

Methods of using mobile Internet devices in the formation of the general scientific component of bachelor in electromechanics competency in modeling of technical objects

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Abstract. An analysis of the experience of professional training bachelors of electromechanics in Ukraine and abroad made it possible to determine that one of the leading trends in its modernization is the synergistic integration of various engineering branches (mechanical, electrical, electronic engineering and automation) in mechatronics for the purpose of design, manufacture, operation and maintenance electromechanical equipment. Teaching mechatronics provides for the meaningful integration of various disciplines of professional and practical training bachelors of electromechanics based on the concept of modeling and technological integration of various organizational forms and teaching methods based on the concept of mobility. Within this approach, the leading learning tools of bachelors of electromechanics are mobile Internet devices (MID) – a multimedia mobile devices that provide wireless access to information and communication Internet services for collecting, organizing, storing, processing, transmitting, presenting all kinds of messages and data. The authors reveals the main possibilities of using MID in learning to ensure equal access to education, personalized learning, instant feedback and evaluating learning outcomes, mobile learning, productive use of time spent in classrooms, creating mobile learning communities, support situated learning, development of continuous seamless learning, ensuring the gap between formal and informal learning, minimize educational disruption in conflict and disaster areas, assist learners with disabilities, improve the quality of the communication and the management of institution, and maximize the cost-efficiency.

Bachelor of electromechanics competency in modeling of technical objects is a personal and vocational ability, which includes a system of knowledge, skills, experience in learning and research activities on modeling mechatronic systems and a positive value attitude towards it; bachelor of electromechanics should be ready and able to use methods and software/hardware modeling tools for processes analyzes, systems synthesis, evaluating their reliability and effectiveness for solving practical problems in professional field.

The competency structure of the bachelor of electromechanics in the modeling of technical objects is reflected in three groups of competencies: general scientific, general professional and specialized professional. The implementation of the technique of using MID in learning bachelors of electromechanics in modeling of technical objects is the appropriate methodic of using, the component of which is partial methods for using MID in the formation of the general scientific component of the bachelor of electromechanics competency in modeling of technical objects, are disclosed by example academic disciplines “Higher mathematics”, “Computers and programming”, “Engineering mechanics”, “Electrical machines”.

The leading tools of formation of the general scientific component of bachelor in electromechanics competency in modeling of technical objects are augmented reality mobile tools (to visualize the objects’ structure and modeling results), mobile computer mathematical systems (universal tools used at all stages of modeling learning), cloud based spreadsheets (as modeling tools) and text editors (to make the program description of model), mobile computer-aided design systems (to create and view the physical properties of models of technical objects) and mobile communication tools (to organize a joint activity in modeling).

Keywords: mobile Internet devices, bachelor of electromechanics competency in modeling of technical objects, a technique of using mobile Internet devices in learning bachelors of electromechanics.

1 Introduction

In previous work [13] it has been established that despite the fact that mobile Internet devices (MID) are actively used by electrical engineers, the methods of using them in the process of bachelor in electromechanics training [4] is considered only in some domestic scientific studies. The article [13] highlights the components of the methods of using MID in the formation of the ICT component of the competence of the bachelor in electromechanics in modeling of technical objects [7; 8], providing for students to acquire basic knowledge in the field of Computer Science and modern ICT and skills to use programming systems, math packages, subroutine libraries, and the like. For processing tabular data, it was proposed to use various freely distributed tools that do not significantly differ in functionality, such as Google Sheets, Microsoft Excel, for processing text data – QuickEdit Text Editor, Google Docs, Microsoft Word. For 3D-modeling and viewing the design and technological documentation, the proposed comprehensive use of Autodesk tools in the training process.

According to the model of the use of mobile Internet devices in the formation of the competence of the bachelor in electromechanics in the modeling of technical objects [6], it is need to develop the methods of using mobile Internet devices in the formation of the general scientific component of the competence of the bachelor in electromechanics in the modeling of technical objects.

To achieve this goal, the following *tasks* must be solved:

1. Identify the leading mobile software tools for the development of competence in applied mathematics and illustrate their use in the academic disciplines “Higher Mathematics” and “Computing Engineering and Programming”.
2. Identify the leading mobile software tools for the development of competences in fundamental sciences and illustrate their use in academic disciplines “Higher Mathematics”, “Theoretical Mechanics and Electrical Machines”.

2 Results of the research

2.1 Use of mobile Internet devices in the formation of competence in applied mathematics

The formation of such a general scientific component of the competence of the bachelor in electromechanics in the modeling of technical objects, as the competence in applied mathematics, involves understanding students of the basic facts, concepts, principles of applied mathematics; mastering the methods of system analysis, construction and research of models of applied problems using the modern ICT tools, establishing their adequacy to real processes and phenomena; knowledge of numerical methods and algorithms for their implementation; determination of the correctness of the applied mathematics methods, the conditionality of the problems and the stability of the algorithms to the errors of the input data; selection and rational use of ready-made software (including computer mathematics systems) for computational experiments to verify hypothetical statements, etc.

Formation of competence in applied mathematics occurs primarily in the study of such disciplines as “Higher Mathematics” and “Computer Science and Programming”. Thus, among the content modules of the “Higher Mathematics” one of the most important for the formation of competence in applied mathematics is module 1 “Elements of linear algebra”, which, in particular, considers the concepts of matrix, matrix types, actions on matrices and their properties, the notion and solution of a system of linear algebraic equations by the Gaussian and the matrix methods.

In order to establish the interdisciplinary connections of the “Higher Mathematics” and “Computer Science and Programming”, it is expedient to consider similar models that are investigated by various means. Thus, before implementing the polynomial model of the approximation of the function of one variable by means of Visual Basic for Application in the third content module of the “Computer Engineering and Programming” it is expedient to consider it in practical lesson on the academic discipline “Higher Mathematics” in the matrix form, which students mastered in module 1 “Elements of linear algebra”.

Output data for constructing a model is a value from the table of the form:

x_{exp}	y_{exp}
x_1	y_1
x_2	y_2
...	...
x_i	y_i
...	...
x_n	y_n

The polynomial expression should be written in the form

$$y = a_p x^p + a_{p-1} x^{p-1} + \dots + a_2 x^2 + a_1 x + a_0$$

Here n – is the number of pairs of values of the form $(x; y)$ in the table, and p – is the order of the polynomial ($p \ll n$).

After substituting each value from a table into a polynomial, we obtain a system of n linear algebraic equations with $p+1$ unknown:

$$\begin{cases} y_1 = a_p x_1^p + a_{p-1} x_1^{p-1} + \dots + a_2 x_1^2 + a_1 x_1 + a_0 \\ y_2 = a_p x_2^p + a_{p-1} x_2^{p-1} + \dots + a_2 x_2^2 + a_1 x_2 + a_0 \\ \dots \\ y_i = a_p x_i^p + a_{p-1} x_i^{p-1} + \dots + a_2 x_i^2 + a_1 x_i + a_0 \\ \dots \\ y_n = a_p x_n^p + a_{p-1} x_n^{p-1} + \dots + a_2 x_n^2 + a_1 x_n + a_0 \end{cases}$$

The main matrices that characterize the system are:

\mathbf{A} – is a matrix column of unknown coefficients of the polynomial:

$$\mathbf{A} = \begin{bmatrix} a_p \\ a_{p-1} \\ \dots \\ a_2 \\ a_1 \\ a_0 \end{bmatrix}$$

\mathbf{X} – the main matrix of the system:

$$\mathbf{X} = \begin{bmatrix} x_1^p & x_1^{p-1} & \dots & x_1^2 & x_1 & 1 \\ x_2^p & x_2^{p-1} & \dots & x_2^2 & x_2 & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ x_i^p & x_i^{p-1} & \dots & x_i^2 & x_i & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ x_n^p & x_n^{p-1} & \dots & x_n^2 & x_n & 1 \end{bmatrix}$$

\mathbf{Y} – is a matrix column of values:

$$\mathbf{Y} = \begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_i \\ \dots \\ y_n \end{bmatrix}$$

A shortened system can be written as a matrix equation:

$$\mathbf{Y} = \mathbf{X}\mathbf{A}$$

The direct solution of such system by methods considered in the first module is impossible due to the fact that the number of equations is greater than the number of unknowns. The same can be said about solving the matrix equation: finding a matrix inverse to the matrix \mathbf{X} , is impossible because matrix \mathbf{X} is not square. To get out of this dead end, we suggest students apply the property of a transposed matrix, namely: the product of a transposed matrix on the output is a square matrix, so we apply this property to both parts of the matrix equation:

$$\mathbf{X}^T\mathbf{Y} = \mathbf{X}^T\mathbf{X}\mathbf{A}$$

The resulting equation contains a new matrix – \mathbf{X}^T , which is a transposed matrix \mathbf{X} . Using the associativity properties of multiplication of matrices, we obtain the following equivalent equation:

$$(\mathbf{X}^T\mathbf{X})\mathbf{A} = \mathbf{X}^T\mathbf{Y}$$

It corresponds to the normal system of linear algebraic equations, for solving which one can use any of the mastered methods – Cramer’s rule, Gaussian elimination or matrix inversion. To use the latter, we make a left multiplication of both parts of the matrix equation on the matrix inversed to the product $\mathbf{X}^T\mathbf{X}$:

$$(\mathbf{X}^T\mathbf{X})^{-1}(\mathbf{X}^T\mathbf{X})\mathbf{A} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{Y}$$

Get the next equivalent equation:

$$\mathbf{I}\mathbf{A} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{Y},$$

where \mathbf{I} – is an identity matrix of dimension $(p+1, p+1)$:

$$\mathbf{A} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{Y}$$

To find the solution, we first suggest using the traditional methods of “manual” solution in order to make sure that the time spent on such work is incommensurate with the time spent on the mathematical description of the model. It pushes for the use of ICT. For matrix models we are propose an electronic spreadsheets. Google Sheets provides to students and teachers the opportunity to put together experimental data and corresponding formulas.

To do this, make a spreadsheet accessible to all students in the academic group and invite each of them to fill in a line corresponding to the student number in the group's journal with a pair "weight – height".

To select a polynomial order, we visualize the entered values and suggest justification of the choice. As a result of the discussion, we agree with the assumption that the line to be held at the smallest distance from all points can be a parabola, so our model will have the quadratic form $y = a_2x^2 + a_1x + a_0$. Accordingly, it is necessary to construct the matrix X from the elements of the column x_{exp} in the second, first and zero degrees, and the matrix Y – from the elements of the column y_{exp} . The X^T matrix is constructed using the transpose function, giving it the parameter range of the values of the matrix X (E3:G32), and the products of $X^T X$ and $X^T Y$ – by calling `mmult(M3:AP5;E3:G32)` and `mmult(M3:AP5;I3:I32)` respectively. We find the inverse to the $X^T X$ matrix with a `minverse(M8:O10)` call and make the left multiplication of it to the $X^T Y$ matrix by calling `mmult(M13:O15;Q8:Q10)`. As a result we obtain A , the matrix of polynomial coefficients (fig. 1).



Fig. 1. Mobile Internet device while working with the model on higher mathematics classes

In fig. 1 shows an updated graph of the ratio of weight and height of students, where the approximated growth values were added to the experimental points, calculated using the formula $y_{calc} = -0,0148x^2 + 2,3669x + 87,4835$. The simulation results make it possible to draw an important conclusion that this model can be simplified to linear without losing adequacy. Since the factor of the second power x does not make a significant contribution to the calculated value of growth; therefore, the ratio of weight and height of students can be described not parabolic, but linear dependence. Such task can be offered for self-study.

The considered algorithm of approximation can be illustrated also on the material of other modules. As shown in [12], the course of higher mathematics in technical universities traditionally ends with the Fourier transform and Fourier series as its partial

case. Considering the high practical significance of this topic for the further professional activity of future engineers-electromechanics, when studying the module 16 “Trigonometric series and their applications”, it is expedient for students to propose solution of the approximation problem by a fragment of a trigonometric series of sequence of points corresponding to the financial series. As a data source, we use the Google Finance online service, which provides the ability to export data to Google Sheets using the function =googlefinance("currency:usduah"; "close"; date(2013;1;9); date(2018;9;9)), the first parameter of which is the currency pair, “US dollar – Ukrainian hryvnia”, the second is the closing price of exchange rates of given currency pair, the third is start date and fourth is end date of the time interval l .

The mathematical model of the renewal dependence is a cosine decomposition of an unknown function $f(x)$ on an interval $[0; l)$:

$$f(x) = \sum_{n=0}^N a_n \cos \frac{\pi n x}{l},$$

where n – is the harmonic number, $N+1$ – is the number of harmonics, a_n – is the Fourier coefficients.

We put the measurement vector (value of the price) in the column matrix \mathbf{Y} of the $l \times 1$ dimension. Due to find the column matrix \mathbf{A} of the Fourier coefficients of by dimension $(N+1) \times 1$ we perform calculation $\mathbf{A} = (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \mathbf{Y}$, where \mathbf{X} – is the matrix of the plan of the dimension $l \times (N+1)$, containing the cosine Fourier coefficients: $\mathbf{X}_{xn} = \cos \frac{\pi n x}{l}$. As the value of the independent variable, apply the measurement number $x = 0 \dots l-1$, and the harmonic number $n = 0 \dots N$.

The call of the googlefinance function in cell A1 will provide two columns of values, the first of which will contain a date, and the second is the price. To determine the value of l we use the function of counting the number of column elements: count(A:A). We assign the number of harmonics manually: $N = 30$. To the first cell of the plan matrix \mathbf{X} (N2) we enter the cos(pi()*N\$1*\$G2/\$E\$1) formula, which will be copied to all other cells of the \mathbf{X} . The matrix column \mathbf{A} are described by the formula – mmult(mmult(minverse(mmult(transpose(N2:AR1693);N2:AR1693));transpose(N2:AR1693));H2:H1693). To calculate the predicted values y_{calc} we use the scalar product of the line matrix to the column matrix \mathbf{A} : mmult(\$N2:\$AR2;\$S\$1696:\$S\$1726) to the J2 cell and distribute it to the entire range.

To analyze the results we draw plots of currency values y obtained from Google Finance and approximated data y_{calc} (fig. 2). The function plot indicates that 30 harmonics in the general case is quite a satisfactory amount for the function estimation, but such amount is not enough to simulation of fast processes with a large amplitude of fluctuations. An example of such phenomena in the electromechanics are the modes of starting the engine, sharp loading of the load and short circuit.

Discussion of this model in several classes provides an opportunity to evaluate its adequacy by forecasting future values of the currency pairs. So, it is advisable to compare the currency values for the dates that were not used when constructing the plan matrix, with the predicted values. To do this, we propose calculating at least three future values of the currency and compare them with the real ones. In fig. 3, the last three

values (1692-1694) were not used in constructing the plan matrix, but they reflect the tendency of the currency change.

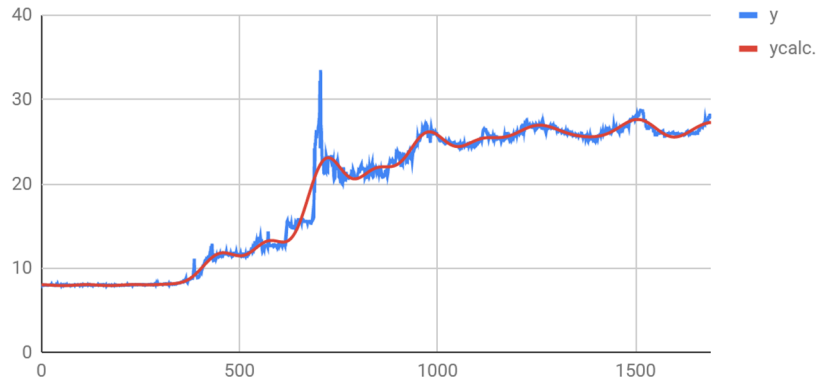


Fig. 2. Dynamics of currency pair “US dollar – Ukrainian hryvnia” and its approximation by Fourier series

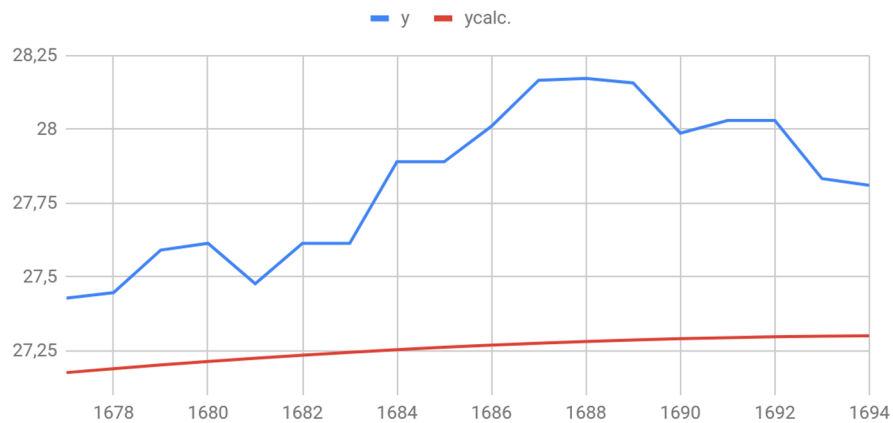


Fig. 3. Forecast of dynamics of currency pair “US dollar – Ukrainian hryvnia” for the period from September 10 till September 12, 2018

In studying the module 7 “Differential calculation of the function of several variables” it is expedient to consider the problem of finding the extremum of a convex function by a gradient descent method. To do this, you can return to the ratio of the two measured values x and y , considered in the first module of the model, but write down its solution using partial derivatives.

The function of communication of these values (hypothesis) is written in the form $h(x) = \theta_0 + \theta_1 x$, or

$$h(x) = \vec{\theta}^T \vec{x} = [\theta_0 \quad \theta_1] \begin{bmatrix} 1 \\ x \end{bmatrix},$$

where $\vec{\theta} = \begin{bmatrix} \theta_0 \\ \theta_1 \end{bmatrix}$ – column matrix (vector-column) of unknown coefficients $\vec{\theta}$, and $\vec{x} = \begin{bmatrix} 1 \\ x \end{bmatrix}$ – non-transposed element of the plan matrix.

Let us construct a function of value, which depends on the parameters of the hypothesis:

$$J(\theta_0, \theta_1) = \frac{1}{2m} \sum_{i=1}^m (h(x_i) - y_i)^2.$$

The function plot has a single extremum (fig. 4). The gradient descent method is based on the fact that starting from a certain initial value of the vector $\vec{\theta}_0$, we will take steps on the surface of the paraboloid in the direction of minimizing the function value, that is, the direction opposite to the gradient vector of the function: $\nabla J(\theta_0, \theta_1) = \left(\frac{\partial J}{\partial \theta_0}, \frac{\partial J}{\partial \theta_1} \right)$.

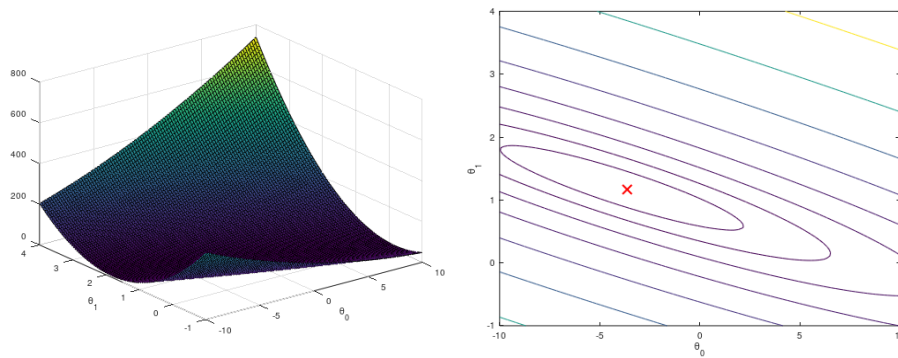


Fig. 4. Function plot (left) and its contour plot (right); the cross indicates the global minimum

The partial derivatives of the function with the respect to the θ_0 and θ_1 are equal:

$$\frac{\partial J}{\partial \theta_0} = \frac{1}{m} \sum_{i=1}^m (h(x_i) - y_i),$$

$$\frac{\partial J}{\partial \theta_1} = \frac{1}{m} \sum_{i=1}^m (h(x_i) - y_i)x_i,$$

The algorithm of the gradient descent method will look:

$$\vec{\theta}_{\text{next}} = \vec{\theta}_{\text{prev}} - \alpha \nabla J(\theta_0, \theta_1),$$

where α – descent speed.

The software implementation of this numerical method can be performed in mobile versions of Scilab [5], MATLAB or Octave. Thus, the function of the value of J can be realized through the scalar product of the defined vectors:

```
function J = computeCostMulti(X, y, theta)
    m = length(y);
    J=1/(2*m)*(X*theta-y)'*(X*theta-y);
end
```

The number of iterations `num_iters` an additional parameter used when implementing the method:

```
function [theta] = gradientDescentMulti(X, y, theta, alpha,
num_iters)
    m = length(y);

    for iter = 1:num_iters
        temp=theta;
        n=size(X,2);
        s=zeros(n,1);
        for j=1:n
            for i =1:m
                s(j,1)=s(j,1)+(X(i,:) *theta-y(i))*X(i,j);
            end;
        end;

        temp=theta-alpha*(1/m)*s;
        theta=temp;
    end
end
```

As a result, we obtain the vector of the parameters $\vec{\theta}$, and can visualize the results of the simulation (fig. 5).

In the content module 9 “Definite and improper integrals” the competence in applied mathematics can be developed on example of the problem of building plot of electrical load. The corresponding code with teacher’s explanations can be offer in SageCell:

```
#Output data
data=[[1,6],[2,7],[3,7.5],[4,7.5],[5,7.5],[6,8],[7,8],[8,10],[9,
13],[10,15],[11,13.5],[12,13.5],[13,11],[14,12],[15,14],[16,11],
[17,10],[18,12],[19,14],[20,14],[21,15],[22,13],[23,12],[24,7]]
p=point((0,0))
S=vector([0,0,0]) # sums by the method of left and right
rectangles, and the trapezoid method
for i in range(len(data)-1):
    p += line([data[i], data[i+1]], color='red')
```

```

p += polygon([data[i], [data[i+1][0], data[i][1]],
[data[i+1][0], 0], [data[i][0], 0], data[i]], color='lightblue')
dt = data[i+1][0]-data[i][0] # integration step
S += vector([data[i][1]*dt, data[i+1][1]*dt,
(1/2)*(data[i][1]+data[i+1][1])*dt])
show(p, figsize=[4,5])
html("Daily electricity consumption calculated:<br><ul><li> left
rectangular method - %s,</li>"
"<li>right rectangular method - %s,</li>"
"<li>trapezoidal rule - %s</li></ul>"%(S[0],S[1],S[2]))

```

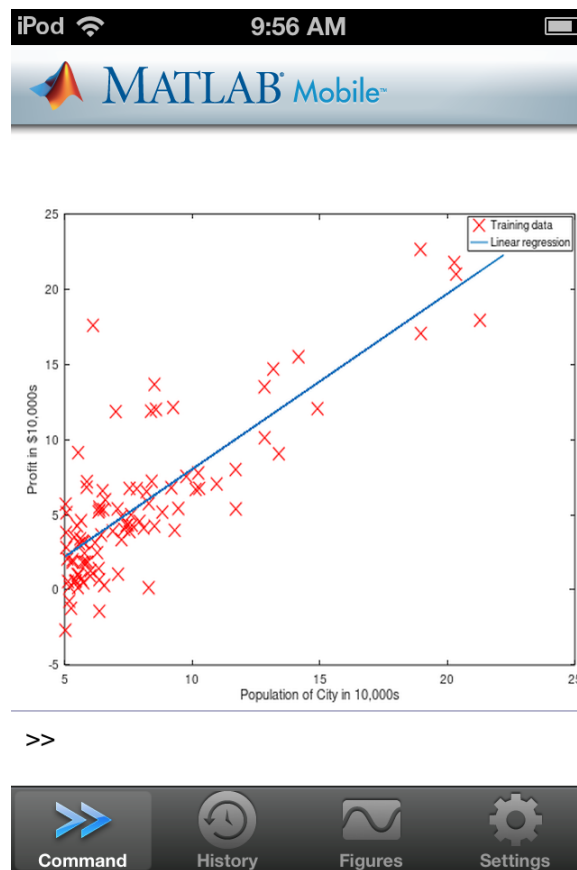


Fig. 5. Visualization of cloud points and regression lines in MATLAB Mobile

To enable students to conduct their own experiments, the teacher can generate a SageCell QR code (fig. 6a), which is processed by a mobile Internet device (fig. 6b).

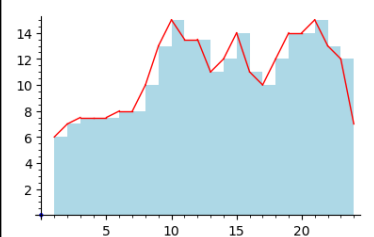
Type some Sage code below and press Evaluate.

```

1 data=[[1,6],[2,7],[3,7.5],[4,7.5],[5,7.5],[6,8],[7,8],[8,10],[9,13],[10,15],[11,13.5],[12,13.5],[13,11],[14,12]]
2 p=point((0,0))
3 S=vector([0,0,0]) # sums by the method of left and right rectangles, and the trapezoidal method
4 for i in range(len(data)-1):
5     p += line([data[i], data[i+1]], color='red')
6     p += polygon([data[i], [data[i+1][0], data[i+1][1]], [data[i+1][0], 0], [data[i][0], 0], data[i]], color='lightblue')
7     dt = data[i+1][0]-data[i][0] # integration step
8     S += vector([data[i][1]*dt, data[i+1][1]*dt, (1/2)*(data[i][1]+data[i+1][1])*dt])
9 show(p, figsize=[4,5])
10 html("Daily electricity consumption calculated:<br><ul><li> left rectangular method - %s,</li></ul>")
11      "<li>right rectangular method - %s,</li>" "<li>trapezoidal rule - %s</li></ul>"%(S[0],S[1],S[2]))
12

```

Evaluate Language: Sage




Daily electricity consumption calculated:

- left rectangular method - 254.5000000000000,
- right rectangular method - 255.5000000000000,
- trapezoidal rule - 255.0000000000000

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a)

17:15 78%

Type some Sage code below and press Evaluate.

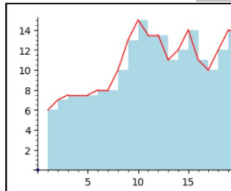
```

1 data=[[1,6],[2,7],[3,7.5],[4,7.5],[5,7.5],[6,8],[7,8],[8,10],[9,13],[10,15],[11,13.5],[12,13.5],[13,11],[14,12]]
2 p=point((0,0))
3 S=vector([0,0,0]) # sums by the method of left and right rectangles, and the trapezoidal method
4 for i in range(len(data)-1):
5     p += line([data[i], data[i+1]], color='red')
6     p += polygon([data[i], [data[i+1][0], data[i+1][1]], [data[i+1][0], 0], [data[i][0], 0], data[i]], color='lightblue')
7     dt = data[i+1][0]-data[i][0] # integration step
8     S += vector([data[i][1]*dt, data[i+1][1]*dt, (1/2)*(data[i][1]+data[i+1][1])*dt])
9 show(p, figsize=[4,5])
10 html("Daily electricity consumption calculated:<br><ul><li> left rectangular method - %s,</li></ul>")
11      "<li>right rectangular method - %s,</li>" "<li>trapezoidal rule - %s</li></ul>"%(S[0],S[1],S[2]))
12

```

Evaluate Language: Sage

Share



Daily electricity consumption calculated:

- left rectangular method - 254.5000000000000,
- right rectangular method - 255.5000000000000,
- trapezoidal rule - 255.0000000000000

Help | Powered by SageMath

b)

Fig. 6. The use of SageCell on the teacher (a) and student (b) devices in the process of learning numerical integration of table-set values

In content module 14 “Linear differential equations of higher orders with constant coefficients” we can illustrate the use of another mobile mathematical system – SMath Studio [9], which allows both analytic and numerical solution of differential equations (fig. 7).

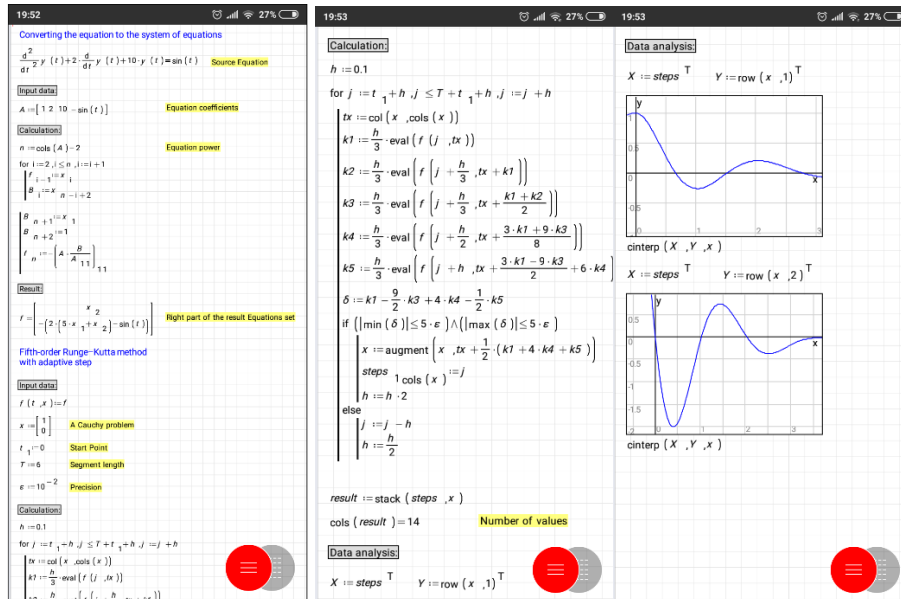


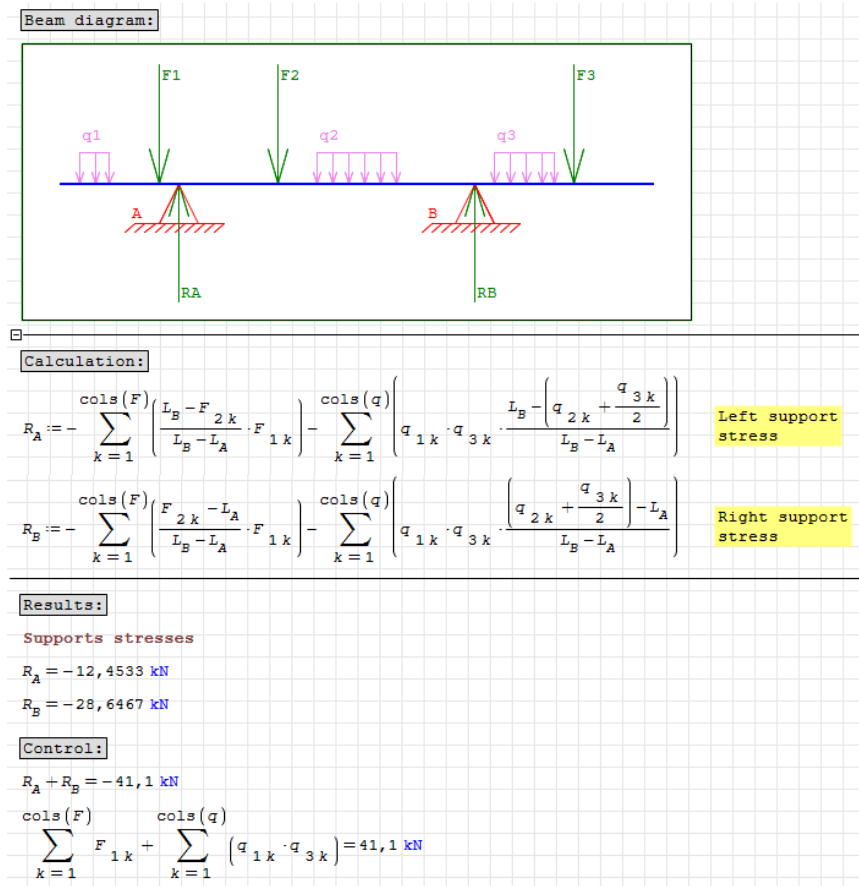
Fig. 7. Using SMath Studio to analyze dynamic systems

2.2 The use of mobile Internet devices in the formation of competence in the fundamental sciences

The formation of a general scientific component of the competence of the bachelor in electromechanics in the modeling of technical objects, such as competencies in fundamental sciences, provides for the acquisition of basic knowledge of the fundamental branches of the natural sciences and mathematics to the extent necessary to obtain the mathematical methods of the electromechanical branch of knowledge; ability to use mathematical methods and methods of natural sciences in research and applied professional activities.

In addition to the content of the “Higher Mathematics”, for the formation of competence in the fundamental sciences, it is necessary to implement the substantive component of the disciplines “Theoretical Mechanics” and “Electrical Machines”.

The purpose of studying the “Theoretical Mechanics” is the getting of knowledge and the acquisition of skills necessary to study the general laws of mechanical movement, the interaction of material bodies based on the laws of classical mechanics, the acquisition of skills to perform calculations for strength, rigidity of structural



c) simulation results

Fig. 8. The model for calculating beams on two supports in SMath Studio

To solve the problem of analysis of kinematic schemes of machines, we use the augmented reality (AR) solutions for intuitive analysis and material design [10].

Dieter Weidlich, Sandra Scherer and Markus Wabner in [11] describe the experience of improving the process of developing machine parts using the virtual and augmented reality systems of Chemnitz Technical University, which developed new methods visualization to study the result of modeling by the finite elements method. The main purpose of software development was the visualization of the direction and stress gradient by 3D glyphs. The finite element method is a numerical method of engineering analysis, used for many types of tasks, such as determining loads and shifts in mechanical objects, or heat transfer and flow dynamics.

Calculating mechanical stresses is fundamental to the analysis of strength behavior in mechanical engineering. Glyphs are a way of graphically coding numeric information. A glyph is a graphic unit that can communicate various data attributes by its appearance (shape, color, orientation, position, and so on). A special characteristic

of glyphs, as compared to simpler concepts, is the number of data attributes that can be communicated. Glyphs are primarily used for representing multidimensional data. Glyph-based methods represent a multitude of tensor values by reflecting tensor eigenvectors and values in terms of shape, size, orientation, and surface characteristics of geometrical primitives such as cubes and ellipses (fig. 9).

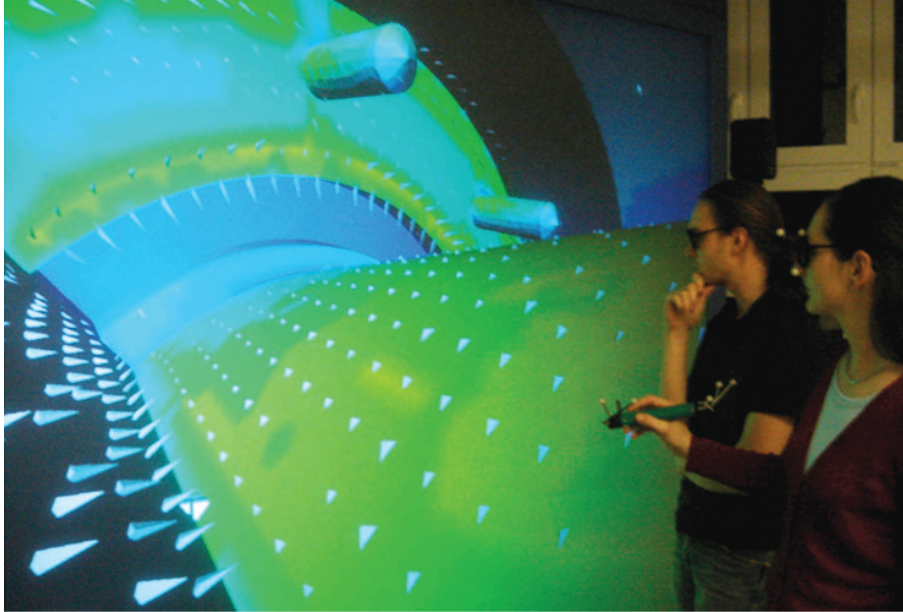


Fig. 9. Visualization of the results of the finite element analysis: the outward glyph vertices reflect tensile loads, and the inward glyphs represent the compression load

Various geometric primitives such as cuboids, tetraeders, spheres, and lines can be used to represent multidimensional data. However, this requires a preliminary study into which shape of glyph is suitable for the data to be represented. Tests have shown that the tetraeder is well-suited for visualizing stress direction and gradient because the tip of the tetraeder indicates an exact direction. In addition to stress direction, the 3D glyphs can also reveal whether the stress is tensile or compressive.

The software developed by the authors of [11] allows switching between the results of structural and thermal analysis and comparing them with a real physical object. In fig. 10 shows the imposition of a finite element model on a real system: the more “hot” the color is, the greater the load. A black and white marker in the user’s hand is necessary for positioning the analysis results.

Michele Fiorentino, Giuseppe Monno and Antonio E. Uva in article [3] identify 6 main ways of using augmented reality in engineering, for each of which are defined aspects like hardware configuration, add-on method, TUI/GUI interactivity level (TUI – Tangible User Interface, material user interface; GUI – Graphical User Interface,

graphical user interface), viewpoint, physical collaboration support and remote collaboration.

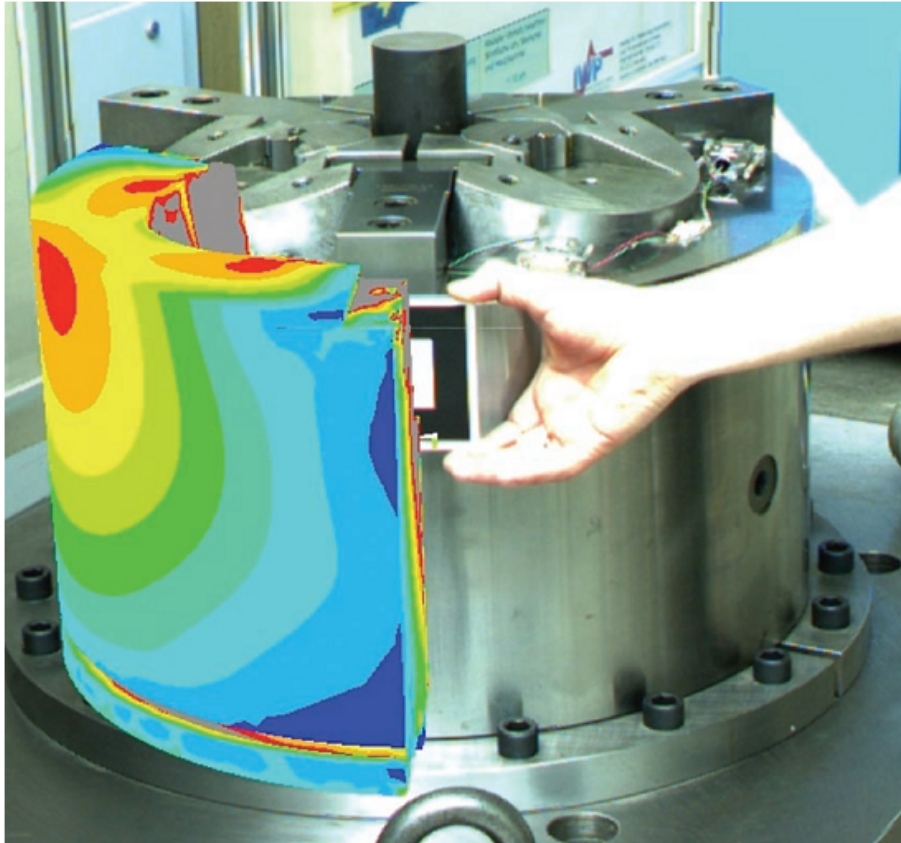


Fig. 10. Display of simulation results on a real object

1. Augmented user

The user wears see-through AR glasses connected to a wearable PC. See-through displays allow the user to be aware of the real industrial environment. This configuration allows maximum mobility for the user letting him work in a large workspace with free hands. The interaction is achieved mostly by TUI with none or limited GUI. Suggested applications for this setup are: inspection, training, etc. Disadvantages may include the display resolution, the limited field of view and the optical tracking robustness in hostile manufacturing environments. In another setup the user holds a handheld (flashlight-like) camera and a wearable PC connected to the network. The user is free to move in the industrial environment and to teleconference with other users remotely logged. The difference compared to previous setup is the viewpoint mobility. The user can move the camera in the industrial environment,

reaching potentially every location under wireless coverage. Local tracking is provided by markers and broadcasted to the system. This scenario is particularly important in maintenance, where remote experts can guide and assist the user. The user loads his customized visualization of the model and broadcasts it remotely. The main advantage of this configuration is the maximum mobility for point of view. This may also lead to an unsteady point of view due to the fact that the user must hold the camera. TUI and GUI interaction is also rather limited.

2. Mobile window

The user holds a tablet PC with a camera on the back side. Tablet displays allow the user to be fully aware of the real industrial environment. This configuration allows a good mobility for the user letting him work in a large workspace but it requires that at least one hand holds the tablet. The interaction is achieved mostly by GUI with the tablet pen. Suggested applications for this setup are: design review, inspection, etc. Disadvantages may include the weight of the tablet and the single-handed interaction limitation.

3. Augmented desktop

The user works on a desktop workstation with a camera pointing on a free area on the desk, which will be the augmented workspace. The AR workspace is limited to the user's desktop and the model interaction is achieved by moving the TUI (augmented technical drawings) and by the traditional desktop GUI with a mouse and a keyboard. In normal use, the TUI is just a support to the ordinary GUI. For this reason, this scenario is suggested for all tasks which involve an heavy use of keyboard entry of numerical or text data: e.g. detailed design, engineering, numerical analysis, etc. The main advantage of this setup is the similarity with the traditional working environment, allowing an easy access even for a non technical user. Users, in fact, find much easier and intuitive the navigation of 3D models using a tangible metaphor. A limiting factor is that it must be implemented in an office-like environment.

4. Augmented workshop

This scenario is similar to the augmented desktop as regards the hardware setup, but it is designed for a production stage environment instead of a clean office desk. The user is on a workbench on the production line where no keyboard or mouse is present. The user can interact by touch screen on industrial monitor and by tangible augmented drawings. An industrial buttonbox can also be used. The main advantages are: both hands free for the user, possibility to display high resolution rendering of the 3D model, comfortable working environment, similar to a non augmented one. Ideal applications may be quality check or guided assembly.

5. Augmented collaborative table

This scenario supports collaborative workspace at best. It consists of a meeting table with the function of shared augmented area and of a large screen. The screen can be vertical or horizontal and eventually have stereographic or holographic display. All

users can access to the augmented shared area with their tokens and they can annotate the model using their own PC laptop for precise GUI input. Remotely located users can join the group and participate with virtual meeting tools. The system will take care of the synchronization of the digital master data including annotations, chat and history. The main applications of this scenario are marketing and design review: the shared workspace can contain virtual CAD models, real pre-production mock ups, on-line technical content and simulation results for collaborative discussion. The main advantages of this scenario are the high collaboration support, the coexistence of real and virtual products and the social contact of real meetings.

6. Augmented presentation

This scenario considers a speaker who wants to present a solution to a large audience. A large screen is the main visualization device. The data management is achieved mainly by TUI in form of digital drawing or mock-up placed on the speaker's stand. The audience can access to the same digital data with personal visualization devices and can add annotations, which are updated in real time for all the members of the discussion.

The characteristics of each method proposed by the authors of [3] are summarized in Table 1.

Table 1. The main ways of using augmented reality in engineering

Scenario	Viewpoint	TUI level	GUI level	Collaboration level	Remote coworking
Augmented user	mobile	high	high	low	medium
Mobile window	mobile	low	high	medium	medium
Augmented desktop	fixed	medium	high	low	high
Augmented workshop	fixed	medium	low	low	low
Augmented collaboration table	fixed	high	medium	high	medium
Augmented presentation	fixed	high	low	medium	medium

The purpose of learning the “Electrical Machines” is the formation of students' theoretical knowledge of the design, principle of operation, the field of use electrical machines and transformers, as well as the acquisition of practical skills related to connecting, operating and determining the parameters of electric machines and micromachines. As a result, a student should be able to draw up electrical circuits and calculate the parameters of the circuit elements, to turn on electrical machines and micromachines, provide experiments to determine the parameters of electrical machines, and perform calculations of the structural elements during the design and repair of electrical machines.

In the process of acquiring theoretical knowledge of the design of electric machines, it is advisable to use mobile augmented reality tools developed by SIKE Software. Training simulator system with augmented reality technology makes it possible to form a complex of knowledge about the structure of electric motors of various types and acquire skills in identifying the component parts of electric motors and the safe, correct and fast order of assembly and disassembly of electric motors (fig. 11). The system can be applied in practical training, laboratory and independent work, examinations, etc.,

and in the process of industrial training – for theoretical interactive training of workers involved in the installation and dismantling of industrial electrical equipment. The program provides access to 3D models with a high degree of accuracy, repeating the structure of real equipment.



Fig. 11. Training system-simulator SIKE Software

Each detail of the design has name, description, and the order of technological operations corresponds to the actual process and is developed in conjunction with the experts of leading industrial enterprises.

This system uses the QR code as a marker on a special card. Another approach is to use a universal marker (fig. 12) or a scene marker containing a real object (fig. 13).



Fig. 12. The model of the Rossi motor reductor in the Augment system is tied to a universal marker

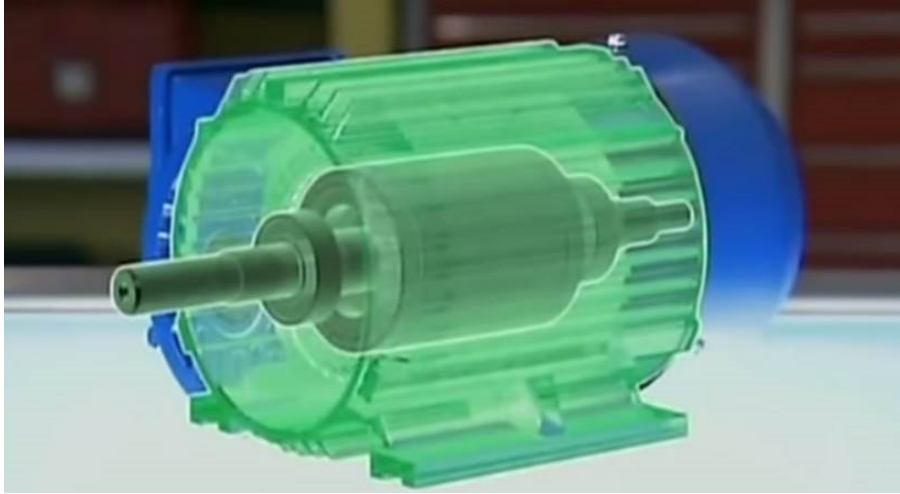


Fig. 13. The asynchronous motor model, which tied to the scene containing the real object in the HP Reveal system

When performing the calculation of a three-phase asynchronous motor after repair and restoration works (module 7 “Three-phase asynchronous machines”) it is advisable to use SMath Studio. Fig. 14 shows the beginning of the calculation of the natural electromechanical and mechanical characteristics of the engine, and fig. 15 shows the calculated mechanical characteristics diagram.

17:20

Calculation and construction of natural electromechanical and mechanical characteristics of the engine with consistent field winding

Engine data: $U_{1H} := 380$ $P_H := 11000$ $n_H := 953$ $E_{2H} := 220$ $E_{2H} := 200$ $I_{2H} := 35,4$

$x_1 := 0,465$ $R_1 := 0,415$ $x_2 := 0,27$ $U_{1\phi H} := 220$ $R_2 := 0,132$ $\frac{M_\kappa}{M_H} := 0,3$ $f_{1H} := 50$ $p := 3$

Calculation:

Calculation of the mechanical characteristics of the asynchronous engine will lead to Closer's refined formula:

$$M := \frac{2 \cdot M_\kappa (1 + a \cdot S_\kappa)}{\frac{S_\kappa}{S} + \frac{S_\kappa}{S} + 2 \cdot a \cdot S_\kappa}$$

where M_κ - critical moment; S_κ - critical slip; $a := \frac{R_1}{R_2}$

Resistance coefficient:

Fig. 14. Setting model parameters and starting the calculation

Models for all content modules of the “Electric Machines” course include Scilab on cloud (<https://cloud.scilab.in/>). To select a model, you must select the main category Electrical Engineering / Electronics & Telecommunication Engineering / Instrumentation & Control Engineering, subcategory Electrical Devices / Machines and

the corresponding course manual (for example book [2] and its corresponding manual [1]). An example of calculating the synchronous speed of a polyphase asynchronous machine in Scilab on cloud:

```
// Example 1.60
clc;clear;close;
// Given data
PA=4;//no. of poles
PB=4;//no. of poles
f=50;//in Hz
V=440;//in volt
//calculations
//Independently with A
Ns=120*f/PA;//in rpm
disp(Ns,"Independently with A, Synchronous speed Ns in rpm is :
");
//Independently with B
Ns=120*f/PB;//in rpm
disp(Ns,"Independently with B, Synchronous speed Ns in rpm is :
");
//Running as cumulative cascaded
Ns=120*f/(PA+PB);//in rpm
disp(Ns,"Running as cumulative cascaded, Synchronous speed Ns in
rpm is : ");
```

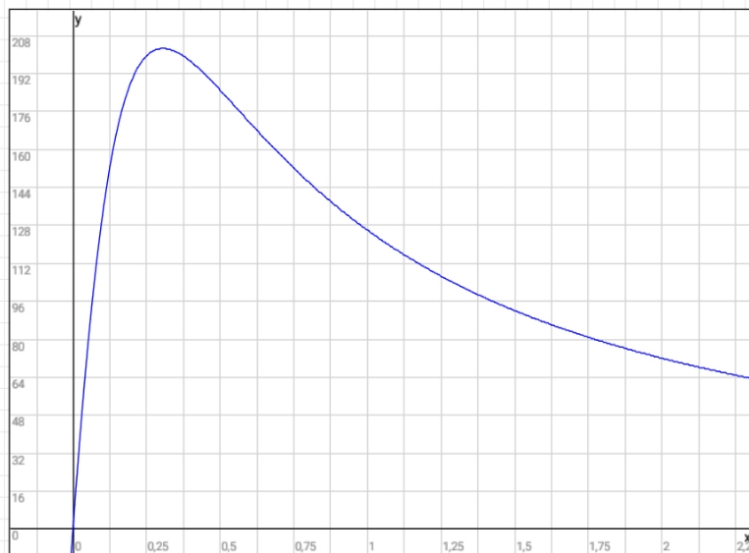


Fig. 15. Diagram of the mechanical characteristics of the engine

The result of calculation according to example 1.60:

Independently with A, Synchronous speed N_s in rpm is : 1500.

Independently with B, Synchronous speed N_s in rpm is : 1500.

Running as cumulative cascaded, Synchronous speed N_s in rpm is : 750.

3 Conclusions

Thus, in the process of forming the general scientific component of the competence of the bachelor in electromechanics in the simulation of technical objects, it is expedient to use the following software of mobile Internet devices:

- mobile augmented reality tools used to visualize the structure of objects and simulation results;
- mobile computer mathematical systems with object (SMath Studio) and character input type (Scilab, Octave, MATLAB, SageCell), which is used at all stages of modeling;
- cloud-oriented tabular processors as modeling tools;
- mobile communication tools for organizing joint modeling activities.

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