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Digital Transformation of Technological Design in the Preparation of Design Engineers: History and Prospects

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Abstract. Significant advances in the implementation of information technology in the educational process cannot occur on their own. Success in this area is ensured by many years of hard work aimed at a gradual transition from the use of traditional teaching methods to automated ones. This transition on the example of implementing a computer-aided design of technological processes is considered. The stages of the formation of this activity are described, starting with systems based on SM EVM (СМ ЭВМ, abbreviation of Система Малых ЭВМ – literally System of Mini Computers. It was the general name for several types of Soviet minicomputers produced in the 1970s and 1980s) operating under the control of a real-time operating system, and ending with electronic complexes for information support of design and technological design based on PDM systems.

Key words: computer-aided process planning, Sukhoi State Technical University of Gomel, use of information technology

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Цифровая трансформация проектирования технологических процессов при подготовке инженеров-проектировщиков: история и перспективы

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Аннотация. Значительные достижения в области внедрения информационных технологий в учебный процесс не могут возникнуть сами по себе. Успех в этой сфере обеспечивается многолетней и упорной работой, направленной на постепенный переход от использования традиционных методов обучения к автоматизированным. Этот переход рассматривается на примере внедрения системы автоматизированного проектирования технологических процессов. Описываются этапы становления этой деятельности, начиная с систем на базе СМ ЭВМ, работающих под управлением ОС РВ, и, заканчивая электронными комплексами для информационной поддержки конструкторско-технологического проектирования на базе PDM-систем.

Ключевые слова: САПР ТП, ГГТУ имени П.О. Сухого, использование информационных технологий

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Introduction. Significant advances in the digital transformation of process design in the training of design engineers cannot occur on their own. Success in this area is ensured by many years of hard work aimed at a gradual transition from the use of traditional design methods to automated. The acceptability of the methods of traditional and automated design of technological processes is the key to the training of highly qualified specialists. For an objective assessment of the current situation, it is necessary to consider the whole path traveled by digital transformation. This path began with the introduction of systems based on SM EVM (СМ ЭВМ, abbreviation of Система Малых ЭВМ – literally System of Mini Computers. It was the general name for several types of Soviet minicomputers produced in the 1970s and 1980s) operating by control systems RSX-11. At present, having gone through many stages, mechanical engineering has reached the level of introduction of electronic systems for information support of design and technological design based on PDM systems.

History. The computer-aided process planning (CAPP) system was used by students when developing a course project in 1995. At this time, the guidelines for the course work on the course "Technology of manufacturing hydraulic drives" for specialty 12.11 "Hydraulic machines, hydraulic drives, hydropneumatic automation" were published [30]. In them, the use of CAPP system was recommended to students. The transition from traditional (manual) design to automated one was dictated by the need to resolve the contradiction between an increase in the complexity and quality of created machines, on the one hand, and a reduction in the time of their moral aging, on the other. Already at that time, covering the beginning of the 90s of the last century, the realization came that future design engineers would have to face a compromise between the desire to improve the technical level of the machines being created and reduce the time and cost of their design. These arguments have become a catalyst for the implementation of computer-aided design systems in the educational process.

Used CAPP system was one of the structural components of CAD of technological preparation of production. This system, when used in a production environment, is a tool of a technologist and a specialist in setting the time standards when performing a process when designing technological processes in a dialogue mode with a computer.

The software of CAPP system allowed:

– to design technological processes in a dialogue mode (direct design method) on the basis of a design drawing, information databases of technological design and materials, as well as designer knowledge;

– to borrow ready-made processes from the database of ready-made technological solutions;

– to edit in the dialogue mode designed or borrowed technological processes;

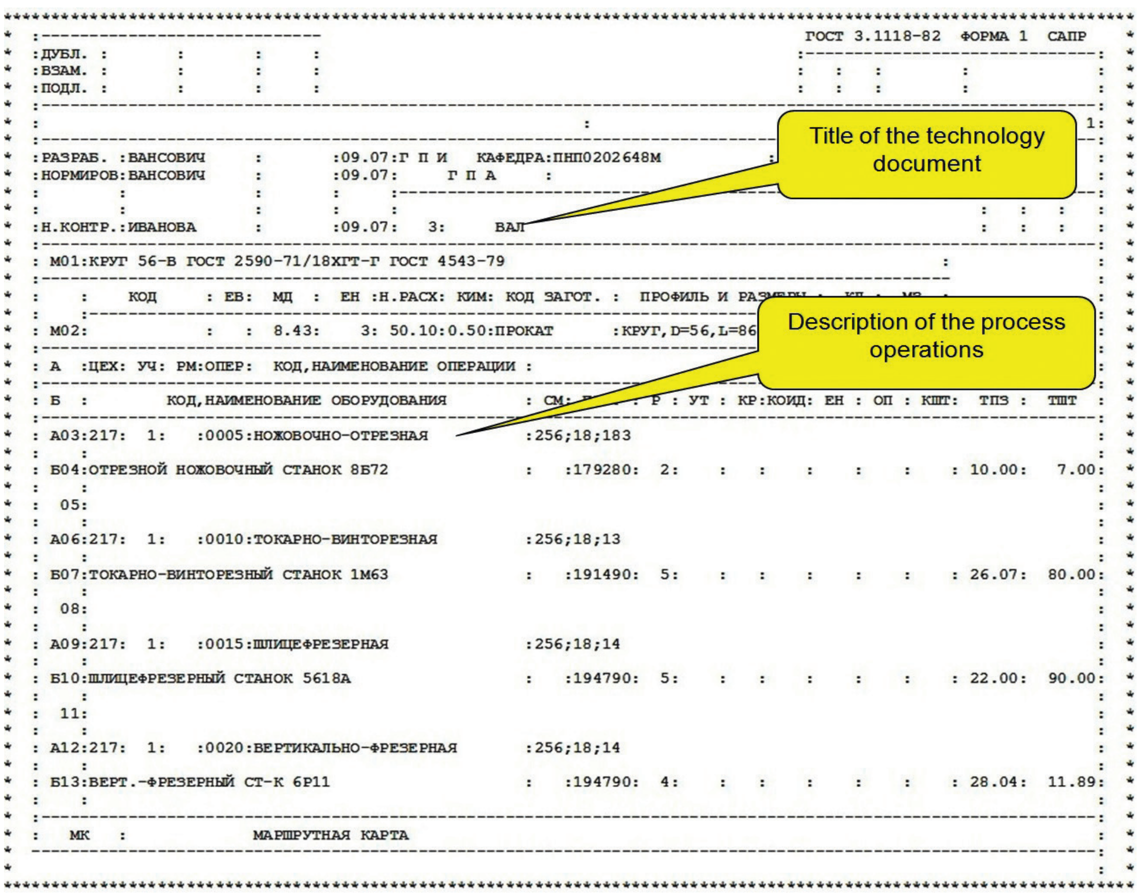


Fig. 1. Sample route map (Route map - a description of the routes along the workshop of the manufactured part)
Рис. 1. Образец заполнения маршрутной карты

– to set the time standards for the implementation of the designed machine operations in dialogue mode;

– to receive on an alphanumeric printing device a complete set of technological documents, including a title page, route and operational maps, sketch maps and equipment sheet.

Examples of route and operational maps are shown in Figures 1 and 2.

The main area of application of the system is the preparation of a single, small-scale, serial and mass engineering production.

CAPP system allowed designing the manufacturing technology of parts for machine-building applications for all types of processing. The work of CAPP system was based on the use of unified systems of design and technological documentation [27].

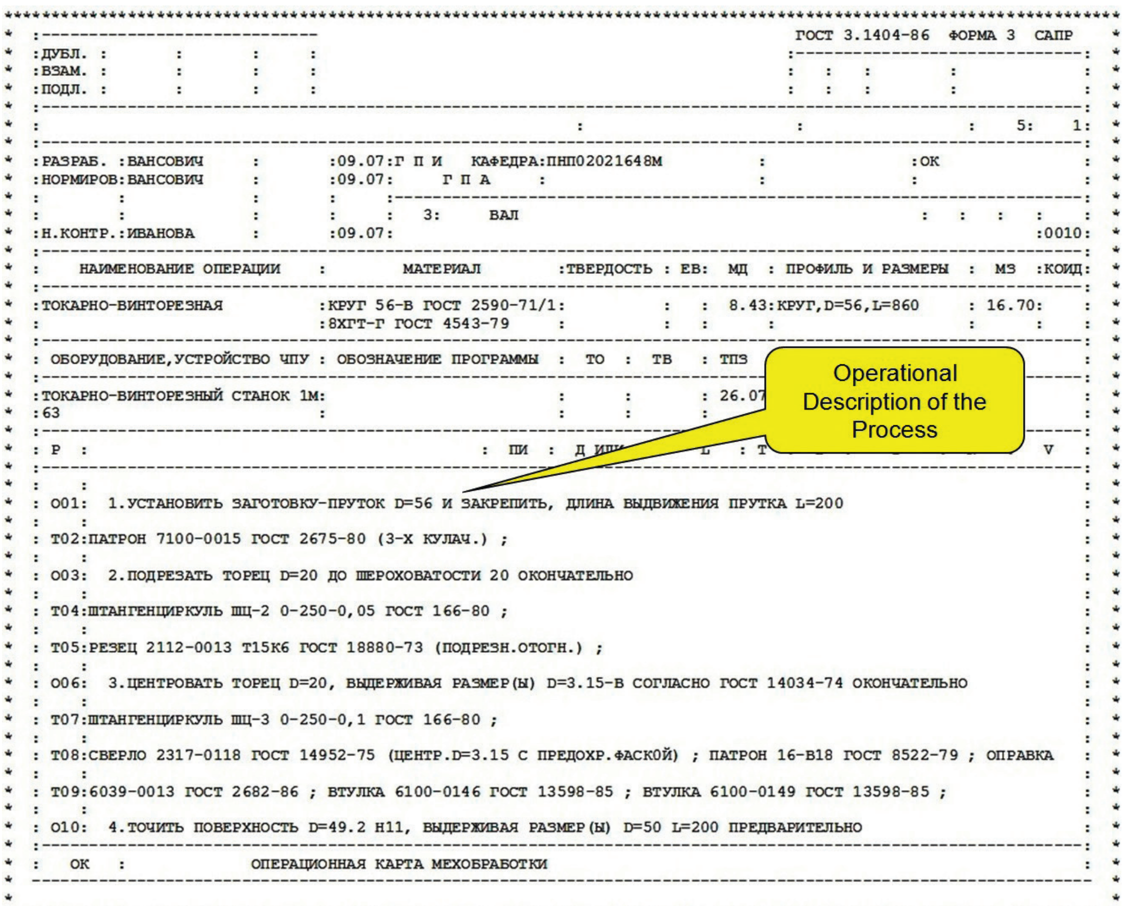
By the beginning of the 2000s, it became obvious that further isolated development of automation systems for designing the product design and its manufacturing technology causes significant damage to the quality of the products. In the textbook on the discipline of CAPP system, published at this time, the organization of the design of technological processes using a single information space and a model of the problematic environment of technological design is already described [24].

The manual also describes the life cycle of a technological document when using the PDM system, presented in Figure 3, provides recommendations for monitoring the design process of the technology and the basic principles of routing business processes are given [24].

All this aimed the educational process of training design engineers to move from designing single (individual) drawings to creating parametric models of 2D drawings for groups of structurally similar parts. The methodology of parametric modeling of parts and information for its practical implementation were published in 2008 in a laboratory workshop [23]. The work with parameters and variables when creating a parametric 2D drawing was described in it step by step.

In addition, the following processes were described:

– creating a 3D model based on a 2D drawing (the weight of the part, its surface area, the coordinates of the center of gravity and the



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: Т05:РЕЗЕЦ 2112-0013 Т15К6 ГОСТ 18880-73 (ПОДРЕЗН.ОТОГН.) ;
: O06:  3.ЦЕНТРОВАТЬ ТОРЕЦ D=20, ВЫДЕРЖИВАЯ РАЗМЕР(Ы) D=3.15-В СОГЛАСНО ГОСТ 14034-74 ОКОНЧАТЕЛЬНО
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: Т08:СВЕРЛО 2317-0118 ГОСТ 14952-75 (ЦЕНТР.D=3.15 С ПРЕДОХР.ФАСКОЙ) ; ПАТРОН 16-В18 ГОСТ 8522-79 ; ОПРАВКА
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: O10:  4.ТОЧИТЬ ПОВЕРХНОСТЬ D=49.2 Н11, ВЫДЕРЖИВАЯ РАЗМЕР(Ы) D=50 L=200 ПРЕДВАРИТЕЛЬНО
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Fig. 2. Operational card (Operational card - a list of transitions, installations and tools used)

Рис. 2. Образец заполнения операционной карты

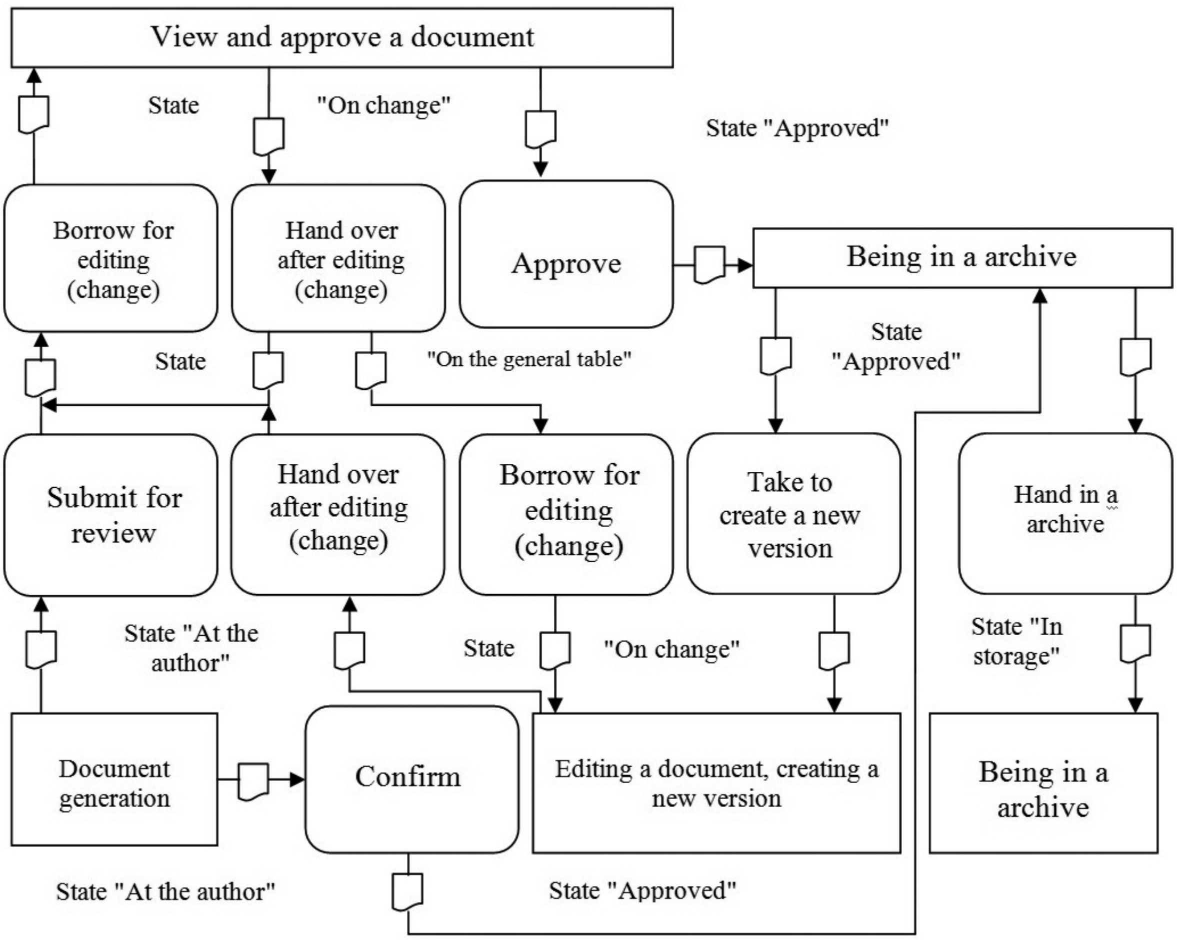

Fig. 3. Document life cycle diagram
Рис. 3. Схема жизненного цикла документа

moments of inertia with respect to the axes X, Y, Z were determined);

– creating a parametric 3D model of the part using the main method;

– creating a 2D drawing from a parametric 3D model of the part.

The skills obtained during the development of the processes described above served as the basis for the typification of design engineering. On the one hand, the parameterization of 2D drawings and 3D models simplified the process of graphic representation of a new part. To do this, it was quite sufficient to fill in the numerical parameters a line in the relational database corresponding to the part designation (or its execution). At the same time, both the 2D drawing and the 3D model were rebuilt automatically for the new version. On the other hand, the parameterization of 2D drawings and 3D models created the prerequisites for the computer design of general technological processes that automate the process of creating specific technological processes (STP).

The next practical step in the direction of digital transformation of the design of technological processes was taken at the Sukhoi State Technical University of Gomel in 2010 with the advent of a new laboratory workshop on discipline "CAPP system" [26]. It was published as an electronic resource and its theoretical part described the process of creating a common technological process in CAPP system TechnoPro and its use for automatic design of technological processes. In the practical part of the workshop, detailed instructions on the development of processes are outlined:

– creation of common technological processes (CTP);

– settings for the procedure for transferring information from a parametric 2D drawing to CAPP system;

– automatic design of single specific technological processes (STP) by parametric adjustment of CTP.

This stage of development of the digital transformation of the design of technological processes was of great practical importance. For the first time, a real practical implementation of the integration of design and technological design was shown.

The theoretical rationale for this integration process was given in the training manual, which was

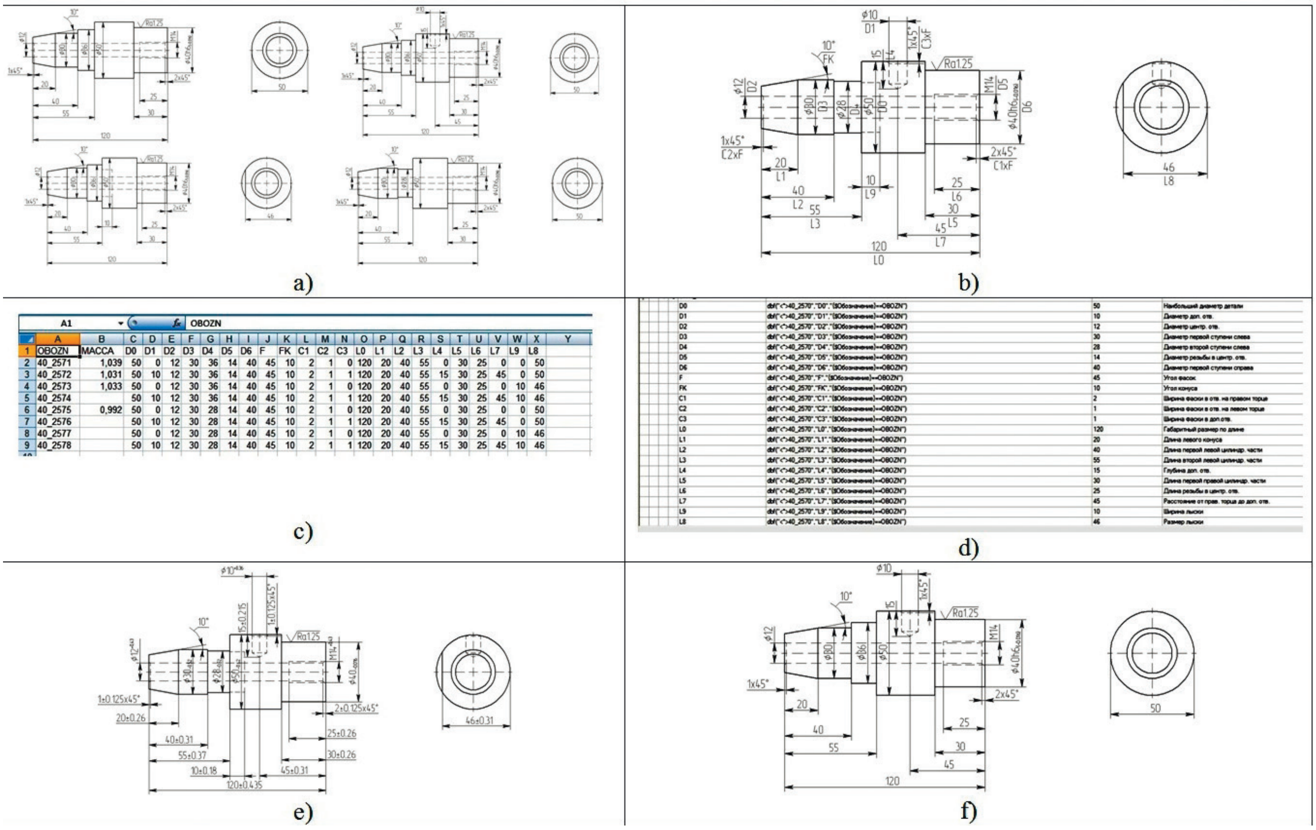

Fig. 4. The scheme of work with parameters and variables when creating a parametric 2D drawing
a) Analysis of drawings included in the group;
b) Formation of a parametric model of parts included in the group;
c) Creation of an external database of design parameters of group parts and its filling;
d) Organization of the process of transferring design parameters of group parts from an external base to the system T-FLEX CAD;
e) Construction of a parametric drawing summarizing all the structural elements of a group of parts;
f) Checking the performance of the parametric model, for example, the second execution of the part.
Рис. 4. Схема работы с параметрами и переменными при создании параметрического 2D-чертежа
a) Анализ чертежей, входящих в группу;
b) Формирование параметрической модели деталей, входящих в группу;
c) Создание внешней базы данных конструктивных параметров деталей группы и ее заполнение;
d) Организация процесса передачи конструктивных параметров деталей группы из внешней базы в систему T-FLEX CAD;
e) Построение параметрического чертежа, обобщающего все конструктивные элементы группы деталей;
f) Проверка работоспособности параметрической модели, на примере второго исполнения детали.

published in 2011 with the stamp of an educational and methodological association and consisted of the following sections:

1 Basic concepts and place of CAPP system in the system of technological preparation of production and product life cycle

2 Technological unification. Varieties of technological design. Functional diagram of CAPP system

3 Initial part information

4 Presentation of conditionally constant information in CAPP system

5 Presentation of information in the language of decision tables

6 Methods of designing TP using a computer

7 Designing TP based on typification

8 TP design by synthesis method

9 Establishing processing routes for individual surfaces

10 Development of a process flow diagram

11 TP design within the processing phase

12 Calculation of technological dimensions

13 Designing operations and complementing the route TP

14 Design transitions TP

15 Supporting subsystems, stages and principles of CAPP system design

16 CAPP system assembly products

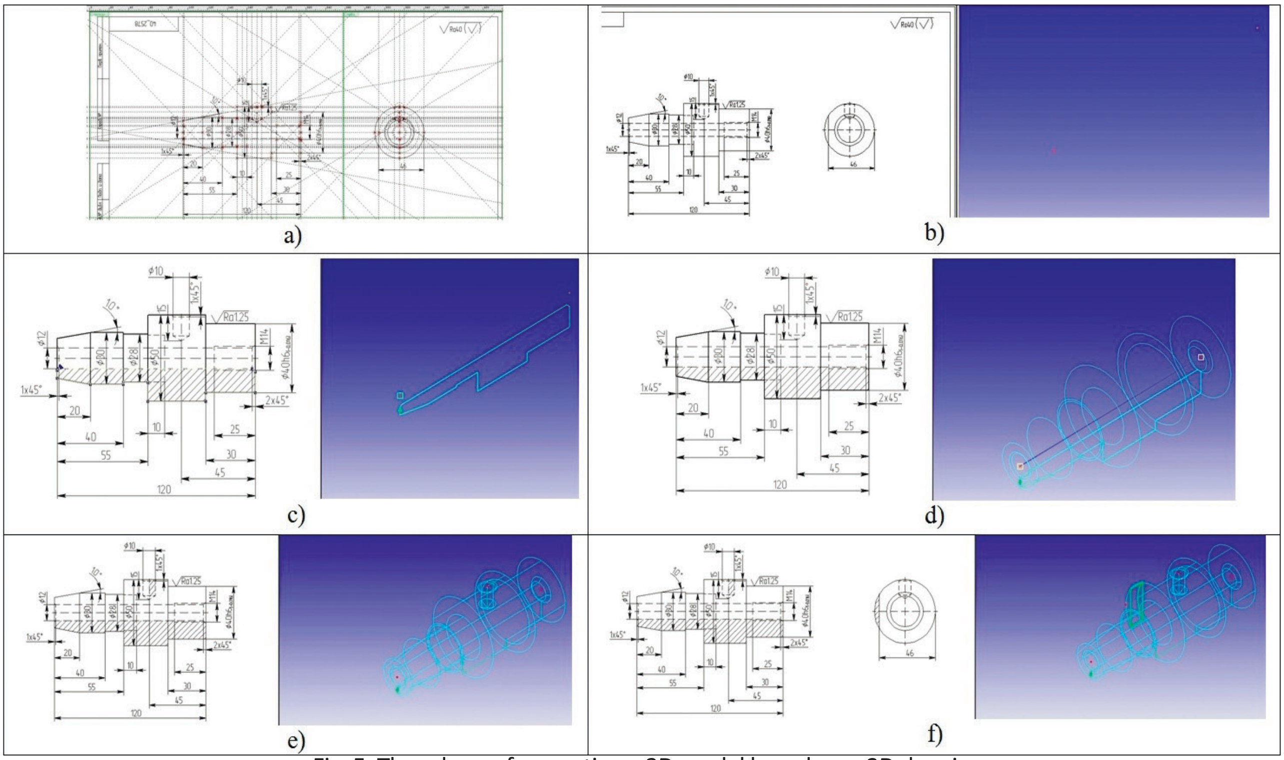

Fig. 5. The scheme for creating a 3D model based on a 2D drawing
a) Creating work planes;
b) Creating two 3D nodes defining the axis of rotation of the 3D profile;
c) Building a 3D part profile;
d) Rotating a 3D part profile;
e) Getting circular hole;
f) Getting flattened surface.
Рис. 5. Схема создания 3D-модели на основе 2D-чертежа
а) Создание рабочих плоскостей;
b) Создание двух 3D-узлов, определяющих ось вращения 3D-профиля;
c) Построение 3D-профиля детали;
d) Вращение 3D-профиля детали;
e) Получение отверстия;
f) Получение лыски.

17 CAD Description [29].

Further improvement of the process of teaching the discipline CAPP system went along the path of creating an electronic educational-methodical complex of the discipline (EEMC CAPP system). Its goal was information support of the educational process.

The process of creating the EEMC CAPP system included the preparation of teaching materials, development of the structure of the complex and its practical implementation. The structure of the complex was developed taking into account its use in the educational process with full-time and part-time (full and shortened) forms of training. A fragment of the structure of the EEMC CAPP system is shown in Figure 8.

At the stage of practical implementation, the structure of the electronic educational-methodical complex of the discipline CAPP system web page was developed.

EEMC CAPP system was created in a web-format based on the FrontPage 2003 system, which is part of Microsoft Office 2003 using a hyperlink system. This ensured its correct display by browsers Microsoft Internet Explorer (version 6.0 and higher), Mozilla Firefox, Opera on monitors with a diagonal of 17 inches or more.

Using the complex provided students with the following functionality:

– easy search for any information on the discipline under study (the student gets into any of the questions of the theoretical or practical course in three clicks: the form of training, the type of occupation, the question);

– viewing training videos and presentations (especially useful for the practical study of software products);

– a significant simplification of the search for information in preparation for the exam or testing

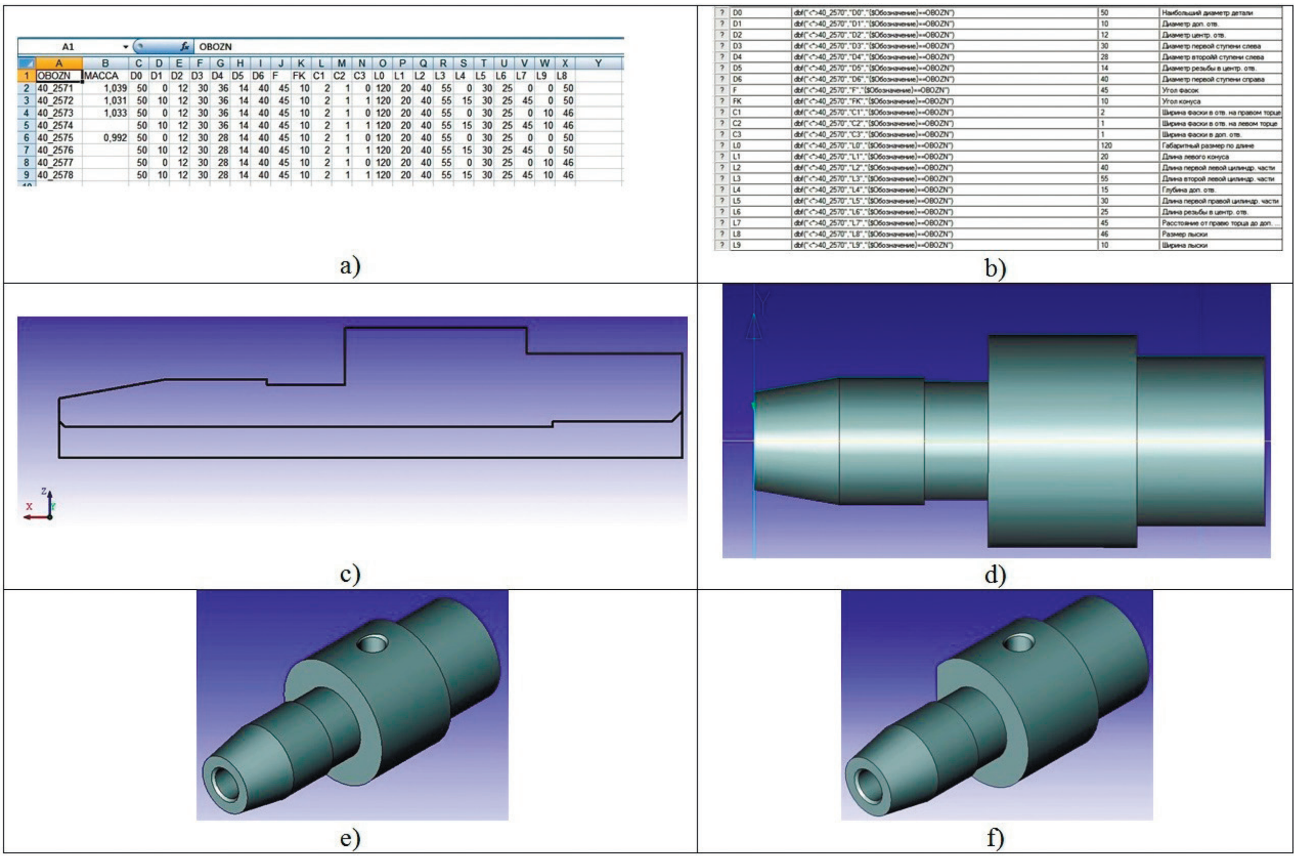

Fig. 6. The scheme for creating a parametric 3D model of the part using the main method
a) Creation of an external database of design parameters of group parts and its filling;
b) Organization of the process of transferring design parameters of group parts from an external base to the system T-FLEX CAD;
c) Creating auxiliary tools for building a 3D model in the main way;
d) Result of rotation of a 3D part profile;
e) Getting circular hole;
f) Getting flattened surface.

Рис. 6. Схема создания параметрической 3D-модели детали основным методом
a) Создание внешней базы данных конструктивных параметров деталей группы и ее заполнение;
b) Организация процесса передачи конструктивных параметров деталей группы из внешней базы в систему T-FLEX CAD;
c) Создание вспомогательных для построения 3D-модели основным способом;
d) Результат вращения 3D-профиля детали;
e) Получение отверстия;
f) Получение лыски.

(the content of the theoretical material is provided with links to the number of the examination question and / or test, as well as an indication of the number of the lecture at which this issue was considered);

– obtaining software used for laboratory work for extracurricular activities (made possible by the inclusion of the Sukhoi State Technical University of Gomel as part of the participants in the support program for educational institutions, approved by the management of Top Systems);

– printing of training materials (each section of the complex has a print version in * .PDF format).

The EEMC CAPP system includes all the information necessary for a successful study of the discipline. Its use ensured the formation of students' knowledge and skills in accordance with the current educational standards.

In 2011-2013 the Sukhoi State Technical University of Gomel as a co-executor participated in the implementation of task № 3.5 of the list of works on the development of the state system of scientific and technical information of the Republic of Belarus for 2011-2013 and for the future until 2015. As part of this assignment, in 2012 a concept was developed to create a vocational education system in the field of development and implementation of integrated design and production systems. The concept was discussed at the XI International Conference

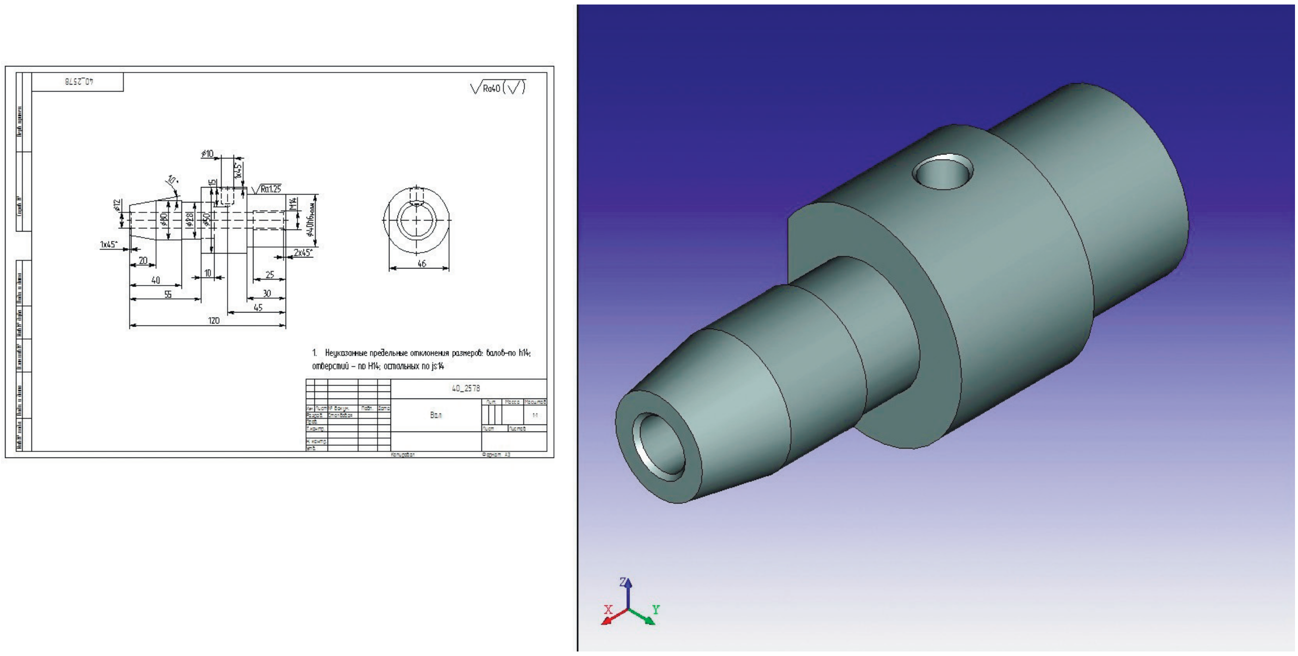

Fig. 7. Scheme for creating a 2D drawing from a parametric 3D model of a part
Рис. 7. Схема создания 2D-чертежа из параметрической 3D-модели детали

"Development of Informatization and the State System of Scientific and Technical Information", which was held on November 15, 2012 in Minsk at the United Institute of Informatics Problems of the National Academy of Sciences of Belarus [22]. When creating the concept, the following work was performed:

1. Data collection on the regulatory framework for the operation of the automation object
2. Analysis of the regulatory framework for the operation of the automation object
3. Development of concept options
4. The choice of a variant of the concept that meets the requirements of the user.

The study showed that the regulatory framework for the introduction of information technology in the educational process of the Sukhoi State Technical University of Gomel as a whole allows increasing the level of information support for students in the framework of existing forms of education (full-time and part-time) [9, 10, 36-40]. However, in order to transfer to a distance learning form, normative documents should be finalized in order to realize the possibility of introducing interactive elements. This will certainly increase the educational effect of the introduction of information technology and the level of personal knowledge and skills of students.

An important issue on the distribution of roles of users of a standard information system for continuing professional education in the field of development and implementation of integrated systems for design and production (TSIO) was considered at the XII International Conference "Development of Informatization and the State System of Scientific and Technical Information" [21]. The conference was held on November 20, 2013 in Minsk at the United Institute of Informatics Problems of the National Academy of Sciences of Belarus. When discussing, the results of the analysis of regulatory documents governing the implementation of the educational function were presented, the basic requirements for the organization of work in the conditions of functioning of the systems, as well as the distribution of roles of TSIO users were identified. Discussion of the role of TSIO users allowed us to draw the following conclusions:

– the Sukhoi State Technical University of Gomel uses TSIO in educational processes (including distance education):

a) continuing education courses organized by the continuing education institute at the university;

b) training students in the study of disciplines related to the development and implementation of integrated systems;

– industrial enterprises and other state organizations of Gomel region use TSIO:

a) in the retraining of managers and specialists in continuing education courses organized by the institute at the university (including distance education);

b) indirectly through young professionals, distributed after graduation.

Despite significant successes in the field of digital transformation, both of CAPP system itself and

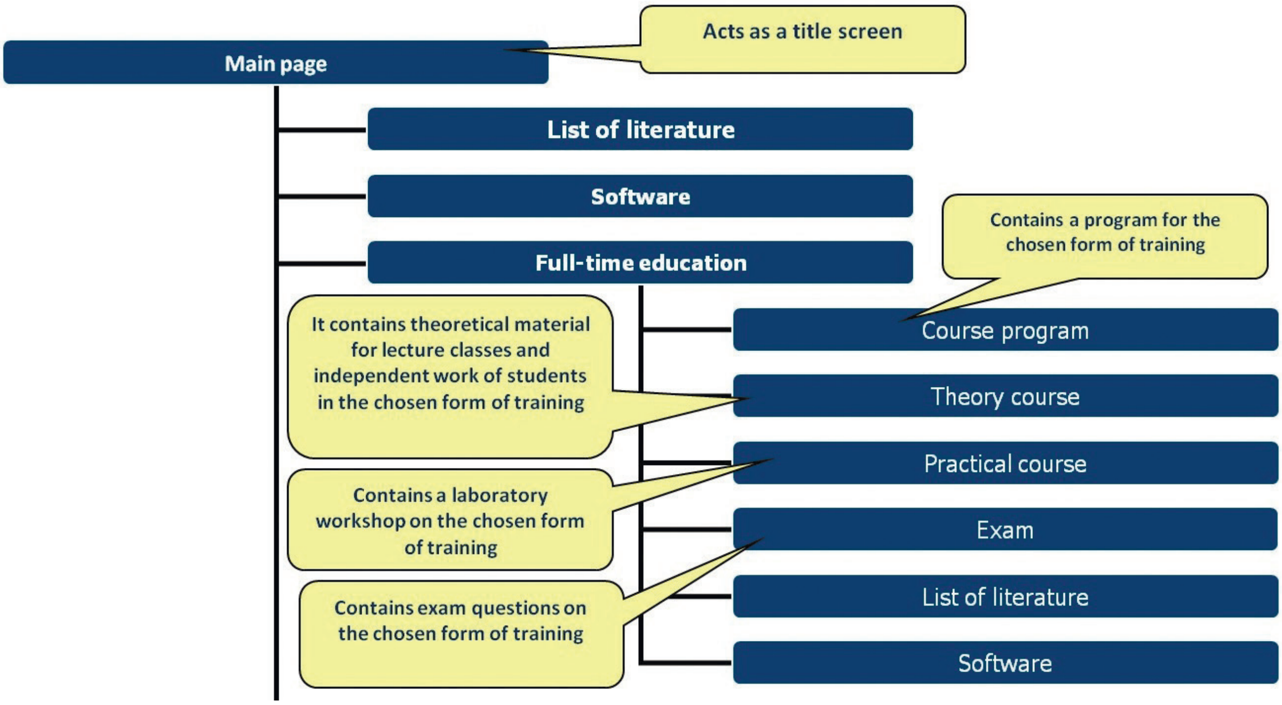

Fig. 8. A fragment of the structure of the electronic educational-methodical complex of the discipline CAPP system

Рис. 8. Фрагмент структуры учебно-методического комплекса по дисциплине «Системы автоматизированного проектирования технологических процессов»

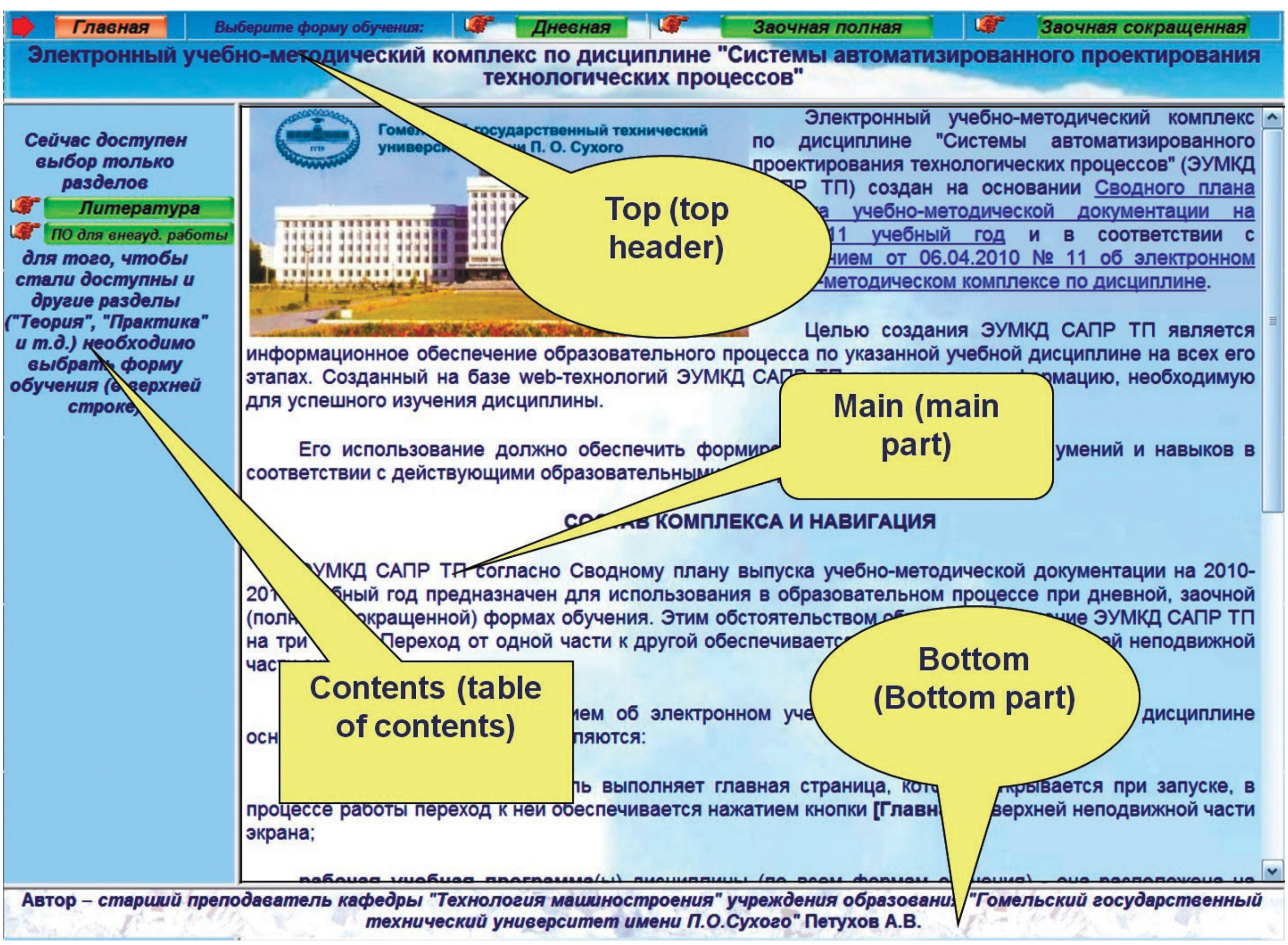

Fig. 9. The structure of the electronic educational-methodical complex of the discipline CAPP system web page

Рис. 9. Структура web-страницы учебно-методического комплекса по дисциплине «Системы автоматизированного проектирования технологических процессов» the teaching of the discipline of the same name, there was one more issue that required careful consideration until 2014. This is a question of an objective assessment of knowledge, skills in the study of discipline [31]. As the study showed, when using the modular rating system for assessing knowledge, abilities and skills (MRS) to solve the described problem, the problem arises of obtaining objective intermediate results for filling out the certification sheets of the current control. This is explained by at least three objective reasons. Firstly, it's rather difficult to break the course so that the deadlines for studying the module coincide with the period of the certification event. Secondly, the midterm control of knowledge, skills and abilities, as well as the protection of the latter in the laboratory module, occur after studying the module, i.e. at a time when students had already begun to study the next. Thirdly, lagging students, in some cases, do not have time to complete or work out missed laboratory work by the time of the certification event and score at least the minimum number of points for this type of educational activity.

However, the experience of using MRS at the stages of ongoing certification in the discipline CAPP system showed that the problems described above can be avoided. The starting point of the decision in this case should be a message not about reporting for the types of training activities included in the module, but about work performed over a certain period, in particular two weeks. At the same time, it becomes possible to constantly monitor students' competencies with the publication of its results in the section "Current knowledge control" of the electronic course of the discipline. The described approach, with all its attractiveness, has one, but a significant drawback. It significantly increases the amount of computational work. This can be avoided by automating the procedure for obtaining an intermediate rating sheet. To this end, an additional special study was carried out as a result of which it was found that initially the following basic requirements were imposed on the MRS information support system:

– comprehensive assessment – the system should provide both an assessment for all types of educational activities and a comprehensive assessment throughout the discipline;

– objectivity – the system should be built on simple, understandable to students and objective criteria that can be numerically evaluated;

– regularity – the system should provide regular (at least once every two weeks) obtaining intermediate results of educational activities of students;

– ease of maintenance – the system should be built on simple and understandable software and ensure normal functioning without resorting to professional programmers [32].

The study showed that the input information used by the system is divided into conditionally constant (the curriculum of the discipline and the numerical values of the accrued rating points by type of academic work and performance assessment criteria) and conditionally variable (class schedule and composition of student groups and subgroups of students for the current academic year).

Based on conditionally constant information, the calculation of standard values of rating points was carried out. The data obtained as a result of the calculation were supplemented by conditionally variable information and used in the formation of the final rating sheet. Thus, when creating the system, comprehensiveness and objectivity of the assessment were ensured.

The regularity of the assessment was provided by the formation of an interim rating sheet once every two weeks. The ease of maintenance of the system was provided by using Microsoft Office Excel as the basis for its construction.

Thus, when automating the procedure for obtaining interim rating statements, the comprehensiveness, objectivity and regularity of the assessment with a significant reduction in the volume of calculations are ensured [31].

The creation of an electronic course in the discipline of CAPP system ensured the availability of basic knowledge and aroused students' interest in research work in this area. Studies conducted in this direction have shown the success of using the electronic course for information support of research work in the study of the discipline of CAPP system [34].

In the 2018-2019 academic year at the Sukhoi State Technical University of Gomel, the first graduation of students in the specialty 1-53 01 01 "Automation of technological processes and production" was carried out. The specific parameters of the specialty and specialization determine that the field of activity of graduates is engineering and instrumentation and the direction of specialization is the automation of technological preparation of production. The training of design engineers with this specialization area includes the implementation of a significant number of course projects. The most important and significant of them is the course project in the discipline "Automated systems for technological preparation of production." The central place in this project is given to the automated design of the technological process of machining the part, that is, the practical use of CAPP system. It is known that course design, as one of the types of independent work of a student, is a solution to an educational or real professional task in the discipline being studied. It helps to consolidate, deepen and generalize the knowledge acquired by students during the study of the theoretical course, with the subsequent application of this knowledge in the complex solution of engineering problems. In this case, the task of providing information on course design is very urgent. One of the ways to solve it is the use of information and communication technologies [33]. The basis of the method is the uses of information support system of course design (ISS CD).

ISS CD provides students with the following opportunities:

– easy, independent of the Internet, access to any information necessary for the implementation of the course project (the student gets into any information source in two “clicks”: the category of information resource and its name);

– a simple way to replicate the system (for this you need to write to the USB-flash drive a folder with an SIO KP of 1.45 GB);

– mobility of work on the project (files with sections of the settlement and explanatory note and drawings can also be recorded on the above-mentioned drive);

– printing (if desired) any information source.

Two years of experience using ISS CD has shown its relevance in the student community. This was facilitated by the fact that, with a small informational addition, the system was also successfully used in graduate design.

Prospects. Currently, there are three main areas in which the digital transformation of the design of technological processes and the teaching of the discipline of CAPP system should and will be developed.

The first area is associated with the introduction of software products that automate the implementation of project management and document management functions. A description of one of these systems, namely T-FLEX DOCs, is given in a workshop on the course "Computer-aided design of technological processes", published in 2015 [25]. It describes the modes of working with documents, files, messages and tasks, and also gives recommendations on using the system to search for objects.

The second direction is the expansion of the use of T-FLEX CAM to obtain control programs for CNC machines.

The third area is associated with the use of 3D models for performing strength calculations.

Conclusion. Significant historical experience in the use of computer-aided design systems in the educational process for the training of highly qualified design engineers in the future guarantees continuous improvement of both the systems themselves and the methods of teaching related disciplines.

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