ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

UDC 37.026:517.933+62:517.933

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DEVELOPMENT OF ENGINEERING SPECIALTIES STUDENTS' RESEARCH SKILLS USING THE THEORETICAL MECHANICS METHODS

Introduction. Whichever areas of human society life considering, the scientific and technological progress does require continuous improvement of instructional methods and learning strategies implemented at higher technical education. A modern engineer should not only have extensive knowledge, but also be able to think individually, consciously determining his search in special field and respective solutions found. This implies mastering a creative approach to researcher activity, non-conventional techniques' using, as well as having the ability both to analyze and predict the results, and to select between thinking paths for finding optimal algorithms to solve problems. Therefore, the development of students' research skills should begin as early as possible, prior to reaching the narrower specialization stage, i.e. already at the early undergraduate stage, and even at the previous one, the secondary school pre-graduation and final years running. However, one of widely known imperfections in the first and second university years education, - in particular, speaking about the mechanical engineering specialties, — is due to insufficient attention to the formation of the initial skills required for independent study and research.

Analysis of recent researches and publications. A comprehensive analysis of approaches to teaching the natural sciences together with new solutions' search represent the subject of major international researches, in particular, in the framework of TIMSS program (Trends in International Mathematics and Science Study), aimed onto studying trends in the mathematics and natural sciences field international programs. So, the report presented at the Forum on International Physics (Washington, February 2010) by Dr. Jozefina Turlo (Poland) specializing in Central Europe region studies, got a high estimate, even exceeding this one the USA studies report obtained; the Dr. J.Turlo study being devoted to an analysis of European educational reforms in the natural sciences field contained several subsequent recommendations [1]. Generalizing study issues, although the natural sciences field shall never become a program for the majority of school graduates, every educational reform should be directed to perform its main task: fostering an assured path to researcher activity for future scientists. Structuring the fundamental sciences' subjects that provide a cornerstone component of future engineers' and researcher' education, we should be aware that the best involvement and interest will be achieved by providing students with opportunities for advanced research and participation in the experimental series; learning activities should never be limited to simple presence at the theoretical lectures.

DOI 10.15276/opu.1.45.2015.34

Therefore the actual requirements to contemporary higher engineering education system do involve developing new flexible methodology for practical training in basic subjects, including theoretical mechanics. Such techniques, as noted by Veretilnyk [2] in the analysis of the national high school system current situation, must satisfy the general requirements, they should rely onto specific real conditions of trainer's work (teaching time amount, students' readiness level, taught subject specificity); still at that necessary is to change the objectives, thus, practical lessons' dedicated purpose. This is especially important for the basic disciplines, i.e. passage from the usual scheme "to determine — to calculate the result following a known algorithm" to the formation of ability "to understand — to compare — to analyze — to make a choice". According to Pomogayev [3], the student needs to be repositioned from a knowledge passive consumer into knowledge active creator who knows how to formulate the problem, to analyze its resolving ways, to find the optimal result and to prove its correctness. This approach components' complete absence or vanishingly small presence represent the apparent lack of any basic subject teaching practical aspects.

However, it can be argued that the theoretical mechanics, like no other subject taught in a technical HEI, provides an opportunity to eliminate this disadvantage, whichever special field considering. The reasons can be summarized as follows:

— The theoretical mechanics science represents a conglomerate of the original, well-organized knowledge of the physical world principles; its basic nature and content embodied with classical mechanics makes background of every natural science;

— In the education system the theoretical mechanics embraces the fundamentals of physics and mathematics cycle, basic for all technical specialties; its subject (mechanical motion and interaction) is inherent to any material body in every technical realization: mechanical structures, machinery, equipment, any constructions. This explains the need for this subject presence at all curricula: not only mechanical specialties' ones, but also non-mechanical specialties of technical HEIs;

— The lectures part of theoretical mechanics course provides a well-structured theoretical material, based on a set of defining provisions (axioms, laws, theorems, principles) seconded with the appropriate mathematical and graphical forms for future practical use. From the point of view of the research skills development, especially important is the course's final part, containing main provisions and principles of classical dynamics (including analytical mechanics), which equations do determine the entire methodology of educational research in this area;

— The practical part of theoretical mechanics course provides a unique variety of techniques and methods for solving mechanical problems, which in the final stage of the course, are usually associated with studying dynamic models of typical mechanisms under some particular embodiment.

Namely these points as above, specific to a theoretical mechanics course taught t a technical institution, make possible the use of an integrated systematic approach to the mechanical systems dynamics study.

Aim of the Research is suggesting and substantiating a new approach to teaching the theoretical mechanics at a technical higher educational institution. This approach will provide in-depth study of theoretical material offered by the curriculum, promoting the development of students' creative abilities to conduct independent research of mechanical systems already at the initial stages of learning. In quality of this approach basis considered is a set of classical dynamics methods, representing a consistent and complete view of theoretical mechanics course.

Main Body. Developing an integrated system approach to the mechanical systems dynamics study in addition to the basic (standard) learning objectives, usually limiting the practical lessons' content, the authors concurrently resolved other problems. The theoretical part of the course allows reaching some additional objectives that enhance the practical lessons' assigned tasks translating them into research tasks domain. Standard options' set is following:

— Practicing skills in the use of classical dynamics' basic equations, including equations conversion to determine the desired result;

— Forming skills in carrying out the algorithmization procedure for obtaining result in solving a particular problem.

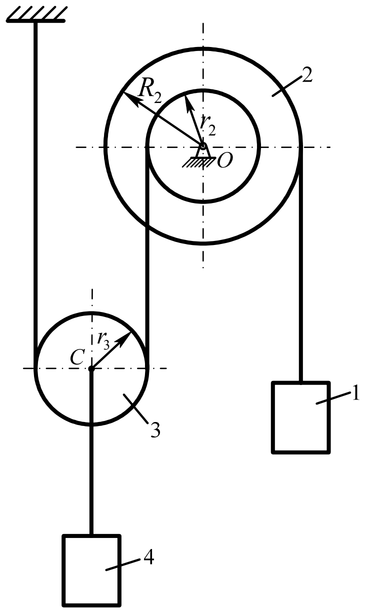

Fig. 1. Typical mechanism scheme

Additional possibilities here include the following:

— Multiple changes in approaches to solve the problem using different assumptions (theories, principles) for results checking and double-checking;

— Comparative analysis of various methods to problem solving with further selection of the optimal variance in accordance with problem setting;

— Purposed control of the mechanical system's (mechanism's) parameters and dynamic characteristics varying the initial data, that allows the studied system modification possibility.

The educational research organization taking into account all those options allows offering to the student an assignment of performing series of various tasks for the same mechanism's standard model. Completing such an assignment, the student not only uses the opportunity to learn and understand the classical dynamics' fundamentals and techniques, but also assimilates the initial research skills directly in the ongoing educational process.

The proposed educational research structure and content are clearly illustrated with the following example. For didactic reasons the process is scheduled as a sequence of steps forming separate tasks. Each assignment, in turn, contains further detailed list of individual tasks, each specific task involving the traditional scheme: "Given [ ] — Find [ ] — Decision [ ] — Answer [ ]". This approach is convenient as we can choose almost any typical model used for standard computational and graphics tasks in the theoretical mechanics. Also possible is to prefer more complex models, corresponding to real existing mechanisms: for each selected model the assignment properly and its content of particular tasks may vary depending on the scale of the planned research and students' capacities. Thus the whole executed research can represent the content of a complex computational and graphical assignment either course work or be part of the students' research work.

Let consider an example of such assignment formulation. To show the elaborated methodology one of typical mechanisms (Fig. 1.) has been selected. The mechanism includes four loaded interlinked bodies. Bodies 1 and 4 represents weights suspended correspondingly to a fixed hoist 2 and a movable hoist 3. The hoist 2, hinge-anchored at point O, represents a bistage pulley with: r_2 — inner and R_2 — outer radii. The hoist 3, suspended to the support, represents an uniform cylinder of r_3 radius. The whole mechanism can be sought as a one-DOF (degree of freedom) mechanical system with ideal bilateral constraint. The system motion is initiated with load 1.

At study results quantitative processing we depart from such data:

— bodies' masses

$$M_1=M_4=8m,\ M_2=4m,\ M_3=16m,$$

where m — fixed amount of mass units;

— relation between radii of hoist 2 stages

$$R_2/r_2=2;$$

— radius of hoists' 2 inertia respectively to the Oz axis, orthogonal to the drawn view plane

$$i_{2z} = r\sqrt{2}\,.$$

Table 1 contains a list of theoretical principles (with corresponding equation), suggested for use at the sought examples, these ones making part of standard theoretical mechanics material taught at the technical universities. The illustrating expressions consider the mechanical system as a whole of single mass points $\{m_k\}_n$, where k — every k-th point's index, n — all points number. The system's single mass points implement some real or virtual displacements when external either internal forces influencing. Every position and corresponding equation together with order number found at the first column are defining the solution method applied to one or another of tasks proposed. The selected solution method serves in basis to apply the standards methodical approaches, taught when in-class practicums, therefore a convenient algorithms is built and the problem solving procedure is implemented.

The proposed training research content for a given typical mechanism appears below as a list of assignments. Each assignment includes a set of individual tasks.

Table 1

Newtonian dynamics' general theorems and analytical mechanics variation principles

№.	Abstract theorem	Symbolic expression	notes
1	Theorem on Impulse Changes	$\frac{d\vec{Q}}{dt} = \vec{F}^e$	$\vec{Q} = \sum_{k=1}^{n} m_k \vec{v}_k$ — main impulse of mass points system; $\vec{F}^e = \sum_{k=1}^{n} \vec{F}_k^e$ — system's external forces main vector
2	Theorem on Angular-Momentum Changes	$\frac{d\vec{L}_O}{dt} = \vec{M}_O^e$	$\vec{L}_O = \sum_{k=1}^{n} (\vec{r}_k \times m_k \vec{v}_k)$ — system's angular momentum respectively to the fixed center O; $\vec{r}_k$ — radius-vector of k-th point; $\vec{M}_O^e = \sum_{k=1}^{n} \vec{M}_O(\vec{F}_k^e)$ — system's external forces main momentum respectively to the center O
3	Theorem on Kinetic Energy Changes	$T - T_O = A^e + A^i$	$T - T_o$ — system's kinetic energy change; $A^e = \sum_{k=1}^{n} A(\vec{F}_k^e)$ — system's resulting external forces work; $A^i = \sum_{k=1}^{n} A(\vec{F}_k^i)$ — system's resulting internal forces work
4	d'Alembert's principle 4.1. 1st vector equation 4.2. 2nd vector equation	$\vec{F}^e + \vec{\Phi}_k = 0$ $\vec{M}_O^e + \vec{M}_O^\Phi = 0$	$\vec{F}^e = \sum_{k=1}^{n} \vec{F}_k^e$ — system's external forces main vector $\vec{\Phi} = \sum_{k=1}^{n} \vec{\Phi}_k$ — inertia forces main vector; $\vec{M}_O^e = \sum_{k=1}^{n} \vec{M}_O(\vec{F}_k^e)$ — system's external forces main momentum respectively to the center O; $\vec{M}_O^\Phi = \sum_{k=1}^{n} \vec{M}_O(\vec{\Phi}_k)$ — system's inertia forces main momentum respectively to the center O
5	Principle of virtual displacements (Lagrange variational principle)	$\sum_{k=1}^{n} \vec{F}_k^a \cdot \delta \vec{r}_k = 0$	$\vec{F}_k^a$ — active force, $\delta \vec{r}$ — virtual displacement for system's k-th point
6	Dynamics general equation (Lagrange – d'Alembert principle)	$\sum_{k=1}^{n} \vec{F}_k^a \cdot \delta \vec{r}_k + \sum_{k=1}^{n} \vec{\Phi}_k \cdot \delta \vec{r}_k = 0$	$\vec{\Phi}_k$ — inertia force for system's k-th point
7	Lagrange equations of the second kind (case of one DOF system)	$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right) - \frac{\partial T}{\partial q} = Q_q$	q — generalized coordinate; $\dot{q}$ — generalized velocity; $Q_q = \frac{1}{\delta q} \sum_{k=1}^{n} \vec{F}_k^a \cdot \delta \vec{r}_k$ — generalized force, where δq — generalized coordinate variation

Assignment 1. Determine the acceleration of load 1, using different solutions ways applied to the entire mechanism's system:

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

Task 1.1. Solve, using the theorem on the change of mechanical system kinetic energy (Table 1, No. 3). The theorem enables to obtain an expression for load's 1 velocity $\vec{v}_1(h)$, where h — its displacement height. Differentiating this expression, the student can get the searched acceleration value.

Task 1.2. Solve, using the Lagrange — d'Alembert principle (Table 1, No. 6).

Task 1.3. Solve, using the Lagrange equations of the second kind (Table 1, No. 7).

Comparing the obtained results the student can conduct their checking and rechecking, and some discrepancy detected, has the possibility to find and fix errors. Students are also encouraged to make a comparative analysis of methods applied and to draw conclusions about their value, convenience and ease of use. The obtained verified result is used at further tasks fulfillment.

Assignment 2. Define the tension force of mechanism's flexible links connecting its member bodies (Fig. 1). Considering the mechanism as a whole, we identify these connections' tension force as internal, so when tasks resolving the member bodies should be considered separately as independent ones, applying to each of them a particular position of the theory (Table 1). When calculations assigned value is: $m = 2$ kg.

Task 2.1. Determine the flexible link's tension strength between bodies 1 and 2 using the d'Alembert's principle (Table 1, No. 4.1 — first vector equation).

Task 2.2. Determine the flexible link's tension strength between hoists 2 and 3, applying the theorem of the mechanical system's angular momentum change to the hoist 2 (Table 1, No. 2).

Task 2.3. Check the obtained result, applying the d'Alembert's principle (Table 1, No. 4.2 — second vector equation).

Task 2.4. Determine the flexible link's tension strength between hoist 3 and the load 4 applying the d'Alembert's principle (Table 1, No. 4.1).

When performing tasks 2.1...2.4 students are encouraged to compare and analyze the effectiveness of different methods and solutions, comparing the results and drawing conclusions.

Assignment 3. Determine the tension force of a flexible connection between the mechanism's hoist 3 and the support in four different ways.

Task 3.1. Solve, applying the d'Alembert's principle to hoist 3 (Table 1, No. 4.2).

Task 3.2. Solve, applying the mechanical system angular momentum change theorem to hoist 3 (Table 1, No. 2).

Task 3.3. Solve, using the d'Alembert's principle (Table 1, No. 4.1).

Task 3.4. Solve considering the impulse changes theorem applied to a mechanical system composed of bodies 3 and 4 (Table 1, No. 1).

This problem complexity relates to that due to the lack of experience a student can face difficulties to get correctly all four decisions with results aligned, so the error is almost inevitable. It is necessary to find and fix those errors, establishing their cause. It is advisable to provide comparative analysis of algorithms and techniques for solving these problems, identifying their peculiarities, as well as to determine the most efficient way of resolving task in terms of this particular study (for the proposed mechanism).

Assignment 4. Using the Lagrange variational principle (Principle of virtual displacements, Table 1, No. 5) consider the conditions of mechanism's forces balance created following two independent methods: increasing the load's 4 mass; applying the braking torque to hoist 2) When calculations assigned value is: $m = 2$ kg).

Task 4.1. Determine how many times the load 4 weight should be increased for equalizing to zero acceleration of the load *1*.

Task 4.2. Determine what braking torque should be applied to the hoist 2 for equalizing to zero acceleration of the load 1.

Students are also encouraged to propose and analyze different ways to achieve the mechanism's forces balance having formulated and independently resolved some additional tasks.

Results. Numerical results obtained on the full range of tasks in the framework of proposed educational research are given in Table 2. Solutions of particular problems do not represent fundamental novelty, and therefore are not shown. In addition, techniques of each method individual application to solve independent tasks are deeply worked out while practical classes in theoretical mechanics [1, 3].

The developed comprehensive approach to the training research has been tested with second-year students of the Institute of Machine-Building Engineering and Institute of Industrial Technology, Design and Management of Odessa National Polytechnic University. The study issues are used in elaboration of calculation- and-graphic work “Use of comparative techniques for solving classical dynamics problems in the study of motion of a holonomic one-DOF mechanical system”. That research results obtained by second-year students were presented at the 47th Conference of ONPU Students and Young Researchers (May 2013).

Table 2

Results of assigned tasks calculation

Value found	Units	Obtained value
Acceleration of load 1	m/s	1,64
Tension of flexible link between load 1 and hoist 2	N	131
Tension of flexible link between hoists 2 and 3	N	249
Tension of flexible link between hoist 3 and support	N	164
Ratio between initial and final load mass 4	–	2
Breaking torque applied to hoist 2	N·m	20

Such an approach being universal in terms of educational research can serve as a reliable basis for the students’ independent work and self-learning, at that the study arrangement principles can be applied not only in theoretical mechanics, but also are relevant for other mechanical engineering field subjects at universities and institutes.

Conclusions. The possibility of complex use of theoretical mechanics’ course standard terms allows developing and strengthening the future professionals’ researcher function already at junior undergraduate stage, and that is crucial not only the most advanced students are involved in such training when extracurricular time, e.g., as part of the students research work, but such improvement also available immediately when practical classes and self-learning activities to the entire study groups cohort.

The proposed approach tasks structure is that for each student the content of study can be selected individually, narrowed or, on the contrary, extending its scope, depending on the tasks, personal capabilities of the student, as well as curriculum. The specificity and possibilities provided by theoretical mechanics as a fundamental subject of physics and mathematics cycle allow virtually unlimited development of the field, improving the elaborated methodology and its application forms.

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АНОТАЦІЯ / АННОТАЦИЯ / ABSTRACT

Т.В. Макарова, А.В. Жукова. **Розвиток навичок дослідження у студентів молодших курсів інженерних спеціальностей методами теоретичної механіки.** Розроблено новий підхід до організації практичних занять для студентів молодших курсів інженерних спеціальностей технічних вузів, що сприяє формуванню у них початкових навичок самостійного дослідження. Для проведення комплексного навчального дослідження безпосередньо в рамках поточного навчального процесу застосовано порівняльні методики розв'язання задач класичної динаміки. Наведено приклад реалізації подібного підходу на основі одного з типових механізмів, характерних для навчальної практики базових інженерних дисциплін. Розгорнуто послідовність взаємопов'язаних завдань — етапів дослідження, де кожне наступне завдання логічно базується на попередньому і містить подальшу деталізацію у вигляді окремих задач. Спосіб розв'язання кожної задачі багаторазово змінюється за рахунок застосування різних теоретичних положень (теорем, принципів). Структура завдань дозволяє змінювати обсяг і зміст дослідження відповідно до навчальної програми дисципліни. Ключовим моментом методології дослідження є проведення порівняльного аналізу отриманих рішень і використаних методик. Принципи організації дослідження дозволяють застосовувати розроблений підхід не тільки в галузі теоретичної механіки, а й для інших технічних дисциплін механічних факультетів університетів та інститутів.
Ключові слова: класична динаміка, дослідницькі навички, порівняльні методики.

Т.В. Макарова, А.В. Жукова. **Развитие навыков исследования у студентов младших курсов инженерных специальностей методами теоретической механики.** Разработан новый подход к организации практических занятий для студентов младших курсов инженерных специальностей технических вузов, способствующий формированию у них начальных навыков самостоятельного исследования. Для проведения комплексного учебного исследования непосредственно в рамках текущего учебного процесса применены сравнительные методики решения задач классической динамики. Приведен пример реализации подобного подхода на основе одного из типовых механизмов, характерных для учебной практики базовых инженерных дисциплин. Развернута последовательность взаимосвязанных заданий — этапов исследования, где каждое последующее задание логически базируется на предыдущем и содержит дальнейшую детализацию в виде частных задач. Способ решения каждой задачи многократно изменяется за счет применения различных теоретических положений (теорем, принципов). Структура заданий позволяет изменять объем и содержание исследования в соответствии с учебной программой дисциплины. Ключевым моментом методологии исследования является проведение сравнительного анализа полученных решений и использованных методик. Принципы организации исследования позволяют применять разработанный подход не только в области теоретической механики, но и для других технических дисциплин механических факультетов университетов и институтов.
Ключевые слова: классическая динамика, навыки исследования, сравнительные методики.

T.V. Makarova, A.V. Zhukova. **Development of engineering specialties students' research skills using the theoretical mechanics methods**. Developed is a new approach to the organization of practical training for undergraduate students of technical universities' engineering specialties which contributes to forming their initial independent research skills. Comparative methods of solving the classical dynamic's problems are used for complex educational research ongoing immediately in the learning process. The considered example is given on the basis of one of the type mechanisms used in teaching basic engineering subjects. Presented is the series of interrelated problems where each subsequent one is logically built on the previous and contains further details in the form of individual tasks. The way to solve each task is repeatedly changed through applying different theoretical bases (theories, principles). The tasks structure allows changes into volume and content of the research in accordance with the curriculum. The research methodology key point refers to a comparative analysis of solutions obtained and techniques applied. The research organisation principles allow using the developed methodology not only in theoretical mechanics, but also other engineering subjects taught at the mechanical engineering faculties of universities and institutes.
Keywords: classical dynamics, study skills, comparative methods.

Received October 10, 2014