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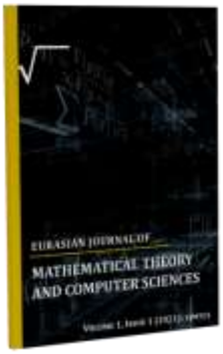

ROBOTOTEXNIK MEXANIZMLARNING MAXSUSLIKLARINI IZLASHDA MATRITSAVIY USULNING QO'LLANISHI

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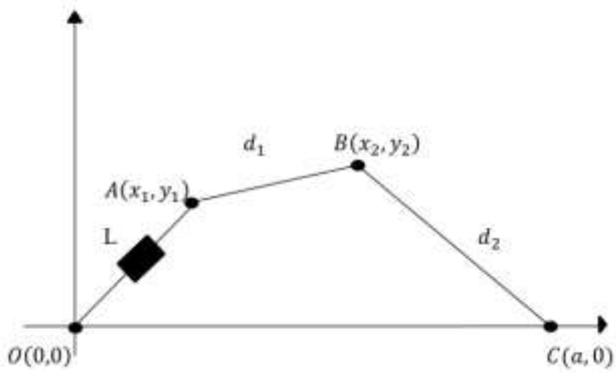
ABSTRACT

Ushbu ishimizda, robototexnikada uchraydigan mexanizmlar o'zining harakatlanish siklida maxsus holatlarga tushadi. Ushbu ishda darajali geometriya usullari yordamida mexanizmning maxsusliklari topiladi va shu maxsuslikning lokal atrofida mexanizmning harakatlanish traektoriyasi hisoblanadi. Mexanizmlarning maxsus holatga tushishini bartaraf etish uchun ularning strukturasini to'liq o'rganishga to'g'ri keladi. Ushbu ish shu muammoni o'rganishga bag'ishlangan.

Robototexnikaning ko'pgina mexanizmlari yuqori erkinlik darajasiga ega. Bu holat esa o'z navbatida mexanizmning harakatlanishi natijasida maxsus holatlarning paydo bo'lishiga olib keladi. Maxsus holatlarning paydo bo'lishi mexanizm xususiyatining o'zgarishiga, yani uning buzilishiga olib keladi. Shuning uchun yaratiladigan robotexnik mexanizmlarning holat funksiyalarining maxsusliklarini o'rganish dolzarb masaladir.

Misol tariqasida to'rtburchakli gidrosilindirik mexanizimning maxsus nuqta atrofida asimtotik yechimini qaraylik. Bunda A, O, B, C nuqtalar quyidagi koordinatalarga ega: $O(0,0)$, $A(x_1, y_1), B(x_2, y_2), C(a, 0)$ va $AB = d_1$, $BC = d_2$ $(d_1, d_2 > 0)$ o'zgarmas kattaliklar, L- musbat o'zgaruvchi kattalik.



Qaralayotgan mexanizmning holat funksiyalarining bog'lanish tenglamalarini quyidagi ko'rinishga ega:

$$\begin{cases} g_1 \stackrel{\text{def}}{=} x_1^2 + y_1^2 = L^2 \\ g_2 \stackrel{\text{def}}{=} (x_2 - x_1)^2 + (y_2 - y_1)^2 = {d_1}^2 \quad (1) \\ g_3 \stackrel{\text{def}}{=} (a - x_2)^2 + y_2^2 = d_2^2 \end{cases}$$

(1) sistemada 3 ta tenglama, 5 ta noma'lumdan iborat, bundan ko'rinadiki, $n = 2$ erkinlik darajasiga ega, ya'ni 2 erkinlik darajasiga ega bo'lgan mexanizmdan iborat.

(1) sistemaning quyidagicha 3x5 tartibli yakobi matritsasi ko'rinishga ega bo'ladi.

$$J = 2\begin{pmatrix} x_1 & y_1 & 0 & 0 & -L \\ x_1 - x_2 & y_1 - y_2 & x_2 - x_1 & y_2 - y_1 & 0 \\ 0 & 0 & x_2 - a & y_2 & 0 \end{pmatrix}$$

Matritsaning 3-tartibli minorlari quyidagilar:

$$M_1 = 8\begin{vmatrix} x_1 & y_1 & 0 \\ x_1 - x_2 & y_1 - y_2 & x_2 - x_1 \\ 0 & 0 & x_2 - a \end{vmatrix} \quad M_2 = 8\begin{vmatrix} x_1 & y_1 & 0 \\ x_1 - x_2 & y_1 - y_2 & y_2 - y_1 \\ 0 & 0 & y_2 \end{vmatrix} \quad M_3 = 8\begin{vmatrix} x_1 & y_1 & -L \\ x_1 - x_2 & y_1 - y_2 & 0 \\ 0 & 0 & 0 \end{vmatrix}$$

$$M_4 = 8\begin{vmatrix} x_1 & 0 & 0 \\ x_1 - x_2 & x_2 - x_1 & y_2 - y_1 \\ 0 & x_2 - a & y_2 \end{vmatrix}$$

$$M_5 = 8\begin{vmatrix} x_1 & 0 & -L \\ x_1 - x_2 & x_2 - x_1 & 0 \\ 0 & x_2 - a & 0 \end{vmatrix} \quad M_6 = 8\begin{vmatrix} x_1 & 0 & -L \\ x_1 - x_2 & y_2 - y_1 & 0 \\ 0 & y_2 & 0 \end{vmatrix}$$

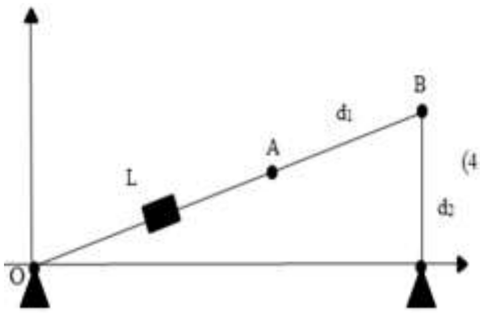
$$M_7 = 8\begin{vmatrix} y_1 & 0 & 0 \\ y_1 - y_2 & x_2 - x_1 & y_2 - y_1 \\ 0 & x_2 - a & y_2 \end{vmatrix} \quad M_8 = 8\begin{vmatrix} y_1 & 0 & -L \\ y_1 - y_2 & y_2 - y_1 & 0 \\ 0 & y_2 & 0 \end{vmatrix}$$

$$M_9 = 8\begin{vmatrix} y_1 & 0 & -L \\ y_1 - y_2 & x_2 - x_1 & 0 \\ 0 & x_2 - a & 0 \end{vmatrix} \quad M_{10} = 8\begin{vmatrix} 0 & 0 & -L \\ x_2 - x_1 & y_2 - y_1 & 0 \\ x_2 - a & y_2 & 0 \end{vmatrix}$$

Bundan: $M_1 = 8(x_2 - a)(x_2y_1 - x_1y_2)$, $M_2 = 8y_2(x_2y_1 - x_1y_2)$, $M_3 = 0$ $M_4 = 8x_1\big(x_2y_1 - x_1y_2 + a(y_2 - y_1)\big)$, $M_5 = 8L(x_2 - x_1)(x_2 - a)$, $M_6 = 8L(x_2 - x_1)y_2$,
$M_7 = 8y_1(x_2y_1 - x_1y_2 + a(y_2 - y_1))$,
$M_8 = 8Ly_2(y_2 - y_1)$, $M_9 = 8L(y_2 - y_1)(x_2 - a)$,
$M_{10} = L\big(x_1y_2 - y_1x_2 + a(y_1 - y_2)\big)$.

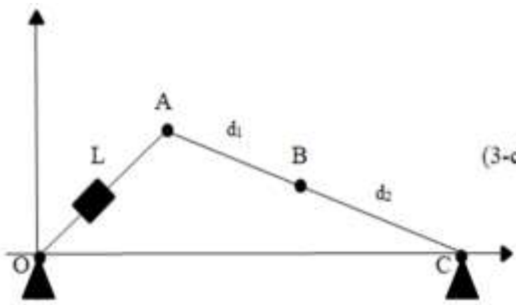
Teorema. To'rtburchakli gidrosilindirik mexanizm ikkinchi tur maxsuslikka erishmaydi.

Isbot. Shartga ko'ra mexanizm ikkinchi tur maxsuslikka erishishi uchun $\forall\ i$ lar uchun $M_i = 0\ (i = \overline{1,10})$ sharti bajarilishi zarur. Lekin bunday holat yuz bermaydi, chunki aniqlanishiga ko'ra $x_1 \neq x_2$, $\mathrm{L} > 0$.



(4-chizma)

M₁=M₂=M₅=M₉=0



(3-chizma)

M₁=M₂=0

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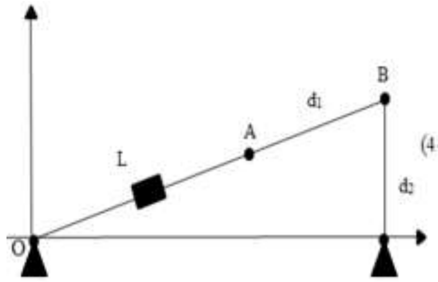
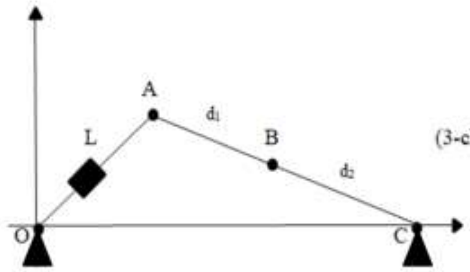


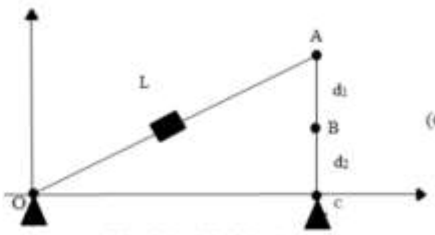
(4-chizma)

$M_1=M_2=M_5=M_9=0$



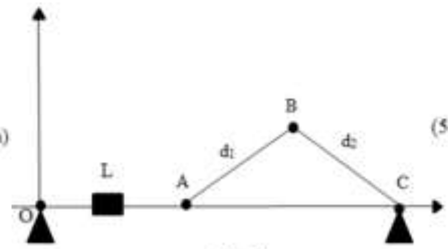
(3-chizma)

$M_1=M_2=0$



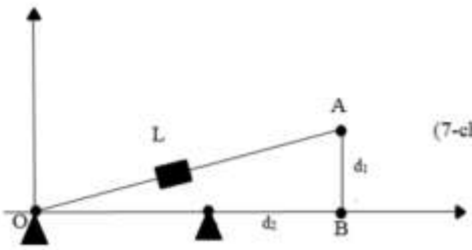
(6-chizma)

$M_1= M_5= M_6=M_9=0$



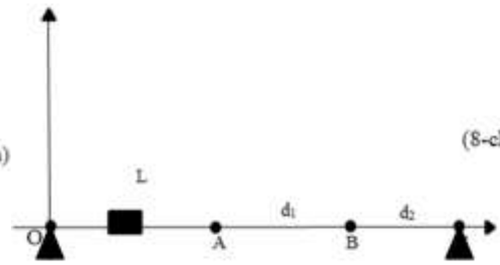
(5-chizma)

$M_7=0$



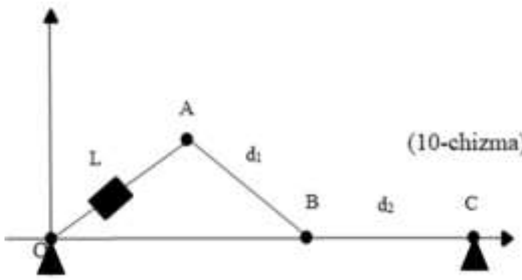
(7-chizma)

$M_2= M_3= M_6=M_8=0$



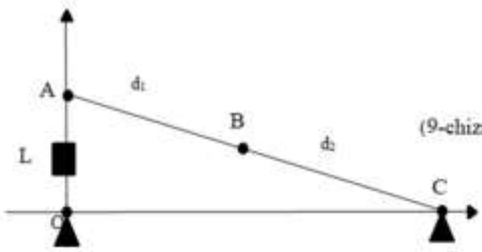
(8-chizma)

$M_1= M_2= M_3= M_4=M_6=M_7= M_8= M_9=M_{10}=0$



(10-chizma)

$M_2= M_6= M_8 =0$



(9-chizma)

$M_1= M_2= M_4 =0$

Endi Nyuton ko'pyoqliklari usuli yordamida P^0 maxsus nuqtaning kichik atrofida (1) sistemaning parametrik yechimlarini izlaymiz. Bunda $P^0(x_1^0, x_2^0, 0,0, L^0)$ (8- chizma.)
(1) sistemada quyidagi koordinatalar almashtirishni olaylik.

$$\begin{cases} x_1 = x_1^0 + z_1 \\ x_2 = x_2^0 + z_2 \\ y_1 = z_3 \\ y_2 = z_4 \\ L = L_0 + z_5 \end{cases} \qquad (2)$$

Bu yerda $z_i\ (i = \overline{1,5})$ lar P^0 maxsus nuqtadan kichik chetlanishdir. Bu qiymatlarni (1) sistemaga qo'yib quyidagi sistemani hosil qilamiz:

$$\begin{cases} g_1 \triangleq (x_1^0 + z_1)^2 + z_3^2 = (L_0 + z_5)^2 \\ g_2 \triangleq (x_2^0 + z_2 - x_1^0 - z_1)^2 + (z_4 - z_3)^2 = {d_1}^2 \\ g_3 \triangleq (a - x_2^0 - z_2)^2 + {z_4}^2 = {d_2}^2 \end{cases} \qquad (3)$$

Tegishli hisoblashlarni bajarib hamda (1) sistema shartlarini hisobga olib, quyidagi sistemaga kelamiz:

$$\begin{cases} {z_1}^2 + 2x_1^0 z_1 + z_3^2 - 2L_0 z_5 - z_5^2 = 0 \\ z_1^2 + 2(x_1^0 - x_2^0)z_1 - 2z_1 z_2 + 2(x_2^0 - x_1^0)z_2 + z_2^2 + (z_4 - z_3)^2 = 0 \\ z_2^2 + 2(x_2^0 - a)z_2 + z_4^2 = 0 \end{cases} \qquad (4)$$

Nyuton ko'pyoqliklari usulini qo'llab (3) sistema uchun quyidagi qisqartma sistemani olamiz.

$$\begin{cases} 2x_1^0 z_1 + z_3^2 - 2L_0 z_5 = 0 \\ 2(x_2^0 - x_1^0)(z_2 - z_1) + (z_4 - z_3)^2 = 0 \\ 2(x_2^0 - a)z_2 + z_4^2 = 0 \end{cases}$$

Bu sistemani yechib:

$$z_1 = \frac{1}{2(a - x_2^0)} z_4^2 + \frac{1}{2(x_2^0 - x_1^0)} (z_4 - z_3)^2$$

$$z_2 = \frac{z_4^2}{2(a - x_2^0)}$$

$$z_5 = \frac{x_1^0}{2L_0(a - x_2^0)} z_4^2 + \frac{x_1^0}{2L_0(x_2^0 - x_1^0)} (z_4 - z_3)^2 + \frac{1}{2L_0} z_3^2.$$

Topilgan $z_i\ (i = \overline{1.5})$ larni qiymatlarini (2) sistemaga qo'yib (1) sistema uchun asimptotik yechimni olamiz:

$$x_1 = x_1^0 + z_1 = x_1^0 + \frac{1}{2(a - x_2^0)} z_4^2 + \frac{1}{2(x_2^0 - x_1^0)} (z_4 - z_3)^2 + \cdots,$$

$$x_2 = x_2^0 + z_2 = x_2^0 + \frac{z_4^2}{2(a - x_2^0)} + \cdots,$$

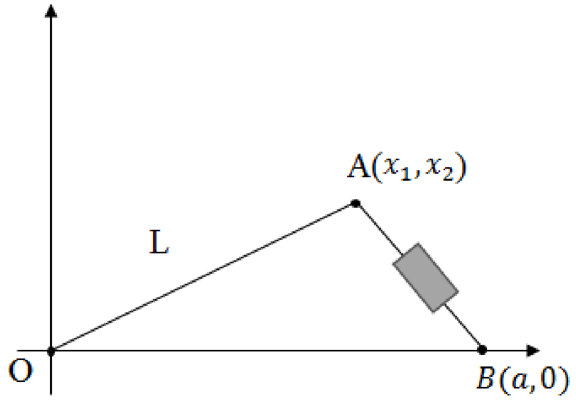
$$y_1 = z_3 + \cdots, \qquad (5)$$

$$y_2 = z_4 + \cdots,$$

$$L = L_0 + z_5 = L_0 + \frac{x_1^0}{2L_0(a - x_2^0)} z_4^2 + \frac{x_1^0}{2L_0(x_2^0 - x_1^0)} (z_4 - z_3)^2 + \frac{1}{2L_0} z_3^2 + \cdots,$$

(1) sistema uchun topilgan (5) yechimlardan ko'rinadiki (8-chizma), mexanizm bunday maxsus holatdan har xil yo'nalish bo'yicha harakatlanishi mumkin va ularni bilib zarur hollarda maxanizmning maxsus holatlarini yo'qotish mumkin, ya'ni mexanizmning parametrlarini o'zgartirib maxsus holatlarga tushmasligini ta'minlash mumkin bo'ladi.

Misol-1. Uchburchakli gidrosilindirik mexanizimning maxsus nuqta atrofida asimtotik yechimini qaraylik. Bunda A, O, B nuqtalar quyidagi koordinatalarga ega: $O(0,0), A(x_1, x_2), B(a, 0)$ va $OA = l$ o'zgarmas kattalik.



Qaralayotgan mexanizmning holat funksiyalarini algebraik shakldа yozamiz:

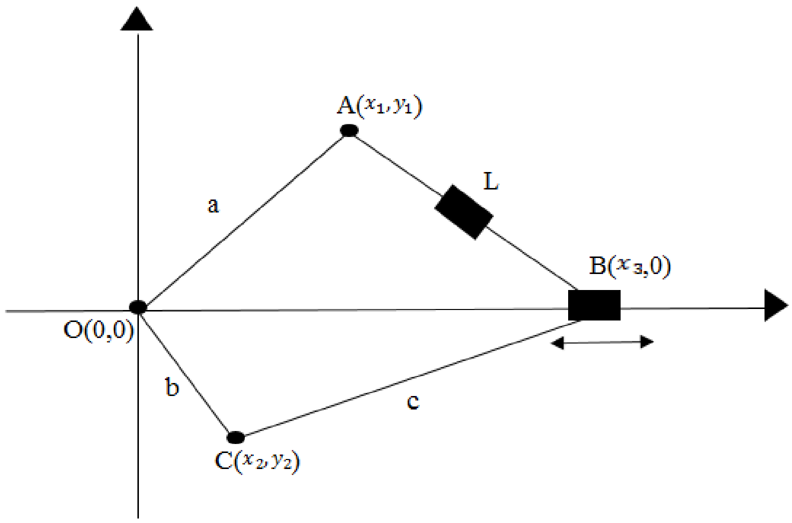
$$\begin{cases} f_1 \stackrel{\text{def}}{=} x_1^2 + x_2^2 = l^2 \\ f_1 \stackrel{\text{def}}{=} (x_1 - a)^2 + x_2^2 = x_3^2 \end{cases} \qquad (10)$$

(10) sistemada 2 ta tenglama, 3 ta noma'lumdan iborat, bundan ko'rinadiki, $n = 1$ erkinlik darajasiga ega, ya'ni 1 erkinlik darajasiga ega bo'lgan mexanizmdan iborat. (10) sistemaning yakobi matritsasi quyidagicha ko'rinishga ega bo'ladi.

$$J = 2\begin{pmatrix} x_1 & x_2 & 0 \\ x_1 - a & x_2 & -x_3 \end{pmatrix}$$

Matritsaning 2- tartibli minorlari 3 ta bo'lib ular quyidagilardir:
Bundan $M_1 = ax_2, M_2 = -x_1\, x_3, M_2 = -x_2\, x_3,$ ekanligi va $M_1 = M_3 = 0$ minorlarning nolga aylanishi mos holda mexanizmning maxsus holatga tushishini anglatadi, ya'ni erkinlik darajasini yuqotishdir. Aga $x_3 = 0$ shart bajarilsa $O, A\ va\ B$ nuqtalar bir to'g'ri chiziqda yotishini anglatadi. $x_2 = 0$ bo'lganda birinchi tur maxsus holatni ifodalaydi. Osongina aniqlash mumkinki barcha M_i lar bir vaqtda nolga aylansa ya'ni $M_i = 0\ (i = \overline{1,3})$ shartlari bajarilsa berilgan mexanizm ikkinchi tur maxsuslikka erishadi.

Misol-2 Yana bir To'rtburchakli gidrosilindirik mexanizimning maxsus nuqta atrofida asimtotik yechimini qaraylik. Bunda A, O, B, C nuqtalar quyidagi koordinatalarga ega: $O(0,0)$, $A(x_1, y_1)$, $B(x_3, 0), C(x_2, y_2)$, va $OA = a$, $OC = b$, $BC = c$ $(b < a < c)$ o'zgarmas kattaliklar, L- musbat o'zgaruvchi kattalik.



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Qaralayotgan mexanizmning holat funksiyalarining bog'lanish tenglamalarini tuzamiz:

$$\begin{cases} g_1 \stackrel{\text{def}}{=} x_1^2 + y_1^2 = a^2 \\ g_2 \stackrel{\text{def}}{=} (x_1 - x_3)^2 + {y_1}^2 = L^2 \\ g_3 \stackrel{\text{def}}{=} (x_2 - x_3)^2 + y_2^2 = c^2 \\ g_4 \stackrel{\text{def}}{=} x_2^2 + y_2^2 = b^2 \end{cases} \qquad (11)$$

(11) sistemada 4 ta tenglama, 6 ta noma'lumdan iborat, bundan ko'rinadiki,
$n = 2$ erkinlik darajasiga ega, ya'ni 2 erkinlik darajasiga ega bo'lgan mexanizmdan iborat.
(11) sistemaning quyidagicha 4x6 tartibli yakobi matritsasi quyidagi ko'rinishga ega bo'ladi.

$$J = 2\begin{pmatrix} x_1 & y_1 & 0 & 0 & 0 & 0 \\ x_1 - x_3 & y_1 & 0 & 0 & x_3 - x_1 & -L \\ 0 & 0 & x_2 - x_3 & y_2 & x_3 - x_2 & 0 \\ 0 & 0 & x_2 & y_2 & 0 & 0 \end{pmatrix}$$

Matritsaning 4-tartibli minorlari quyidagilar:

$$M_1 = 16\begin{vmatrix} x_1 & y_1 & 0 & 0 \\ x_1 - x_3 & y_1 & 0 & 0 \\ 0 & 0 & x_2 - x_3 & y_2 \\ 0 & 0 & x_2 & y_2 \end{vmatrix} \quad M_2 = 16\begin{vmatrix} x_1 & y_1 & 0 & 0 \\ x_1 - x_3 & y_1 & 0 & x_3 - x_1 \\ 0 & 0 & x_2 - x_3 & x_3 - x_2 \\ 0 & 0 & x_2 & 0 \end{vmatrix}$$

$$M_3 = 16\begin{vmatrix} x_1 & y_1 & 0 & 0 \\ x_1 - x_3 & y_1 & 0 & -L \\ 0 & 0 & x_2 - x_3 & 0 \\ 0 & 0 & x_2 & 0 \end{vmatrix} \quad M_4 = 16\begin{vmatrix} x_1 & y_1 & 0 & 0 \\ x_1 - x_3 & y_1 & 0 & x_3 - x_1 \\ 0 & 0 & y_2 & x_3 - x_2 \\ 0 & 0 & y_2 & 0 \end{vmatrix}$$

$$M_5 = 16\begin{vmatrix} x_1 & y_1 & 0 & 0 \\ x_1 - x_3 & y_1 & 0 & -L \\ 0 & 0 & y_2 & 0 \\ 0 & 0 & y_2 & 0 \end{vmatrix} \quad M_6 = 16\begin{vmatrix} x_1 & y_1 & 0 & 0 \\ x_1 - x_3 & y_1 & x_3 - x_1 & -L \\ 0 & 0 & x_3 - x_2 & 0 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$M_7 = 16\begin{vmatrix} x_1 & 0 & 0 & 0 \\ x_1 - x_3 & 0 & 0 & x_3 - x_1 \\ 0 & x_2 - x_3 & y_2 & x_3 - x_2 \\ 0 & x_2 & y_2 & 0 \end{vmatrix} \quad M_8 = 16\begin{vmatrix} x_1 & 0 & 0 & 0 \\ x_1 - x_3 & 0 & 0 & -L \\ 0 & x_2 - x_3 & y_2 & 0 \\ 0 & x_2 & y_2 & 0 \end{vmatrix}$$

$$M_9 = 16\begin{vmatrix} x_1 & 0 & 0 & 0 \\ x_1 - x_3 & 0 & x_3 - x_1 & -L \\ 0 & x_2 - x_3 & x_3 - x_2 & 0 \\ 0 & x_2 & 0 & 0 \end{vmatrix} \quad M_{10} = 16\begin{vmatrix} x_1 & 0 & 0 & 0 \\ x_1 - x_3 & 0 & x_3 - x_1 & -L \\ 0 & y_2 & x_3 - x_2 & 0 \\ 0 & y_2 & 0 & 0 \end{vmatrix}$$

$$M_{11} = 16\begin{vmatrix} y_1 & 0 & 0 & 0 \\ y_1 & 0 & 0 & x_3 - x_1 \\ 0 & x_2 - x_3 & y_2 & x_3 - x_2 \\ 0 & x_2 & y_2 & 0 \end{vmatrix} \quad M_{12} = 16\begin{vmatrix} y_1 & 0 & 0 & 0 \\ y_1 & 0 & 0 & -L \\ 0 & x_2 - x_3 & y_2 & 0 \\ 0 & x_2 & y_2 & 0 \end{vmatrix}$$

$$M_{13} = 16\begin{vmatrix} y_1 & 0 & 0 & 0 \\ y_1 & 0 & x_3 - x_1 & -L \\ 0 & x_2 - x_3 & x_3 - x_2 & 0 \\ 0 & x_2 & 0 & 0 \end{vmatrix} \quad M_{14} = 16\begin{vmatrix} y_1 & 0 & 0 & 0 \\ y_1 & 0 & x_3 - x_1 & -L \\ 0 & y_2 & x_3 - x_2 & 0 \\ 0 & y_2 & 0 & 0 \end{vmatrix}$$

$$M_{15} = 16\begin{vmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & x_3 - x_1 & -L \\ x_2 - x_3 & y_2 & x_3 - x_2 & 0 \\ x_2 & y_2 & 0 & 0 \end{vmatrix}$$

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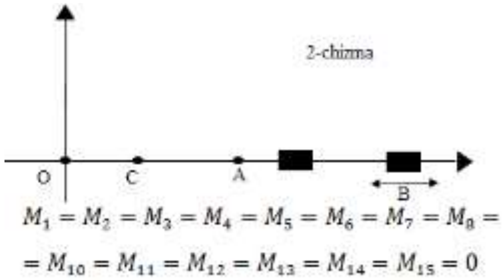
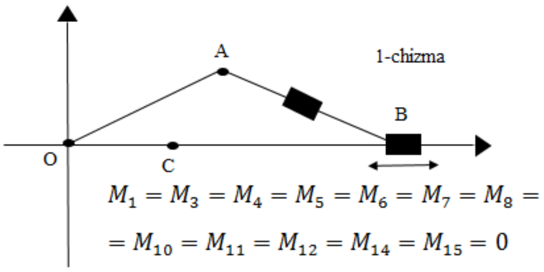
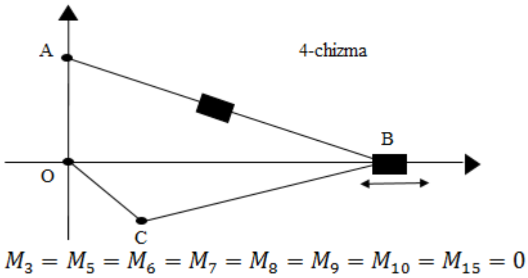
Bundan: $M_1 = -16{x_3}^2 y_1 y_2$; $M_2 = 16x_2x_3y_1(x_2 - x_3)$; $M_3 = 0$;
$M_4 = 16x_3y_1y_2(x_2 - x_3)$; $M_5 = 0$; $M_6 = 0$; $M_7 = 16x_1x_3y_2(x_1 - x_3)$;
$M_8 = 16x_1x_3y_2L$; $M_9 = 16x_1x_2L(x_3 - x_2)$; $M_{10} = 16x_1y_2L(x_3 - x_2)$;
$M_{11} = 16x_3y_1y_2(x_1 - x_3)$; $M_{12} = 16x_3y_1y_2L$; $M_{13} = 16x_2y_1L(x_3 - x_2)$;
$M_{14} = 16y_1y_2L(x_3 - x_2)$; $M_{15} = 0$;

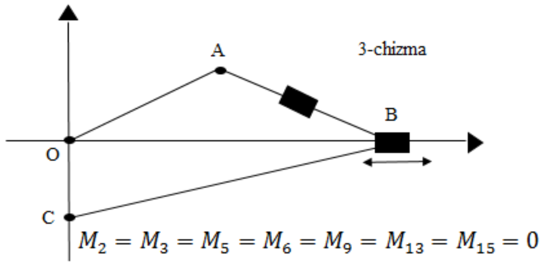
Teorema. To'rtburchakli gidrosilindirik mexanizm ikkinchi tur maxsuslikka erishmaydi.

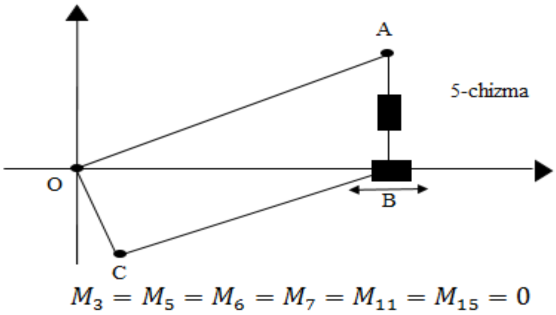
Isbot. Shartga ko'ra mexanizm ikkinchi tur maxsuslikka erishishi uchun $\forall\, i$ lar uchun $M_i = 0$ $(i = \overline{1,10})$ sharti bajarilishi zarur. Lekin bunday holat yuz bermaydi, chunki aniqlanishiga ko'ra $b \neq c$ va $L > 0$

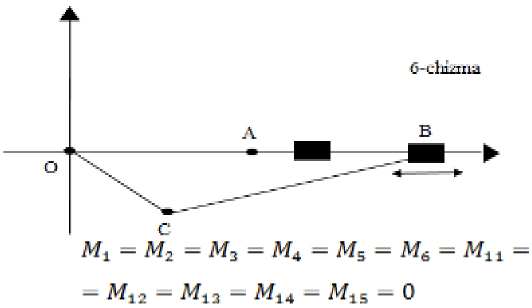












Endi Nyuton ko'pyoqliklari usuli yordamida P^0 maxsus nuqtaning kichik atrofida (11) sistemaning parametrik yechimlarini izlaymiz. Bunda $P^0(x_1^0, x_2^0, x_3^0, 0,0, L_0)$ (2-chizma.)
(11) sistemada quyidagi koordinatalar almashtirishni olaylik.

$$\begin{cases} x_1 = x_1^0 + z_1 \\ x_2 = x_2^0 + z_2 \\ x_3 = x_3^0 + z_3 \\ y_1 = z_4 \\ y_2 = z_5 \\ L = L_0 + z_6 \end{cases} \qquad (12)$$

Bu yerda $z_i\ (i=\overline{1,6})$ lar P^0 maxsus nuqtadan kichik chetlanishdir. Bu qiymatlarni (11) sistemaga qo'yib quyidagi sistemani hosil qilamiz:

$$\begin{cases} g_1 \triangleq (x_1^0+z_1)^2+z_4^2=a^2 \\ g_2 \triangleq (x_1^0+z_1-x_3^0-z_3)^2+z_4^2=(L_0+z_6)^2 \\ g_3 \triangleq (x_2^0+z_2-x_3^0-z_3)^2+z_5^2=c^2 \\ g_4 \triangleq (x_2^0+z_2)^2+{z_5}^2=b^2 \end{cases} \qquad (13)$$

Tegishli hisoblashlarni bajarib hamda (11) sistema shartlarini hisobga olib, quyidagi sistemaga kelamiz:

$$\begin{cases} {z_1}^2+2x_1^0z_1+z_4^2=0 \\ (z_1-z_3)^2+2(x_1^0-x_3^0)z_1-2(x_1^0-x_3^0)z_3+z_4^2-{z_6}^2-2L_0z_6=0 \\ (z_2-z_3)^2+2(x_2^0-x_3^0)z_2-2(x_2^0-x_3^0)z_3+z_5^2=0 \\ {z_2}^2+2x_2^0z_2+z_5^2=0 \end{cases} \qquad (14)$$

Nyuton ko'pyoqliklari usulini qo'llab (13) sistema uchun quyidagi qisqartma sistemani olamiz.

$$\begin{cases} 2x_1^0z_1+z_4^2=0 \\ 2(x_1^0-x_3^0)z_1-2(x_1^0-x_3^0)z_3+z_4^2-2L_0z_6=0 \\ 2(x_2^0-x_3^0)z_2-2(x_2^0-x_3^0)z_3+z_5^2=0 \\ 2x_2^0z_2+z_5^2=0 \end{cases}$$

Bu sistemani yechib:

$$z_1=-\frac{z_4^2}{2x_1^0}$$

$$z_2=-\frac{z_5^2}{2x_2^0}$$

$$z_3=\frac{x_3^0}{2x_2^0(x_2^0-x_3^0)}z_5^2$$

$$z_6=\frac{1}{2L_0}\left(\frac{x_3^0}{x_1^0}z_4^2-\frac{x_1^0x_3^0-{x_3^0}^2}{{x_2^0}^2-x_2^0x_3^0}z_5^2\right)$$

Topilgan $z_i\ (i=\overline{1.6})$ larni qiymatlarini (12) sistemaga qo'yib (11) sistema uchun asimptotik yechimni olamiz:

$$x_1=x_1^0+z_1=x_1^0-\frac{z_4^2}{2x_1^0}+\cdots,$$

$$x_2=x_2^0+z_2=x_2^0-\frac{z_5^2}{2x_2^0}+\cdots,$$

$$x_3=x_3^0+z_3=x_3^0+\frac{x_3^0}{2x_2^0(x_2^0-x_3^0)}z_5^2+\cdots,$$

$$y_1=z_4+\cdots, \qquad (15)$$

$$y_2=z_5+\cdots,$$

$$L=L_0+z_5=L_0+\frac{1}{2L_0}\left(\frac{x_3^0}{x_1^0}z_4^2-\frac{x_1^0x_3^0-{x_3^0}^2}{{x_2^0}^2-x_2^0x_3^0}z_5^2\right)+\cdots,$$

topiladi.

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