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♦

СЕРИЯ ГЕОЛОГИИ И ТЕХНИЧЕСКИХ НАУК

♦

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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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CALCULATION AND VISUALIZATION OF OSCILLATING SYSTEMS

Abstract. The article presents the calculation and visualization of natural, damping and forced oscillations of a harmonic oscillator. The input parameters are the natural frequency, the initial coordinates and velocities of the system, the frequency of the driving force and its amplitude. The program is worked out and calculations and visualization of the oscillating system are carried out using the MatLab language: there are the graphs of the coordinates and system velocities versus time for natural, damping and forced oscillations of the harmonic oscillator. For damping oscillations such graphs are drawn at various magnitudes of the damping coefficients. The system of differential equations is solved by using the ode45 procedure. The program allows carrying out the experiments at different values of the input parameters. It is shown that the coordinate and velocity amplitudes of the damping harmonic oscillations exponentially decrease with time and asymptotically approach zero. This happens because the friction force work dissipates the oscillator energy. In a forced oscillation the system oscillates with the frequency of the driving force. There are assignments for student's self study. The results of calculation and visualization of the oscillating systems are used in the theoretical mechanics.

Key words: harmonic oscillator, natural, damped and forced oscillations, damping coefficient, natural frequency, driving force.

Introduction. Nowadays all educational institutions of Kazakhstan are provided with computer hardware and software, interactive boards and internet. Almost all teachers have completed language and computer courses for professional development. Hence the educational institutions have all conditions for using computer training programs and models for performing computer laboratory works. During several years we have been conducting the work on organization computer laboratory works on physics with use of resources of the Fizikon Company [1, 2] which are developed at Al-Farabi Kazakh National University by V.V.Kashkarov and his group. Some of worksheet templates for computer laboratory works are introduced in educational process of our university and schools of the Southern Kazakhstan [3-31]. Students of the physics specialties 5B060400 and 5B011000 successfully master the discipline "Computer modeling of physical phenomena" which is the logical continuation of the disciplines "Information technologies in teaching physics" and "Use of electronic textbooks in teaching physics". The aim of this discipline is to study and learn the MATLAB program language [32] system, acquaintance with its huge opportunities for modeling and visualization of physical processes. The present article is devoted to calculation and visualization of natural, damping and forced oscillations of a harmonic oscillator by using the package of MATLAB applied programs.

Formulation of the problem. **The natural oscillations of a harmonic oscillator (spring-mass system)** is described by differential equation of the second order:

$$\ddot{x} + \omega^2 x = 0$$

where $\omega^2 = \frac{k}{m}$, and k is the rigidity of the spring, m is the mass of the oscillator.

For solving this equation we transform it into two differential equations of the first order and then use the ode45 procedure.

$$\frac{d\upsilon_x}{dt}+\omega^2 x=0,\quad \frac{dx}{dt}=\upsilon_x$$

Let us to introduce new denotations z(1)= x; z(2)=dx/dt and then write the initial equation in the form of system of differential equations of the first order. Solution of these equations requires creation of m-file under the name Oscillator.m.

The listing of m-file

```
function dy=Oscillator(t,z);
global w; %input the natural frequency of a harmonic oscillator
dy=zeros(2,1);% input the column-vector with dimension 2 x1
dy(1)=z(2);% input the equivalent differential equation
dy(2)=-w^2*z(1);% input the equivalent differential equation
end
```

The parameters of the oscillator are introduced in the command line in the form of comments.

In the command line we write

```
>> global w; % cyclic frequency
>> k=9; % rigidity coefficient
>> m=1; % the oscillator mass
>> T=2*pi*sqrt(k/m); % calculation of the oscillation period
>> w=2*pi/T; % calculation of the natural cyclic frequency
>> r0=[0.5 1]; % the initial conditions
>> [t,Z]=ode45('Oscillator',[0:5*T/5000:5*T],r0); % solution of the system of % ordinary differential
   equations (ODE)
>> figure(1); plot(t,Z(:,1)); % visualization of the dependence x=x(t)
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 1.

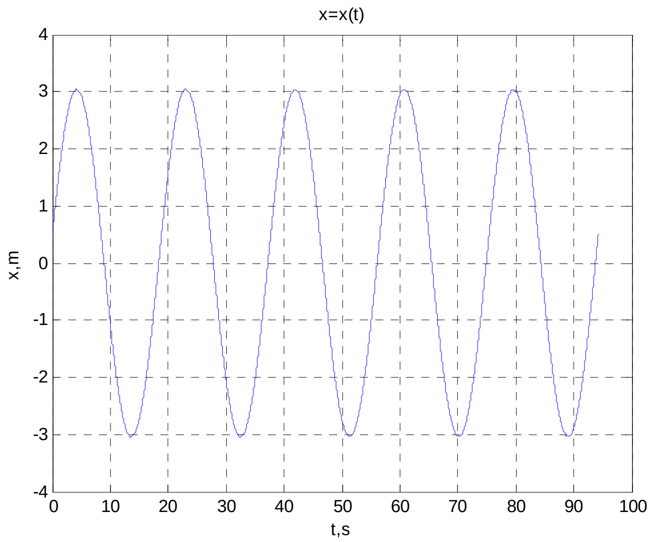

Figure 1 – The graph of the harmonic oscillator coordinate versus time

```
>> figure (2); plot(t,Z(:,2)); % visualization of the dependence v=v(t)
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 2.

```
>> figure(3);plot(Z(:,1),Z(:,2));% visualization of the trajectory in the phase plane
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 3.

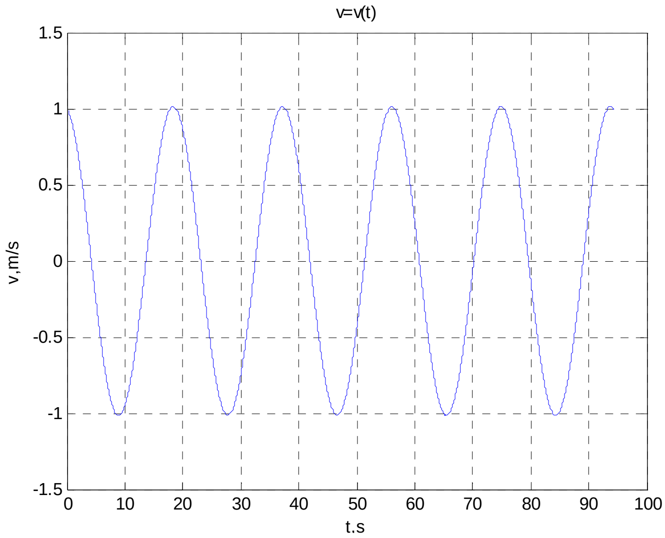

Figure 2 – The graph of the harmonic oscillator velocity versus time

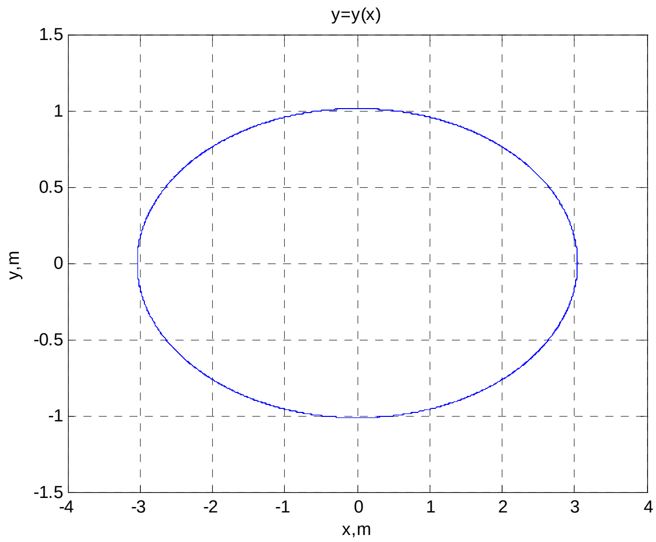

Figure 3 – Phase trajectory of the harmonic oscillator

The damping oscillations of the harmonic oscillator occur at the action of two forces: the restoring force *f = -kx* and the friction force *f1 = -cdx/dt.* Hence the equation of the damping oscillation is

$$m\frac{d^2x}{dt^2}+c\frac{dx}{dt}+kx=0$$

It is necessary to solve this equation for the given mass and rigidity coefficient.

$$\frac{d^2x}{dt^2}=-\beta\frac{dx}{dt}-\omega^2x$$

where $\beta=\frac{c}{m}$, $\omega^2=\frac{k}{m}$. For solving this equation we transform it into two differential equations of the first order and then use the ode45 procedure.

$$\frac{d\upsilon_x}{dt}=-\beta\upsilon_x-\omega^2x;\ \ \upsilon_x=\frac{dx}{dt}$$

At first, we introduce new denotations y(1) = x; y(2) = dx/dt and then write the initial equation in the form of system of differential equations of the first order:

$$\frac{dy_1}{dt} = y_2, \quad \frac{dy_2}{dt} = -\omega^2 y_1 - \beta y_2$$

Then we create the m-file of the function oscil describing the right sides of this system of equations.
The listing of the m-file of the function oscil

```
function dydt=oscil(t,y)
global w2 b; % input the global variables
dydt=[y(2); -w2*y(1)-b*y(2)];
```

Let us find the solution of the system of equations using the oe45 procedure and draw the graphs
In the command line we write

```
>> global w2 b; % input the global variables
>> w2=4; b=0.25; % input the parameters of the oscillator
>> x=2; %the initial coordinate
>> vx0=0; % the initial velocity
>> [t,y]=ode45(@oscil,[0 30],[2;0]); % solution of the ODE
>> plot(t, y(:, 1), '-', t, y(:, 2), '--') % drawing the graphs of the coordinate and % velocity versus time
>> grid on % drawing the coordinate grid
>> xlabel('time t'); % input the title of the x axis
>> ylabel('solution x'); % input the title of the y axis
>> legend('coordinate','velocity'); % input the legend of coordinate and velocity
>> title('Solution of oscillations equation '); % input the title of the graph
```

The result is presented in the figure 4

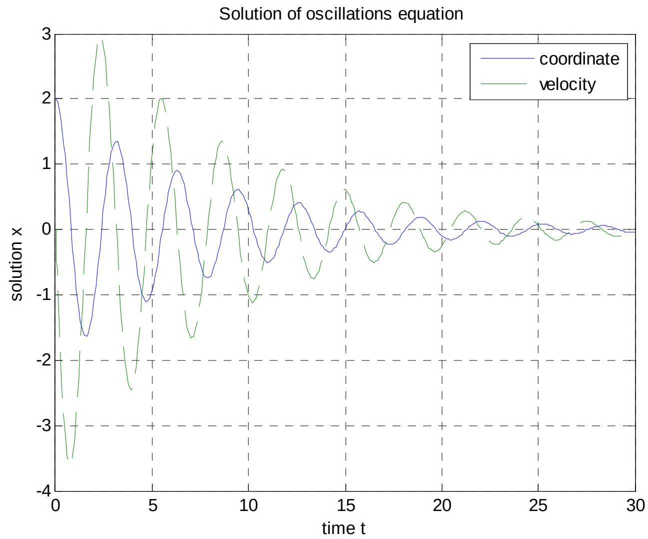

Figure 4 – The dependence of the velocity and coordinate of the harmonic oscillator upon the time

```
>> % The damping coefficient b=0.5
>> w2=4; b=0.5; % input the oscillator parameters
>> x=2; %the initial coordinate
>>vx0=0; % the initial velocity
>> [t,y]=ode45(@oscil,[0 30],[2;0]); % solution of the ODE
>> plot(t, y(:, 1), '-', t, y(:, 2), '--') % drawing the graphs of the coordinate and %velocity versus time
>> grid on % drawing the coordinate grid
>> xlabel('time t'); % input the title of the x axis
>> ylabel('solution x'); % input the title of the y axis
>> legend('coordinate','velocity'); % input the legend of coordinate and velocity
>> title('Solution of oscillations equation '); % input the title of the graph
```

The result is presented in the figure 5

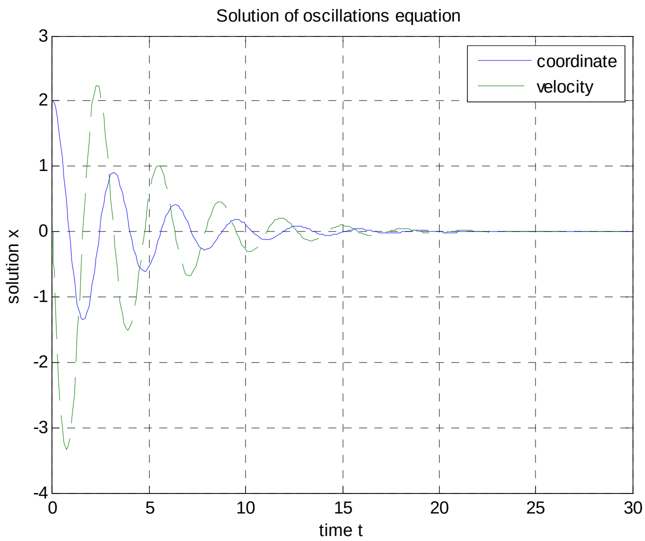

Figure 5 – The dependence of the velocity and coordinate of the harmonic oscillator upon the time at $b = 0.5$

The forced oscillations of a harmonic oscillator occur under the action of a driving force *F(t)*. Let the driving force be a periodical one obeying the law

$$F(t) = F_0 \cos(\omega t)$$

where F_0 = const is the amplitude of the driving force, ω is the cyclic frequency.

$$\frac{d^2x}{dt^2} = -\beta\frac{dx}{dt} - \omega^2 x + \frac{F_0}{m}\cos(\omega_d t)$$

where $\beta = \frac{c}{m}$, $\omega^2 = \frac{k}{m}$ is the square of the natural frequency of the harmonic oscillator, ω_d is the cyclic frequency of the driving force and $f = \frac{F_0}{m}$. Let us write the initial differential equation of the second order in the form of two differential equations of the first order:

$$\frac{d\upsilon_x}{dt} = -\beta\upsilon_x - \omega^2 x + \frac{F_0}{m}\cos(\omega_d t); \quad \upsilon_x = \frac{dx}{dt}$$

Introducing the denotations y1 = x, y2 = dx/dt we rewrite the above given two differential equations of the first order as the followings

$$\frac{dy_1}{dt} = y_2, \quad \frac{dy_2}{dt} = -\omega^2 y_1 - \beta y_2 + f\cdot\cos(\omega_d t)$$

Then create the m-file function oscilb describing the right sides of this system of equations.

The listing of m-file of the function oscilb

```
function dydt=oscilb(t,y)
global w b wd f; % input the global variable
dydt=[y(2); -w*y(1)-b*y(2)+ f *cos(wd * t)];
```

We find the solution of the system of equations using the ode45 procedure and draw the graph.

In the command line we write:

```
>> global w b wb f; % input the global variable
>> w=4; b=0.5; wd=6; f=4;
>> x=2; vx0=0;
```

```
>> [t,y]=ode45(@oscilb,[0 30],[2;0]);
>>plot(t,y(:,1),'-',t,y(:, 2),'--');
>> grid on
```

The result is presented in the figure 6

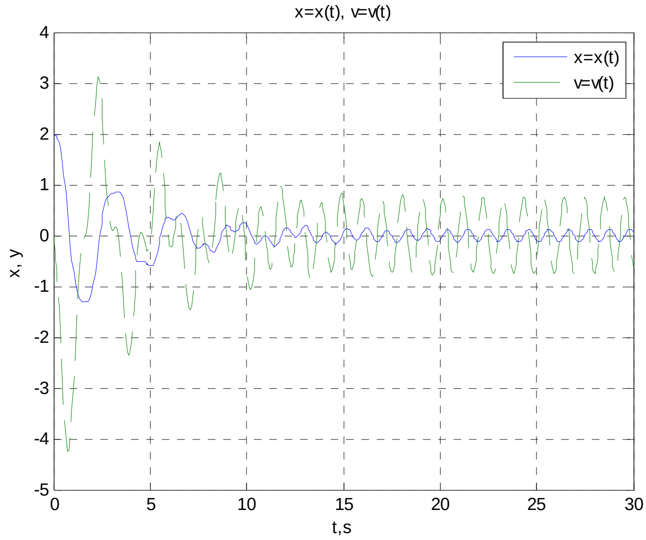

Figure 6 – The dependence of the velocity and coordinate of the harmonic oscillator upon the time at w = 4, $b = 0.5$, $w_d = 6$, f =4

```
>> plot(t,y(:,1))
>> grid on
```

The result is presented in the figure 7

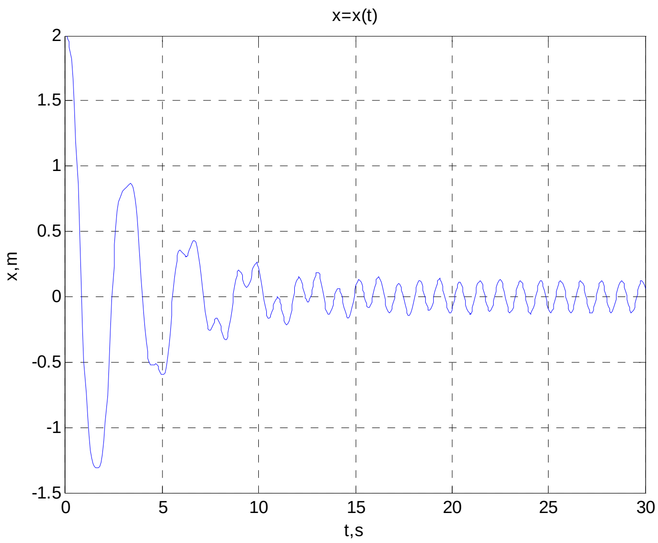

Figure 7 – The graph of the coordinate versus time during the forced oscillation at w = 4, $b = 0.5$, $w_d = 6$, f =4

```
>> plot(t,y(:,2))
>> grid on
```

The result is presented in the figure 8

The figures 4 and 5 show that the amplitudes of the coordinate and velocity of the harmonic oscillator in its damping oscillation exponentially decrease with time and asymptotically approach zero.

This is because the friction force work dissipates the energy of the oscillator.

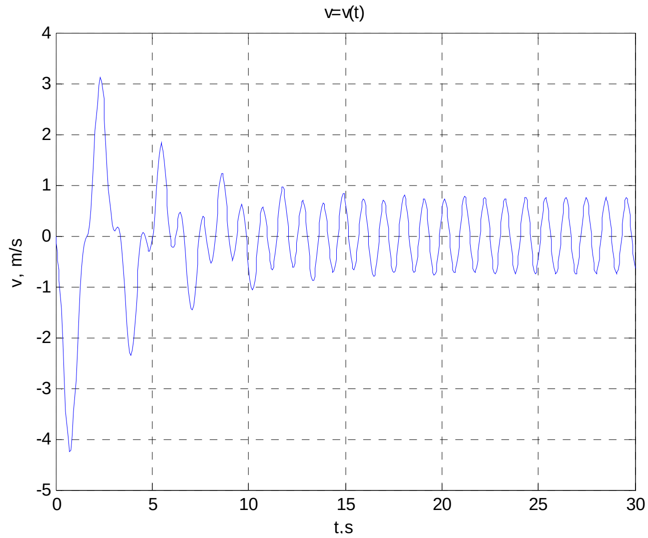

Figure 8 – The graph of the velocity of forced oscillations versus time at w = 4, *b* = 0.5, w_d = 6, f =4

The figures 7 and 8 present that at the action of a driving force the oscillation amplitude after a certain time stops decreasing and becomes constant because the oscillation occurs at the frequency of the driving force.

Conclusion. The article presents the calculation and visualization of natural, damping and forced oscillations of a harmonic oscillator. The input parameters are the natural frequency, the initial coordinates and velocities of the system, the frequency of the driving force and its amplitude. The program is worked out and calculations and visualization of the oscillating system are carried out using the MatLab language: there are the graphs of the coordinates and system velocities versus time for natural, damping and forced oscillations of the harmonic oscillator. For damping oscillations such graphs are drawn at various magnitudes of the damping coefficients. The system of differential equations is solved by using the ode45 procedure. The program allows carrying out the experiments at different values of the input parameters. There are assignments for student's self study. The results of calculation and visualization of the oscillating systems are used in the theoretical mechanics.

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ТЕРБЕЛМЕЛІ ЖҮЙЕНІ ЕСЕПТЕУ ЖӘНЕ БЕЙНЕЛЕУ

Аннотация. Гармоникалық осцилляторның еркін, өшпелі және мәжбүр тербелістерін есептеу мен бейнелеу ұсынылады. Осциляторның параметрлері ретінде оның өзіндік жиілігі, бастапқы координаталары мен жылдамдығы, мәжбүрлеуші күштің жиілігі алынған. Тербелмелі жүйені Matlab программалық ортасында есептеу мен бейнелеу үшін программа құрылған: гармоникалық осцилляторның еркін, өшпелі және мәжбүр тербелістері есептеліп, оның координаталары мен қозғалу жылдамдамдығының уақытқа тәуелділік графиктері салынған. Өшпелі тербелі үшін өшу коэффициентінің әр түрлі мәндеріндегі графиктер салынған. Дифференциалдық теңдулер жүйесін шешу үшін ode45 процедурасы қолданылды. Программа тербедмелі жүйенің парметрлерін өзгерте отырып экспериметтер жүргізуге мүмкіндік береді.

Есептеулер мен бейнелеулер нәтижесінде өшпелі тербелістің координаталар мен жылдамдық амплитудаларының уақыт өткен сайын экспоненциалды кемитіні көрсетілген, себебі үйкеліс күшінің жұмысы есебінен осциллятордың энергиясы шашырайды. Ал, мәжбүр тербелісте белгілі бір уақыттан соң тербеліс амплитудасы тұрақталатыны көрсетілген және қалған уақыта мәжбүрлеуші жиелікте тербеледі.

Өз бетінше жұмыс атқаруға арналған тапсырмалар берілген. Ұсынылған есептеулер мен бейнелеу нәтижелері теориялық механикада қолданылады.

Түйін сөздер: гармоникалық осциллятор, еркін, өшпелі және мәжбүр тербелістер, өшу коэффициенті, өзіндік, мәжбүрлеуші жиілік, сыртқы күш.

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РАСЧЕТ И ВИЗУАЛИЗАЦИЯ КОЛЕБАТЕЛЬНЫХ СИСТЕМ

Аннотация. Предлагается расчет и визуализация свободного, затухающего и вынужденного колебаний гармонического осциллятоора. Входными параметрами являются частота собственного колебания, начальные координаты и скорости системы, частота вынуждающей силы и ее амплитуда. Составлена программа и проведены расчеты и визуализация колебательной системы в среде Matlab: построены графики зависимости координат и скорости системы от времени при свободном, затухающем и вынужденном колебаниях гармонического осциллятора. Для затухающего колебания построены такие графики для разных значений коэффициента затухания. При решении системы дифференциальных уравнений использована процедура ode45. Программа позволяет проводить эксперименты при различных значениях входных параметров. Показано, что амплитуда координаты и скорости затухающего гармонического осциллятора экспоненциально уменьшается со временем и асимптотически приближаетя к нулю. Эот связанно с рассеиванием энергии осциллятора за счет работы сил трения. При вынужденном колебании через определенное время колебание системы стабилизируется, что связано с тем что, после окончания затухания дальнейшее колебание происходит с частотой вынуждающей силы. Даны задания для самостоятельной работы. Результаты расчетов и визуализаций применяются в теоретической механике.

Ключевые слова: гармонический осциллятор, свободные, затухающие и вынужденные колебания, коэффициент затухания, собственная, частота, вынуждающая сила.

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