Computer technologies in the education of mechanical engineers

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Abstract. The paper shows an example of using an algorithm for studying the mechanism by analytical methods in the process of teaching students the basics of the theory of mechanisms and machines. This method is also applicable for cam and gear mechanisms. The algorithm is based on an object-oriented approach and represents the mechanism as a set of objects of two types: links and kinematic pairs. The objects of the mechanism are characterized by matrices: functions of position, incidence, inertial characteristics, and active force action. The algorithm allows you to write the result of the analysis of the mechanism in a closed form and implement it in the framework of a mathematical package.

1. Introduction

Engineering education should be based not only on reference materials and instructions, but also on an understanding of the processes controlled by the engineer. To do this, an engineer, firstly, needs knowledge of mathematics and physics, and secondly, needs the ability to build models of real objects. It is a properly constructed object model that will allow you to apply modern research methods when studying a real object.

The object model must meet two basic requirements: adequacy and applicability. You can create a complex model that takes into account most of the properties of a real object, but the methods and means available to the engineer to implement these methods due to the complexity of the model equations will not allow you to get the final result.

You can use a simple model and get a result quickly enough, but this result will be significantly different from the experiment. In these two sentences, such characteristics of the model as complexity and adequacy are hidden.

The task of the research engineer, and it’s him who is more familiar with the object than the physicist and mathematician who develops research methods, is just the selection of such a pair "model-object", which will allow you to get the final result of the required accuracy with the available computing resources. The resources are computer technology, software, and professional qualifications.

Future research engineers should have a normal education of applied mathematicians and be prepared to work with mathematical packages such as MathCAD, MAPLE, FEMAP.

2. Materials and methods

2.1. Object-oriented approach to mechanism analysis

Until the end of the last century, in engineering disciplines such as theoretical mechanics, the theory of mechanisms and machines, and the resistance of materials, training was conducted on examples in
which the result can be obtained on sheets of paper. The study of more complex objects and the
solution of more complex problems, characterized by a large number of differential or algebraic
equations, is impossible without computer technology. And computer technologies require a different
approach, when operations are performed not with one object, but with an entire class of objects. An
example is the use of the finite element method in strength calculations or the analytical method in
the study of mechanisms. The present work is devoted to the analytical method of studying the
mechanisms. Let us consider the use of computer technologies on the example of the study of plane
mechanisms with holonomic stationary connections.

Analytical methods have been known since the days of D'Alembert and Lagrange, but using them
for multi-link mechanisms leads to bulky mathematical expressions that are almost impossible to work
with "manually".

We propose an object-oriented approach, when all the links and kinematic pairs of the mechanism,
as objects, are characterized by primary or passport matrices, and obtaining the final result is
analytical transformations of these matrices in accordance with the task and the rules of mechanics and
mathematics.

The practical implementation of the analytical method of research in the framework of the
academic discipline "Theory of Mechanisms and Machines" (TMM) should be "transparent" in terms
of the applied laws of mechanics and their implementation by mathematical methods. The student
must see, understand and explain at which step of the analysis algorithm a particular rule of mechanics
or mathematics is implemented. This is provided by the open source code of the programs used.

This approach to the presentation of the material teaches the student to operate not with an abstract
sequence of actions set out in the instructions and fragmentary knowledge from the reference
literature, but with a coherent concept of mechanism analysis based on the laws of mechanics
embodied in the shell of a mathematical package.

2.2. The concept of studying the mechanism by the analytical method
The mechanism is characterized by generalized geometric and physical parameters. Generalized
parameters are independent values that are sufficient to represent the mechanism under consideration
and perform its research.

The method of organizing the generalized parameters should be convenient for using the methods
of analytical mechanics and mathematics. It should be implemented in programs written for math
packages. The practical implementation of the mechanism study should be possible within the
framework of the TMM training course.

2.3. Experience of presentation of the material
The author's course in the theory of mechanisms and machines has been taught since 2001 in higher
technical educational institutions of the city of Irkutsk (IrNRTU, IrSAU, IrSTU).

The materials of the author's course are approved at different sites [3-4; 7] and are presented in two
volumes of the textbook "Analytical methods for the study of plane mechanisms", published in IrSTU
in 2014 [1; 2].

2.4. Stages of mechanism analysis
The study of the mechanism is divided into six classical stages: modeling, structural analysis,
geometric analysis, kinematic analysis, dynamic analysis, and force analysis.

2.5. Modeling the mechanism
At the modeling stage, the researcher states the fact, which bodies can be considered as a link of the
mechanism, determines the geometric and inertial characteristics of each link. Evaluates how large the
deformation of the links is during the operation of the mechanism, and whether it can be neglected
within the planned error of the study.

At this stage, the relative mobility of the connected links must be established; due to the contact of
which surfaces there are restrictions in relative motion; what kinematic pairs can idealize these
connections, and with what error.
If the object is complex, then the work of determining the geometric and inertial characteristics is also not simple. Especially when this object (for example, a human) is inseparable. A number of works [5-6; 8] on the analysis of human sports movements were carried out using this method.

2.6. Structural analysis of the mechanism

Structural analysis is the easiest to understand. It is the numbering of links and kinematic pairs, the compilation of the first passport matrix of the mechanism that is the matrix of the incidence of its moving links and a one-dimensional array of kinematic pairs. In conclusion, the number of degrees of mobility of the mechanism is determined.

2.7. Geometric analysis of the mechanism

The geometric analysis starts from the selection of one generalized coordinate, if the mechanism is single-moving, or with the selection of several generalized coordinates. In the second volume of the textbook [2], the analysis of mechanisms with several degrees of freedom is considered.

After selecting the generalized coordinate, it is necessary to write for each link the expressions for the coordinates of the center of mass and the expression for the angular coordinate of the link as a function of the lengths of the links and the only variable one that is the generalized coordinate of the mechanism. Similar triples should be written for each kinematic pair.

From such triples, the following two passport matrices of the mechanism are constructed, the matrix of the position functions of the moving links and the matrix of the position functions of the kinematic pairs.

2.8. Kinematic analysis of the mechanism

Kinematic analysis by the analytical method is a purely mathematical operation-differentiation. You should correctly write down the result of differentiating the position function as a complex function when determining the speed, and when determining the acceleration, write down the result of differentiating the product of complex functions.

Unlike the graphoanalytic method, the values of velocities and accelerations for a given generalized coordinate, velocity, and acceleration are not determined here. The task of kinematic analysis is to express the speed analogs and acceleration analogs of characteristic points, which will be used in dynamic analysis.

Thus, in kinematic analysis, with the help of symbolic operations of the mathematical package, the passport matrices of position functions are transformed into matrices of analogs of velocities and analogs of accelerations of characteristic points of the mechanism.

2.9. Dynamic analysis of the mechanism

Dynamic analysis of the mechanism begins with the formation of a matrix of inertial characteristics of the links of the mechanism. Each link is assigned a triple number-the mass, again the mass, and the moment of inertia of the link relative to the axis passing through the center of mass and perpendicular to the plane in which the link moves. Then, according to the rule used earlier, a matrix of inertial characteristics of the mechanism links is constructed from these columns-triples.

In the next step, by compiling the newly created passport matrix with the matrices of analogs of velocities and analogs of accelerations, two scalar functions of the inertia coefficients of the mechanism of the first and second orders are obtained (one of them is the reduced mass or the reduced moment of inertia of the mechanism). These are the coefficients of the future differential equation of motion of the mechanism.

In the next step, the last passport matrix of the mechanism is made – the matrix of active force action. And it is done in the same way by arranging in a row the triples that characterize each link, which is under the influence of external active forces and the reaction forces of kinematic pairs. It is these two groups of forces that determine the stresses during the operation of the mechanism. Determining the situations when and in which places the maximum destructive stresses occur in each link, creating a structure that is close to equal strength. This is the next direction of work.

Returning to the two groups of forces acting on the link during operation, we note that the active forces must be represented in the form of two projections of the main vector and the projection of the
main moment brought to the center of mass. This is the passport triple for each link, from which it is necessary to make a passport matrix of active force influence.

Similarly, we need to consider each kinematic pair and present as yet unknown reaction forces in the form of two projections of the main vector and the main moment brought to the center of this kinematic pair. Then, from these triples, construct a matrix of reaction forces of kinematic pairs. This matrix will be determined at the very last stage of the power analysis of the mechanism.

The next step in the dynamic analysis of the mechanism is to determine the scalar value of the generalized force of the mechanism. This function of the generalized coordinate is determined by the scalar product of the vectorized matrix of velocity analogues and the matrix of active force action.

If only constant or positional forces act on the links of the mechanism (this is the case considered in the educational process), then you can write the first and second integral of the differential equation of motion of the mechanism. So we explicitly write the expression for the generalized velocity and generalized acceleration as a function of the generalized coordinate of the mechanism (naturally, we plot these functions graph). Solving a well-known differential equation in finite differences, you can go to the functions of time (here you need a productive processor).

In the educational process described in the manual [1; 2], various variants of dynamic analysis are solved. The simplest, when the motion is known, is to find the missing forces (usually the driving forces). Or the direct problem of dynamics, when all the active forces are fully known, it is necessary to determine the law of motion. Or a combined problem, when it is necessary to determine a variable constant parameter of the mechanism or an initial generalized speed that provides a given unevenness of movement.

In any variant of dynamic analysis, its penultimate stage is the determination of all the inertia forces, naturally organized by the same triples (two projections of the main vector and the main moment of inertia forces, brought to the center of mass of the link).

The last stage of dynamic analysis is the summation of two fully known matrices (the active force action matrix and the D'Alembert inertia force matrix).

In the work two operations are used for creating arrays, one of them is the construction of a matrix from one-dimensional arrays-columns, the second is the vectorization of the matrix by columns or by rows. This operation involves arranging the columns or rows of the matrix in order in one column or one row. The last stage of dynamic analysis ends with the preparation of a one-dimensional array-row, which first contains all the projections of the main vectors of forces on the X-axis, then on the Y-axis, then the main moments of forces. Such an array is formed for known inertia forces and active forces and an array for unknown reaction forces of kinematic pairs.

2.10. Power analysis of the mechanism

The power analysis of the mechanism is based on the D'Alembert principle. Three dynamic equilibrium equations are written for each moving link of the mechanism. In addition, equations are created for the tangent components of the reaction of kinematic pairs, which are the complement of the equation of bonds.

The peculiarity of force analysis is that the matrices of the system of these linear relatively known and unknown components of the forces of algebraic equations are obtained from the passport matrices of the mechanism, namely: the incidence matrix of the moving links of the mechanism, crowning the structural analysis, and the matrices of the functions of the position of the links and kinematic pairs, crowning the geometric analysis.

The definition of a one-dimensional array of components of the reaction forces of kinematic pairs is reduced to writing the solution of the matrix equation of dynamic equilibrium as a function of the generalized coordinate of the mechanism.

3. Discussion and Conclusion

The algorithm for studying the mechanism is designed to be presented in the framework of the TMM lecture course. It reflects the educational aspects related to the demonstration of the laws of mechanics and mathematics. When constructing this algorithm, the goal was to minimally interfere with the
analysis process when entering data about the mechanism. This implies the use of generalized mechanism parameters and passport matrices.

During the analysis stages several checks are made. The first check is the coincidence of the animation of the mechanism obtained from the matrices of the functions of the position of the links and kinematic pairs with the representation of the movement of the mechanism under study.

The last check, which covers all possible errors, is based on the fact that the analysis algorithm used generates one more algebraic equation than is necessary. In [1] it is called "excluded". After determining all the quantities, this equation, of course, should turn into an identity. To be more precise, in the case of a numerical solution of the problem, the difference between the difference of its right and left parts from zero characterizes the error of calculations.

References

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