w');
37
38
39
40
41 %for i = 1.0: 0.1: 2.0
42 %forrange(0.0, 0.01, 1.0, eq, x1, x2, x3, p4, p6, x2val, x3val, matrix, fileID,
        fileIDcheck, fileIDplot1, fileIDplot2, fileIDplot3);
43 forrange(1.0, 2.0, 0.1, eq, x1, x2, x3, p4, p6, x2val, x3val, matrix, fileID,
        fileIDcheck, fileIDplot1, fileIDplot2, fileIDplot3);
44 forrange(2.0, 10.0, 1.0, eq, x1, x2, x3, p4, p6, x2val, x3val, matrix, fileID,
        fileIDcheck, fileIDplot1, fileIDplot2, fileIDplot3);
45 forrange(10.0, 100.0, 10.0, eq, x1, x2, x3, p4, p6, x2val, x3val, matrix, fileID,
        fileIDcheck, fileIDplot1, fileIDplot2, fileIDplot3);
46 forrange(100.0, 10000.0, 100.0, eq, x1, x2, x3, p4, p6, x2val, x3val, matrix, fileID,
         fileIDcheck, fileIDplot1, fileIDplot2, fileIDplot3);
47 %forrange(1000.0, 10000.0, 1000.0, eq, x1, x2, x3, p4, p6, x2val, x3val, matrix,
        fileID, fileIDcheck, fileIDplot1, fileIDplot2, fileIDplot3);
48
49
50 fclose(fileID);
51 fclose(fileIDcheck);
52 fclose(fileIDplot1);
53 fclose(fileIDplot2);
54 fclose(fileIDplot3);
55
56 %fileIDplot = fopen('forplot.txt','r');
57 A = load('forplot1.txt');
58 B = load('forplot2.txt');
59 C = load('forplot3.txt');
60 %loglog(A(:,1),A(:,2));
61 %hold on;
62 loglog(B(:,1),B(:,2));
63 hold on;
64 loglog(C(:,1),C(:,2));
65 hold off;
66
67
68 function [] = forrange(left, right, step, eq, x1, x2, x3, p4, p6, x2val, x3val,
        matrix, fileID, fileIDcheck, fileIDplot1, fileIDplot2, fileIDplot3)
69 for i = left: step: right
70     %p4 = i;
71     %i = 10;
72     inner = subs(eq, p4, i);
73     x2tmp = subs(x2val, p4, i);
74     x3tmp = subs(x3val, p4, i);
75     p6tmp = subs(p6, p4, i);
76     %check = subs(res, p4, i);
77     mtmp = subs(matrix, p4, i);
78
79     fprintf(fileID, 'p4 = %e \n', i);
80     fprintf(fileIDcheck, '%e\n', i);
81
82     %solution = sym(solve(inner, x1,'IgnoreProperties', true));
83     %solution = solve(res, x1);
84     solution = solve(inner, x1);
```

```matlab
     if (isempty(solution)==false)
          x11 = solution(1, 1);
          x12 = solution(2, 1);
          x13 = solution(3, 1);


          fprintf(fileID, 'x11 = %e x12 = %e \n', x11, x12);
          if (isAlways(x11 > 0) == true)
            x21 = subs(x2tmp, x1, x11);
            x31 = subs(x3tmp, x1, x11);
            p6res = subs(p6tmp, x1, x11);
            p6res = subs(p6res, x2, x21);
            p6res = subs(p6res, x3, x31);

            m1 = subs(mtmp, x1, x11);
            m1 = subs(m1, x2, x21);
            m1 = subs(m1, x3, x31);

            %k = cond(double(m1));
            k = 0;

            fprintf(fileID, 'x21 = %e x31 = %e p6 = %e cond = %f\n', x21, x31, p6res, k)
    ;
            %p6check = (8.4e-6 * x21 + x11 * x21 - 2 * x31) / 1.7778e-5 * i + x21;

            %check1 = subs(res, x1, x11);
            fprintf(fileIDcheck, '%e %e %e %e\n', x11, x21, x31, p6res);
            fprintf(fileIDplot1, '%e %e \n', i, p6res);

          end
          if (isAlways(x12 > 0))
            x22 = subs(x2tmp, x1, x12);
            x32 = subs(x3tmp, x1, x12);
            p6res = subs(p6tmp, x1, x12);
            p6res = subs(p6res, x2, x22);
            p6res = subs(p6res, x3, x32);

            m2 = subs(mtmp, x1, x12);
            m2 = subs(m2, x2, x22);
            m2 = subs(m2, x3, x32);
            %k = cond(double(m2));
            k = 0;
            fprintf(fileID, 'x22 = %e x32 = %e p6 = %e, cond = %f \n', x22, x32, p6res,
    k);
            %p6check = (8.4e-6 * x22 + x12 * x22 - 2 * x32) / 1.7778e-5 * i + x22;



            %check2 = subs(res, x1, x12);
            %check2 = subs(check2, p4, i);
            %fprintf(fileID, 'check = %f \n', check2);
            fprintf(fileIDcheck, '%e %e %e %e\n', x12, x22, x32, p6res);

            fprintf(fileIDplot2, '%e %e \n', i, p6res);
          end
          if (isAlways(x13 > 0) == true)
            x23 = subs(x2tmp, x1, x13);
            x33 = subs(x3tmp, x1, x13);
            p6res = subs(p6tmp, x1, x13);
            p6res = subs(p6res, x2, x23);
            p6res = subs(p6res, x3, x33);

            m3 = subs(mtmp, x1, x13);
```

```matlab
            m3 = subs(m3, x2, x23);
            m3 = subs(m3, x3, x33);
            %k = cond(double(m3));
            k = 0;
            fprintf(fileID, 'x23 = %e x33 = %e p6 = %e cond = %f \n', x23, x33, p6res, k
    );
            %p6check = (8.4e-6 * x23 + x13 * x23 - 2 * x33) / 1.7778e-5 * i + x23;

            %check3 = subs(check, x1, x13);
            %fprintf(fileID, 'check = %f \n', check3);
            fprintf(fileIDcheck, '%e %e %e %e\n', vpa(x13), x23, x33, p6res);

            fprintf(fileIDplot3, '%e %e \n', i, p6res);
        end
        fprintf(fileID, '\n');
    end

end
end
```