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РЕСПУБЛИКИ КАЗАХСТАН

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**ФИЗИКА-МАТЕМАТИКА
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E-mail: assanova@math.kz, anarasanova@list.ru**APPLICATION OF POLYGONAL METHOD
TO SOLVE OF PERIODIC PROBLEM FOR LOADED
AND INTEGRO-DIFFERENTIAL PARABOLIC EQUATIONS**

Abstract. In the first section, we investigate the periodic boundary value problem for a loaded parabolic equations in a rectangular domain. Using the polygonal method we construct of an algorithms for finding solutions of the periodic boundary value problem for loaded parabolic equations. And the convergence of algorithms is proved. Conditions of unique solvability of the investigated problem are established in the terms of initial data. In the second section, we investigate the periodic boundary value problem for parabolic integro-differential equation in a rectangular domain. The polygonal method develops on parabolic integro-differential equation. Algorithms for finding solutions of the periodic boundary value problem for parabolic integro-differential equations are constructed, and their convergence is proved. Conditions of unique solvability of the investigated problem are established in the terms of initial data.

Key words: periodic problem, loaded parabolic equations, integro-differential parabolic equations, polygonal method, algorithm, unique solvability.

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Loaded partial differential equations parabolic type arise in the study of various processes of physics, chemistry, biology, ecology and others [1-5]. Another important class of problems closely related to evolutionary integro-differential equations in partial derivatives are the parabolic integro-differential equations and boundary value problems for them [6-12]. The conditions for unique solvability, the assessment of solutions and their derivatives in terms of the geometric characteristics of the coefficients, the right-hand side, boundary values, and the region where linear boundary value problems for loaded partial differential equations are given, find in numerous applications in the qualitative theory of boundary value problems.

In [13] by using the polygonal method on the spatial variable the boundary value problem for a parabolic equation has been reduced to the solving of family of the Cauchy problem for a system of ordinary differential equations. Using the parametrization method [14] there were established the effective estimates of solutions through the initial data [15]. This approach will be developed on the parabolic loaded and integro-differential equations. There will be developed a constructive method for the solving of periodic boundary value problems for parabolic loaded and integro-differential equations.

By polygonal method on spatial variable the periodic and nonlocal boundary value problems for parabolic integro-differential equations will be reduced to a family of Cauchy problems for systems of ordinary integro-differential equations. On the basis of parameterization method the algorithms for finding the solution will be built and the conditions of unique solvability of the considered problem will be established.

1. Periodic boundary value problem for loaded parabolic equations

We consider a periodic boundary value problem for a loaded parabolic equation

$$\frac{\partial u}{\partial t} = a(t, x) \frac{\partial^2 u}{\partial x^2} + c(t, x)u(t, x) + \alpha(t)u(\theta, x) + f(t, x), \quad (t, x) \in \Omega = (0, T) \times (0, \omega), \quad (1.1)$$

$$u(0, x) = u(T, x), \quad x \in [0, \omega], \quad (1.2)$$

$$u(t, 0) = \psi_0(t), \quad u(t, \omega) = \psi_1(t), \quad t \in [0, T], \quad (1.3)$$

where $a(t, x) \geq a_0 > 0$, $c(t, x) \leq 0$, $f(t, x)$ are continuous with respect to t , Holder continuous with respect to x , $\alpha(t)$ is continuous function on $[0, T]$. It is assumed that the functions $\psi_0(t)$, $\psi_1(t)$ are sufficiently smooth and satisfy the matching conditions $\psi_0(0) = \psi_0(T)$, $\psi_1(0) = \psi_1(T)$.

The parametrization method is applied to the periodic boundary value problem (1.1)-(1.3). Let $\lambda(x) = u(0, x)$ and in a problem (1.1)-(1.3) we will carry out replacement $u(t, x) = \lambda(x) + \tilde{u}(t, x)$, where $\tilde{u}(t, x)$ is a new unknown function. Then the periodic boundary value problem (1.1)-(1.3) reduce to the following problem

$$\begin{aligned} \frac{\partial \tilde{u}}{\partial t} &= a(t, x) \frac{\partial^2 \tilde{u}}{\partial x^2} + c(t, x)\tilde{u}(t, x) + \alpha(t)\tilde{u}(\theta, x) + \\ &+ a(t, x)\ddot{\lambda}(x) + c(t, x)\lambda(x) + \alpha(t)\lambda(x) + f(t, x), \quad (t, x) \in \Omega, \end{aligned} \quad (1.4)$$

$$\tilde{u}(0, x) = 0, \quad x \in [0, \omega], \quad (1.5)$$

$$\tilde{u}(t, 0) + \lambda(0) = \psi_0(t), \quad \tilde{u}(t, \omega) + \lambda(\omega) = \psi_1(t), \quad t \in [0, T], \quad (1.6)$$

$$\tilde{u}(T, x) = 0, \quad x \in [0, \omega]. \quad (1.7)$$

From conditions (1.5) and (1.6) follows

$$\lambda(0) = \psi_0(0), \quad \lambda(\omega) = \psi_1(0).$$

The problem (1.4)-(1.7) is an initial-boundary value problem for a loaded parabolic equation with a parameter. An algorithm for finding the solution of the problem (1.4)-(1.7) is constructed, which consists of two stages: 1) the solving of the initial-boundary value problem for the loaded parabolic equation (1.4)-(1.6) at the fixed parameter by means of a justification polygonal method [42-43]; 2) determination of the parameter from the relation (1.7).

The first stage of the algorithm. We consider an auxiliary initial-boundary value problem for the loaded parabolic equation

$$\frac{\partial \tilde{u}}{\partial t} = a(t, x) \frac{\partial^2 \tilde{u}}{\partial x^2} + c(t, x)\tilde{u}(t, x) + \alpha(t)\tilde{u}(\theta, x) + \tilde{f}(t, x), \quad (t, x) \in \Omega, \quad (1.8)$$

$$\tilde{u}(0, x) = 0, \quad x \in [0, \omega], \quad (1.9)$$

$$\tilde{u}(t, 0) = \psi_0(t) - \psi_0(0), \quad \tilde{u}(t, \omega) = \psi_1(t) - \psi_1(0), \quad t \in [0, T], \quad (1.10)$$

where function $\tilde{f}(t, x)$ is continuous with respect to t , and is Holder continuous with respect to x .

The scheme of the polygonal method with respect to the problem (1.8)-(1.10). We take $h > 0$ and make a discretization by $x: x_i = ih, i = \overline{0, N}, Nh = \omega, \tilde{u}_i(t) = \tilde{u}(t, ih)$. The problem (1.8)-(1.10) is replaced by the following form

$$\frac{\partial \tilde{u}_i}{\partial t} = a_i(t) \frac{\tilde{u}_{i+1} - 2\tilde{u}_i + \tilde{u}_{i-1}}{h^2} + c_i(t)\tilde{u}_i + \alpha(t)\tilde{u}_i(\theta) + \tilde{f}_i(t), \quad \tilde{u}_i(0) = 0, \quad i = \overline{0, N}, \quad (1.11)$$

$$\tilde{u}_0(t) = \psi_0(t) - \psi_0(0), \quad \tilde{u}_N(t) = \psi_1(t) - \psi_1(0), \quad t \in [0, T]. \quad (1.12)$$

Owing to linearity of system for $\forall h > 0$, there exists a unique solution of problem (1.11): $\{\tilde{u}_1(t), \dots, \tilde{u}_{N-1}(t)\}$ defined on $[0, T]$.

Taking the functions \tilde{u}_{i+1} , \tilde{u}_{i-1} and the loaded term to the right-hand side of every i th equation of the system (1.11), we applied the estimate from [15]:

$$\|\tilde{u}_i\| = \max_{t \in [0, T]} \{|\tilde{u}_i(t)|\} \leq \frac{1}{2} \|\tilde{u}_{i-1}(t)\| + \frac{1}{2} \|\tilde{u}_{i+1}(t)\| + \frac{1}{2} \left\| \frac{\alpha(t)}{a_i(t)} \tilde{u}_i(\theta) \right\| h^2 + \frac{1}{2} \left\| \frac{\tilde{f}_i(t)}{a_i(t)} \right\| h^2.$$

Let $\xi_i = \|\tilde{u}_i\|$. Then, we obtain the following estimate

$$\xi_i \leq \frac{1}{2} \xi_{i-1} + \frac{1}{2} \xi_{i+1} + \frac{1}{2} \left\| \frac{\alpha(t)}{a_i(t)} \right\| h^2 \xi_i + \frac{1}{2} \left\| \frac{\tilde{f}_i(t)}{a_i(t)} \right\| h^2, \quad i = \overline{1, N-1}. \tag{1.13}$$

Suppose that $\frac{1}{2} \max_{t \in [0, T]} \left\| \frac{\alpha(t)}{a_i(t)} \right\| h^2 \leq \chi < 1$, $i = \overline{1, N-1}$, from inequality (1.13), we have

$$\xi_i \leq \frac{1}{2(1-\chi)} \xi_{i-1} + \frac{1}{2(1-\chi)} \xi_{i+1} + \frac{1}{2(1-\chi)} \left\| \frac{\tilde{f}_i(t)}{a_i(t)} \right\| h^2, \quad i = \overline{1, N-1}. \tag{1.14}$$

Next, using sweep up and down, from (1.14) we get

$$\begin{aligned} \|\tilde{u}_i\| \leq & \frac{N-i}{N(1-\chi)} \|\tilde{\psi}_0\| + \frac{i}{N(1-\chi)} \|\tilde{\psi}_1\| + \frac{N-i}{N(1-\chi)} \sum_{j=1}^i \left\| j \frac{\tilde{f}_j(t)}{a_j(t)} \right\| h^2 + \\ & + \frac{i}{N(1-\chi)} \sum_{j=i+1}^{N-1} \left\| (N-j) \frac{\tilde{f}_j(t)}{a_j(t)} \right\| h^2 \leq K_1, \end{aligned}$$

where $\tilde{\psi}_0(t) = \psi_0(t) - \psi_0(0)$, $\tilde{\psi}_1(t) = \psi_1(t) - \psi_1(0)$.

From this inequality it follows the next assertion

Theorem 1.1. *Let*

a) *the assumptions with respect to the data of problem (1.1)-(1.3) are fulfilled;*

b) *the inequality $\frac{1}{2} \max_{t \in [0, T]} \left\| \frac{\alpha(t)}{a_i(t)} \right\| h^2 \leq \chi < 1$ is valid, where $a_i(t) = a(t, ih)$, $i = \overline{0, N}$.*

Then problem (1.8)–(1.10) has a unique classical solution $\tilde{u}^(t, x)$, and for it the estimate holds:*

$$\begin{aligned} \max_{t \in [0, T]} |\tilde{u}^*(t, x)| \leq & \frac{\omega - x}{\omega(1-\chi)} \max_{t \in [0, T]} |\psi_0(t) - \psi_0(0)| + \frac{x}{\omega(1-\chi)} \max_{t \in [0, T]} |\psi_1(t) - \psi_1(0)| + \\ & + \frac{\omega - x}{\omega(1-\chi)} \int_0^x z \cdot \max_{t \in [0, T]} \left| \frac{\tilde{f}(t, z)}{a(t, z)} \right| dz + \frac{x}{\omega(1-\chi)} \int_x^\omega (\omega - z) \cdot \max_{t \in [0, T]} \left| \frac{\tilde{f}(t, z)}{a(t, z)} \right| dz. \end{aligned}$$

Integrating equation (1.8) by variable t and accounting condition (1.10), we have

$$\begin{aligned} \tilde{u}(t, x) = & \int_0^t a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau + \int_0^t a(\tau, x) d\tau \cdot \ddot{\lambda}(x) + \int_0^t c(\tau, x) \tilde{u}(\tau, x) d\tau + \\ & + \int_0^t c(\tau, x) d\tau \cdot \lambda(x) + \int_0^t \alpha(\tau) d\tau \cdot \tilde{u}(\theta, x) + \int_0^t \alpha(\tau) d\tau \cdot \lambda(x) + \int_0^t f(\tau, x) d\tau. \tag{1.15} \end{aligned}$$

From expression (1.15), we determine the value of function $\tilde{u}(t, x)$ for $t = \theta$:

$$\tilde{u}(\theta, x) = \frac{1}{1 - \int_0^\theta \alpha(\tau) d\tau} \left\{ \int_0^\theta a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau + \int_0^\theta a(\tau, x) d\tau \cdot \ddot{\lambda}(x) + \int_0^\theta c(\tau, x) \tilde{u}(\tau, x) d\tau + \right. \\ \left. + \int_0^\theta c(\tau, x) d\tau \cdot \lambda(x) + \int_0^\theta \alpha(\tau) d\tau \cdot \lambda(x) + \int_0^\theta f(\tau, x) d\tau \right\}.$$

Here, we suppose that $\int_0^\theta \alpha(\tau) d\tau \neq 1$ and introduce the notation $\beta(\theta) = \frac{1}{1 - \int_0^\theta \alpha(\tau) d\tau}$. Then,

the expression (1.15) has the following form

$$\tilde{u}(t, x) = \int_0^t a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau + \int_0^t a(\tau, x) d\tau \cdot \ddot{\lambda}(x) + \int_0^t c(\tau, x) \tilde{u}(\tau, x) d\tau + \\ + \int_0^t c(\tau, x) d\tau \cdot \lambda(x) + \int_0^t \alpha(\tau) d\tau \cdot \lambda(x) + \int_0^t f(\tau, x) d\tau + \\ + \int_0^t \alpha(\tau) d\tau \cdot \beta(\theta) \left\{ \int_0^\theta a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau + \int_0^\theta c(\tau, x) \tilde{u}(\tau, x) d\tau + \right. \\ \left. + \int_0^\theta a(\tau, x) d\tau \cdot \ddot{\lambda}(x) + \int_0^\theta c(\tau, x) d\tau \cdot \lambda(x) + \int_0^\theta \alpha(\tau) d\tau \cdot \lambda(x) + \int_0^\theta f(\tau, x) d\tau \right\}. \quad (1.16)$$

From expression (1.16), we determine the value of function $\tilde{u}(t, x)$ for $t = T$ and replace in the condition (1.7):

$$\left[\int_0^T a(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau \beta(\theta) \int_0^\theta a(\tau, x) d\tau \right] \ddot{\lambda}(x) = \\ = - \left[\int_0^T c(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau + \int_0^T \alpha(\tau) d\tau \beta(\theta) \left\{ \int_0^\theta c(\tau, x) d\tau + \int_0^\theta \alpha(\tau) d\tau \right\} \right] \cdot \lambda(x) - \\ - \int_0^T a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau - \int_0^T c(\tau, x) \tilde{u}(\tau, x) d\tau - \\ - \int_0^T \alpha(\tau) d\tau \beta(\theta) \left[\int_0^\theta a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau + \int_0^\theta c(\tau, x) \tilde{u}(\tau, x) d\tau \right] - \\ - \int_0^T f(\tau, x) d\tau - \int_0^T \alpha(\tau) d\tau \beta(\theta) \int_0^\theta f(\tau, x) d\tau. \quad (1.17)$$

At fixed $\tilde{u}(t, x)$ the relation (1.17) with condition $\lambda(0) = \psi_0(0)$, $\lambda(\omega) = \psi_1(0)$ is two-point boundary value problem for differential equation second order with respect to λ .

The second stage of the algorithm. We consider the auxiliary problem on the interval $[0, \omega]$

$$\left[\int_0^T a(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau \beta(\theta) \int_0^\theta a(\tau, x) d\tau \right] \ddot{\lambda}(x) =$$

$$= - \left[\int_0^T c(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau + \int_0^T \alpha(\tau) d\tau \beta(\theta) \left\{ \int_0^\theta c(\tau, x) d\tau + \int_0^\theta \alpha(\tau) d\tau \right\} \right] \cdot \lambda(x) - g(x), \quad (1.18)$$

where $g(x)$ is continuous function on $[0, \omega]$.

From the matching condition we obtain

$$\lambda(0) = \psi_0(0), \quad \lambda(\omega) = \psi_1(0). \quad (1.19)$$

The problem (1.18), (1.19) is a two-point boundary value problem for a second-order differential equation with respect to a function $\lambda(x)$.

Let

$$\begin{aligned} \tilde{a}(x) &= \int_0^T a(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau \beta(\theta) \int_0^\theta a(\tau, x) d\tau, \\ \tilde{b}(x) &= \int_0^T c(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau + \int_0^T \alpha(\tau) d\tau \beta(\theta) \left\{ \int_0^\theta c(\tau, x) d\tau + \int_0^\theta \alpha(\tau) d\tau \right\}, \end{aligned}$$

The following assertion given of a conditions unique solvability to problem (1.18), (1.19).

Theorem 1.2. *Let*

a) *the assumptions with respect to the data of problem (1.1)-(1.3) are fulfilled;*

b) *the condition $\int_0^\theta \alpha(\tau) d\tau \neq 1$ is valid;*

c) *the condition $\int_0^T a(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau \beta(\theta) \int_0^\theta a(\tau, x) d\tau \neq 0$ is valid for all $x \in [0, \omega]$;*

d) *the inequality holds: $\max \left(1, \frac{2}{\omega} \right) [e^{\alpha\omega} - 1 - \alpha\omega] < 1$, wher*

$$e \quad \alpha = \max \left(1, 1 / \max_{x \in [0, \omega]} |\tilde{a}(x)| \right) \cdot \max \left(\max_{x \in [0, \omega]} |b(x)|, 1 \right).$$

Then problem (1.18), (1.19) has a unique solution $\lambda^(x)$.*

Theorems 1.1 and 1.2 given of the conditions unique solvability of auxiliary problems (1.8)-(1.10) and (1.18), (1.19) in the terms of initial data.

On each step of the algorithm: 1) the initial-boundary value problem for the parabolic integro-differential equation is solved at a fixed $\lambda(x)$; 2) a two-point boundary value problem for a second-order differential equation is solved at a fixed $\tilde{u}(t, x)$.

Conditions of Theorems 1.1 and 1.2 guarantee of realizable and convergence of proposed algorithm.

2. Periodic boundary value problem for parabolic integro-differential equations

We consider periodic boundary value problem for parabolic integro-differential equations

$$\frac{\partial u}{\partial t} = a(t, x) \frac{\partial^2 u}{\partial x^2} + c(t, x) u(t, x) + \alpha(t) \int_0^t u(\tau, x) d\tau + f(t, x), \quad (t, x) \in \Omega, \quad (2.1)$$

$$u(0, x) = u(T, x), \quad x \in [0, \omega], \quad (2.2)$$

$$u(t, 0) = \psi_0(t), \quad u(t, \omega) = \psi_1(t), \quad t \in [0, T], \quad (2.3)$$

where $a(t, x) \geq a_0 > 0$, $c(t, x) \leq 0$, $f(t, x)$ - are continuous with respect to t , Holder continuous with respect to x , $\alpha(t)$ is continuous function on $[0, T]$. It is assumed that the functions $\psi_0(t)$, $\psi_1(t)$ are sufficiently smooth and satisfy the matching conditions $\psi_0(0) = \psi_0(T)$, $\psi_1(0) = \psi_1(T)$.

To the periodic boundary-value problem (2.1)-(2.3) we apply the parametrization method. Suppose $\lambda(x) = u(0, x)$, and in the problem (2.1)-(2.3) we make a substitution $u(t, x) = \tilde{u}(t, x) + \lambda(x)$, where

$\tilde{u}(t, x)$ is a new unknown function. Then the periodic boundary value problem (2.1) - (2.3) reduces to the following equivalent problem

$$\frac{\partial \tilde{u}}{\partial t} = a(t, x) \left[\frac{\partial^2 \tilde{u}}{\partial x^2} + \ddot{\lambda}(x) \right] + c(t, x) [\tilde{u}(t, x) + \lambda(x)] + \alpha(t) \int_0^t \tilde{u}(\tau, x) d\tau + \alpha(t) \lambda(x) + f(t, x), \quad (2.4)$$

$$(t, x) \in \Omega,$$

$$\tilde{u}(0, x) = 0, \quad x \in [0, \omega], \quad (2.5)$$

$$\tilde{u}(t, 0) + \lambda(0) = \psi_0(t), \quad \tilde{u}(t, \omega) + \lambda(\omega) = \psi_1(t), \quad t \in [0, T], \quad (2.6)$$

$$\tilde{u}(T, x) = 0, \quad x \in [0, \omega]. \quad (2.7)$$

From the conditions (2.5) and (2.6) follows $\lambda(0) = \psi_0(0)$, $\lambda(\omega) = \psi_1(0)$.

The problem (2.4) - (2.7) is an initial-boundary value problem for parabolic integro-differential equation with a parameter. An algorithm for finding the solution of problem (2.4) - (2.7) is constructed, which consists of two stages.

The first stage of the algorithm. We consider an auxiliary initial-boundary value problem for the parabolic integro-differential equation

$$\frac{\partial \tilde{u}}{\partial t} = a(t, x) \frac{\partial^2 \tilde{u}}{\partial x^2} + c(t, x) \tilde{u}(t, x) + \alpha(t) \int_0^t \tilde{u}(\tau, x) d\tau + \tilde{f}(t, x), \quad (t, x) \in \Omega, \quad (2.8)$$

$$\tilde{u}(0, x) = 0, \quad x \in [0, \omega], \quad (2.9)$$

$$\tilde{u}(t, 0) = \psi_0(t) - \psi_0(0), \quad \tilde{u}(t, \omega) = \psi_1(t) - \psi_1(0), \quad t \in [0, T], \quad (2.10)$$

where function $\tilde{f}(t, x)$ is continuous with respect to t , and is Holder continuous with respect to x .

The scheme of the polygonal method in relation to the problem (10.8) - (10.10). We take $h > 0$ and make a discretization by x : $x_i = ih$, $i = \overline{0, N}$, $Nh = \omega$, $\tilde{u}_i(t) = \tilde{u}(t, ih)$. The problem (2.8) - (2.10) is replaced by the following

$$\frac{d\tilde{u}_i}{dt} = a_i(t) \frac{\tilde{u}_{i+1} - 2\tilde{u}_i + \tilde{u}_{i-1}}{h^2} + c_i(t) \tilde{u}_i + \alpha(t) \int_0^t \tilde{u}_i(\tau) d\tau + \tilde{f}_i(t), \quad \tilde{u}_i(0) = 0, \quad i = \overline{0, N}, \quad (2.11)$$

$$\tilde{u}_0(t) = \psi_0(t) - \psi_0(0), \quad \tilde{u}_N(t) = \psi_1(t) - \psi_1(0), \quad t \in [0, T]. \quad (2.12)$$

Owing to linearity of system for $\forall h > 0$, there exists a unique solution of problem (2.11): $\{\tilde{u}_1(t), \dots, \tilde{u}_{N-1}(t)\}$ defined on $[0, T]$.

Taking the functions \tilde{u}_{i+1} , \tilde{u}_{i-1} and the integral term to the right-hand side of every i th equation of the system (2.11), we applied the estimate from [15]:

$$\|\tilde{u}_i\| = \max_{t \in [0, T]} \{\tilde{u}_i(t)\} \leq \frac{1}{2} \|\tilde{u}_{i-1}\| + \frac{1}{2} \|\tilde{u}_{i+1}\| + \frac{1}{2} \left\| \frac{\alpha(t)}{a_i(t)} \int_0^t \tilde{u}_i(\tau) d\tau \right\| h^2 + \frac{1}{2} \left\| \frac{\tilde{f}_i(t)}{a_i(t)} \right\| h^2.$$

Let $\xi_i = \|\tilde{u}_i\|$. Then, we obtain the following estimate

$$\xi_i \leq \frac{1}{2} \xi_{i-1} + \frac{1}{2} \xi_{i+1} + \frac{1}{2} \left\| \frac{\alpha(t)}{a_i(t)} \right\| h^2 T \xi_i + \frac{1}{2} \left\| \frac{\tilde{f}_i(t)}{a_i(t)} \right\| h^2, \quad i = \overline{1, N-1}. \quad (2.13)$$

Suppose that $\frac{1}{2} \max_{t \in [0, T]} \left\| \frac{\alpha(t)}{a_i(t)} \right\| Th^2 \leq \chi < 1$, $i = \overline{1, N-1}$, from inequality (2.13) we get

$$\xi_i \leq \frac{1}{2(1-\chi)} \xi_{i-1} + \frac{1}{2(1-\chi)} \xi_{i+1} + \frac{1}{2(1-\chi)} \left\| \frac{\tilde{f}_i(t)}{a_i(t)} \right\| h^2, \quad i = \overline{1, N-1}. \quad (2.14)$$

Further, using sweep up and down, from (2.14) we have

$$\begin{aligned} \|\tilde{u}_i\| \leq & \frac{N-i}{N(1-\chi)} \|\tilde{\psi}_0\| + \frac{i}{N(1-\chi)} \|\tilde{\psi}_1\| + \frac{N-i}{N(1-\chi)} \sum_{j=1}^i \left\| j \frac{\tilde{f}_j(t)}{a_j(t)} \right\| h^2 + \\ & + \frac{i}{N(1-\chi)} \sum_{j=i+1}^{N-1} \left\| (N-j) \frac{\tilde{f}_j(t)}{a_j(t)} \right\| h^2 \leq K_2, \end{aligned}$$

where $\tilde{\psi}_0(t) = \psi_0(t) - \psi_0(0)$, $\tilde{\psi}_1(t) = \psi_1(t) - \psi_1(0)$.

From this inequality it follows the next assertion

Theorem 2.1. *Let*

a) *the assumptions with respect to the data of problem (2.1)-(2.3) are fulfilled;*

b) *the inequality $\frac{1}{2} \max_{t \in [0, T]} \left\| \frac{\alpha(t)}{a_i(t)} \right\| Th^2 \leq \chi < 1$ is valid, where $a_i(t) = a(t, ih)$, $i = \overline{0, N}$.*

Then problem (2.8)–(2.10) has a unique classical solution $\tilde{u}^(t, x)$, and for it the estimate holds:*

$$\begin{aligned} \max_{t \in [0, T]} |\tilde{u}^*(t, x)| \leq & \frac{\omega - x}{\omega(1-\chi)} \max_{t \in [0, T]} |\psi_0(t) - \psi_0(0)| + \frac{x}{\omega(1-\chi)} \max_{t \in [0, T]} |\psi_1(t) - \psi_1(0)| + \\ & + \frac{\omega - x}{\omega(1-\chi)} \int_0^x z \cdot \max_{t \in [0, T]} \left| \frac{\tilde{f}(t, z)}{a(t, z)} \right| dz + \frac{x}{\omega(1-\chi)} \int_x^\omega (\omega - z) \cdot \max_{t \in [0, T]} \left| \frac{\tilde{f}(t, z)}{a(t, z)} \right| dz. \end{aligned}$$

Integrating equation (2.8) by variable t and accounting condition (2.10), we have

$$\begin{aligned} \tilde{u}(t, x) = & \int_0^t a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau + \int_0^t a(\tau, x) d\tau \cdot \ddot{\lambda}(x) + \int_0^t c(\tau, x) \tilde{u}(\tau, x) d\tau + \\ & + \int_0^t c(\tau, x) d\tau \cdot \lambda(x) + \int_0^t \alpha(\tau) \int_0^\tau \tilde{u}(\tau_1, x) d\tau_1 d\tau + \int_0^t \alpha(\tau) d\tau \cdot \lambda(x) + \int_0^t f(\tau, x) d\tau. \end{aligned} \tag{2.15}$$

From expression (2.15), we determine the value of function $\tilde{u}(t, x)$ for $t = T$ and replace in the condition (2.7):

$$\begin{aligned} \int_0^T a(\tau, x) d\tau \cdot \ddot{\lambda}(x) = & - \left[\int_0^T c(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau \right] \cdot \lambda(x) - \\ & - \int_0^T a(\tau, x) \frac{\partial^2 \tilde{u}(\tau, x)}{\partial x^2} d\tau - \int_0^T c(\tau, x) \tilde{u}(\tau, x) d\tau - \int_0^T \alpha(\tau) \int_0^\tau \tilde{u}(\tau_1, x) d\tau_1 d\tau - \int_0^T f(\tau, x) d\tau. \end{aligned} \tag{2.16}$$

The second stage of the algorithm. We consider the auxiliary problem

$$\int_0^T a(\tau, x) d\tau \cdot \ddot{\lambda}(x) = - \left[\int_0^T c(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau \right] \cdot \lambda(x) - g(x), \tag{2.17}$$

where $g(x)$ is continuous function on $[0, \omega]$.

From the matching condition we obtain

$$\lambda(0) = \psi_0(0), \quad \lambda(\omega) = \psi_1(0). \tag{2.18}$$

The problem (2.17), (2.18) is the two-point boundary value problem for the second-order differential equation with respect to a function $\lambda(x)$.

$$\text{Let } \tilde{a}_1(x) = \int_0^T a(\tau, x) d\tau, \quad \tilde{b}_1(x) = \int_0^T c(\tau, x) d\tau + \int_0^T \alpha(\tau) d\tau,$$

The following assertion given of a conditions unique solvability to problem (2.17), (2.18).

Theorem 2.2. *Let*

a) *the assumptions with respect to the data of problem (2.1)-(2.3) are fulfilled;*

b) *the condition $\int_0^T a(\tau, x) d\tau \neq 0$ is valid for all $x \in [0, \omega]$;*

c) *the inequality holds: $\max\left(1, \frac{2}{\omega}\right) [e^{\alpha\omega} - 1 - \alpha\omega] < 1$, where*

$$\alpha = \max\left(1, 1/\max_{x \in [0, \omega]} |\tilde{a}_1(x)|\right) \cdot \max\left(\max_{x \in [0, \omega]} |b_1(x)|, 1\right).$$

Then problem (2.17), (2.18) has a unique solution $\lambda^(x)$.*

Theorems 2.1 and 2.2 given of the conditions unique solvability of auxiliary problems (2.8)-(2.10) and (2.17), (2.18) in the terms of initial data.

On each step of the algorithm: 1) the initial-boundary value problem for the parabolic integro-differential equation is solved at a fixed $\lambda(x)$; 2) a two-point boundary value problem for a second-order differential equation is solved at a fixed $\tilde{u}(t, x)$.

Conditions of Theorems 2.1 and 2.2 guarantee of realizable and convergence of proposed algorithm. The proof of the convergence of the proposed algorithms is based on the results of the work [16-23].

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А.Т. Асанова

СЫНЫҚТАР ӘДІСІНІҢ ЖҮКТЕЛГЕН ЖӘНЕ ИНТЕГРАЛДЫҚ-ДИФФЕРЕНЦИАЛДЫҚ ПАРАБОЛАЛЫҚ ТЕНДЕУЛЕР ҮШІН ПЕРИОДТЫ ЕСЕПТІ ШЕШУГЕ ҚОЛДАНЫЛУЫ

Аннотация. Бірінші бөлімде жүктелген параболалық теңдеу үшін периодты есеп тіктөртбұрышты облыста қарастырылады. Сынықтар әдісін пайдалана отырып біз жүктелген параболалық теңдеулер үшін периодты есепті шешудің алгоритмдерін құрамыз. Алгоритмнің жинақтылығы дәлелденеді. Зерттеліп отырған есептің шешілімділік шарттары бастапқы берілімдер терминдерінде берілген. Екінші бөлімде интегралдық-дифференциалдық параболалық теңдеу үшін периодты есеп тіктөртбұрышты облыста қарастырылады. Сынықтар әдісі интегралдық-дифференциалдық параболалық теңдеулерге дамытылады. Интегралдық-дифференциалдық параболалық теңдеулер үшін периодты есептің шешімін табу алгоритмдері құрылған және олардың жинақтылығы дәлелденген. Зерттеліп отырған есептің шешілімділік шарттары бастапқы берілімдер терминдерінде берілген.

Тірек сөздер: периодты есеп, жүктелген параболалық теңдеулер, интегралдық-дифференциалдық параболалық теңдеулер, алгоритм, бірімәнді шешілімділік.

А.Т. Асанова

ПРИМЕНЕНИЕ МЕТОДА ЛОМАННЫХ К РЕШЕНИЮ ПЕРИОДИЧЕСКОЙ ЗАДАЧИ ДЛЯ НАГРУЖЕННОГО И ИНТЕГРО-ДИФФЕРЕНЦИАЛЬНОГО ПАРАБОЛИЧЕСКИХ УРАВНЕНИЙ

Аннотация. В первой части рассматривается периодическая задача для нагруженного параболического уравнения в прямоугольной области. Используя метод ломаных мы строим алгоритмы нахождения решения периодической краевой задачи для нагруженных параболических уравнений. Доказывается сходимость алгоритма. Условия разрешимости исследуемой задачи даются в терминах исходных данных. Во второй части рассматривается периодическая задача для интегро-дифференциального параболического уравнения в прямоугольной области. Метод ломаных развивается на интегро-дифференциальные параболические уравнения. Построены алгоритмы нахождения решения периодической краевой задачи для интегро-дифференциальных параболических уравнений и доказана их сходимость. Условия разрешимости исследуемой задачи даются в терминах исходных данных.

Ключевые слова: периодическая задача, нагруженные параболические уравнения, интегро-дифференциальные параболические уравнения, метод ломаных, алгоритм, однозначная разрешимость.

МАЗМҰНЫ

<i>Асанова А.Т.</i> Сынықтар әдісінің жүктелген және интегралдық-дифференциалдық параболалық теңдеулер үшін периодты есепті шешуге қолданылуы	5
<i>Сергазина А.М., Есмаханова Қ.Р., Ержанов К.К., Тунгушбаева Д.И.</i> (1+1)-өлшемді локалды емес фокусталған сызықты емес шредингер теңдеуі үшін дарбу түрлендіруі.....	14
Боос Э.Г. , <i>Темиралиев Т*, Избасаров М., Самойлов В.В., Покровский Н.С., Турсунов Р.А.</i> Импульсі 32 ГЭВ/С антипротон-протондық аннигиляциялық реакциясында екінші реттік зарядталған бөлшектердің бұрыштық корреляциясы.....	22
<i>Бошқаев Қ.А., Жәми Б.А., Қалымова Ж.А., Бришева Ж.Н.</i> Шекті температуралар мен жалпы салыстырмалық теориясының әсерлерін ескергендегі статикалық ақ ергежейлі жұлдыздар.....	27
<i>Мурзахметов А.Н., Федотов А.М., Гришко М.В., Дюсембаев А.Е.</i> Әлеуметтік-экономикалық қоғамдарда инновацияның таралуын модельдеу.....	39
<i>Оразбаев С.А., Рамазанов Т.С., Досболаев М.Қ., Габдуллин М.Т., Әмірбеков Д.Б.</i> Жоғары жиілікті разряд плазмасында супергидрофобты беттер алу әдісі.....	45
<i>Сарсенбаев Х.А., Хамзина Б.С., Колдасова Г.А., Исаева Г.Б.</i> Ұңғымаларды игеру кезінде ұңғымаларды шаюдағы отандық және шетелдік технологияларды қолдану ерекшеліктері	52
<i>Қабылбеков К.А., Омашова Г.Ш.</i> MATLAB жүйесін қолданып жылу тасымалдауды зерттеуге арналған зертханалық жұмыстарды орындауды ұйымдастыру.....	56
<i>Исадыков А.Н., Иванов М.А., Нурбакова Г.С., Сайдуллаева Г.Г., Рустембаева С.Б.</i> В–S ауысуының формфакторларын есептеу	67
<i>Нурбакова Г.С., Хабыл Н., Валиолда Д.С., Тюлемисов Ж.Ж.</i> $\Lambda_b \rightarrow \Lambda_c$ Ауысуы үшін формфакторлар.....	78
<i>Жақып-тегі К. Б.</i> Ойдан шығарылған аймақтар әдістемесінің гидродинамикадағы репрезентаттығы	85
<i>Мусрепова Э., Жидебаева А.Н., Шалданбаев А.Ш.</i> Сингуляр әсерленген, бірінші ретті теңдеудің, Кошилік есебін шешудің операторлық әдістері.....	96
<i>Исадыков А.Н., Иванов М.А., Нурбакова Г.С., Жаугашева С.А., Мұратхан Ж.</i> Кварктардың коварианттық моделінде $V_s \rightarrow \phi$ ауысуы.....	108
<i>Жақып-тегі К. Б.</i> «Дарси заңының» сүзгі теориясындағы компилятивтігі	115
<i>Глуценко Н.В., Горлачев И.Д., Желтов А.А., Киреев А.В., *Мұқашев Қ.М., Платов А.В.</i> УКП-2-1 үдеткішімен жүргізілетін физикалық эксперименттерді орындауды автоматтандыру.....	131
<i>Қабылбеков К.А., Омашова Г.Ш.</i> MATLAB жүйесін қолданып гидродинамикадан компьютерлік зертханалық жұмыстарды орындауды ұйымдастыру.....	139
<i>Байдуллаев С., Байдуллаев С.С.</i> Жердің тәулік дәуірлі электр токтары.....	146
<i>Моисеева Е.С., Найманова А.Ж.</i> Көлденең үрленетін ағынша мен жылдамдығы дыбыс жылдамдығынан жоғары ағыспен әсерлесу механизмдеріне кіре берістегі шекаралық қабаттың әсері.....	154
<i>Глуценко Н.В., Горлачев И.Д., Желтов А.А., Киреев А.В., *Мұқашев Қ.М., Платов А.В.</i> УКП-2-1 үдеткішімен жүргізілетін физикалық эксперименттерді орындауды автоматтандыру.....	163
<i>Ахмедиярова А.Т., Мамырбаев О.Ж.</i> Петри желісімен қалалық жол көлігі қозғалысын модельдеу.....	171

СОДЕРЖАНИЕ

<i>Асанова А.Т.</i> Применение метода ломаных к решению периодической задачи для нагруженного и интегро-дифференциального параболических уравнений	5
<i>Сергазина А.М., Есмаханова К.Р., Ержанов К.К., Тунгушбаева Д.И.</i> Преобразования Дарбу для (1+1)-мерного нелокального фокусированного нелинейного уравнения шредингера.....	14
<i>Боос Э.Г., Темирлиев Т.*</i> , <i>Избасаров М., Жаутыков Б.О., Самойлов В.В., Покровский Н.С., Турсунов Р.А.</i> Угловые корреляции вторичных заряженных частиц в реакциях антипротон-протонной аннигиляции ПРИ 32 ГЭВ/С.....	22
<i>Бошкаев К.А., Жами Б.А., Калымова Ж.А., Бришева Ж.Н.</i> Статические белые карлики с учетом эффектов конечных температур и общей теории относительности.....	27
<i>Мурзахметов А.Н., Федотов А.М., Гришко М.В., Дюсембаев А.Е.</i> Моделирование распространения инновации в социально-экономических системах.....	39
<i>Оразбаев С.А., Рамазанов Т.С., Досболаев М.Қ., Габдуллин М.Т., Өмірбеков Д.Б.</i> Способ получения супергидрофобных поверхностей в плазме ВЧ разряда.....	45
<i>Сарсенбаев Х.А., Хамзина Б.С., Колдасова Г.А., Исаева Г.Б.</i> Особенности применения отечественных и зарубежных технологий промывки скважин при освоении скважин.....	52
<i>Кабылбеков К.А., Омашова Г.Ш.</i> Организация выполнения компьютерных лабораторных работ по исследованию теплопереноса с применением системы MATLAB.....	56
<i>Исадыков А.Н., Иванов М.А., Нурбакова Г.С., Сайдуллаева Г.Г., Рустембаева С.Б.</i> Вычисление формфакторов В-S перехода.....	67
<i>Нурбакова Г.С., Хабыл Н., Валиолда Д.С., Тюлемисов Ж.Ж.</i> Формфактор для перехода $\Lambda_b \rightarrow \Lambda_c$	78
<i>Джакупов К.Б.</i> Репрезентативность метода фиктивных областей в гидродинамике.....	85
<i>Мусрепова Э., Жидебаева А.Н., Шалданбаев А.Ш.</i> Об операторных методах решения сингулярно возмущенной задачи Коши для обыкновенного дифференциального уравнения первого порядка с переменным коэффициентом.....	96
<i>Исадыков А.Н., Иванов М.А., Нурбакова Г.С., Жаугашева С.А., Муратхан Ж.</i> $V_s \rightarrow \phi$ переход в ковариантной модели кварков.....	108
<i>Джакупов К.Б.</i> Компилятивность “Закона Дарси” в теории фильтрации.....	115
<i>Глуценко Н.В., Горлачев И.Д., Желтов А.А., Киреев А.В., *Мукашев К.М., Платов А.В.</i> Автоматизация проведения физических экспериментов на ускорителе УСП-2-1.....	131
<i>Кабылбеков К.А., Омашова Г.Ш.</i> Организация выполнения компьютерных лабораторных работ по гидродинамике с применением системы MATLAB.....	139
<i>Байдуллаев С., Байдуллаев С. С.</i> Земные электрические токи с суточными периодами.....	146
<i>Моисеева Е.С., Найманова А.Ж.</i> Влияние толщины пограничного слоя на входе на механизмы взаимодействия сверхзвукового потока с поперечно дувимой струей.....	154
<i>Глуценко Н.В., Горлачев И.Д., Желтов А.А., Киреев А.В., Мукашев К.М., Платов А.В.</i> Автоматизация проведения физических экспериментов на ускорителе УСП-2-1.....	163
<i>Ахмедиярова А.Т., Мамырбаев О.Ж.</i> Моделирование транспортных систем города с помощью сетей Петри.....	171

CONTENTS

<i>Assanova A.T.</i> Application of polygonal method to solve of periodic problem for loaded and integro-differential parabolic equations	5
<i>Sergazina A., Yesmakhanova K., Yerzhanov K., Tungushbaeva D.</i> Darboux transformation for the (1+1)-dimensional nonlocal focusing nonlinear schrödinger equation.....	14
<i>Boos E., Temiraliyev T., Izbasarov M., Zhautykov B., Samoilov V., Pokrovsky N., Tursunov R.</i> Angle correlations of secondary charged particles in the reactions of antiproton-proton annihilation at 32 GEV/S.....	22
<i>Boshkayev K.A., Zhami B.A., Kalymova Zh.A., Brisheva Zh.N.</i> Static white dwarfs taking into account the effects of finite temperatures and general relativity.....	27
<i>Murzakhmetov A.N., Fedotov A.M., Grishko M.B., Dyusembaev A.E.</i> Modeling of distribution of innovation in socio-economic systems.....	39
<i>Orazbayev S.A., Ramazanov T.S., Dosbolayev M.K., Gabdullin M.T., Omirbekov D.B.</i> The method of obtaining hydrophobic surfaces in the plasma of rf discharge.....	45
<i>Sarsenbayev Kh.A., Khamzina B.S., Koldassova G.A., Issayeva G.B.</i> Features of application of domestic and foreign technologies of washing of wells at development of wells	52
<i>Kabyzbekov K. A., Omashova G. SH.</i> Organization of implementation of computer laboratory works for the study of heat transfer with the use of MATLAB system.....	56
<i>Issadykov A.N., Ivanov M.A., Nurbakova G.S., Saidullaeva G.G., Rustembayeva S.B.</i> Calculation of B-S transition form factors	67
<i>Nurbakova G.S., Habyln, Valiolda D.S., Tyulemissov Zh. Zh.</i> Form factors for $\Lambda_b \rightarrow \Lambda_c$ transition.....	78
<i>Jakupov K.B.</i> Representation of the method of the fiction areas in hydrodynamics.....	85
<i>Musrepova E., Zhidebaeva A.N., Shaldanbaeva Sh.</i> On operator methods for solving a singularly perturbed Cauchy problem for an ordinary differential equation of the first order with a variable coefficient.....	96
<i>Issadykov A.N., Ivanov M.A., Nurbakova G.S., Zhaugasheva S.A., Muratkhan Zh.</i> $B_s \rightarrow \phi$ Transition in covariant quark model.....	108
<i>Jakupov K.B.</i> Complicability of the "Darcy law" in the filtration theory.....	115
<i>Gluschenko N.V., Goralchev I.D., Zheltov A.A., Kireev A.V., Mukshev K.M., Platov A.V.</i> Automation of experimentation at Accelerator UKP-2-1	131
<i>Kabyzbekov K. A., Omashova G. SH.</i> Organization of implementation of computer laboratory works on hydrodynamics with application of MATLAB.....	139
<i>Baydullaev S., Baydullaev S. S.</i> Earth electric currents with diurnal periods.....	146
<i>Moisseyeva Ye., Naimanova A. E.</i> Effect of boundary layer thickness at inlet on patterns of interaction of supersonic flow with transverse injected jet.....	154
<i>Gluschenko N.V., Goralchev I.D., Zheltov A.A., Kireev A.V., Mukshev K.M., Platov A.V.</i> Automation of experimentation at accelerator UKP-2-1	163
<i>Akhmediyarova A.T., Mamyrbayev O.</i> Modeling of transport system with the help of Petri net.....	171

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