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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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K. A. Kabylbekov[1], Kh. K. Abdrakhmanova[1], G. Sh. Omashova[1], K.M. Lakhanova[2], Zh. A. Abekova[1]

[1]M. Auezov South Kazakhstan state University (SKSU), Shymkent, Kazakhstan,
[2]H. A. Yassavi International Kazakh-Turkish University (IKTU), Turkistan, Kazakhstan.
E-mail: kenkab@mail.ru, khadi_kab@mail.ru, gauhar_omashova@mail.ru, abekova68@mail.ru

ORGANIZATION OF COMPUTER LABORATORY WORK "CALCULATION AND VISUALIZATION OF SMALL FORCED OSCILLATIONS"

Abstract. In the article there are calculations and visualizations of forced oscillations of the system under the action of constant and variable forces: 1. $F=const=F_0$; 2. $F=at.$; 3. $F=F_0exp(-\alpha t)$; 4. $F=F_0exp(-\alpha t)cos(\beta t)$. The graphs of dependence of the above given forces on the time are drawn in one graphic window. The programs for calculation and visualization of the forced oscillations under the action of the given forces are presented. The graphs of dependence of the one-dimensional forced oscillations on the time are submitted. Formulas (1-4), describing the laws of oscillations, are difficult for understanding the features of oscillations. Their visualization makes the nature of the system oscillations more evident and clear.

For the solution of this task the MATLAB language is used. It is known that the MATLAB language has opportunities for modeling and visualization of physical processes. MATLAB allows presenting visually the complicated formulas in the form of graphs that considerably makes easier the comprehension of the nature of the process or the phenomenon.

Aim of the work: To work out the program for calculations and visualizations of forced oscillations of the system under the action of the force *F(t)* if at the initial time $t = 0$ the system is at rest in an equilibrium state ($x(t=0)=0$, $\upsilon(t=0)=0$).

The results of this study can be used on theoretical mechanics classes of the higher school.

Key words: forced oscillations, visualization, oscillation graph, amplitude.

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 [3–29]. 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 program language of the MATLAB system [30], acquaintance with its huge opportunities for modeling and visualization of physical processes. This article is devoted to organization of performance of the laboratory work "Calculation and visualization of the system undergoing one-dimensional small oscillations" using the MATLAB language.

The aim of the work is to work out the program for calculations and visualizations of forced oscillations of the system under the action of the force *F(t)* if at the initial time $t = 0$ the system is at rest in an equilibrium state ($x(t=0)=0$, $\upsilon(t=0)=0$). (The problems are taken from [31]. They were solved at practical classes on classical mechanics).

Methods. The program for calculation and visualization of forces acting on the system:

```
>> F0=1; m=0.2; w=1; % input the parameters
>> t=0:pi/10:2*pi; % input the time vector
>> subplot(2,2,1);plot(t,F0,'k-') % plotting the graph in the first sub-window
>> a=1; F=a.*t; % input the parameters
>> subplot(2,2,2);plot(t,F,'k-') % plotting the graph in the second sub-window
>> grid on% drawing the coordinate grid
>> F0=1; alfa=0.5; %
>> F=F0.*exp(-alfa.*t); %
>> subplot(2,2,3);plot(t,F,'k-') % plotting the graph in the third sub-window
>> grid on% drawing the coordinate grid
>> beta=0.2;alfa=0.5; % input the parameters
>> F=F0.*exp(-alfa.*t).*cos(beta.*t); % calculation of the acting force
>> subplot(2,2,4);plot(t,F,'k-') % plotting the graph in the fourth sub-window
>> grid on% drawing the coordinate grid
```

Results and discussion. The result is presented in the figure 1.

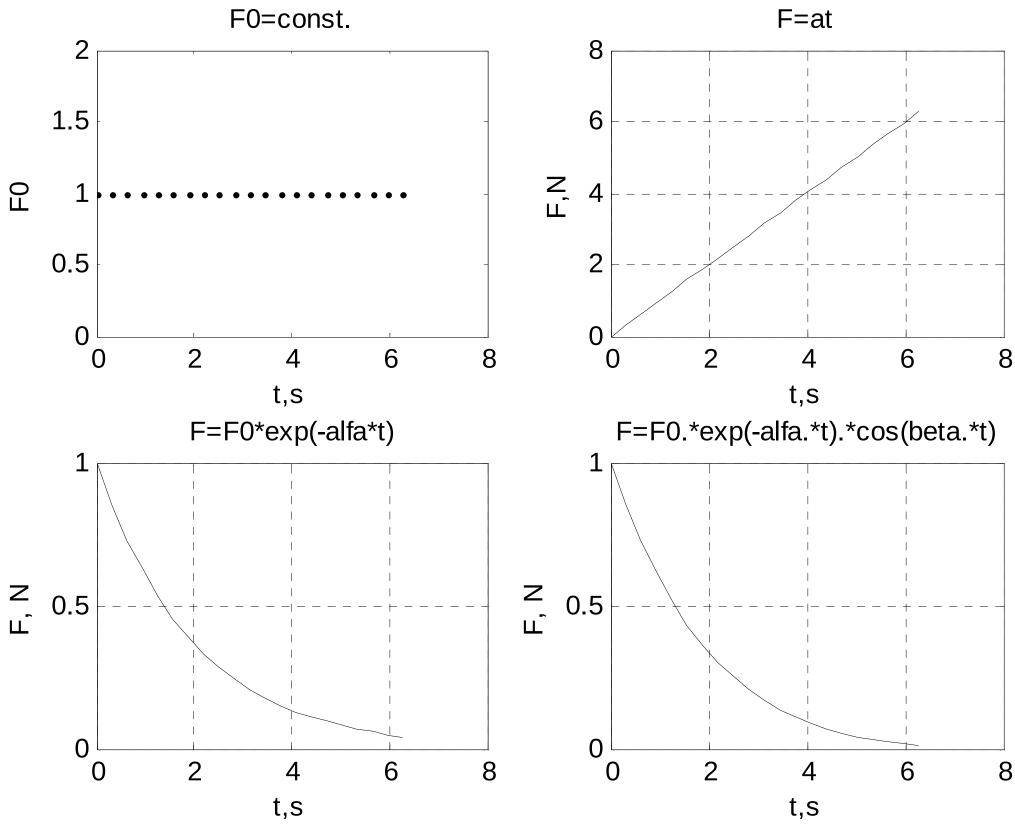

Figure 1 – The graphs of acting forces versus time in one graphic window

1. $F=const=F_0$. Under the action of a constant force the system is displaced from its equilibrium position and oscillates about this position according to the equation:

$$x=\frac{F_0}{m\omega^2}\left(1-\cos\omega t\right), \tag{1}$$

where m is the mass of the system, ω is the oscillation frequency.

The program for calculation and visualization:
>> F0=1; m=0.2; w=1; % input the parameters
>> t=0:pi/10:2*pi; % input the time vector
>> x=F0.*(1-cos(w.*t))./m*w.^2; %
>> plot(t,x) % plotting the graph
>> grid on% drawing the coordinate grid
The result is presented in the figure 2.

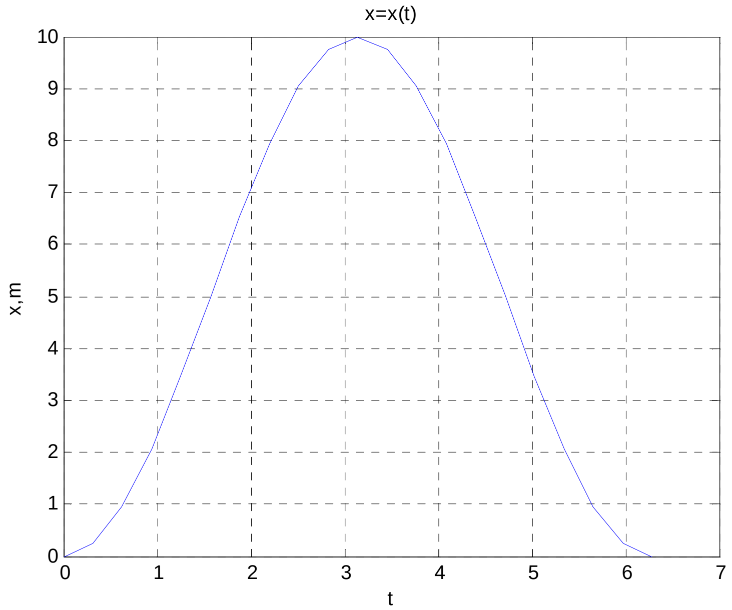

Figure 2 – The graph of displacement *x* versus time *t*

2. $F = at$, $a = 1$; The force is directly proportional to the time. Oscillation obeys the following law:

$$x = \frac{a}{m\omega^3}\left(\omega t - \sin \omega t\right) \quad (2)$$

The program for calculation and visualization:
>> a=1; % input the parameters
>> x=a.*(w*t-sin(w.*t))./m*w.^3; % calculation of the system oscillation
>> plot(t,x) % plotting the graph
>> grid on% drawing the coordinate grid
The result is presented in the figure 3.
3. $F=F_0 exp(-\alpha t)$; The force exponentially decreases with time. Oscillation obeys the following law:

$$x = \frac{F_0}{m\left(\omega^2 + \alpha^2\right)}\left(e^{-\alpha t} - \cos \omega t + \frac{\alpha}{\omega}\sin \omega t\right) \quad (3)$$

The program for calculation and visualization:
>> F0=1; alfa=0.5; % input the parameters
>> F=F0.*exp(-alfa.*t); % calculation of the acting force
>> plot(t,F) % plotting the graph
>> grid on% drawing the coordinate grid
The result is presented in the figure 4.

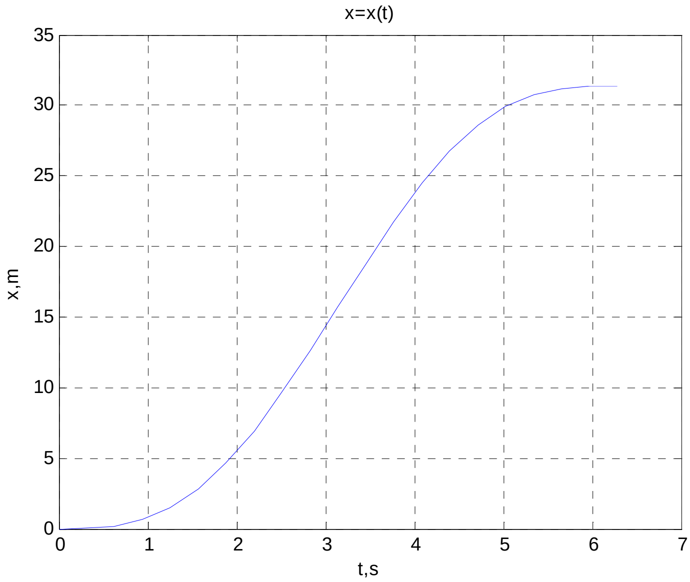

Figure 3 – Oscillation of the system under the action of the force proportional to time

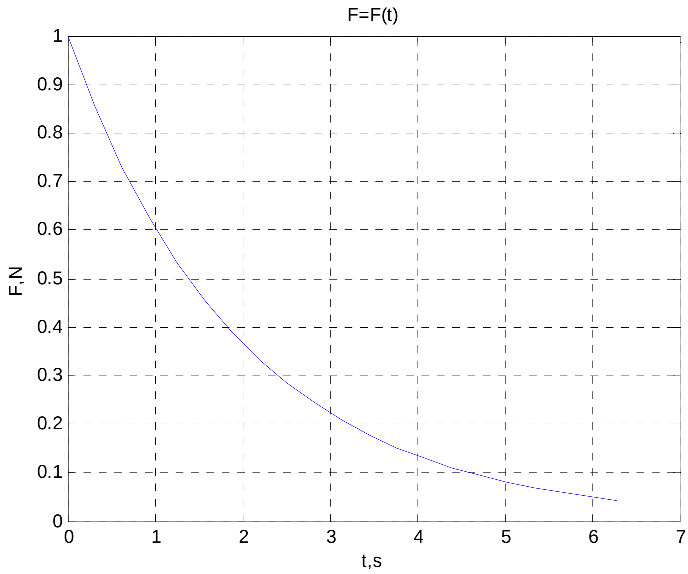

Figure 4 – The graph of the acting force versus time

```
>> A=F0/(m*w.^2+m*0.5.^2); % calculation of the first factor
>> B=exp(-0.5.*t)-cos(w.*t)+0.5*sin(w.*t)./w; % calculation of the second factor
>> x=A.*B; % calculation of the oscillation
>> plot(x,t) % plotting the graph
>> grid on% drawing the coordinate grid
```

The result is presented in the figure 5.

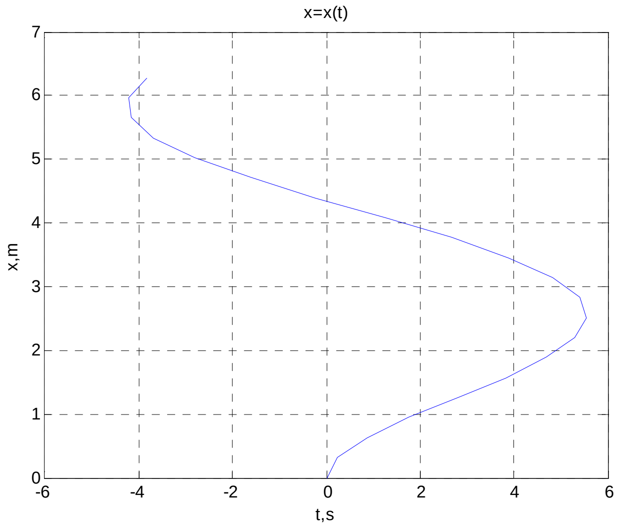

Figure 5 – Oscillation of the system under the action of the force $F=F_0 exp(-\alpha t)$

4. $F=F_0 exp(-\alpha t)cos(\beta t)$. The solution of an inhomogeneous linear differential equation describing the oscillations under the action of such driving force is very complicated to understand its nature. It is easier to realize the solution in the form of graph using the following program for calculation and visualization:

```
>> beta=0.2;alfa=0.5; % input the parameters
>> F0=1; m=0.2; w=1; % input the parameters
>> t=0:pi/10:2*pi; % input the time vector
>> F=F0.*exp(-alfa.*t).*cos(beta.*t); % calculation of the acting force
>> plot(t,F); % plotting the graph
>> grid on% drawing the coordinate grid
```

The result is presented in the figure 6.

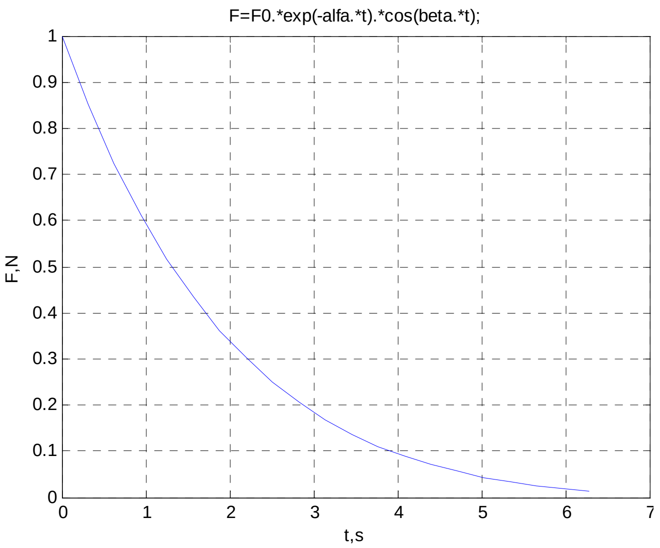

Figure 6 – The graph of the acting force versus time

Oscillation under the action of the given force obeys the following equation:

$$x = \frac{F_0}{m\left[\left(\omega^2+\alpha^2-\beta^2\right)^2+4\alpha^2\beta^2\right]}\left\{-\left(\omega^2+\alpha^2-\beta^2\right)\cos\omega t + \right. \tag{4}$$

$$\left. + \frac{\alpha}{\omega}\left(\omega^2+\alpha^2+\beta^2\right)\sin\omega t + e^{-\alpha t}\left[\left(\omega^2+\alpha^2-\beta^2\right)\cos\beta t - 2\alpha\beta\sin\beta t\right]\right\}$$

Program for calculation and visualization:

```
>> beta=0.2;alfa=0.5; % input the parameters
>> A1=F0./m*((w.^2+alfa.^2-beta.^2).^2+4*alfa.^2*beta.^2);% calculation of factor
>> B1=-(w.^2+alfa.^2-beta.^2).*cos(w.*t); % calculation of the first term
>> C=alfa.*(w.^2+alfa.^2+beta.^2).*sin(w.*t); % calculation of the second term
>> D=exp(-alfa.*t).*((w.^2+alfa.^2-beta.^2).*cos(beta.*t)-2*alfa*beta.*sin(beta.*t));% calculation
   of the third term
>> x=A1.*(B1+C+D); % calculation of the product of the factor and the sum of the terms
>> plot(x,t) % plotting the graph
>> grid on% drawing the coordinate grid
```

The result is presented in the figure 7.

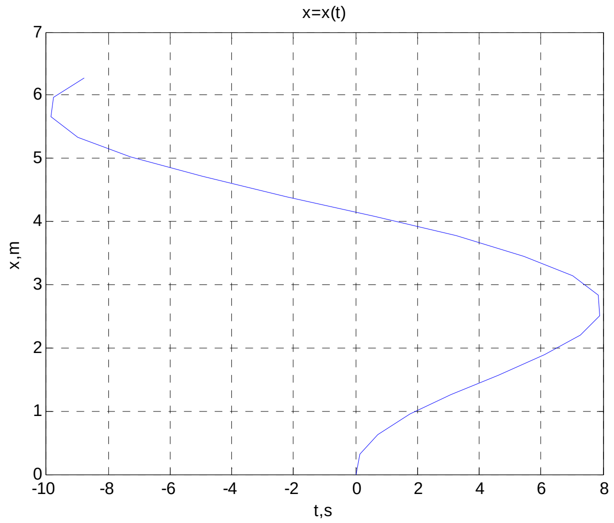

Figure 7 – Oscillation of the system under the action of the force $F=F_0exp(-\alpha t)cos(\beta t)$

The graphs of oscillations of the system under the actions of forces $F=F_0exp\ (-\alpha t)$ and $F=F_0exp(-\alpha t)cos(\beta t)$ for a longer time interval of oscillations are shown in figure 8. For comparison convenience the graphs are drawn in one graphic window. Below there is the program for calculation and visualization of oscillations in one graphic window:

```
>> t=0:pi/10:8*pi; input the time vector
>> A=F0/(m*w.^2+m*0.5.^2); % calculation of the first term
>> B=exp(-0.5.*t)-cos(w.*t)+0.5*sin(w.*t)./w; % calculation of the second term
>> x=A.*B; % calculation of the oscillation
>> subplot(2,2,1);plot(t,x);
>> grid on
>> beta=0.2;alfa=0.5; % input the parameters
>> A1=F0./m*((w.^2+alfa.^2-beta.^2).^2+4*alfa.^2*beta.^2);% calculation of the factor
>> B1=-(w.^2+alfa.^2-beta.^2).*cos(w.*t); % calculation of the first term
>> C=alfa.*(w.^2+alfa.^2+beta.^2).*sin(w.*t); % calculation of the second term
>> D=exp(-alfa.*t).*((w.^2+alfa.^2  beta.^2).*cos(beta.*t)2*alfa*beta.*sin(beta.*t));%calculation
   of the third term
>> x=A1.*(B1+C+D); % calculation of the oscillation
>> subplot(2,2,2);plot(t,x);
>> grid on
```

The result is presented in the figure 8.

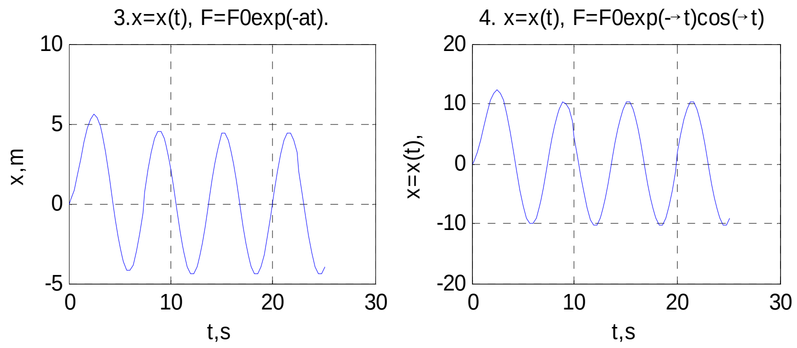

Figure 8 – The graphs of oscillations of the system under the action of forces
$F=F_0exp\ (-\alpha t)$ and $F=F_0exp(-\alpha t)cos(\beta t)$ in one graphic window

Here is the program for calculation and visualization of forces in one graphical window:

```
F0=1; alfa=0.5; % input the parameters
F=F0.*exp(-alfa.*t); % calculation of the acting force
>> plot(t,F) % plotting the graph grid on% drawing the coordinate grid
>> hold on
>> F=F0.*exp(-alfa.*t).*cos(beta.*t); % calculation of the acting force
>> plot(t,F,'-+'); % plotting the graph
```

The result is presented in the figure 9.

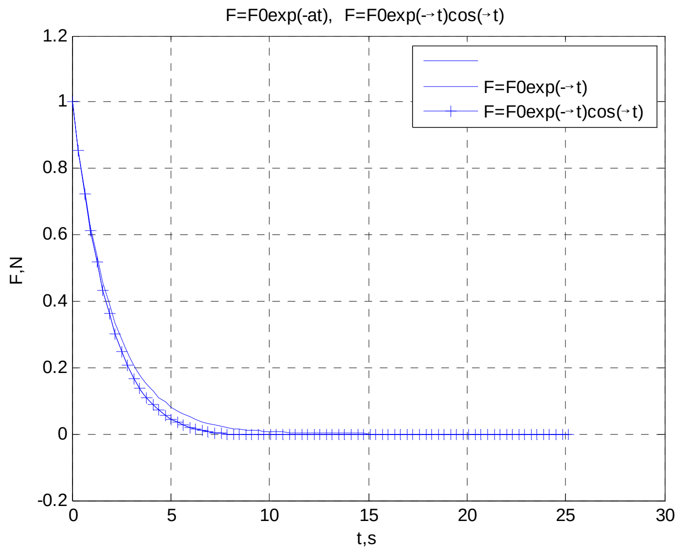

Figure 9 – The graphs of acting forces versus time

Conclusion. Formulas (1)-(4) describing the laws of oscillations are difficult for understanding the features of oscillations. Their visualization makes them more evident and clear.

Oscillations of the system under the actions of forces $F=F_0exp\ (-\alpha t)$ and $F=F_0exp(-\alpha t)cos(\beta t)$ at first sight seem to be similar (see figures 5 and 7) since the graphs of these forces as a function of time are similar (see figures 4 and 6). However, if to draw the oscillations for a longer time (Fig. 8.), then it can be noticed that as the time goes on the oscillations begin to differ markedly from each other: under the action of the force $F=F_0exp(-\alpha t)$ the oscillation amplitude decreases considerably during the first 12 seconds, and further it decreases not so much; under the action of the force $F=F_0exp(-\alpha t)cos(\beta t)$ the oscillation amplitude during the first 5 seconds increases and further practically doesn't change., i.e. the oscillation stabilizes.

So, the use of the MATLAB language for calculation and visualization of small forced oscillations shows that it is an effective tool for studying the complicated oscillations.

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К. А. Қабылбеков[1], Х. К. Абдрахманова[1], Г. Ш. Омашова[1], К. М. Лаханова[2], Ж. А. Абекова[1]

[1]М. Әуезов атындаңы Оңтүстік Қазақстан мемлекеттік университеті. Шымкент, Казахстан,
[2]Х. А. Яссауи атындағы қазақ-түрік халықаралық университиті. Түркістан, Казахстан

«АУЫТҚУЫ АЗ МӘЖБҮР ТЕРБЕЛІСТЕРДІ ЕСЕПТЕУ МЕН БЕЙНЕЛЕУГЕ» АРНАЛҒАН КОМПЬЮТЕРЛІК ЗЕРТХАНАЛЫҚ ЖҰМЫСТЫ ОРЫНДАУДЫ ҰЙЫМДАСТЫРУ

Аннотация. Тербеліс жүйесіне тұрақты және айнымалы күштер әсерінен туындаған мәжбүр тербелістерді есептеу мен бейнелеу программалары ұсынылады: 1. $F=const=F_0$. 2. $F=at$. 3. $F=F_0exp(-\alpha t)$. 4. $F=F_0exp(-\alpha t)cos(\beta t)$. Берілген күштердің уақытқа тәуелділік графиктері бір терезеде салынған. Аталған күштердің әсерінен тербелген жүйенің бірөдшемді мәжбүр тербелісін есептеу мен бейнелеудің MATLAB жүйесіндегі программалары келтірілген. Мәжбүр тербелістердің уақытқы тәуелділік графиктері салынған. Мәжбүр тербелістерді сипаттайтын формулалар физика тұрғысынан түсініксіздеу, ал оларды график арқылы бейнелегенде тербеліс сипаты айқындалып, физика тұрғысынан түсінуге болады.

Бұл мәселені шешу үшін MATLAB тілі қолданылады. Физикалық процесстерді модельдеу және бейнелеу барысында MATLAB тілінің орасан зор мүмкіндіктері бар екені мәлім. MATLAB күрделі формулаларды график түрінде бейнелеуге мүмкіндік береді, бұл процестің немесе құбылыстың табиғатын түсінуін айтарлықтай жеңілдетеді түседі.

Мақаланың мақсаты $F(t)$ күштің әсерінен болған мәжбүр тербелісті есептеуге және бейнелеуге арналған MATLAB тілінде бағдарлама жасау. Зерттеу шарты бойынша бастапқы уақытта t = 0 жүйенің жылдамдығы тепе-теңдік күйде нольге тең деп аламыз, яғни жуйе тыныштық күйде болады ((t = 0) = 0, $\upsilon(t = 0) = 0$).

Зерттеу нәтижелері жоғары оқу орындарындағы теориялық механика дәрістерінде қолдануға болады.

Түйін сөздер: мәжбүр тербеліс, бейнелеу, тербелу уақыты, амплитуда.

К. А. Кабылбеков[1], Х. К. Абдрахманова[1], Г. Ш. Омашева[1], К. М. Лаханова[2], Ж. А. Абекова[1]

[1]Южно-Казахстанский государственный университет им. М. Ауезова (ЮКГУ), Шымкент, Казахстан,
[2]Международный Казахско-Турецкий университет им. Х. А. Яссави (МКТУ), Туркестан, Казахстан

ОРГАНИЗАЦИЯ КОМПЬЮТЕРНОЙ ЛАБОРАТОРНОЙ РАБОТЫ «ВЫЧИСЛЕНИЕ И ВИЗУАЛИЗАЦИЯ МАЛЫХ ВЫНУЖДЕННЫХ КОЛЕБАНИЙ»

Аннотация. В статье рассматриваются вычисления и визуализации вынужденных колебаний системы под действием постоянных и переменных сил: 1. $F=const=F_0$; 2. $F=at.$; 3. $F=F_0exp(-\alpha t)$; 4. $F=F_0exp(-\alpha t)cos(\beta t)$. Графики зависимости вышеупомянутых сил от времени представлены в одном графическом окне. Приведены программы для вычисления и визуализации вынужденных колебаний под действием данных сил. Представлены графики зависимости одномерных вынужденных колебаний от времени. Формулы (1-4), описывающие законы колебаний, являются трудными для понимания особенностей колебаний. Их визуализация делает природу колебаний системы более очевидной и ясной.

Для решения данной задачи использован язык MATLAB. Известно, что язык MATLAB обладает огромными возможностями для моделирования и визуализации физических процессов. MATLAB позволяет наглядно представить сложные формулы в виде графиков, что значительно облегчает понимание природы процесса или явления.

Цель данной статьи разработать программу на языке MATLAB для вычислений и визуализаций вынужденных колебаний системы под действием силы $F(t)$ если в начальный момент времени $t = 0$ система находится в покое в равновесном состоянии ($x(t=0)=0$, $\upsilon(t=0)=0$).

Результаты исследования могут быть использованы на занятиях по теоретической механике в высших учебных заведениях.

Ключевые слова: вынужденные колебания, визуализация, график колебания, амплитуда.

Сведения об авторах:
Кабылбеков К.А. – к.ф-м.н., доцент кафедры «Физика» ЮКГУ им.М.Ауезова
Абдрахманова Х.К. – к.х.н., доцент кафедры «Физика» ЮКГУ им. М. Ауезова
Омашева Г.Ш. – к.ф-м.н., доцент кафедры «Физика» ЮКГУ им. М. Ауезова
Лаханова К.М. – докт. с.-х. наук, профессор кафедры морфологии МКТУ им. Х. А. Ясави.
Абекова Ж.А. – к.ф-м.н., доцент кафедры «Физика» ЮКГУ им. М. Ауезова

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