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NOMIDAGI TATU FARG'ONA FILIALI

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ON A NON-CORRECT PROBLEM FOR A BIHARMONIC EQUATION IN A SEMICIRCLE

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Annotation: This article addresses a non-correct problem for a biharmonic equation within a semicircular domain. It explores the conditional correctness of the problem and establishes stability through a rigorous theorem. The study employs Fourier series and regularization methods, demonstrating the existence of approximate solutions despite the lack of continuous dependence on initial data. By utilizing Hilbert space concepts and Fredholm equations, the article proposes a framework for constructing reliable approximations. This work contributes to understanding complex mathematical physics problems, specifically those involving biharmonic equations in unconventional geometries.

Keywords: Biharmonic equation, semicircle, non-correct problem, approximate solution, Laplace operator, conditional correctness, stability theorem, Fourier series, regularization method, Hilbert space, Fredholm equation

Introduction: In this work, an approximate solution of one problem for a biharmonic equation in a semicircle is studied for conditional correctness. Thus,this study is aimed not only at deepening the theoretical understanding of the properties of the biharmonic equation in a semicircle,but also at developing practical methods for solving incorrect problems.[2].The results of the work can be useful both in theory and in applications realed to mathematical modeling of processes in science and technology.[4].

Literature Analysis Methodology: 1. Task. You want to find a function $U(\rho,\varphi)$ that meets the following conditions:

$$\Delta^2 U(\rho,\varphi)=0 \quad \text{in} \quad D=\left\{(\rho,\varphi): 0<\rho<b,\ 0\le\varphi\le\frac{\pi}{2}\right\} \tag{1}$$

$$U(\rho,0)=U\left(\rho,\frac{\pi}{2}\right)=0,\ \ 0\le\rho\le b, \tag{2}$$

$$\Delta U(\rho,0)=\Delta U(\rho,\frac{\pi}{2})=0,\ 0<\rho<b, \tag{3}$$

$$U(a,\varphi)=0,\ 0\le\varphi\le\frac{\pi}{2}, \tag{4}$$

$$\frac{\partial U(a,\varphi)}{\partial\rho}=f(\varphi),\quad 0<\varphi<\frac{\pi}{2}, \tag{5}$$

where $0<a<b$, $f(\varphi)$ *is* a given function, $\Delta-$ a Laplace operator.

2. Let us show that in the problem there is no continuous dependence of the solution on the data. Indeed, the function

$$U_m(\rho,\varphi)=\varepsilon\frac{\rho^2-a^2}{2a}\left(\frac{\rho}{a}\right)^m Sin\ m\varphi \tag{6}$$

is the solution of problem (1)-(5) with $f(\varphi)=\varepsilon\, Sin2m\varphi$.

It follows from (6) that for any constants $0<\varepsilon<1,\ c>0$ and variables $\varphi\in(0,\frac{\pi}{2})$,, it $\rho\in(a,b)$ is possible to select such ε and m so that the inequalities are satisfied

$$\left\|\varepsilon\, Sin\, m\varphi\right\|_{L_2(0,\frac{\pi}{2})}\le\varepsilon; \qquad \left\|U_m(\rho,\varphi)\right\|_{L_2(0,\frac{\pi}{2})}>c$$

.

3. The following theorem is valid, characterizing the stability of the solution of problem (1)-(5).

Theorem. If the function $U(\rho,\varphi)$ satisfies the relations:

$$\left\|U(\rho,\varphi)\right\|_{L_2(0,\frac{\pi}{2})}\le M, \tag{7}$$

$$\left\|\frac{\partial U(a,\varphi)}{\partial\rho}\right\|_{L_2(0,\frac{\pi}{2})}\le\varepsilon, \tag{8}$$

$$U(a,\varphi)=0,\ 0\le\varphi\le\frac{\pi}{2}, \tag{9}$$

$$\Delta U(\rho,0)=U(\rho,0)=U(\rho,\frac{\pi}{2})=\Delta U(\rho,\frac{\pi}{2})=0,\ \ 0\le\rho\le b$$

, (10)

then the inequality is fulfilled

$$\left\|U(\rho,\varphi)\right\|_{L_2(0,\frac{\pi}{2})}\le\frac{\left|\rho^2-a^2\right|}{b^2-a^2}\cdot M\left(\frac{\rho}{b}\right)^{2\lambda(\varepsilon)},$$

(11)

where $\lambda(\varepsilon)$ is the root of the equation

$$\frac{b^2-a^2}{2a}\left(\frac{b}{a}\right)^{2\lambda}=\frac{M}{\varepsilon} \tag{12}$$

Proof. The solution of problem (1)-(5) can be written in the form of:

$$U(\rho,\varphi)=\frac{\rho^2-a^2}{2a}\sum_{k=1}^{\infty}\left(\frac{\rho}{a}\right)^{2k}a_k\sin 2k\varphi \tag{13}$$

From (7), (8), (13) it follows that

$$\left\|U(\rho,\pi)\right\|_{L_2(0,\frac{\pi}{2})}=\frac{4}{\pi}\int_0^{\frac{\pi}{2}}U^2(\rho,\varphi)\,d\varphi=\frac{\left(\rho^2-a^2\right)^2}{4a^2}\sum_{k=1}^{\infty}\left(\frac{\rho}{a}\right)^{4k}a_k^2 \tag{14}$$

$$\sum_{k=1}^{\infty}\left(\frac{b}{a}\right)^{4k}a_k^2\le M^2 \tag{15}$$

$$\sum_{k=1}^{\infty}a_k^2\le\varepsilon^2 \tag{16}$$

The sum in the right-hand side (14) reaches a conditional maximum at $C_k=0$, $k\ne p,q$ and C_p , C_q satisfies one of the three ratios [1]:

$$\left.\begin{aligned}&a_p^2+a_q^2=\varepsilon^2\\&\left(\frac{b}{a}\right)^{4p}a_p^2+\left(\frac{b}{a}\right)^{4q}a_q^2=\frac{4a^2}{b^2-a^2}M^2\end{aligned}\right\}, \tag{17}$$

$$a_p=0, \tag{18}$$

$$a_q=0, \tag{19}$$

where p, q $(p<q)$ are some numbers.

Let the ratio (17) take place. Then

$$a_p^2=\frac{\varepsilon^2\left(\frac{b}{a}\right)^{4q}-\frac{4a^2}{b^2-a^2}M^2}{\left(\frac{b}{a}\right)^{4q}-\left(\frac{b}{a}\right)^{4p}}\ge 0 \tag{20}$$

$$a_q^2=\frac{\frac{4a^2}{b^2-a^2}M^2-\varepsilon^2\left(\frac{b}{a}\right)^{4p}}{\left(\frac{b}{a}\right)^{4q}-\left(\frac{b}{a}\right)^{4p}}\ge 0 \tag{21}$$

From (20), (21) it follows that [5].

$$\frac{b^2-a^2}{2a}\left(\frac{b}{a}\right)^{2p}\le\frac{M}{\varepsilon}\le\frac{b^2-a^2}{2a}\left(\frac{b}{a}\right)^{2q} \tag{22}$$

By virtue of (13), (19) - (21) we get

$$\left\|U(\rho,\varphi)\right\|_{L_2(0,\frac{\pi}{2})}\le\frac{\left|\rho^2-a^2\right|}{b^2-a^2}\cdot M\left(\frac{\rho}{b}\right)^{2\lambda(\varepsilon)},$$

(23)

where $\lambda(\varepsilon)$ is the root of the equation (12)

Let there now be a relation (18). Then

$$\|U(\rho,\varphi)\|^2_{L_2(0,\frac{\pi}{2})} = \frac{\rho^2-a^2}{4a^2}\left(\frac{\rho}{a}\right)^{4q} a_q^2$$

and by virtue of (15), (16)

$$a_q^2 \le \varepsilon^2$$

$$\frac{b^2-a^2}{4a^2}\left(\frac{b}{a}\right)^{4q} a_q^2 \le M^2$$

From here

$$\|U(\rho,\varphi)\|_{L_2(0,\frac{\pi}{2})} \le \frac{\rho^2-a^2}{b^2-a^2} M \left(\frac{\rho}{b}\right)^{2\lambda(\varepsilon)},$$

(24)

where $\lambda(\varepsilon)$ is the root of the equation (12).

In the case of ratio (19), inequality (24) is similar.

The statement of the theorem follows from (23) and (24).[6].

4. Consider a family of linear operators B_n dependent on an integer parameter, defined as follows:

$$B_n f(\varphi) = \frac{\rho^2-a^2}{2a}\sum_{k=1}^{n} a_k \left(\frac{\rho}{a}\right)^{4k} \sin 2k\varphi \quad ;$$

(25)

here a_k are the Fourier coefficients of the function $f(x)$. The family of operators B_n will be regular, if $f(\varphi)$ $U(\rho,\varphi)$ the solution is also considered as elements of Hilbert spaces $L_2(0,\frac{\pi}{2})$ [9]. Now we get an estimate of the efficiency of applying this family to the solution of the problem of constructing an approximate solution from approximate data. Suppose that the problem (1)-(5) is conditionally correct and the set of correctness is determined by the inequality (6).

Let it $f(\varphi)$ be known with precision δ, i.e. the element $f_\delta(\varphi)$:

$$\| f(\varphi) - f_\delta(\varphi)\|_{L_2(0,\frac{\pi}{2})} \le \delta$$

(26)

Let us take as an approximate solution of problem (1)-(4) the function:

$$U_{n\delta}(\rho,\varphi) = B_n f_\delta(\varphi) = \frac{\rho^2-a^2}{2a}\sum_{k=1}^{n} a_k \left(\frac{\rho}{a}\right)^{4k} sin2k\varphi$$

, (27)

Where is

$$a_k = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f_\delta(\varphi) sin2k\varphi\, d\varphi$$

The exact solution of problem (1)-(4) in the set of correctness (5) has the form:

$$U(\rho,\varphi) = \frac{\rho^2-a^2}{2a}\sum_{k=1}^{\infty} a_k \left(\frac{\rho}{a}\right)^{4k} sin2k\varphi \quad ;$$

(28)

In here

$$a_k = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f_\delta(\varphi) sin2k\varphi\, d\varphi \qquad (29)$$

Let's estimate the difference between $U_{n\delta}(\rho,\varphi)$ and $U(\rho,\varphi)$:

$$\begin{aligned}
&\| U(\rho,\varphi) - U_{n\delta}(\rho,\varphi)\|_{L_2\left(0,\frac{\pi}{2}\right)} = \\
&= \left\| U(\rho,\varphi) - U_n(\rho,\varphi) + U_n(\rho,\varphi) - U_{n\delta}(\rho,\varphi)\right\|_{L_2\left(0,\frac{\pi}{2}\right)} \le \\
&\le \left\| U_n(\rho,\varphi) - U_{n\delta}(\rho,\varphi)\right\|_{L_2(0,\frac{\pi}{2})} + \left\| U(\rho,\varphi) - U_n(\rho,\varphi)\right\|_{L_2(0,\frac{\pi}{2})} = \\
&= \| B_n f(\varphi) - B_n f_\delta(\varphi)\|_{L_2\left(0,\frac{\pi}{2}\right)} + \| B_n f(\varphi) - U(\rho,\varphi)\|_{L_2\left(0,\frac{\pi}{2}\right)} = \\
&= | B_n[f_\delta(\varphi) - f(\varphi)]\|_{L_2\left(0,\frac{\pi}{2}\right)} + \| B_n[f(\varphi) - U(\rho,\varphi)]\|_{L_2\left(0,\frac{\pi}{2}\right)} \le \\
&\le \delta \| B_n \|_{L_2\left(0,\frac{\pi}{2}\right)} + \| B_n f(\varphi) - U(\rho,\varphi)\|_{L_2\left(0,\frac{\pi}{2}\right)}
\end{aligned}$$

(30)

From (28) (29) it follows that

$$\|B_n\|_{L_{2(0,\frac{\pi}{2})}} = \frac{\rho^2-a^2}{2a}\left(\frac{\rho}{a}\right)^{2n}, \qquad (31)$$

$$\left\|B_n f(\varphi)-U(\rho,\varphi)\right\|^2_{L_{2(0,\frac{\pi}{2})}}=\frac{\left(\rho^2-a^2\right)^2}{4a^2}\sum_{k=n+1}^{\infty}\left(\frac{\rho}{a}\right)^{4k}a_k^2 \quad (32)$$

Amount on the right side (32) provided (15)

$$\frac{b^2-a^2}{4a^2}\sum_{k=1}^{\infty}\left(\frac{b}{a}\right)^{4k}a_k^2\le M^2$$

reaches the maximum value when the coefficients a_k are equal to:

$$a_k=0,\quad k\ne n+1;\quad a_{k+1}=\frac{2aM}{b^2-a^2}\left(\frac{a}{b}\right)^{2(k+1)}$$

and, therefore,

$$\left\|B_n f(\varphi)-U(\rho,\varphi)\right\|_{L_{2(0,\frac{\pi}{2})}}\le\frac{\rho^2-a^2}{b^2-a^2}M\left(\frac{\rho}{b}\right)^{2(n+1)} \quad (33)$$

Therefore

$$\left\|U(\rho,\varphi)-U_{n\delta}(\rho,\varphi)\right\|_{L_{2\left(0,\frac{\pi}{2}\right)}}\le\omega(M,n,\delta) \quad (34)$$

Where is

$$\omega(M,n,\delta)=\left(\rho^2-a^2\right)\left[\left(\frac{\rho}{a}\right)^{2n}\frac{\delta}{2a}+\left(\frac{\rho}{b}\right)^{2(n+1)}\frac{M}{b^2-a^2}\right]$$

Note that the effectiveness of regularization depends on the choice of the regularization parameter n, which can be determined from the equation

$$\frac{b^2\left(a^2-b^2\right)}{2a\rho^2}\left(\frac{b}{a}\right)^{2n}=\frac{M}{\delta}.$$

With a fixed accuracy δ approximated to a given value of the parameter n, at which it is achieved, $\inf\omega(M,n,\delta)$ it will be optimal in the sense of estimation (34).

5. Let the constant number M, which participates in the inequality (6), which determines the set of correctness of the problem (1)-(5), be unknown.

Let's consider the auxiliary task:

$$\Delta^2U(\rho,\varphi)=0 \quad \text{в} \quad D=\left\{(\rho,\varphi):0<\rho<b,\ 0\le\varphi\le\frac{\pi}{2}\right\} \quad (35)$$

$$\Delta U(b,\varphi)=g(\varphi),\ 0\le\varphi\le\frac{\pi}{2}, \quad (36)$$

$$U(b,\varphi)=0,\ 0\le\varphi\le\frac{\pi}{2}, \quad (37)$$

$$U(\rho,0)=U(\rho,\frac{\pi}{2})=0,\ 0\le\rho\le b, \quad (38)$$

$$\Delta U(\rho,0)=\Delta U(\rho,\frac{\pi}{2})=0,\ 0\le\rho\le b, \quad (39)$$

Problem (35)-(39) is correctly set and the solution to this problem is as follows:

$$U(\rho,\varphi)=\frac{\rho^2-a^2}{2a}\sum_{k=1}^{\infty}a_k\left(\frac{\rho}{a}\right)^{4k}sin2k\varphi \quad ; (40)$$

In here

$$a_k=\frac{4}{\pi}\int_0^{\frac{\pi}{2}}f_\delta(\varphi)s\,sin2k\varphi\,d\varphi \quad (41)$$

Results: The solution of the ill-posed problem (1)-(4) will be sought in the form of series (40), where $g(\varphi)$ it is considered as an unknown function. From condition (2) taking into account (41) we obtain the integral Fredholm equation of the first kind with respect to the function $g(\varphi)$:

$$\int_0^{\pi}K(\varphi,s)g(s)ds=f(\varphi), \quad (42)$$

Where is

$$K(\varphi,s)=\frac{(a^2-b^2)}{2\pi}\sum_{k=1}^{\infty}\left(\frac{a}{b}\right)^k\frac{sink\varphi\,sinks}{k+1} \quad (43)$$

An approximate solution (36) is constructed by the method of regularization by A.N. Tikhonov [3].

It should be noted that in the case when region D is the upper half-band, problem (1)-(5) is studied in [7].

Conclusion: This study presents a comprehensive framework for addressing a non-correct problem for a biharmonic equation within a semicircular domain. By exploring the conditional correctness of the problem and proving stability through a rigorous theorem, the research advances the understanding of ill-posed problems in mathematical physics. [8].

The application of Fourier series and Hilbert space concepts to formulate and analyze solutions, demonstrating the utility of these mathematical tools in unconventional geometries. The integration of regularization methods, particularly Tikhonov's approach, to construct approximate solutions and address the inherent instability of the problem. The establishment of a theoretical framework using Fredholm equations, which enables reliable approximation despite the lack of continuous dependence on initial data.

The results not only provide a deeper insight into the mathematical structure of biharmonic equations but also highlight practical methodologies for resolving such problems in applications involving complex geometries. Future work could explore the extension of these methods to other geometries and domains, as well as their application to real-world scenarios in engineering and physics.

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