Visualization and analysis of gear drives parameters with the help of computer-aided mathematics systems

Svetlin Stoyanov
University of Ruse "Angel Kanchev", 8 Studentska str., POB 7017, Ruse, Bulgaria
SStoyanov@Uni-Ruse.BG

Abstract: *The visualisation capabilities of the main software systems for computer-aided mathematics are reviewed. The advantages of the software system Matlab are described. The system is appropriate when visualization and analysis of engineering data are required. The author sets out to highlight the three-dimensional graphics and optimization synthesis of gear drives.*
Keywords*: THREE-DIMENSIONAL GRAPHICS, COMPUTER-AIDED MATHEMATICS, SOFTWARE SYSTEMS, MATLAB, GEAR DRIVES, LOAD CAPACITY, EFFICIENCY COEFFICIENT, MAXIMAL TORQUE*

1. Overview of the visualization capabilities of the leading systems for computer-aided mathematics

The contemporary growth of software systems provides powerful new opportunities in all areas of engineering and science. For example, in [14] is presented a study about applications of leading software systems for piezoelectric beams investigations. The development of extremely low power electronics and wireless systems has led to a strong interest in the fields of energy harvesting and development of miniature generators. Typically, these devices are used to power sensors and wireless communication systems, enabling standalone wireless sensors that are cheap to deploy. In the area of the mechanical structure vibrations investigations and the multiphysics simulations, four software systems have the lead positions. These are: ***ABAQUS***, ***COMSOL***, ***SolidWorks***, and ***MATLAB***. The software system ***MATLAB*** is a system for "*computer aided mathematics*" and "*matrix laboratory*", but in fact this software system is often used from scientist and engineers to solve mathematical models that describes problems in the area of the mechanical structure vibrations and the multiphysics simulations.

In [11, 12, 18] are presented selected investigations of structure vibrations conducted with the help of contemporary mechanical engineering software systems. Also, in [1, 11, 13, 14] are described investigations on gear transmissions performed with the finite element method in the integrated working environment of the system ***ABAQUS***.

In addition to studies described above, in this work the author set out to highlights the visualization capabilities of the leading systems for computer-aided mathematics: *MATLAB*, *Wolfram Mathematics*, and *Maple*.

1.1. Wolfram Mathematics

Wolfram Language provides powerful functions that automate the process of creating cognitively and aesthetically compelling representations of structured and unstructured data. This is valid not only for points, lines, and surfaces, but also for graphs and networks. This is available due to many original algorithms developed at ***Wolfram Research***.

On Fig. 1 and Fig. 2 are shown some examples for the visualization capabilities of ***Wolfram Mathematics*** [5, 6].

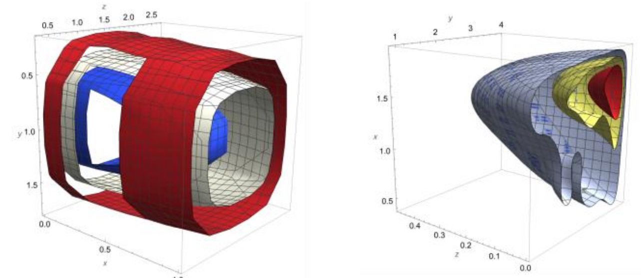

Fig. 1. *Boundaries and solutions of partial differential equations*

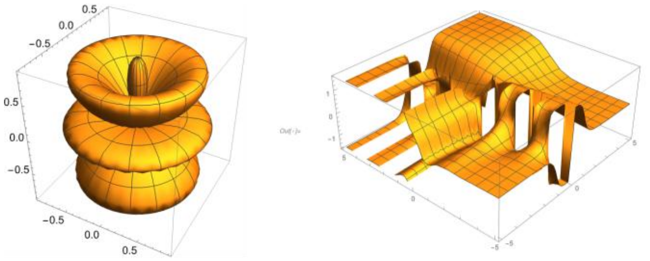

Fig. 2. *Spherical 3D graph and plot of a function with singularities*

1.2. MATLAB

The name "***MATLAB***" comers from ***MATrix LABoratory*** and has been chosen because of the powerful capabilities of this software system for working with matrices. Using this, the system ***MATLAB*** solves the problem of visualization of three-dimensional data in one. The data is plotted on a three-dimensional mesh with point size showing value of it. Edge color changes via *z* axis to distinguish coordinate of points easier. One can compare sets of data, track changes in data over time, or show data distribution. Also, the plots can be created programmatically using graphics functions or interactively using the *Plots tab* at the top of the ***MATLAB*** desktop.

Software system ***MATLAB*** incudes a tool with graphical user interface (GUI) for data interpolation – Fig. 3. This together with the discussed in the next paragraph optimization capabilities gives richest abilities to build automatized software for optimization and design of gear transmissions [2, 3, 19, 20].

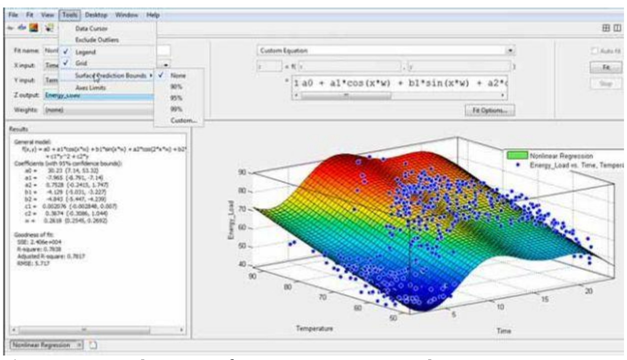

Fig. 3 *An example picture from* ***MATLAB*** *interpolation GUI*

MATLAB Optimization Toolbox provides functions for finding parameters that minimize or maximize objectives while satisfying constraints [4, 7]. The toolbox includes solvers for linear programming (LP), mixed-integer linear programming (MILP), quadratic programming (QP), second-order cone programming (SOCP), nonlinear programming (NLP), constrained linear least squares, nonlinear least squares, and nonlinear equations.

Optimization problems can be defined with functions and matrices or by specifying variable expressions that reflect the underlying mathematics. One can use automatic differentiation of objective and constraint functions for faster and more accurate solutions.

The toolbox solvers can be used to find optimal solutions to continuous and discrete problems, perform tradeoff analyses, and incorporate optimization methods into algorithms and applications. Also, ***MATLAB Optimization Toolbox*** gives abilities to perform design optimization tasks, including parameter estimation, component selection, and parameter tuning.

1.3. Maple

Maple is a software tool that combines a powerful mathematics engine with an interface that makes it easy to manage calculations. It provides an environment that can maximize the value of calculation efforts. With Maple, one can easily validate, document, retain, reuse, and modify your calculations, reducing risk while saving time and effort in both current and future projects.

As ***MATLAB*** provides simulation environment named ***SimScape***, ***Maple*** has a tool named ***MapleSim***. It gives ability to simulate the dynamics of diverse physical systems, including mechanical systems. This is illustrated on Fig. 4 as an indicator for the visualization capacities of ***Maple***.

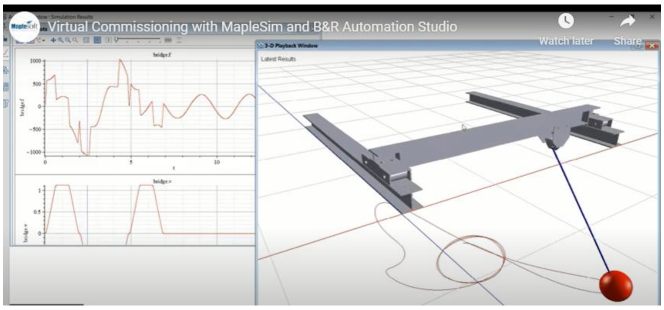

Fig. 4. *Virtual commissioning with MapleSim and B&R Automation Studio*

MapleSim has libraries with mechanical elements, for example bodies and joints. But these elements are idealized – the bodies are right and non-deformable, and the joints are without energy loses or with linear energy loses model. So, this is suitable for engineering tasks, but is insufficient for scientific investigations. In these cases, the systems ***ABAQUS*** or ***ANSYS*** are usually used [11, 15, 16, 18].

1.4. Conclusions

It can be concluded that, the software systems ***MATLAB***, ***Wolfram Mathematics***, and ***Maple*** have approximately equal three-dimensional plotting capabilities. The difference is that the system ***Wolfram Mathematics*** can be labeled as more mathematic scientists orientated, than the ***MATLAB***, which is more suitable for machine engineers and scientists. Also, while other programing languages usually work with numbers one at a time, ***MATLAB*** operates on whole matrices and arrays. Along with that ***MATLAB*** is one of the best choices when optimization needs to be done [1].

For the reasons described above, the *MATLAB* was chosen for the purposes of this investigation.

2. Description of the developed software

To interpolate and visualize the calculated in [8, 9] data, a software in the integrated working environment of the system ***MATLAB*** is developed. This gives two new abilities, as follows:

- ⇨ An ability to directly signify the relations between three parameters (or even between four parameters, if the color in set as independent indicator);
- ⇨ An ability to render relations in uninterrupted three-dimensional space (or even in four-dimensional space, if the color in set as independent indicator).

A generalized flow-chart of the developed software is presented on Fig. 5. It follows a description of each step of the flow-chart.

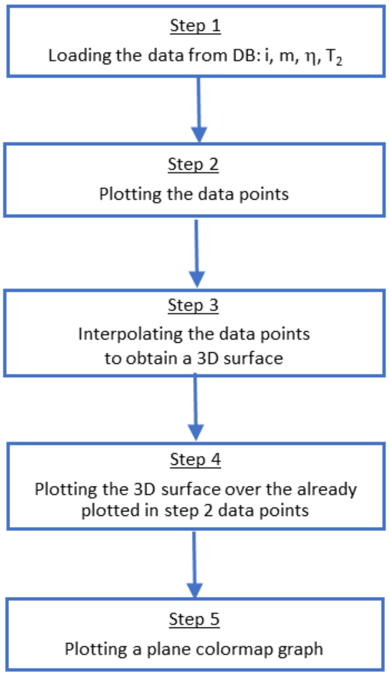

Fig. 5. *A flow-chart of the the developed software*

<u>Step 1: Loading the input data.</u> The input data is structured as a table with colons for: gears module *m*, transmission ratio *i*, coefficient of the efficiency *η*, and output torque T_2. The data can be loaded from plain text files, binary ***MATLAB*** files (*.mat) or from ***Excel*** datasheets.

<u>Step 2: Plotting the data points</u>. On this step, the software visualizes 3D coordinate system, label the axis with corresponding notations, set the axis limits and increment, and visualize appropriate grid. Then, the data points are plotted as solid red points – Fig. 6.

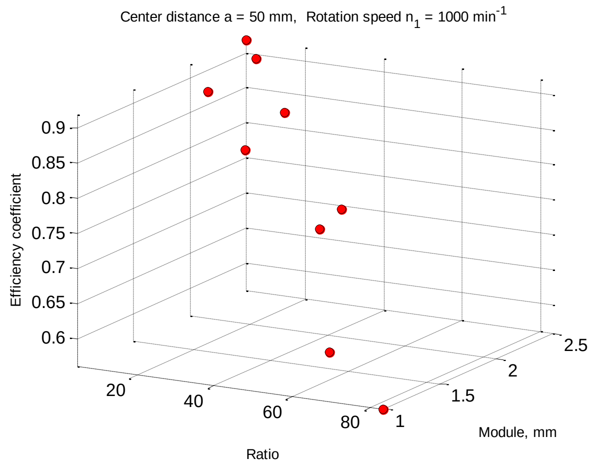

Fig. 6. *A 3D plot of the data points loaded*

<u>Step 3: Interpolate the data points</u>. The function ***interp3*** of the system ***MATLAB*** is used. The function syntactic is:

Vq = interp3(X , Y , Z, V, Xq, Yq, Zq),

where: *Vq* contains the interpolated values of a function of three variables at specific query points using linear interpolation. The results always pass through the original sampling of the function;

X, *Y*, and *Z* contains the coordinates of the sample points;

V contains the corresponding function values at each sample point;

Xq, *Yq*, and *Zq* contains the coordinates of the query points.

Step 4: Plotting the 3D surface. On this step, the surface obtained is superimposed on the data points plotted in Step 2. Also, a legend is visualized – Fig. 7.

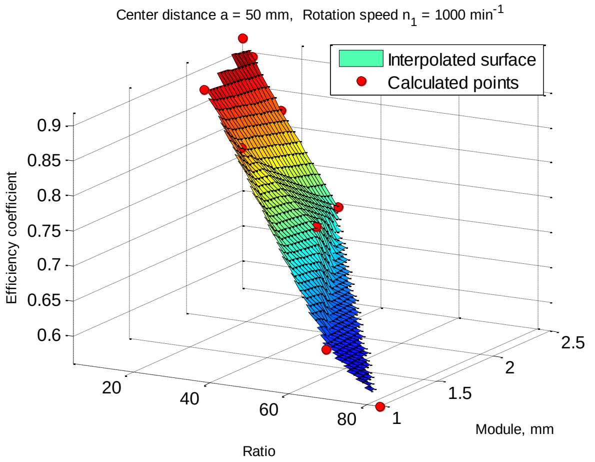

Fig. 7. Efficiency coefficient in relation from ratio and module

Step 5: Plotting a plane colormap graph. On this step, a new figure is plotted – Fig. 8. It is a plane graph – the efficiency coefficient values are indicated with a color map starting from dark blue and ending with dark red color.

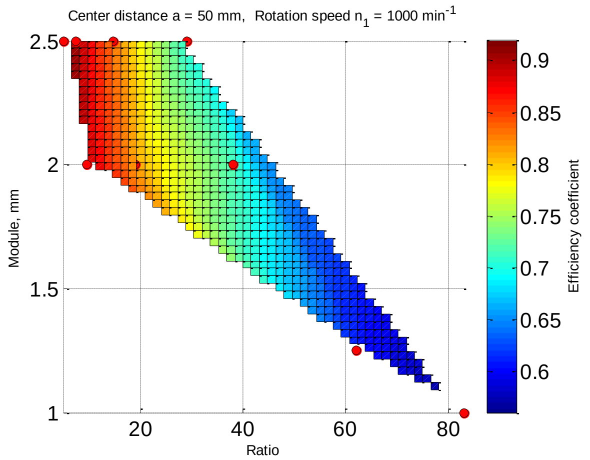

Fig. 8. Color map representation

In combination with computer-aided design software, the software developed gives an ability the investigation to be continued with development of an automatized optimization and design system. This can be done in the integrated working environment of the software systems ***MATLAB*** and ***SolidWorks***.

MATLAB also provides some frequently used minor capabilities, for example: saving the graphs created to image files, save the numerical results in plain text format or binary format files, export the results to MS Excel software, etc.

3. Results

The graphical visualizations obtained with the software created are presented and analyzed completely in [17]. In this paper, selected results are presented on the following figs. On Fig. 9 is shown a surface with a data point lower than other points in the plane interpolated surface. That is in the top left corner, i.e., in the area with higher values of the efficiency coefficient. From Fig. 9, it can be observed that the efficiency coefficient increases with the increase of the module and the decrease of the ratio.

The software system ***MATLAB*** gives the ability multiple three-dimensional surfaces to be superimposed. On Fig. 10b are presented two three-dimensional relations together for center distance a = 63 mm and rotation speed n_1 = 1500 min^{-1}. With this approach, one plot can represent the dependence of the efficiency coefficient from the ratio and module, and at the same time from the ratio and output torque. From Fig. 10, it can be observed that efficiency coefficient grows with decreasing the output torque and the ratio.

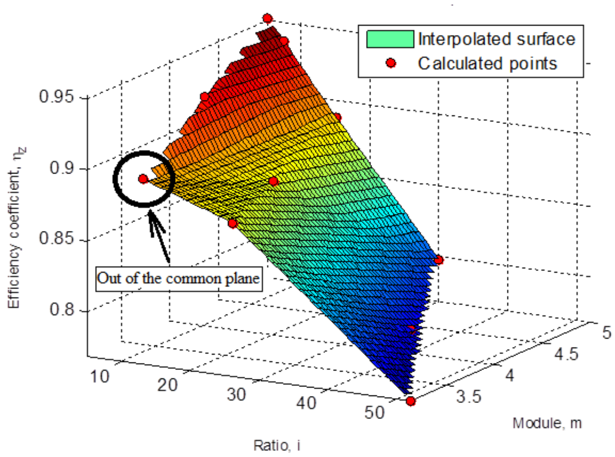

Fig. 9. *Efficiency coefficient in relation from ratio and module for center distance a = 100 mm and rotation speed n_1 = 1500 min^{-1}.*

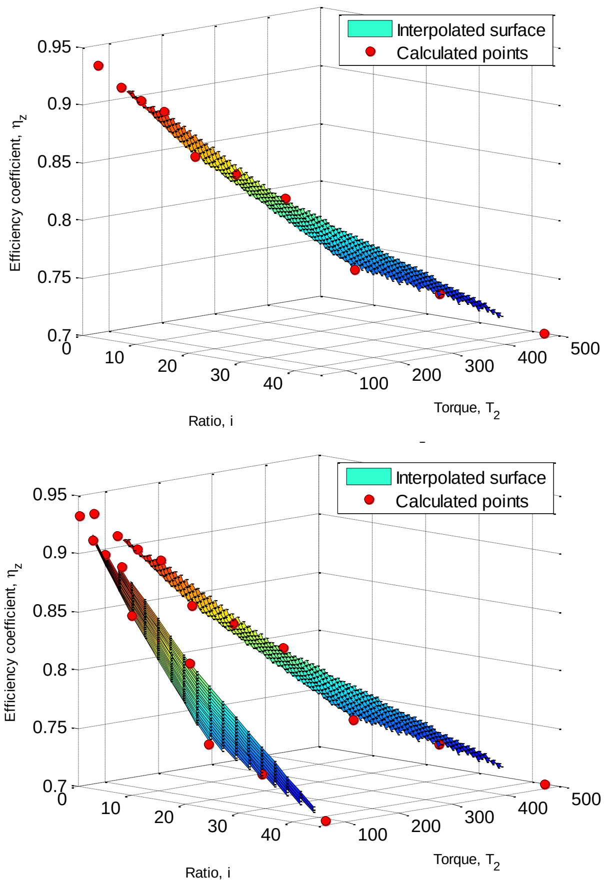

Fig. 10. *Efficiency coefficient for center distance a = 63 mm and rotation speed n_1 = 1500 min^{-1}: a – efficiency coefficient in function of ratio and torque; b – with superimposed surface of efficiency coefficient in function of ratio and module.*

4. Conclusions

The capabilities of the main software systems for computer-aided mathematics are reviewed. In this work the author set out to highlights the visualization capabilities of the leading systems for computer-aided mathematics: MATLAB, Wolfram Mathematics, and Maple.

It can be concluded that, the software systems ***MATLAB***, ***Wolfram Mathematics***, and ***Maple*** have approximately equal three-dimensional plating capabilities. The difference is that the system ***Wolfram Mathematics*** can be labeled as more mathematic scientists orientated, than the ***MATLAB***, which is more suitable for machine engineers and scientists. ***MATLAB*** is a programming and numeric computing platform used by millions of engineers and scientists to analyze data, develop algorithms, and create models. It combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly. Also, ***MATLAB*** includes the *Live Editor* for creating scripts that combine code, output, and formatted text in an executable notebook. In this work the author set out to highlights the visualization capabilities, so it is important that the ***MATLAB*** provides built-in libraries for visualizations. The built-in plots can be used to visualize engineering data, gain insights, and identify underlying patterns and trends. One can choose from the relevant plots presented, based on the selected data. This lets the optimal visualization to be done.

For the reasons described above, the ***MATLAB*** was chosen for the purposes of this study. Then, software for data interpolation and three-dimensional visualization are developed. The software is oriented to gear drives. Therefore, this investigation is continued in [17], were visualization and analysis of worm gear drives efficiency and load capacity are performed. This includes 3D graphical representation of the efficiency coefficient and maximal torque values for several combinations of modules, ratios, center distances, etc. Also, in [17] important conclusions are made, for example that the efficiency coefficient increases with the increase of the module and the decrease of the ratio.

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