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QARSHILIKLI ERKINLIK DARAJASI BIRGA TENG BO'LGAN MEXANIK SISTEMANING ERKIN TEBRANISHI

Annotatsiya. *Bu ishda Kulon qarshilikli erkinlik darajasi birga teng bo'lgan mexanik sistemaning erkin tebranishi masalasi yechilgan. Mexanik sistemaning tebranishlar tenglamasi Nyutonning ikkinchi qonuni orqali olingan. Olingan tebranishlar tenglamasi Laplasning integral almashtirishi orqali yechiladi. Sonli natijalar olinib tahlil qilingan.*

Kalit so'zlar*: erkinlik darajasi, Laplasning integral almashtirishi, inersiya kuchi, Nyutonning ikkinchi qonuni, erkin tebranishlar chastotasi.*

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Аннотация. *В данной работе решена задача о свободных колебаниях механической системы с кулоновским сопротивлением степени свободы, равной единице. Уравнение колебаний механической системы получено с использованием второго закона Ньютона. Полученное уравнение колебаний решено с использованием интегрального преобразования Лапласа. Получены и проанализированы численные результаты.*

Ключевые слова*: степени свободы, интегральное преобразование Лапласа, инерционная сила, второй закон Ньютона, частота свободных колебаний.*

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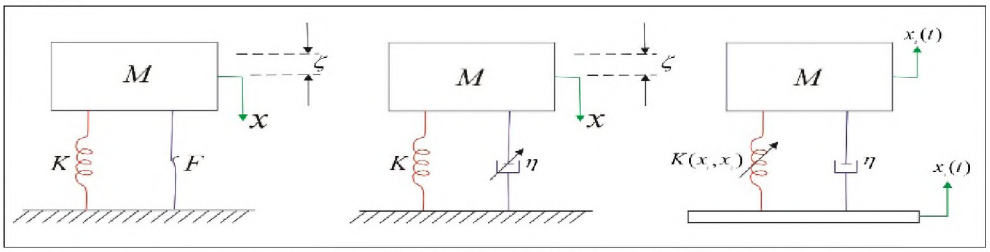
Annotation. *In this work, the problem of free oscillations of a mechanical system with a Coulomb resistance degree of freedom equal to one is solved. The oscillation equation of the mechanical system is obtained using Newton's second law. The obtained oscillation equation is solved using Laplace's integral transformation. Numerical results are obtained and analyzed.*

Keywords: *degrees of freedom, Laplace's integral transformation, inertial force, Newton's second*

law, frequency of free oscillations.

Kirish. Hozirgi zamonda texnika va texnologiyaning judda tez rivojlanishi oqibatida vibratsion tebranishlar va shovqinga qarshi kurashish dolzarb muammo hisoblanadi [1,2]. Zamonaviy uchuvchi apparatlar, aviatsiya, kemasozlik, mashinasozlik va qurilish sohasidagi taraqqiyot qurilmalarning har xil turdagi dinamik yuklanishlar ta'sirlardan hosil bo'ladigan dinamik kuchlanish–deformatsiya holatini nihoyatda aniq ximoyalashni talab etadi [3,4]. Uchuvchi apparatlar, samolyotsozlik va harakatlanuvchan transportlarning ko'p qismlari deformatsiyalanuvchan qobiqsimon elementlardan tashkil topgan bo'ladi [5,6]. Ularda hosil bo'ladigan tebranish (vibratsiya)lar va shovqinlarni qamaytirish masalasi ikkiga bo'lib o'rganish bilan dunyoning ko'pchilik olimlar va tadqiqotchilar izlanishlar olib borishmoqda [8,9].

Tadqiqot metodologiyasi. Erkinlik darajasi birga teng bo'lgan 1-rasmda tasvirlangan mexanik sistemalarni ko'ramiz:



1-rasm. Kulon qarshilikli mexanik Sistema.

Kulon qarshilikli mexanik sistemani harakat differensial tenglamasi Nyutonning ikkinchi qonunini orqali olinadi.

$$M\frac{d^2x}{dt^2} = -Kx \pm F, \tag{1}$$

bunda F-Kulon demfirlash friksion kuch, M -amortizatsiyaga uchraydigan massa, K-elastiklik koyeffitsenti, x-massaning harakat qonuni.

Ushbu tenglama haqiqiy bo'lishi uchun, dastlab, harakat sodir bo'lishi kerak, ya'ni, siljish ζ bo'lishi kerak bo'lgan prujina kuchi ishqalanish kuchi F dan oshib ketishini ta'minlash kerak: $K\zeta > F$. Agar ζ "o'lik mintaqa" deb atalgan tizimni ichida yotsa, harakat sodir bo'lmaydi:

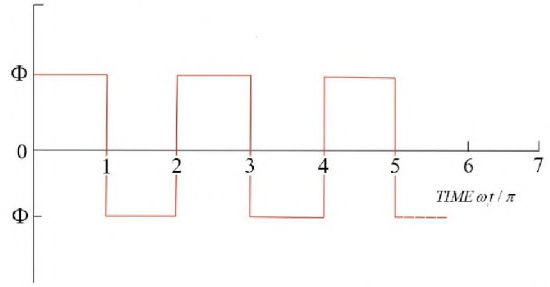
$$x = \pm\frac{F}{K} = \pm\frac{\Phi}{\omega_0{}^2}. \tag{2}$$

Bu yerda $\Phi = \dfrac{F}{M}$, ω_0 bu tizimning erkin chastotasi.

Agar tebranishning ketma-ket amplitudalari o'lik mintaqadan tashqariga tushsa, u holda M uchun harakat tenglamasi quyidagicha bo'ladi:

$$\frac{d^2x}{dt^2} + \omega_0{}^2 x = \Theta(t), \tag{3}$$

bu yerda $\Theta(t)$ ni o'zgarishi 2-rasmda keltirilgan:



2-rasm. Koulomb amortizatorining harakatga qarshiligini tavsiflovchi "kvadrat to'lqin" funksiyasi; parametr $\Phi = F / M$.

Endi (3) tenglamaning Laplas almashtirishi quyidagicha bo'ladi:

$$(p^2+\omega_0^2)\overline{x} = p\zeta + L\Theta(t) \tag{4}$$

Tasvirda $L\Theta(t)$ quyidagicha bo‘ladi:

$$L\Theta(t) = L(\Phi) - L(2\Phi)_{t>\pi/\omega_0} + L(2\Phi)_{t>2\pi/\omega_0} - L(2\Phi)_{t>3\pi/\omega_0} + \dots$$

$$= \int_0^\infty e^{-pt}\Phi dt + 2(-1)^n \int_{n\pi/\omega_0}^\infty e^{-pt}\Phi dt + 2(-1) \tag{5}$$

$$= \frac{\Phi}{p} + (-1)^n \frac{\Phi}{p} e^{-n\pi p/\omega_0}, \quad n = 1,2,3,....$$

Natijada (4)-tenglamaning yechimi quyidagicha bo‘ladi:

$$\overline{x} = p^2\zeta T(\omega_0) + \Phi T(\omega_0)(1 - 2e^{-\pi p/(\omega_0)} + 2e^{-2\pi p/(\omega_0)} - 2e^{-3\pi p/(\omega_0)} + \dots). \tag{6}$$

Xevisaydning siljish teoremasini qo‘llash [10] orqali yuqoridagi tasvirda berilgan yechim (6) ni teskari orginalini topish mumkin bo‘ladi:

$$x = \zeta \cos\omega_0 t + \frac{\Phi}{\omega_0^2}\{(1-\cos\omega_0 t)_{t>0} - 2[1-\cos(\omega_0 t - \pi)]_{t>\pi/\omega_0} \tag{7}$$

$$+2[1-\cos(\omega_0 t - 2\pi)]_{t>2\pi/\omega_0} - 2[1-\cos(\omega_0 t - 2\pi)]_{t>3\pi/\omega_0} \dots\}.$$

Bu tenglama $t = 0,\ \pi/\omega_0,\ 2\pi/\omega_0,\ 3\pi/\omega_0, \dots, \zeta, (-\zeta + 2\Phi/\omega_0^2)$ va $(\zeta - 4\Phi/\omega_0^2), (-\zeta + 6\Phi/\omega_0^2), \dots$ qiymatlarini qabul qilganda paydo bo‘ladigan tebranishning amplitudalarni ketma-ket ko‘rsatadi. Ya’ni, har bir yarim sikl uchun tebranish amplitudasi miqdori quyidagi miqdorda kamayadi: $2\Phi/\omega_0^2 = 2F/K$.

Yuqorida tasvirlangan 1,b-rasmdagi nochiziqli qarshilikli (tezlik kvadratiga mutanosib bo‘lsa), u holda *M* massaning harakat differensial tenglamasi quyidagicha bo‘ladi:

$$M\frac{d^2x}{dt^2} = -Kx \pm \eta\left(\frac{dx}{dt}\right)^2, \tag{8}$$

bu yerda η doimiy emasdir. Shunday qilib, birinchi yarim sikl uchun (8) quyidagilarni ko‘ramiz:

$$\frac{d^2x}{dt^2} - \Delta\left(\frac{dx}{dt}\right)^2 + \omega_0^2 x = 0,\ \Delta = \frac{\eta}{M} \tag{9}$$

Laplas almashtrish orqali (9) ni quyidagicha yozamiz:

$$(p^2+\omega_0^2)\overline{x} = p\zeta + \Delta L(\dot{x})^2\ . \tag{10}$$

Endi *M* massaning siljishi quyidagi shaklda yozilishi mumkin:

$$x = x_0(t) + \Delta x_1(t) + \Delta^2 x_2(t) + \dots,$$

bunda $x = x_0(t)$ -tenglama yechimiga birinchi yaqinlashish, $x_n(t)$ hali aniqlanmagan vaqt funksiyalari. Bundan tashqari, mexanik sistemani ω_Δ berilgan chastotasi quyidagicha topiladi:

$$\omega_\Delta^2 = \omega_0^2 + \Delta C_1 + \Delta^2 C_2 + \dots, \tag{11}$$

Bu yerda C_n hali baholanmagan konstantalardir. Masalani yechishda nochiziqlik darajasi yetarlicha kichik deb taxmin qilinadi. (8)-tenglama endi quyidagicha yozilishi mumkin:

$$(p^2+\omega_\Delta^2)\overline{x}_0 + \Delta[(p^2+\omega_\Delta^2)\overline{x}_1 - C_1\overline{x}_0 - L(\dot{x}_0)^2] +$$
$$+\Delta^2[(p^2+\omega_\Delta^2)\overline{x}_2 - C_1\overline{x}_1 - C_2\overline{x}_0 - 2L(\dot{x}_0\dot{x}_1) = p\zeta. \tag{12}$$

Ushbu tenglama barcha qiymatlari uchun Δ va Δ^2 koyeffitsiyentlari individual ravishda nolga teng bo‘lishi kerak:

$$(p^2+\omega_\Delta^2)\overline{x}_0 = p\zeta,\ (p^2+\omega_\Delta^2)\overline{x}_1 = C_1\overline{x}_0 + L(\dot{x}_0)^2,$$

va

$$(p^2+\omega_\Delta^2)\overline{x}_2 = C_1\overline{x}_0 + C_2\overline{x}_0 + 2L(\dot{x}_0\dot{x}_1),$$

birinchi tenglamadan $\overline{x}_0 = \zeta p^2 T(\omega_\Delta)$, shunday qilib, $x_0 = \zeta\cos\omega_\Delta t$. Ushbu tenglama (9) turdagi tenglamaning yechimiga birinchi yaqinlashishdir. Shunda chastota, taxminan, quyidagicha bo‘-ladi:

$$\omega_\Delta = \omega_0 \tag{13}$$

(10) tenglamadan

$$\overline{x}_1 = \zeta C_1 p^3 T^2(\omega_\Delta) + \zeta^2 pT(\omega_\Delta)L({\omega_\Delta}^2\sin^2\omega_\Delta t).$$

Yuqorida keltirilgan tenglamani tasvirdagi yechimini quyidagicha yozish mumkin:.

$$\overline{x}_1 = \zeta C_1 p^3 T^2(\omega_\Delta) + \left(\frac{\zeta^2{\omega_\Delta}^2}{2}\right)T(\omega_\Delta) - \left(\frac{\zeta^2 p^2}{6}\right)[T(\omega_\Delta) - T(2\omega_\Delta)].$$

Orginaldagi yechimi quyidagicha bo‘ladi:

$$x = \left(\frac{\zeta C_1}{2\omega_\Delta}\right)t\sin\omega_\Delta t + \left(\frac{\zeta^2}{2}\right)(1-\cos\omega_\Delta t) - \left(\frac{\zeta^2}{6}\right)(\cos\omega_\Delta t - \cos 2\omega_\Delta t).$$

Natija va tahlil. Ushbu tenglamaning birinchi amplitudasi vaqt o‘tishi bilan doimiy ravishda oshib boradi, natijada tajribaga zid keladi, binobarin, haqiqiy yechimni olish uchun quyidagicha $C_1 = 0$.

(9) tenglamaning ikkinchi yondashuvi quyidagicha bo‘ladi:

$$x = \zeta\cos\omega_\Delta t + \left(\frac{\Delta\zeta^2}{6}\right)(3 - 4\cos\omega_\Delta t + \cos 2\omega_\Delta t), \tag{14}$$

Bu yerda (14) tenglamadan yana quyidagi aniq bo‘ladi: $\omega_\Delta = \omega_0$. Yechim quyidagicha bo‘ladi:

$$\overline{x}_2 = \zeta C_2 p^3 T^2(\omega_\Delta) + \left(\frac{2\zeta^2{\omega_\Delta}^2}{3}\right)pT(\omega_\Delta)L[(\sin\omega_\Delta t)(2\sin\omega_\Delta t - \sin 2\omega_\Delta t)]$$

$$= \zeta C_2 p^3 T^2(\omega_\Delta) - \left(\frac{2\zeta^2{\omega_\Delta}^2}{3}\right)\left[T(\omega_\Delta) - \left(\frac{p^3}{2}\right)T^2(\omega_\Delta)\right.$$

$$\left. - p^3 T(\omega_\Delta)T(2\omega_\Delta) + \left(\frac{p^3}{2}\right)T(\omega_\Delta)T(3\omega_\Delta)\right]$$

$$= \zeta C_2 p^3 T^2(\omega_\Delta)\left[C_2 + \left(\frac{\zeta^2(\omega_\Delta)^2}{3}\right)\right] - \left(\frac{\zeta^3}{72}\right)\left[48{\omega_\Delta}^2 T(\omega_\Delta)\right.$$

$$\left. 13p^2T(\omega_\Delta) + 16p^2T(2\omega_\Delta) - 3p^2T(3\omega_\Delta)\right].$$

Ushbu tenglamaning dastlabki muddati vaqt o‘tishi bilan ortib boradigan miqdorning o‘zgarishidir, shuning uchun bunga mos keluvchi va haqiqiy yechim bu:

$$C_2 = \frac{-\zeta^2 \omega_\Delta{}^2}{3}.$$

Natijani berish uchun tenglamaning ikkinchi tomonini shunchaki tasvirdagi yechimi quyidagicha bo‘ladi:

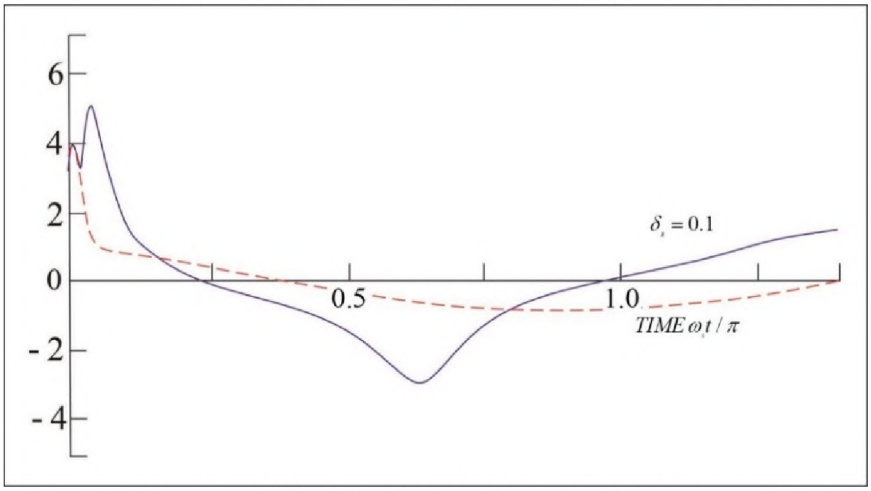
$$x_2 = \left[\zeta \cos\omega_\Delta t + \left(\frac{\Delta\zeta^2}{6}\right)(3 - 4\cos\omega_\Delta t + \cos 2\omega_\Delta t \right. \\ \left. - \left(\frac{\Delta^2\zeta^3}{72}\right)(48 - 61\cos\omega_\Delta t + 16\cos 2\omega_\Delta t - 3\cos 3\omega_\Delta t)\right]. \quad (15)$$

Ushbu yaqinlashishda

$$\omega_\Delta = \frac{\omega_0}{[1 + (\Delta^2\zeta^2 / 3)]^{1/2}}$$

Tebranishning T_1 birinchi yarim siklini yakunlash uchun zarur bo‘lgan vaqti to‘g‘ridan to‘g‘ri (15) tenglamadan kelib chiqadi:

$$T_1 = \frac{\pi}{\omega_\Delta} = \frac{\pi}{\omega_0}\left(1 + \frac{\Delta^2\zeta^2}{3}\right)^{1/3} \approx \frac{\pi}{\omega_0}\left(1 + \frac{\Delta^2\zeta^2}{6}\right).$$



3-rasm. Tezlanishning vaqt bo‘yicha o‘zgarishi.

Xulosa. Sonli natijalalar ikkinchi yaqinlashish uchun 3-rasmda tasvirlangan. Rasmda tezlanishni vaqt bo‘yicha o‘zgarishi keltirilgan. Ko‘rinib turbdiki, harakat vaqt bo‘yicha juda sekin so‘nar ekan.

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MATRITSAVIY YUQORI YARIM TEKISLIKDA INTERPOLATSION KETMA-KETLIKLAR

Annotatsiya. *Ushbu maqolada* $\mathbb{C}^n\left[m\times m\right]$ *fazodagi matritsaviy yuqori yarim tekislikda interpolatsion ketma-ketliklar va ularning xossalari keltirilgan. Matritsaviy yuqori yarim tekislikda interpolatsion ketma-ketliklar uchun yetarlilik sharti funksional analiz va ko'p kompleks o'zgaruvchili funksiyalar nazariyasi bilan bog'liq holda isbot qilingan.*

Kalit so'zlar: *maritsaviy yuqori yarim tekislik, interpolatsiya, Hardi fazosi, Blyashka ko'paytmasi.*

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ИНТЕРПОЛЯЦИОННЫЕ ПОСЛЕДОВАТЕЛЬНОСТИ В МАТРИЧНОЙ ВЕРХНЕЙ ПОЛУПЛОСКОСТИ

Аннотация. *В данной статье рассмотрены интерполяционные последовательности и их свойства в матричной верхней полуплоскости пространства* $\mathbb{C}^n\left[m\times m\right]$. *В настоящей статье достаточное условие для интерполяционных последовательностей в матричной верхней полуплоскости доказано с использованием методов функционального анализа и теории функций нескольких комплексных переменных.*

Ключевые слова: *матричная верхняя полуплоскость, интерполяция, пространство Харди, произведение Бляшке.*

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INTERPOLATION SEQUENCES IN THE MATRIX UPPER HALF-PLANE

Annotation. *This article presents interpolation sequences and their properties in the matrix upper half-plane of the space* $\mathbb{C}^n\left[m\times m\right]$. *In this paper, a sufficient condition for interpolation sequences in the matrix upper half-plane is proved using methods of functional analysis and the theory of several complex variables.*

Key words: *matrix upper half-plane, interpolation, Hardy space, Blaschke product.*

Kirish. Kompleks analiz nazariyasining muhim bo'limlaridan biri bu analitik funksiyalar sinfida interpolyatsiya masalalarini o'rganishdir. Ushbu masalalar ko'plab amaliy va nazariy yo'nalishlarda – signalni qayta tiklash, raqamli analiz, matematik fizika tenglamalarini yechishda katta ahamiyatga ega. Ayniqsa, analitik funksiyalar fazolarida (masalan, Hardi, Bergman, Dirixle fazolari) interpolatsion ketma-ketliklarning mavjudlik shartlarini aniqlash, ularning xossalarini o'rganish va konstrutsiya usullarini ishlab chiqish ilmiy tadqiqotlar uchun dolzarb hisoblanadi.

Adabiyotlar tahlili. Yagona bog'langan sohalarda interpolatsion ketma-ketliklar analitik funksiyalarning xossalarini o'rganishda muhim rol o'ynaydi. Karleson teoremasi [1] kompleks tekislikdagi birlik doirada interpolatsion ketma-ketlikni tavsiflaydi. Berndtson esa [2] $\mathbb{C}^n$ fazodagi birlik shar ichidagi interpolatsion ketma-ketlik uchun yetarlilik shartini keltiradi. [*3*] va [4;5-bob] ishlarda $\mathbb{C}\left[m\times m\right]$ fazosidagi umumlashgan birlik doira ichidagi interpolatsion ketma-ketliklarning xossalari ko'rsatilgan. Ushbu maqolada matritsaviy yuqori yarim tekislikda interpolatsion ketma-ketliklar uchun yetarlilik sharti keltirilgan.