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METHODS OF MODELING PHYSICAL PROCESSES IN MATHCAD

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In the context of modern educational realities, characterized by strict criteria for assessing students' knowledge, high academic workload, reduced hours of study, as well as outdated and insufficient equipment, the problem of improving the quality of education is becoming particularly acute. In this regard, the training of specialists within the framework of the credit education system highlights the need to develop new conceptual approaches to the organization of educational and methodological activities and the active introduction of modern information and communication technologies into the educational process. This implies the widespread use of information technology and personal computers for modelling a variety of physical phenomena, both in the framework of training and in the implementation of ongoing knowledge control. This paper demonstrates that the use of modern applied software packages in the educational process can significantly transform the methodology of studying certain sections of the physics course, providing visual visualization of the results of solving problems using these applied tools.

For a clearer demonstration of physical phenomena, this article presents modelling of complex systems described by second-order differential equations using the MathCad software environment. Using the odesolve function built into Mathcad, a graph of the addition of two harmonic oscillations was obtained. The method of solving differential equations presented in this paper can be used to model various other physical processes considered in the physics course. The main purpose of this work is to master the methods of modelling non-stationary physical processes in the Mathcad environment using the odesolve function, using the example of oscillatory movements. In addition, the article highlights the importance of using physical models in the educational process. This allows not only to visualize complex processes, but also contributes to a deeper understanding of the principles underlying physical phenomena.

Keywords: odesolve function, physical processes and models, complex systems, ordinary differential equations of the first and second orders, addition of two harmonic oscillations, modeling of physical processes.

MATHCAD-ТАҒЫ ФИЗИКАЛЫҚ ПРОЦЕСТЕРДІ МОДЕЛЬДЕУ ӘДІСТЕРІ

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Студенттердің білімін бағалаудың қатаң критерийлерімен, жоғары оқу жүктемесімен, оқу сағаттарының қысқартылған көлемімен, сондай-ақ ескірген және жеткіліксіз жабдықтармен сипатталатын қазіргі білім беру шындықтары жағдайында білім беру сапасын арттыру мәселесі ерекше өткір болып отыр. Осыған байланысты, кредиттік оқыту жүйесі шеңберінде мамандарды даярлау Оқу-әдістемелік қызметті ұйымдастырудың жаңа тұжырымдамалық тәсілдерін әзірлеу және білім беру процесіне заманауи ақпараттық-коммуникациялық технологияларды белсенді енгізу қажеттілігін бірінші орынға қояды. Бұл оқыту шеңберінде де, білімнің ағымдағы бақылауын жүзеге асыру кезінде де әртүрлі физикалық құбылыстарды модельдеу үшін ақпараттық технологиялар мен дербес компьютерлерді кеңінен қолдануды білдіреді. Бұл жұмыста оқу процесінде заманауи қолданбалы бағдарламалық пакеттерді қолдану физика курсының кейбір бөлімдерін зерттеу әдістемесін айтарлықтай өзгертуге мүмкіндік беретіндігі, осы қолданбалы құралдарды қолдана отырып, есептерді шешу нәтижелерін көрнекі түрде визуализациялауды қамтамасыз ететіндігі көрсетілген.

Физикалық құбылыстарды неғұрлым нақты көрсету үшін бұл мақалада Mathcad бағдарламалық ортасын қолдана отырып, екінші ретті дифференциалдық теңдеулермен сипатталған күрделі жүйелерді модельдеу ұсынылған. Mathcad-қа енгізілген odesolve функциясының көмегімен екі гармоникалық тербелісті қосу графигі алынды. Жұмыста ұсынылған дифференциалдық теңдеулерді шешу әдісі физика курсында қарастырылатын әртүрлі басқа физикалық процестерді модельдеу үшін пайдаланылуы мүмкін. Бұл жұмыстың негізгі мақсаты тербелмелі қозғалыстар мысалында odesolve функциясын қолдана отырып, Mathcad ортасындағы стационарлық емес физикалық процестерді модельдеу әдістерін игеру болып табылады. Сонымен қатар, мақалада білім беру процесінде физикалық модельдерді қолданудың маңыздылығы көрсетілген. Бұл күрделі процестерді елестетуге ғана емес, сонымен қатар физикалық құбылыстардың негізінде жатқан принциптерді тереңірек түсінуге мүмкіндік береді.

Түйінді сөздер: odesolve функциясы, физикалық процестер мен модельдер, күрделі жүйелер, бірінші және екінші ретті қарапайым дифференциалдық теңдеулер, екі гармоникалық тербелісті қосу, физикалық процестерді модельдеу.

МЕТОДЫ МОДЕЛИРОВАНИЯ ФИЗИЧЕСКИХ ПРОЦЕССОВ В MATHCAD

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В условиях современных образовательных реалий, характеризующихся строгими критериями оценки знаний студентов, высокой учебной нагрузкой, сокращенным объемом учебных часов, а также устаревшим и недостаточным оборудованием, проблема повышения качества образования становится особенно острой. В связи с этим, подготовка специалистов в рамках кредитной системы обучения выдвигает на первый план необходимость разработки новых концептуальных подходов к организации учебно-методической деятельности и активного внедрения современных информационно-коммуникационных технологий в образовательный процесс. Это подразумевает широкое применение информационных технологий и персональных компьютеров для моделирования разнообразных физических явлений, как в рамках обучения, так и при осуществлении текущего контроля знаний. В настоящей работе демонстрируется, что применение современных прикладных программных пакетов в учебном процессе позволяет существенно трансформировать методику изучения некоторых разделов курса физики, обеспечивая наглядную визуализацию результатов решения задач с использованием этих прикладных средств.

Для более четкой демонстрации физических явлений, в данной статье представлено моделирование сложных систем, описываемых дифференциальными уравнениями второго порядка, с применением программной среды MathCad. При помощи функции odesolve, встроенной в Mathcad, был получен график сложения двух гармонических колебаний. Представленный в работе способ решения дифференциальных уравнений может быть использован для моделирования различных других физических процессов, рассматриваемых в курсе физики. Основная цель этой работы заключается в освоении методов моделирования нестационарных физических процессов в среде Mathcad с использованием функции odesolve, на примере колебательных движений. Кроме того, в статье подчеркивается важность применения физических моделей в образовательном процессе. Это позволяет не только визуализировать сложные процессы, но и способствует более глубокому пониманию принципов, лежащих в основе физических явлений.

Ключевые слова: функция odesolve, физические процессы и модели, сложные системы, обыкновенные дифференциальные уравнения первого и второго порядков, сложения двух гармонических колебаний, моделирование физических процессов.

Introduction. Modern requirements for the training of qualified personnel using credit technology used in higher education dictate the need to create innovative approaches to the organization of educational activities and the integration of modern information and communication tools into the educational process. This implies the active use of digital technologies and personal computers for modelling various physical phenomena both in the framework of training and for conducting ongoing knowledge control. The use of computer technology stimulates students' interest in the discipline being studied, simplifies and accelerates the process of mastering new knowledge and verifying their assimilation, which ultimately contributes to improving the quality of education and a deeper understanding of the material. Replacing traditional lecture demonstrations with their digital counterparts makes it possible to significantly optimize the time spent on their presentation and explanation.

Practice shows that introducing students to computer demonstrations before starting to study a topic, as a preliminary stage, is more effective. The clarity, complexity and interactivity inherent in these programs make them indispensable assistants for both students and teachers. The variety of functions offered by the programs makes the learning process more exciting and productive. In this regard, the study of methods for modelling physical processes using modern application software packages is becoming particularly relevant at the present time [1].

In the credit-modular learning system, an electronic summary becomes one of the options for using modern information technologies in lectures. It differs from an electronic textbook and is developed mainly for the teacher, taking into account his individual teaching style. A multimedia presentation is a key tool in the preparation of an electronic summary. And for a clearer demonstration of certain processes using mathematical modelling, programs such as Mathcad, Matlab and other analogues are used.

As part of our approach, we opt for Mathcad when considering key sections of the theoretical part of the course, as well as materials from practical and laboratory work.

Training complexes developed using digital technologies are a specialized type of technical training tools. Their goal is to simplify the teacher' s work, eliminate monotonous operations, and ensure a high level of learning and skill development.

The use of computers is inextricably linked with the solution of many issues related to the improvement of physical education. Automated learning systems can be used as a supplement to lectures and for a more detailed explanation of the material, for the implementation of ongoing knowledge control at seminars, as well as for the purpose of automating laboratory workshops [2].

For some areas of training, laboratory practice is a key form of education. The main objective of the workshop is to empirically test the theoretical concepts of the discipline under study, to create a clear understanding of the basic principles and ways of their implementation among students, to develop a scientific worldview among future professionals, as well as to form practical skills and experimentation skills.

The realization of creative abilities and professional growth are achieved to the maximum extent through the practical application of acquired knowledge. Laboratory work helps students understand the relationship between theory and practice, demonstrates current trends in the development of experimental science and stimulates interest in independent scientific research and a creative approach. Computer-based learning systems are widely used at all stages of laboratory activities, including experiment planning, data processing and analysis, and the design of research results. In cases where the computer is not the direct object of study, its function is to support ongoing activities [3].

A program that simulates physical experience should be perceived as an integrated part of an interconnected set of educational tools. Computer visualization tools allow you to transform the results into dynamic and understandable images, displaying the dependence of the solution on the set

parameters on a graphical screen. This brings the computational experiment closer to real conditions. Interacting with such a model is fascinating and helps students intuitively understand the essence of fundamental physical equations, developing their scientific intuition. It is important to note that numerical experiment makes it possible to predict previously unknown phenomena and analyse systems that are inaccessible for physical reproduction [4].

Materials and methods. The creation of computer laboratory work dates back to the 90s of the last century, which was made possible by the availability of microcomputers, the development of conversational interfaces, machine graphics and animation technologies. The basis of such educational projects were the methods of machine modelling, which radically changed the approach to physics and gave impetus to the emergence of a new scientific field - computational physics. ”Virtual” laboratory work is educational computer experiments that adequately complement traditional physical experiments conducted in real conditions [5].

The laboratory workshop is aimed at in-depth mastering of theoretical material, familiarization with methods of measuring various physical quantities and development of students’ skills of independent experimental activity. Laboratory experiments are active and relatively autonomous tasks: after studying the theoretical part, the student, under the guidance of a teacher, takes measurements of specified physical quantities, analyses the data obtained, builds graphs and works with them, and then independently formulates conclusions based on the work performed. Thus, laboratory practice plays an important role in the development of research skills among students [6].

There are many examples of phenomena and processes that can be used to create models with varying degrees of realism, covering all areas of physics. An important advantage is that the use of computer modelling in the study of various branches of physics opens up huge potential opportunities by providing modern technologies and specialized programs. These tools not only expand the horizons of research, but also significantly increase them.

Modern approaches to the preparation of students in technical disciplines indicate the importance of teaching not only the basic materials and techniques of work in the specialty, but also the use of various methods of analysis and modelling. However, given the limited time of classes and the physical condition of laboratory equipment, it is necessary to reconsider traditional ideas about the pedagogy of natural science disciplines. This is especially true of fundamental disciplines such as physics, which is central to the development of the engineering approach.

The need to use application software in the learning process is associated with trends towards increasing various requirements for the clarity and effectiveness of the disclosed material, as well as the need for effective preparation of students to work with technology. This article describes how the new Mathcad mathematical modelling system can significantly improve the study of physical processes.

For example, modelling of forced oscillations without taking into account resistance under the influence of an external periodic force is shown. The application of /odesolve for solving second-order ordinary differential equations is demonstrated. The constructed graphs make it possible not only to reveal deeper and more meaningful aspects of the very nature of the process under consideration, but also to study its behaviour in comparison with the given initial conditions. These methods are also important for developing students’ skills in interpreting mathematical models of studied physical phenomena.

The Mathcad program creates other opportunities for teachers: it becomes possible to introduce dynamic models into educational materials, which makes it possible to replace some traditional calculations using computers and facilitate the study of complex systems. At the same time, the use of such approaches leads to the formation of engineering thinking among students, which is necessary for further professional activity.

In addition, it is worth emphasizing that the main purpose of this work is to explain that the use of Mathcad helps to solve a specific problem from a physics course, as well as to prove the importance of digital technologies in the educational process. The modelling approach used can be applied to the study of other physical systems, such as electrical circuits, heat transfer, and wave phenomena.

In our opinion, the Mathcad package is the most adapted for the educational process, as it includes a text editor, a computing module, and a graphics processor. Mathcad is a universal system that can be used in various fields of science and technology where mathematical methods are used. Writing commands in Mathcad in a language close to standard mathematical formulas makes it much easier to set and solve problems [7].

Mathcad implements functionality for finding solutions to partial differential equations, as well as for solving systems of such equations. The Mathcad toolkit makes it possible to find solutions to parabolic and hyperbolic equations in one dimension (using one spatial and one temporal variable). Despite the apparent limitations of this set of tasks, it covers a significant part of the problems that arise in the physical and engineering fields.

In Mathcad, to solve ordinary differential equations using numerical methods, you can choose between the Given/odesolve solution block and built-in functions, for example, rkfixed, which were used in previous versions. The use of the Given/odesolve solution block is usually considered preferable due to the clarity of the problem formulation and presentation of the results obtained. At the same time, the built-in functions provide the user with more control over the settings of the numerical solution.

Mathcad implements a specialized built-in function designed for numerical solution of differential equations. It has the following syntax: Odesolve (x, b[, steps]).

To solve the Cauchy problem, it is necessary to set the initial conditions and determine the endpoint of the integration interval. These parameters, along with the equation, are formatted in the Given block, after which the odesolve function is called. It is important to consider a number of nuances when using it. If the number of step steps is set, the calculations are performed with a constant integration step. Otherwise, an adaptive step selection method is used.

The functional scheme of Odesolve(x, b, [step]) looks like this: it forms a function that is the result of solving a differential equation. This function is intended to be used inside a block starting with the Given statement.

Here:

- x is the independent variable over which the integration takes place, and it must be represented by a real number.

- b is the value of the endpoint of the interval where the integration is performed.

- step is an optional parameter that defines the increment step size of the integration variable.

MathCAD has the ability to solve differential equations directly numerically, where the highest derivative is expressed explicitly (that is, the equation has the form a).

$$\frac{d^2}{dt^2}x(t) - sin(\frac{d}{dt}x(t)) = -x(t)$$

To solve a differential equation, you can use the odesolve function and the specialized Given-Odesolve block. This block includes:

1. The Given keyword, which initiates the decision process.

2. The differential equation itself, written in the usual mathematical form, but with some changes:

a) the logical equality operator is used to denote equality (entered by pressing Ctrl - =);

b) the integrated function is always specified with an explicit argument (for example, x(t), and not just x); c) derivatives can be denoted using the standard operators $\frac{d}{dx}$, $\frac{d^n}{dx^n}$ and, or using the derivative symbols obtained by pressing Ctrl-F7 (for example, x’(t), x’ ’(t)).

3. Setting the initial or boundary conditions for the integrable function and its derivatives (except

for the highest one). These values are also set using the logical equality operator. The number of set values must correspond to the order of the equation. For example, for a second-order equation $\frac{d^2x(t)}{dt^2} + \frac{dx(t)}{dt} = -x(t)$ it is necessary to specify the initial values of the function and its first derivative, for example: x(0) = 1; x'(0) = 0.5. The derivative symbol «'» is entered using the keyboard shortcut Ctrl-F7.

The Odesolve function. The required first parameter is the name of the independent variable. The second required parameter specifies the final value of this variable. The optional third parameter specifies the number of steps used for numerical integration. Odesolve returns a function as a result of its work, which is a numerical approximation of the solution of a differential equation in a given range of values of an independent variable. The resulting function can be used to calculate the values of the desired function at any point in the interval, as well as to visualize the solution as a graph.

Let' s consider an example: let' s find a solution to the previously considered differential equation in the range of values of the variable t from 0 to 5. Let' s determine the values of x for t equal to 2 and 4, and also plot the resulting solution (see Fig.1) [8].

Listing 1. Solving a second-order equation for values of t=0..5

Given

$\frac{d^2}{dt^2}x(t) + \frac{d}{dt}x(t) = -x(t)$

$x'(0) = 0.5 \quad x(0) = 1$

$x := odesolve(t, 5)$

$x(2) = 0.36 \quad x(4) = -0.178$

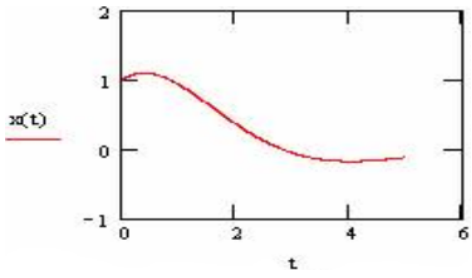


Fig.1 - Graph of the second-order equation for values t=0..5

Listing 2. The solution of this differential equation b(a) and the derivative of the solution function is c(a)

Given

$\frac{d^2}{da^2}b(a) + a^2 \cdot \frac{d}{da}b(a) + a \cdot b(a) = e^a \cdot \cos a$ The differential equation is given

$b(0) = -8 \quad b'(0) = 3$ Initial conditions are set

$b := odesolve(a, 5, 100)$ The solution of the differential equation is given

$c(a) := \frac{d}{da}b(a)$ Calculating the derivative of b(a)

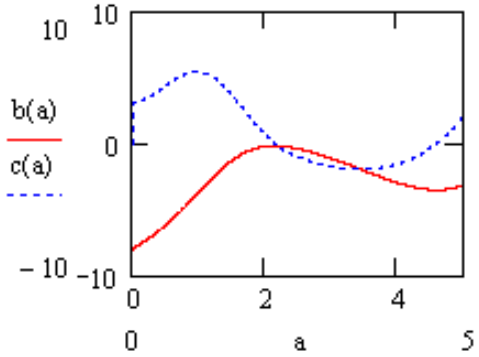


Fig.2 - The graph of the solution of a given differential equation b(a) and the derivative of the solution function - c(a)

Remarks:

1. The equation must be linear with respect to the highest derivative.

2. The number of specified initial or boundary conditions within the block must be equal to the order of the equation.

3. When writing an equation to indicate the derivatives of a function, use the special buttons from the Math panel or ' (stroke) - [Ctrl+F7], for the equal sign = [Ctrl+=] (including for additional conditions).

4. The end point must be larger than the start point.

5. Initial and boundary conditions of mixed type are not allowed (f'(a)+f(a)=5).

6. The desired function in the block must necessarily have an argument (f(x)).

Based on the above illustrations, this article demonstrates various approaches to solving

ordinary differential equations used to model oscillatory phenomena in physics. In particular, using the odesolve function in the Mathcad program, a graph of the addition of two harmonic oscillations was obtained. This process is described by equation $y'' + qy = a\sin wt$, which is studied in the section of the physics course "Vibrations and waves".

Listing 3. Solution of the Cauchy problem for second-order ordinary differential equations

Given

$a := 1 \quad q := 1.5 \quad w := 1$

$y''(t) + q \cdot y(t) = a \cdot \sin w \cdot t$

$y'(0) = -1 \quad y(0) = 0$

$t := 0, 0.2..100$

$y := odesolve(t, 60)$

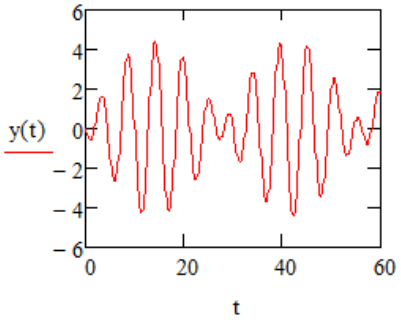


Fig.3 - The graph obtained by adding two harmonic oscillations

The novelty of the work is that the considered methods for solving differential equations differ from those previously proposed in that it is focused on modelling physical processes, which is characterized by a simple methodology and is suitable for use by students without special training.

Results and discussion. The presented methods for solving differential equations in Mathcad can be used to model oscillatory physical processes, as well as an example of solving other physical problems. As a result of these modeling works, the user receives a ready-made model of the system and can only arbitrarily set the initial conditions and control all the parameters of the model during the numerical experiment. The resulting nonlinear model is widely used in the study of branches of physics: mechanics, electricity and magnetism, vibrations and waves. It can also be used during lectures, practical, laboratory classes, as an element of information technology. Why was Mathcad chosen because it has a simple methodology and is suitable for students to use without special training. [9]

This development aimed to deepen students' understanding of fundamental physical principles, their interdependence and logical structure; to facilitate the understanding of the relationship between different physical quantities, to compare the real behaviour of an object, analytical expressions and their visual representation. An interactive platform is being created for the user, allowing them to freely experiment with mathematical models describing physical objects, phenomena, and processes.

Students are able to use simple object models as building blocks to develop complex systems. Instead of simply performing laboratory work according to ready-made instructions, they can create new circuits using existing models, and even adapt these models to their needs. By understanding the principles of interaction of elements, establishing information links between them and analysing the system' s response to external influences, the user learns how to manage complex systems, organically combining the study of physics with computer science. At the same time, what is especially important, computer science becomes a tool for students with obvious practical applications.

Modern software packages stand out because they allow you to enter mathematical expressions or functions to perform numerical calculations, set various values for the variables used, create graphical representations of simulation results, generate random numbers (to simulate random processes), perform logical operations, which makes it possible to apply a variety of numerical methods. When using Mathcad, the student is freed from the need to write code for a computational algorithm and create auxiliary program blocks. Mathcad significantly reduces the amount of monotonous computing work. Mastering Mathcad

is easy and fast, without requiring in-depth study of voluminous manuals, writing notes, or memorizing complex rules for study and practical application. The simplicity of Mathcad lies in the fact that you can get a solution to the problem in a short time [10].

The integration of modern applied software tools into educational practice opens up new horizons for teaching physics and computer science. This allows us to review traditional approaches to the study of topics involving large, routine calculations, solving differential equations, graphical representation of data and visualization of results. Thanks to the software packages, complex tasks that were previously available only through analytical calculations can now be solved using numerical computer modelling methods that offer significant advantages. This approach allows not only to simplify the learning process, but also to make it more visual and understandable for students. The use of numerical methods expands the boundaries of cognition, allowing us to study physical systems in dynamics and from various points of view, which was inaccessible with an exclusively analytical approach. Thus, modern application packages are becoming an indispensable tool in education, increasing the effectiveness of learning and stimulating interest in the study of physics and computer science. [11].

Currently, computer modeling and computational experiments are a sought-after approach to the study of physical processes. This method is characterized by unique features, advantages, and limitations that distinguish it from other methods of analyzing physical systems. It is important that university students have knowledge of computer models, numerical methods used to study various objects, and confidently use modern software. Thanks to modern application programs, complex systems of equations are solved instantly, graphs of the studied dependencies are plotted, and experiments that are difficult to reproduce in reality are modelled.

Conclusion. Consequently, the use of applied software in the educational process makes it possible to draw conclusions based on theoretical principles, compare them with experimental data and make changes to the original model. To display the real system and acquire skills in the field of modeling, an algorithm was created and a program for adding two harmonic vibrations was written. In addition, the user can engage in design and research work, which makes it possible to coordinate the creation, testing and improvement of innovative systems, for example, technical devices, devices and mechanisms. In this context, the Mathcad software package is a valuable learning tool, allowing you to teach various subjects (numerical methods, computer modeling of physical phenomena, mathematical modeling, physics, and others) at a more in-depth level [12].

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