CAD/CAE/CAM when teaching the discipline “Fundamentals of machine design”

A N Sirotenko and S A Partko
Don State Technical University, 1, Gagarin area, Rostov-on-Don 344000, Russian Federation

E-mail: parlana@rambler.ru

Abstract. The issue of training a future engineer in design and technology specialization is considered. For the effective assimilation of the acquired knowledge, improvement of the skills of using CAD and traditional design techniques in teaching the design and use of CAD, the principle of "end-to-end design" is applied. For a workshop in several disciplines, one task is used. This makes it easier for the student to adapt to the new discipline and accelerates its learning. When teaching a new discipline, a future engineer not only designs elements of an already known structure using CAD/CAE/CAM capabilities, but also corrects previously obtained design and technological solutions. Thus, not only new design skills are acquired, but the quality of the already acquired knowledge is improved.

1. Introduction
Modern engineering education is characterized by a high saturation of digital technologies. This feature significantly accelerates not only the design process of a product at all stages of its life cycle, but also provides informational support to the activities of an engineer. Creation of competitive products is impossible without CAD/CAE/CAM [1,2]. Digital technologies accompany all design stages: creation of drawing documentation; carrying out strength, static, dynamic calculations; support of product manufacturing technology; design project. This requires a specialist to be confident in the most various types of CAD [1,3].

In large enterprises or participation in mass production, the engineer, most often, develops the CAD skills characteristic of his specialization and relevant to the CAD enterprise. At small enterprises, along with the main production, which often encloses research and development activities, the requirements for the engineering and technical staff are traditionally formed based on the conditions for the universalization of skills. Solving research problems, for example, in the field of strength of parts [4-6], including those made of composite materials, or solving problems of dynamics [7-9] requires an engineer to own specialized CAD systems. This leads to the increasing integration of design and technological education in the preparation of a modern engineer, in fact, forming a specialist in design and technology bias.

2. Main part
“Machine parts” is one of the disciplines in which a future engineer learns to design parts and assemblies based on their performance criteria, international and national standards. But it is impossible to design a competitive product considering only the design component. It is necessary to choose a manufacturing
technology, constructively take into account the technological peculiarities of machining and assembly operations, without this effective design is impossible.

Such a requirement, undoubtedly, significantly increases the teaching load on the student, which explains the division of these professions in the industries of the last century. However, the rapid development of CAD in recent decades has made it possible not only to automate a significant part of design and technological work, but also to combine design and technological CAD into one software product. This makes it possible to implement the idea of “end-to-end design”? and to use in the process of several teaching disciplines one, the initial task from the workshop of the discipline “Machine parts”. This teaches the student to work out the design in detail and in the process of solving problems in other disciplines, one way or another, requires a return to the design of mechanical transmission parts and the refinement of techniques, design solutions. At the Department of Fundamentals of Machine Design, Don State Technical University, the principle of "end-to-end design" is used in teaching the disciplines "Machine parts", "CAD of technical systems", "Technological foundations of design." If desired, the student can receive another individual assignment.

When teaching the discipline "Machine parts", the student experiences difficulties not only in correctly determining the criterion for the performance of a part and applying calculation methods, but also in using standard and typical elements. The search for standard elements, typical design solutions requires experience in working with reference literature and design atlases and takes a significant amount of time. Practice shows that the correct application of compulsory technological elements by students in the design directly depends on the level of knowledge of the technology of manufacturing and assembling machines. For example, a student's typical questions when creating working documentation are often: drilling and threading depth; the size and shape of the groove for the exit of the grinding wheel or cutter; roughness, geometric tolerances and surface deviations; allowances for galvanic and thermal operations; presence/absence of tides and casting corners; processing compatibility, method of exposing and type of connection of parts, etc. Searching for such data in reference books takes a lot of time. The correctness of applying the tolerances of the surface deviation depends on the choice of design and technological bases.

Most of the workshop in the discipline "Machine parts" concerns the design of mechanical transmissions. The initial design stage consists in creating a schematic diagram of the drive, choosing an energy source and subsequent kinematic, energy and power calculation of its parameters. CAD APM WinMachine allows to significantly speed up these procedures. For the direct design of mechanical transmissions, students use either APM Mechanic or the KOMPAS-3D mechanical transmission and shaft design module.

Trainees with good drawing skills and practical engineering experience actually do not perform traditional 2D rendering of the gear arrangement and immediately create its 3D model (figure 1).

![Figure 1. Arrangement of gears and supports of a two-stage helical gearbox.](image-url)
Clarification of the structural elements of the layout details is carried out using the electronic libraries of CAD design applications KOMPAS. Figure 2 shows the design of the driven shaft of the gearbox. The transition from 2D to 3D model occurs automatically, upon completion of the calculation. An important feature is the ability to quickly and repeatedly adjust the design by changing the technological elements and the type of connections.

![Figure 2. Design of the drive shaft of the gearbox with automatic generation of a 3D model.](image)

The process of creating an assembly 3D model is accompanied by serious work with electronic libraries of connections. For the convenience of working with an assembly, parts of the 3D model can have different colors, which is especially important in complex assemblies. The detailing of the arrangement of units, the placement of gear parts is evaluated not only by cuts, sections, with the exception of visualization of specific parts, but also by using their transparency. Figure 3 shows the placement of the gears, dipstick, and drain plug. The dip angle for the dipstick is selected taking into account the gap of the dipstick needle in the threaded hole so as to minimize the length.

![Figure 3. Assembly 3D model of a gearbox with a colored and transparent structure.](image)

Design and verification calculations of machine parts connections are carried out both “manually” and using APM WinMachine. This forms the skill of design without the help of CAD and reinforces the theoretical knowledge of the discipline.
The creation of working drawings is accompanied by the formation of dimensional chains and the assignment of surface deviation tolerances, which is often ahead of lecture courses in the relevant disciplines. The application of the calculation of dimensional chains CAD KOMPAS allows to partially remove the questions and speed up the process of assigning tolerances.

![Figure 4. Creation of a 3D model by geometric and dimensional parameterization.](image)

All the capabilities of CAD/CAE/CAM cannot be used and studied when performing a workshop on "Machine parts", therefore, the student gets the skills to apply tabular, dimensional, geometric parameterization when performing practical tasks in the discipline "CAD of technical systems". Tabular parameterization is performed in the Excel environment and concerns the creation of a calculation and reference table for designing an already known design of a gear wheel and a gearbox shaft [12,13].

![Figure 5. Creating a NC program for turning a shaft structural element in CAD/CAE/CAM Teflex.](image)

The manufacturability of the hull structure, assembly elements is checked and refined during the course of the workshop on the "Technological foundations of design" discipline. The skills of parameterization of the model, the basics of creating control programs for CNC machining of parts are formed when studying the discipline "CAD of technical systems".

The control program is generated automatically for a given section of the previously created and parameterized 3D model (Figure 5). For correct generation, the student learns to navigate in the CNC machine park, tool base. He needs to know the purpose of tools, correctly select and orientate them in the tool block, assign cutting modes, know the fixtures and the theory of basing and technology, and the features of machining. According to the selected processing strategy, the student generates a control program [10,14]. A small section of the control program is created "manually", the efficiency of automatic generation and "manual" programming is compared, and proposals are made for adjusting the design of the workpiece.

3. Conclusions and discussion
The solution to students of practical problems of several disciplines on the example of an already known design facilitates the assimilation of disciplines, accelerates the formation of design skills, taking into
account the technological features of design. This approach makes it possible to more rationally adapt the previously acquired knowledge when studying other disciplines, since the student works with a structure already well known to him. It can be argued that constant work with the same structure narrows the student's horizons. I agree, but the training cycle of a future engineer is not limited to the listed disciplines and workshops, and the theory of other disciplines compensates for this shortcoming. It is especially worth noting that despite the widespread use of CAD/CAE/CAM in the design and technological activities of an engineer, in R&D and small enterprises, not only the skill of competent use of CAD is required. The creation of a single unique machine and device cannot do without the traditional sketching of a structure on graph paper using a control and measuring tool.

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