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MULLER'S METHOD FOR SOLVING NONLINEAR FUNCTIONAL EQUATIONS WITH COMPLEX VARIABLES

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1. Муминов.К.К,Чилин.И.В. *Эквивалентность кривых в конечномерных пространствах,* LAP LAMBERT Academic Publishing, 2015.
2. Хаджиев Дж. *Приложение теории инвариантов к дифференциальной геометрии кривых,* Ташкент. ФАН, 1988.
3. Александров П.С. *Курс аналитической геометрии и линейной алгебры* — М.: Наука, 1979. — 512 с.
4. Г. Буземан, П. Келли. *Проективная геометрия и проектиные метрики*-ИЗДАТЕЛЬСТВО ИНОСТРАННОЙ ЛИТЕРАТУРЫ, Москва-1957.

MULLER'S METHOD FOR SOLVING NONLINEAR FUNCTIONAL EQUATIONS WITH COMPLEX VARIABLES

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Annotation. *The study and prediction of the deformation properties of the materials studied in the work is possible on the basis of mathematical modeling of deformation and relaxation processes. In this article, we give an algorithm for solving a nonlinear functional equation with complex variables resulting from mathematical modeling of problems concerning the properties of a deformable solid.*

Keywords: *research, deformation, coefficient, dynamic problems, differential equations, algorithm, method, solutions, shell, oscillation, construction.*

KOMPLEKS O'ZGARUVCHILI NOCHIZIQLI FUNKSIONAL TENGLAMALARNI YECHISHNING MYULLER USULI

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Annotatsiya. *Qaralayotgan materiallarning deformatsion xossalarini tadqiqot va bashorat qilish, deformatsiya va relaksatsiya jarayonlarni matematik modellashtirish orqali amalga oshiriladi. Ushbu maqolada biz deformatsiyaluvchi qattiq jismlarni xossalarini oid masalalar matematik modellashtirish jaroyonida uchraydigan kompleks o'zgaruvchili nochiziqli funksional tenglamalarni yechishning Myuller usuli qo'llab algoritmi keltirilgan.*

Kalit so'zlar: *tadqiqot, deformatsiya, koeffitsient, dinamik masalalar, differensial tenglama, algoritm, usul, yechim, qobiq, tebranish, konstruksiya.*

МЕТОД МЮЛЛЕРА ДЛЯ РЕШЕНИЯ НЕЛИНЕЙНЫХ ФУНКЦИОНАЛЬНЫХ УРАВНЕНИЙ С КОМПЛЕКСНЫМИ ПЕРЕМЕННЫМИ

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Аннотация. *Исследование и прогнозирование деформационных свойств изучаемых в работе материалов возможно на основе математического моделирования деформационных и релаксационных процессов. В данной статье мы даем алгоритм решения нелинейного функционального уравнение с комплексными переменными получающегося процессе математического моделирование задач касательно свойств деформируемого твёрдого тела.*

Ключевые слова: *исследование, деформация, коэффициент, динамические задачи, дифференциальное уравнения, алгоритм, метод, решение, оболочка, колебание, конструкция.*

Introduction. The development of a unified approach to solving the problems of the dynamics and interaction of multiply connected structurally-inhomogeneous shell structures, which are an arbitrary composition of multilayer shells of revolution and rings, the creation and implementation of an appropriate software package with a high level of automation of all stages of calculations oriented to computer use significantly increase the design efficiency and are a major scientific problem of great economic importance. This paper is dedicated to solving this problem.

To solve boundary value problems of the theory of shells, the behavior of which can be described by a system of ordinary differential equations of the first order, the method of numerical integration (MNI), based on reducing the boundary value problem to a number of Cauchy problems, turned out to be the most effective one. In 1961, S.K. Godunov [3] proposed the MNI with ortho-normalization of a solution at intermediate points, which later made a leap in solving boundary value problems in the mechanics of a deformable rigid body.

The orthogonal sweep method (OSM), although less general compared to the FEM, has a greater simplicity, compactness, and flexibility, which make it possible to quickly restructure the software when proceeding to solve new problems.

All this was the basis for its effective application in the present paper and, accordingly, an extension to the solution of boundary value problems with complex quantities.

Literature review. For the first time in solving the problems of determining the stress-strain state of shells of revolution, the method was used by Ya.M. Grigorenko and his students [4, 5, 6, 7, 8, 9]; V.P., Myachenkov, and A.N. Frolov suggested using this method to solve the problems of stability and vibrations of shells of revolution [10]; V.P. Maltsev and V.I. Myachenkov used it to solve the dynamics problems of shells of revolution [11].

In publications by Ya.M. Grigorenko, V.I. Myachenkov, A.N. Frolov, V.P. Maltsev, and others [12] the MHI was thoroughly researched and brought to a universal form to be used in solving a variety of problems in structural mechanics and mechanics of a deformable rigid body.

The success achieved in the development of the MNI based on orthogonal sweep made it possible to use a modification of the displacement method in A.V. Aleksandrov's form [13] to create methodological foundations for calculating multiply connected structurally-inhomogeneous shell structures, in particular, the ones interacting with soil or fluid.

Moreover, the statement and numerical implementation of the proposed methodology are developed and generalized in the framework of the mathematical theory of viscoelasticity [16], modern methods of averaging, and freezing [14, 15], variational principles of the dynamics. They are based on a single approach that uses a discrete-continuous model of the structure and the orthogonal sweep method, generalized on the solution of complex boundary value problems, for calculating the stiffness matrices of shell elements.

Research Methodology. Structurally inhomogeneous multiconnected structures that represent arbitrary composition of laminated axisymmetric shells of revolution and circular frames and prismatic structures, consisting, respectively, of laminated cylindrical shells with noncircular cross-section and rectilinear stringers, are composed, as a rule, a set of elastic and viscoelastic deformable elements, materials and bonds with significantly different rheological properties. The problem of studying solutions to dynamic problems in relation to hydraulic structures remains complex and poorly studied. Experience in implementing mathematical models and algorithms in the design practice of a number of enterprises and design organizations of various branches of hydraulic structures shows its extremely high efficiency in solving dynamic and other problems associated with the construction and the most complex and cumbersome processes of strength processing.

The Muller's method was used to find complex values of natural oscillation frequencies of structurally inhomogeneous shell structures, i.e., to find the roots of a nonlinear functional equation in complex variables.

$$D(\widetilde{\omega}) = |P(\widetilde{\omega})| = 0 \qquad (1)$$

The question of convergence of the iterative process proposed by Muller also requires research. In practice, this problem is solved as follows.

The algorithm for determining the frequencies and forms of vibrations of structurally inhomogeneous shell structures provides for the output of a computer Protocol for searching the roots of equation (1), i.e. the calculator can always use this Protocol to control the iterative process. In addition, one of the results of the algorithm is the relative accuracy of determining these roots achieved during the solution process. Some data from these protocols are shown in tables 1-2. the solution Protocol contains the following data: the number of waves in the longitudinal direction (N); real (QR) and imaginary (QI) components of the complex frequency value $\widetilde{\omega}^*$; real (DR) imaginary (DI) components of the determinant mantissa $|P(\widetilde{\omega})|$; order of the determinant (IS $|P(\widetilde{\omega})|$).

The final values of the oscillation frequency for the first example (Table.1) $\widetilde{\omega}^* = 4{,}09759$; ($\widetilde{\omega}_I^* = 0{,}0748687$); relative accuracy $\varepsilon_R = 3.54 \cdot 10^{-6}$;
$\varepsilon_I = 6.80 \cdot 10^{-5}$

Table 1

SOLUTION PROTOCOL

QR	QI	DR	DI	IS
5.4593E+00	0.0000E+00	9.7342E+00	-2.0188E+00	80
5.4675E+00	0.0000E+00	9,9396E-01	-2.0294E-01	81
5.4757E+00	0.0000E+00	1.0151E+00	-2.0387E-01	81
5.1447E+00	-3.0728E-01	3.1727E+00	-3.9077E+00	80
4.9792E+00	-5.1567E-01	1.0939E+00	-3.5966E+00	80
4.74I6E+00	-8.43I3E-01	-7.6850E-01	-2.8779E+00	80
4.4801E+00	-1.3494E-01	8.5936E-01	-6.3399E-01	80
4.2435E+00	-3.9976E-02	3.5008E+00	-6.7106E-01	79
4.0974E+00	-5.0428E-02	2.2221E+00	4.8778E+00	78
4.0977E+00	-7.5445E-02	-3.9219E-01	-1.2154E+00	77
4.0976E+00	-7.4869E-02	-6.1493E-01	-5.9784E-01	74

Table 2

SOLUTION PROTOCOL

QR	QI	DR	DI	IS
2.8474E+01	0.0000E+00	-7.0908E+00	4.3724E-01	93
2.8517E+01	0.0000E+00	-7.1773E+00	4.5420E-01	93
2.8560E+01	0.0000E+00	-7.2633E+00	4.7109E-01	93
2.5678E+01	-2.7600E-01	-7.3030E+00	-6.4527E-01	91
2.5654E+01	-2.8160E-01	-7.2172E+00	-1.6035E+00	89
2.5654E+01	-2.8169E-01	1.1318E-01	1.5549E+00	86

The final values of the oscillation frequency for the second example (table 2) $\omega_R{}^* = 25{,}6535$; $\omega_I^* = 0{,}281688$; relative accuracy $\varepsilon_R = 4{,}11986 \cdot 10^{-8}$; $\varepsilon_I = 5{,}24144 \cdot 10^{-6}$.

The first three lines in the solution Protocol represent the initial approximations of $\omega_0, \omega_0(1-\varepsilon)$, $\omega_0(1-2\varepsilon)$. The following lines are iterations by Muller.

Presented in table.2 example refers to the most "unsuccessful" (8 iterations; a large difference in frequencies for elastic and viscoelastic problems - 5.4593 and 4.0976). Usually, finding the complex frequency value of structurally inhomogeneous prismatic structures requires from 2 to 4 iterations to determine it with a given accuracy.

As a test example, we studied the proper vibrations of cylindrical shells of rotation, pinched at the ends with geometric parameters (as we did earlier in the construction of stiffness matrices of shell elements) by symmetry or antisymmetry. As one example, we will give the oscillation forms for the structure whose cross-section is shown in Figure 1.

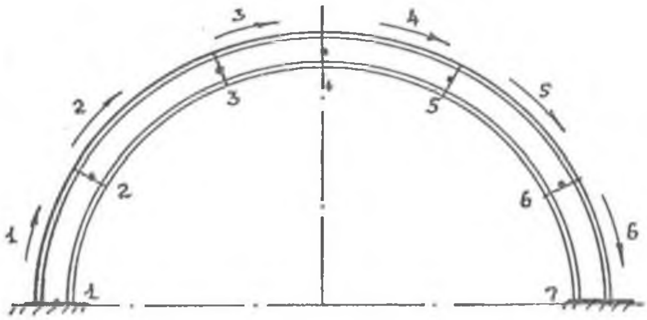

Figure 1. Cross section of a three-layer cylindrical shell

Analysis and results. The design scheme consists of six cylindrical shells of a single type: each shell element contains 10 orthogonalization points. The results of determining the vibration form of this structure (deflection w) are presented in table 3.

Table 3

Sequential number of the shell element					
1	**2**	**3**	**4**	**5**	**6**
0.00E+00	1.88E-01	-2.25E-01	9.98E-06	2.25E-01	-1.881E-01
-2.62E-02	3,501E-01	-4.78E-01	2.97E-01	-3.23E-02	-3.15E-02
-8.78E-02	4.97E-01	-7.03E-01	5.67E-01	-2.69E-02	1.02E-01
-1.611-01	6.101E-01	-8.76E-01	7.86E-01	-4. 63E-01	1.991E-01
-2.23E-01	6.721E-01	-9.79E-01	9.34E-01	-6.00E-01	2.51E-01
-2.57E-01	6.701E-01	-1.00E+00	1.00E+00	-6.70E-01	2.57E-01
-2.5IE-01	6.001E-01	-9.34E-01	9.79E-01	-6.72E-01	2.23E-01
-1.99E-01	6.631E-01	-7.86E-01	8.76E-01	-6.10E-01	1.61E-01
-1.02E-01	2.691E-01	-5.67E-01	7.031E-01	-4.97E-01	8.78E-02
3.15E-02	3.231E-02	-2.97E-01	4.78E-01	-3.50E-01	2.62E-02
1.881E-01	-2.251E-01.	9.981E-06	2.25E-01	-1.88E-01	-6.61E-17

This table shows the complete antisymmetry of the waveform. Since in this case, the deflection at node 4 (the end of the 3rd and beginning of the 4th shell element) must be identically equal to zero, its value is $w_4 = 9{,}98^{-}10^{-6}$ just I represents a relative error in determining the oscillation form of the construction in question. In practice, with relative accuracy $\varepsilon = 0.001$, when determining the frequency of natural vibrations, the shape of the vibrations is determined with an accuracy of 4-5 significant digits.

Comparison with known exact analytical solutions (an elastic rectangular plate supported on all ends, an elastic closed cylindrical shell supported on all ends)-showed the full functionality of the algorithms. By decreasing the number of points orthogonalization (up to 100) and increase the specified relative accuracy of determination of frequencies (up to $\varepsilon = 10^{-10}$) was able to obtain a true solution with the relative accuracy $\varepsilon = 10^{-13}$ and deviation from sinusoid, de heralding 10^{-11}.

We will calculate several composite elastic prismatic structures using the programs developed by us, using the same V.V.Novozhilov relations for shell elements and classical relations of the theory of rectilinear rods. The calculation based on the algorithms developed in this work showed a match in all significant numbers.

Convergence methods and the proposed algorithm for the case of given vibrations of shell structures was tested in 2 stages: were built amplitude - frequency characteristics of vibrations of the considered constructions and resonant frequencies were compared with frequencies of free oscillations. With an accuracy of up to the 3rd sign, the resonant frequencies are compared with the corresponding natural oscillation frequencies. Further, the solutions of the static problem for a round plate, cylindrical and conical shells [17] were compared with the solutions for displacements obtained by the proposed method at zero frequency of the disturbing force. At the same time, the relative discrepancy between the results did not exceed 1.2 %.

For viscoelastic structures with pronounced structural heterogeneity, the convergence problem was solved as follows. Since it was not possible to find known solutions (with a given three - parameter relaxation core) or experimental data for the multi-connected structurally inhomogeneous structures under consideration in the available literature, the correctness of generalization of the proposed methodology and developed algorithms to complex arithmetic was checked as follows. For different viscosity values, the eigen frequencies of the round plate, cylindrical and conical shells were determined. the numerical values of the latter were compared with each other and with solutions of the elastic problem. A similar study was conducted in the problems of forced oscillations. As an example, the lowest resonant amplitudes of a round viscoelastic plate are given, depending on the viscosity of the material. For the relaxation core $R(t) = Ae^{-\beta t}t^{\alpha-1}$, the parameter of the core A varied. The calculation results are shown in Table 4.

Table 4

Parameter A of Core $R(t)$, $(\alpha = 0{,}1 \quad \beta = 0{,}05)$	Resonant amplitude in the center
0,01	40,7
0,02	27,3
0,03	13,9

Conclusion/Recommendations. Comparative analysis of frequencies and mode shapes, damping coefficients, resonance frequencies and amplitude value of vibrations of different elements of the considered axisymmetric and prismatic structurally inhomogeneous shell structures with the existing research results [1], [11], [18] make positive findings on the convergence and accuracy of the developed algorithms in this class of engineering structures and can be recommended in practice of computer aided design (CAD).

References

1. Myachenkov V I, Maltsev V P 1984 Methods and algorithms for calculating spatial structures on computer Mechanical Engineering p 278

2. Mavlanov T. 2020 Development of methods and algorithms for calculating shell structures taking into account structural inhomogeneity and interaction with various media TIIAME p 200

3. Grigorenko Ya M, Bespalova E I, 1971 Numerical solution of boundary value problems of the statics of orthotropic layered shells of revolution on a M-220 computer Methodological supplies –(Kiev, Naukova dumka) pp 151
4. Grigorenko Ya M, 1973 Isotropic and anisotropic layered shells of rotation of variable stiffness (Kiev, Naukova dumka) 228 p.
5. Grigorenko Y M, Vasilenko A T and Pankratova N D 1977 Calculation of non-circular cylindrical shells (Kiev, Naukova dumka) pp 404
6. Grigorenko Ya M, Mukoed A P, 1979 The solution of problems of the theory of shells on a computer (Kiev, Vishcha shkola) pp 279
7. Grigorenko Ya M, Kitaygorodsky A B, Semenova V V, Sudavtsova G K and Shinkar A I 1980 Calculation of orthotropic laminated shells of revolution with variable stiffness on an computer (Kiev, Naukova dumka) pp 102
8. Grigorenko Ya M, Vasilenko A T 1981 Methods for calculating shells V 4 Theory of shells of variable stiffness (Kiev, Naukova dumka) pp 543
9. Grigolyuk E I, Maltsev V P, Myachenkov V I and Frolov A N 1971 On a method for solving the problems of stability and vibrations of shells of revolution ,Reports of USSR Academy of Sciences MTT 1 pp 9-19
10. Maltsev A A, Maltsev V P and Myachenkov V I 1979 Dynamics of axisymmetric shell structures In Applied problems of strength and plasticity Mechanics of deformable systems Interuniversity collection Gorky GSU pp 150 - 158
11. Maltsev A A 1982 Dynamic loading of thin-walled prismatic structures In book Calculation of transport and building structures using computer Proc MIET 618 M MIET pp 16-23
12. Alexandrov A V 1963 The displacement method for calculating slab and beam structures In Proceedings of MIIT Transzheldorizdat 174 4-18.
13. Filatov A N 1974 Asymptotic methods in the theory of differential and integro-differential equations (Tashkent, FAN) p 216
14. Mavlanov T, Karimov A 1979 On the free forced vibrations of the fundamental slabs of silo structures Reports of AS UzSSR series Tech. Sci 4 pp 43-47
15. Vestyank AV, Gorshkov A G and Tarlakovsky D T 1983 Unsteady interaction of deformable bodies with the environment M, AISTI Russian AS 15 pp 69-121
16. Koltunov V P, Mayboroda A S and Kravchuk 1983 Applied mechanics of a deformable solid (Vysshaya shkola) p 350
17. Strength, stability, fluctuations. Handbook, Vol. 10, (edited by Birger I. A) M.:1968
18. Urzhumtsev Yu. S., Mayboroda V. P. 1984 Technical means and methods for determining the strength characteristics of structures made of polymers. Moscow: Mashinostroenie, -168 p.
19. Sh Salimov 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **883** 012191
20. Sh Salimov et al 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **883** 012192

CONSERVATIVE SCHEMES OF THE NON-STATIONARY PROBLEM FOR THE OPTIMAL SELECTION OF THE LOCATION OF HEAT SOURCES IN THE ROD

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National University of Uzbekistan

МУНДАРИЖА

ФИЗИКА-МАТЕМАТИКА ФАНЛАРИ
01.00.00 ФИЗИКО-МАТЕМАТИЧЕСКИЕ НАУКИ
PHYSICAL AND MATHEMATICAL SCIENCES

КИМЁ ФАНЛАРИ
02.00.00 ХИМИЧЕСКИЕ НАУКИ
CHEMICAL SCIENCES

БИОЛОГИЯ ФАНЛАРИ
03.00.00 БИОЛОГИЧЕСКИЕ НАУКИ
BIOLOGICAL SCIENCES