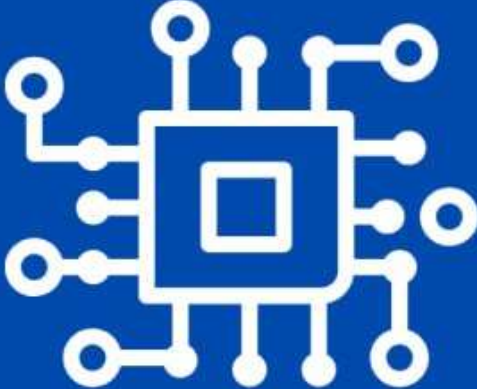




TECH SCIENCE

ISSN 3030-3702

**TEXNIKA FANLARINING
DOLZARB MASALALARI**

**TOPICAL ISSUES OF TECHNICAL
SCIENCES**



№ 2 (3) 2025

TECHSCIENCE.UZ

№ 2 (3)-2025

**TEXNIKA FANLARINING DOLZARB
MASALALARI**

**TOPICAL ISSUES
OF TECHNICAL SCIENCES**

TOSHKENT-2025

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Mazkur jurnal O'zbekiston Respublikasi Oliy ta'lim, fan va innovatsiyalar vazirligi huzuridagi Oliy attestatsiya komissiyasi Rayosatining 2025-yil 8-maydagi 370-son qarori bilan texnika fanlari bo'yicha ilmiy darajalar yuzasidan dissertatsiyalar asosiy natijalarini chop etish tavsiya etilgan ilmiy nashrlar ro'yxatiga kiritilgan.

Muassislar: "SCIENCEPROBLEMS TEAM" mas'uliyati cheklangan jamiyati;
Jizzax politexnika insituti.

**TECHSCIENCE.UZ- TEXNIKA
FANLARINING DOLZARB MASALALARI**
elektron jurnali 15.09.2023-yilda
130343-sonli guvohnoma bilan davlat
ro'yxatidan o'tkazilgan.

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IKKINCHI TARTIBLI NOKLASSIK TENGLAMALAR SISTEMASI UCHUN CHEGARAVIY MASALA

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Annotatsiya. Ushbu maqolada ikkinchi tartibli noklassik tenglamalar sistemasiga oid chegaraviy masala o'rganiladi. Masala boshlang'ich, chegaraviy va tikish shartlari bilan birgalikda qaraladi. Masalaning yechimi mavjud bo'lishi, yagonaligi hamda shartli turg'unligi nuqtai nazaridan tahlil qilinadi. Shuningdek, yechim uchun aprior baho olinadi va masalaning shartli korrektilik to'plami aniqlanadi. J. Adamar ta'rifiga asoslanib, masalaning umumiy holda nokorrektligi ko'rsatiladi. Bundan tashqari, ushbu ishda spektral masala ham tahlil qilinib, uning xos sonlari va xos funksiyalari aniqlanadi. Ushbu xos funksiyalarning Riesz bazisi tashkil qilishi isbotlanadi va ularning asosida masalaning regulyarlashtirish usuli orqali taqribiy yechimi quriladi. Tadqiqot natijalari nokorrekt masalalar uchun turg'un yechimlar olishda muhim nazariy asos bo'lib xizmat qiladi.

Kalit so'zlar: ikkinchi tartibli tenglamalar sistemasi, Nokorrekt masala, Chegaraviy masala, Boshlang'ich shart, Tikish sharti, Spektral masala, Xos sonlar, Xos funksiyalar, Aprior baho, Shartli korrektilik, Shartli turg'unlik, Regulyarlashtirish usuli, Riesz bazisi, Transsendent tenglama, Musbat ildizlar, Funktsional analiz, Yechimning yagonaligi, Taqribiy yechim, Ekvivalent norm, Adamar sharti.

BOUNDARY POINT PROBLEM FOR A SYSTEM OF SECOND-ORDER NONCLASSICAL EQUATIONS

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Abstract. This article studies a boundary value problem for a system of second-order nonclassical equations. The problem is considered together with initial, boundary, and constraint conditions. The solution of the problem is analyzed from the point of view of existence, uniqueness, and conditional stability. Also, an a priori estimate is obtained for the solution and the conditional correctness set of the problem is determined. Based on the definition of J. Adamard, the general ill-posedness of the problem is shown. In addition, in this work, the spectral problem is also analyzed and its eigenvalues and eigenfunctions are determined. It is proved that these eigenfunctions form a Riesz basis, and an approximate solution of the problem is constructed on their basis by the regularization method. The results of the research serve as an important theoretical basis for obtaining stable solutions for ill-posed problems

Keywords: system of second-order equations, Irregular problem, Boundary problem, Initial condition, Betting condition, Spectral problem, Eigenvalues, Eigenfunctions, A priori estimate, Conditional correctness, Conditional stability, Regularization method, Riesz basis, Transcendent equation, Positive roots, Functional analysis, Uniqueness of solution, Approximate solution, Equivalent norm, Adamer condition.

DOI: <https://doi.org/10.47390/ts3030-3702v3i2y2025N03>

Berilgan $\Omega = \{(x, t) : -l < x < l, x \neq 0, 0 < t < T\}$ sohada

$$\begin{cases} u_{tt} + \operatorname{sgn} x \cdot u_{xx} + a_1 \cdot u + b_1 \cdot v = 0 \\ v_{tt} + \operatorname{sgn} x \cdot v_{xx} + a_2 \cdot v + b_2 \cdot u = 0 \end{cases} \quad (1)$$

Tenglamalar sistemasini qaraymiz, bu yerda a_i, b_i - berilgan haqiqiy sonlar, $b_i \neq 0, i = 1, 2$, $(a_1 - a_2)^2 + 4b_1b_2 > 0$.

Masala. (1) tenglamalar sistemasini, boshlang'ich

$$\left. \begin{aligned} u|_{t=0} &= \varphi_1(x), & u_t|_{t=0} &= \psi_1(x), \\ v|_{t=0} &= \varphi_2(x), & v_t|_{t=0} &= \psi_2(x), \end{aligned} \right\} \quad -l \leq x \leq l \quad (2)$$

shartlar, chegaraviy

$$\left. \begin{aligned} u|_{x=l} &= u|_{x=-l} = 0, \\ v|_{x=l} &= v|_{x=-l} = 0, \end{aligned} \right\} \quad 0 \leq t \leq T \quad (3)$$

shartlar va tikish

$$\left. \begin{aligned} u|_{x=-0} &= u|_{x=+0}, & u_x|_{x=-0} &= u_x|_{x=+0}, \\ v|_{x=-0} &= v|_{x=+0}, & v_x|_{x=-0} &= v_x|_{x=+0} \end{aligned} \right\} \quad (4)$$

shartlarni qanoatlantiruvchi $(u(x, t), v(x, t))$ funksiyalar juftligini toping, bu yerda $\varphi_i(x), \psi_i(x)$ - yetarlicha silliq berilgan funksiyalar bo'lsin, $i = 1, 2$.

Ushbu ishda qarayotgan (1) – (4) masalaning yechimi uchun aprior baho olinadi va masalaning shartli korrektilik to'plami aniqlanadi. Masala yechimining yagonaligi va shartli turg'unligi haqidagi teoremlar isbotlanadi. Korrektilik to'plamida regulyarlashtirish usuli bilan masalaning taqribiy yechimi quriladi.

Endi (1) - (4) masalaning nokorrektiligini ko'rsatamiz. Faraz qilamiz, $a_1 = 1, a_2 = 0, b_1 = 1, b_2 = 2, \varphi_2(x) = 0, \psi_2(x) = 0, \varphi_1(x) = \frac{1}{\lambda_k} \cdot X_k(x), \psi_1(x) = \frac{1}{\lambda_k} \cdot X_k(x)$ bo'lsin. U qarayotgan masalaning yechimi quyidagi ko'rinishda

$$\begin{aligned} u(x, t) &= \frac{1}{\mu_k} ch(\sqrt{\mu_k - 2t}) \cdot X_k(x), \\ v(x, t) &= \frac{1}{\mu_k} ch(\sqrt{\mu_k - 2t}) \cdot X_k(x). \end{aligned}$$

ifodalanadi, bu yerda k - fiksirlangan natural son,

$$X_k(x) = \begin{cases} \frac{\sin \sqrt{\mu_k}(x-l)}{\sqrt{l} \cos \sqrt{\mu_k} l}, & 0 < x \leq l, \\ \frac{\operatorname{sh} \sqrt{\mu_k}(x+l)}{\sqrt{l} \operatorname{ch} \sqrt{\mu_k} l}, & -l \leq x < 0, \end{cases}.$$

$\mu_k - \operatorname{th} \sqrt{\mu} + \operatorname{tg} \sqrt{\mu} = 0$ tenglamaning musbat ildizi.

Agar

$$\lim_{\mu_k \rightarrow \infty} \varphi_{1k}(x) \rightarrow 0, \quad \lim_{\mu_k \rightarrow \infty} \psi_{1k}(x) \rightarrow 0$$

bo'lganda masalaning yechimi

$$\lim_{\mu_k \rightarrow \infty} u(x, t) \rightarrow \infty, \quad \lim_{\mu_k \rightarrow \infty} v(x, t) \rightarrow \infty$$

kelib chiqadi. Demak, bundan ko'rinib turibdiki qaralayotgan masala boshlang'ich berilganlarga uzliksiz bog'liq emas. Ya'ni J. Adamarning korrektlik ta'rifidagi shartlardan uchinchi buziladi.

Spektral masala. Uning xos sonlari va xos funksiyalari

Ushbu paragrafda spektral masala qaralgan bo'lib, uning xos sonlari va ularga mos xos funksiyalar topilgan.

Spektral masala. μ parametrning shunday qiymatlarini topingki, natijada

$$\operatorname{sgn} x \cdot X''(x) + \mu \cdot X(x) = 0 \quad (5)$$

$$X(-l) = X(l) = 0,$$

$$X(-0) = X(+0), \quad (6)$$

$$X'(-0) = X'(+0)$$

masala notrivial yechimga ega bo'lsin. Ushbu spektral masala xos sonlari va xos funksiyalari dastlab [2] adabiyotda keltirilgan.

$$\operatorname{sgn} x \cdot X''(x) + \mu \cdot X(x) = 0$$

1-Hol. $\mu > 0$ bo'lsin.

$$-1 \leq x < 0,$$

$$-X''(x) + \mu \cdot X(x) = 0$$

$$k = \pm \sqrt{\mu}$$

$$X(x) = C_1 \cdot e^{\sqrt{\mu}x} + C_2 \cdot e^{-\sqrt{\mu}x}$$

$$X'(x) = C_1 \cdot \sqrt{\mu} \cdot e^{\sqrt{\mu}x} - C_2 \cdot \sqrt{\mu} \cdot e^{-\sqrt{\mu}x}$$

$$0 < x \leq 1,$$

$$X''(x) + \mu \cdot X(x) = 0$$

$$k = \pm i \sqrt{\mu}$$

$$X(x) = C_3 \cdot \cos \sqrt{\mu}x + C_4 \cdot \sin \sqrt{\mu}x$$

$$X'(x) = -C_3 \cdot \sqrt{\mu} \cdot \sin \sqrt{\mu}x + C_4 \cdot \sqrt{\mu} \cdot \cos \sqrt{\mu}x$$

(1), (2) masalalarning xos funksiyalari:

agar $\mu_k^+ > 0$ bo'lganda

$$X_k^+(x) = \begin{cases} \frac{\sin \sqrt{\mu_k^+}(x-l)}{\sqrt{l} \cos \sqrt{\mu_k^+} l}, & 0 < x \leq l, \\ \frac{\operatorname{sh} \sqrt{\mu_k^+}(x+l)}{\sqrt{l} \operatorname{ch} \sqrt{\mu_k^+} l}, & -l \leq x < 0, \end{cases}. \quad (7)$$

2-Hol. $\mu < 0$ bo'lsin.

$-1 \leq x < 0$,

$$-X''(x) + \mu \cdot X(x) = 0$$

$$k = \pm i\sqrt{\mu}$$

$$X(x) = C_5 \cdot \cos \sqrt{-\mu}x + C_6 \cdot \sin \sqrt{-\mu}x$$

$$X'(x) = -C_5 \cdot \sqrt{-\mu} \cdot \sin \sqrt{-\mu}x + C_6 \cdot \sqrt{-\mu} \cdot \cos \sqrt{-\mu}x$$

$0 < x \leq 1$,

$$X''(x) + \mu \cdot X(x) = 0$$

$$k = \pm \sqrt{-\mu}$$

$$X(x) = C_7 \cdot e^{\sqrt{-\mu}x} + C_8 \cdot e^{-\sqrt{-\mu}x}$$

$$X'(x) = C_7 \cdot \sqrt{-\mu} \cdot e^{\sqrt{-\mu}x} - C_8 \cdot \sqrt{-\mu} \cdot e^{-\sqrt{-\mu}x}$$

(5), (6) masalalarning xos funksiyalari:

$\mu_k^- < 0$ bo'lgan hol uchun

$$X_k^-(x) = \begin{cases} \frac{\operatorname{sh} \sqrt{|\mu_k^-|}(x-l)}{\sqrt{l} \operatorname{ch} \sqrt{|\mu_k^-|} l}, & 0 < x \leq l, \\ \frac{\sin \sqrt{|\mu_k^-|}(x+l)}{\sqrt{l} \cos \sqrt{|\mu_k^-|} l}, & -l \leq x < 0. \end{cases} \quad (8)$$

Ikkala holdayam μ_k -lar ushbu $\operatorname{tg} \sqrt{\mu} l = -\operatorname{th} \sqrt{\mu} l$ transsendent tenglamaning ildizlari hisoblanadi.

Shunday qilib, (5), (6) spektral masalaning xos sonlari quyidagi

$$\mu_k^{\pm} \approx \pm \left(-\frac{\pi}{4l} + \frac{\pi k}{l} \right)^2, k \in N \quad (1.3.5)$$

formula orqali aniqlanadi.

Ushbu [3] ishning natijasiga ko'ra (5), (6) spektral masalaning xos sonlari $\{\mu_k^+\}_{k=1}^{\infty}, \{-\mu_k^-\}_{k=1}^{\infty}$ o'suvchi ketma-ketlik tashkil qiladi va xos funksiyalari $X_k^+(x), X_k^-(x)$.

Aytaylik, $\|u\|^2 = (u, u)$, bu yerda $(u, v) = \int_{-1}^1 uv dx$ bundan tashqari,

$$\begin{aligned} (\operatorname{sgn} x X_k^+, X_l^-(x)) &= 0, \forall k, l \\ (\operatorname{sgn} x X_k^+, X_l^+(x)) &= \begin{cases} 1, & k = l, \\ 0, & k \neq l, \end{cases} \\ (\operatorname{sgn} x X_k^-, X_l^-(x)) &= \begin{cases} -1, & k = l, \\ 0, & k \neq l, \end{cases} \end{aligned}$$

bu yerda $k, l \in N$.

Quyidagi formula bilan aniqlanadigan norma

$$\|u(x, t)\|_0^2 = \sum_{k=1}^{\infty} (\operatorname{sgn} x u(x, t), X_k^+)^2 + \sum_{k=1}^{\infty} (\operatorname{sgn} x u(x, t), X_k^-)^2 \quad (9)$$

H_0 fazodagi boshlang'ich normaga ekvivalent.

[3] natijasiga ko'ra $\{X_k^+(x)\}, \{X_k^-(x)\}$ xos funksiyalar H_0 da Riesz bazissini tashkil qiladi.

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ISSN: 3030-3702 (Onlayn)
САЙТ: <https://techscience.uz>

TECHSCIENCE.UZ

**TEXNIKA FANLARINING DOLZARB
MASALALARI**

№ 2 (3)-2025

TOPICAL ISSUES OF TECHNICAL SCIENCES

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Jizzax politexnika insituti.

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FANLARINING DOLZARB MASALALARI**
elektron jurnali 15.09.2023-yilda
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ro'yxatidan o'tkazilgan.

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