Aspects of Teaching "Advanced Gears" for Future Mechanical Engineers Within "Bachelor of Sciences" Programs at Technical Universities

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Abstract Innovative development of important mechanical engineering industries necessitates very high demands on graduates of engineering universities who plan to devote their professional activity to gears, specifically: their qualification by the time of graduation, their knowledge, abilities and skills in regard to innovation, and their communication abilities. The present paper analyzes the recent trends and fundamental aspects of higher education in Russia with regard to the successful training of gear experts at a technical university within the Bachelor program. Issues related to the teaching of various courses involving gears within the curricula of mechanical engineers and obtainment of a BS are also considered in the paper. Attention is paid to foreign language (English) competences for future gear experts. Agreement on the valid syllabi for mechanical engineers and requirements specified for graduates by the present manufacturing industry is studied through the example of one of the most sought-after majors in the field of mechanical engineering.

Keywords Gears · Innovation development of production · Teaching gears in technical universities

1 Introduction

As is known, gears find wide application in all engineering spheres, in many cases defining the important technical and economic parameters of corresponding machines and devices. Though gears represent a traditional type of mechanism (cases of the application of gears in the 2nd century BC are known), nevertheless, they have been continuously upgraded [2, 11]. Development of gears and methods

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for their design, simulation and production in the 20th century and further into the 21st century was strongly affected by the introduction of computers.

In accordance with various estimations, the world market for production and consumption of gears increases annually by 4–6%. This explains the interest in gears of scientists, designers, manufacturers and consumers of these products, and also of economists who study the trends in different spheres of production for the purpose of economic forecasts on their development and reasonable planning.

The four most significant markets for gears include the car industry, general-purpose mechanical engineering (including machine-tool engineering, lifting and handling engineering, etc.), the aerospace industry and ship-building.

The largest gear manufacturers in the world are the USA, Japan, Germany, Italy, France and others.

Along with the car industry (representing about 80% of all gear consumption), one of the most significant markets for gears is valve engineering as a part of general-purpose mechanical engineering. In the last 20 years, successful developments have been made in Russia in the field of investigation, production and operation of new drives for pipeline valves that are highly competent with traditional world analogs.

Prospects for further wide application of gears are related to the increase in their load-carrying capacity with simultaneous reductions in mass and overall dimension and cost parameters.

Therefore, innovative development of important mechanical engineering industries necessitates very high demands on graduates of engineering universities who plan to devote their professional activity to gears, specifically: their qualification by the time of graduation, their knowledge, abilities and skills in the field of innovation, and also their communication abilities.

Nowadays, gear experts are required to continuously upgrade the drive equipment, and develop new mechanisms on the basis of already existing gears while accounting for the rapid appearance of new methods for design, analysis, production and testing of gears.

At the present time, there is an obvious contradiction between the necessity to increase the efficiency of an innovative manufacturing system, insufficient rates of reformation of the educational system and low-performing levels of professional competences of engineering experts, a clear indication of the urgent need for development of innovative mechanisms for formation of professional competences as applied to the requirements for training an expert engineer.

Recent trends and fundamental aspects of development of higher education in Russia with regard to the successful training of gear experts at a technical university within the bachelor program are further studied in this paper. Issues related to the teaching of various courses involving gears within the training of mechanical engineers and obtainment of a BS are also considered. Agreement on the valid syllabi for mechanical engineers and requirements specified for graduates by the present manufacturing industry is studied through the example of one of the most popular majors in the field of mechanical engineering—“Design and manufacturing preparation of mechanical engineering production" (DMPMEP) at the Federal State Budget Education Institution of Higher Education "Kalashnikov Izhevsk State Technical University" (Kalashnikov ISTU).

2 Recent Trends and Fundamental Aspects of Higher Education in Russia with Regard to Training Gear Experts at a Technical University Within the Bachelor Program

Changes in the educational system related to the formation of scientific and educational complexes, the extension of paid educational services, and the integration of education and industry are forcing us to reconsider approaches to higher professional education. Let us further consider some statistical data related to higher educational institutions and the number of enrolled students. At present, there are 950 institutions of higher education (IHE) in the territory of the Russian Federation, more than 60% of which have obtained state status. Table 1 shows that the number of IHE has not grown recently.

The recent trends require the development of an educational infrastructure to react flexibly to the changes in the present production specifications. Particular requirements are specified for students of the "Design and manufacturing preparation of mechanical engineering production" major, since this is the exact scope that is subject to extremely rapid innovations in the field of gears. Peculiarities in the efficient progressive development of mechanical engineering production require the creation of a systematic interaction between employers and students in order to result in the accumulation and application of new knowledge and improvement of the process of formation of professional competences.

Orientation of education to the individual professional developments within the system of training and retraining of gear experts for our regional industry illuminates the problem of creating the conditions for activation of self-knowledge, self-development of students and experts, and alteration of their attitude towards their own achievements in the field of professional activity.

The traditional system of professional training of students of the "Design and manufacturing preparation of mechanical engineering production" major is

Table 1 Dynamics of the number of IHE and their students

Indicators	2005	2010	2015
Number of IHE	1071	980	950
Number of state IHE among them	662	578	548
Number of students (in thousands)	6884	5647	5209
Student enrollment (in thousands)	1743	1399	1192
Numbers of graduates (in thousands)	1012	1468	1226

characterized by excessive differentiation, insufficient mobility and variability, doubling of the contents at different stages of education and orientation towards studying specific (sometimes out of date) techniques. Modernization of the professional training of gear experts actualizes the innovative educational process's ability to excel with regard to integration of the subjects and harmonization of their interests. Trends towards training reformation directed at integrating subjects of educational, manufacturing and innovation processes imply the following activities:

- Correction of educational programs (development of the range of additional programs of different education levels and profiles, introduction of elements of multi-profiles and variative training).
- Development of strategic partnership (improvement of practical education, formation of social control, enlargement of the number of strategic partners, provision of homogeneity in manufacturing support).
- Control of education quality (introduction of innovative educational techniques, adoption of international standards of training and development of a system of quality control, quality auditing, organization of new majors in training mechanical engineers, special training of the teaching staff).
- Development of individual trajectories of training mechanical engineers (development of techniques for personal enhancement, formation of models of expert competences and professional and psychological features of the personality, optimization of training terms, mobility and differentiation of training).

Development of the successive professional training of mechanical engineers for the "Design and manufacturing preparation of mechanical engineering production" major implies structural reorganization of the whole educational process, beginning from secondary school and continuing on into professional educational institutions with organizations of scientific research and production engineering activities. The result of implementing the system of enhanced professional training will be an alignment of the training quality with the requirements of the innovative industrial production complex.

As applied to the Udmurt Republic of the Russian Federation, the program of development for training engineering personnel in the field of gears is first related to implementation of the program of development of mechanical engineering and the metal machining industries. Dynamics of characteristics for activity of the industrial enterprises of the Udmurt Republic are determined by the growth of the industrial production index due to the growth in production volumes of such enterprises as "Votkinsky zavod" OJSC, "Izhevsky motozavod Aksion holding" OJSC, "Elecond" OJSC, "IEMZ "Kupol" OJSC, and "Reduktor" OJSC. The rate of growth of the shipped products within the mechanical engineering industry for the last year was 109.5%, and the cost of the shipped products of their own production exceeded 350 billion rubles. The Udmurt industrial enterprises have developed programs of professional improvement for themselves. In 2016, "Sarapulsky radiozavod" OJSC organized various types of education for its 2600+ employees and "ChMZ" OJSC involved about 3600 of its employees. It cost about 8 million rubles to train the personnel of "ChMZ" OJSC. Another enterprise, "Concern Kalashnikov" OJSC, paid great attention to education, and now has its own educational production center, while for the higher professional education, it created strong links with Kalashnikov ISTU [12].

Meeting the requirements for innovative development of the industrial sector of the Udmurt Republic in regard to the professional training of gear experts accounting for enhanced education demands the creation of a principally new educational process for training mechanical engineers. The special terms of this education are: provision of integration of education, science and production, innovative character of content in the training and educational process, competence of the teaching staff and readiness of the students. The personality of a student and his/her potential are the determining factors in the enhanced training, since his/her interest in constant self-improvement in regard to professional activity makes it possible to create the process of efficient generation and the development of competences.

Analysis of availability of gear experts for enterprises has shown that the main problem is in disagreement on the specifications required by employers in regard to the level of professional training of experts and the ability of the educational system to meet these specifications. The specific character of mechanical engineering and its innovative development necessitates agreement as to the contents and techniques of education designed to fit the demands of production and the character of innovations, and consideration of the globalization processes and world achievements. Therefore, generation of professional competences for future gear experts requires introduction of new, activity-oriented educational techniques to be implemented within the integration of education, science and production.

In spite of the variety of investigations dedicated to the problem of the professional training of mechanical engineers, little attention is paid to the development of conceptual fundamentals of the educational process when training gear experts, due to the specifics. There are no investigations revealing the interaction of factors in the professional growth of the expert, reflecting both professional needs and preferences and trends in the development of mechanical engineering. In this regard, determination of the aspects of forming professional competences for mechanical engineers with regard to the enhanced training is very urgent.

The innovative educational complex of the DMPMEP department implies the process of development of student competences with regard to their individual features. It allows for flexible reactions to individual changes in the professional competences of the student, and gives him/her a right to choose his/her own professional educational trajectory, thus providing for a continuously enhanced training of engineers for the gear industry. In order to obtain the qualitative professional competences, it is necessary to provide certain conditions of formation of a future gear expert, one of them being the individual trajectory of accumulation of professional competences.

Analysis of publications has shown that there are several approaches to the aspect of formation of an individual educational trajectory. The most developed approach is the pedagogical one, which interprets individual educational trajectories as a definite sequence of elements within the educational activity. The basis for studying the individual trajectory of the student is the model of directions of achieving the educational standard, when the choice of how to implement the standard depends on the individual features of each student.

The innovative approach to training gear experts implies the development of content in accordance with the professional functions of the employee, problems to be solved and the competence necessary to solve them; for this purpose, the structurization of description components into educational programs is carried out with regard to inter-disciplinary links. Differentiation of educational levels within the multi-level system is based on the development of the various levels of competence achieved by the student. Techniques for the development of competences implement the conditions for establishing the competence experience: consideration of cognitive problems within a professional situation; variability of educational routes allowing creative abilities and individuality to be revealed; increase in the role of individual styles, approaches, and personal systems of the cognitive and practical professional activity of students when passing from one education level to the next.

The infrastructure component of studying the educational trajectory is widely represented in works on models of continuous education, since the idea of continuous education is not a mechanical motion from pre-school to the post-graduate education; it represents a harmonic process of cyclic renewal of the personality at each stage. One can consider here the experience of technopolises, business-incubators and technoparks as the most successful types of integration of science and production within a system of continuous education and training experts for innovative production. Taking into account that, based solely on the optimal combination of three components (educational, scientific and production) within the educational process, one can train a many-sided expert, the development of a principally new, distributed educational scientific production environment for steering experts in the prioritized directions of science and engineering based on innovative techniques of education and deep integration of the scientific, educational and production processes is possible only within innovative educational university complexes [1].

Therefore, when creating the trajectory for training the expert within innovation economics, it is necessary to assess the individual level of development of professional competences of the future mechanical engineer and to choose the proper educational vector. In general, the process of training a gear expert can be presented as stages in a life cycle, in accordance with the model of cycles for intellectual activity characterizing the accumulation of intellectual capital based on obtainment of information and fresh knowledge and the subsequent comprehension of techniques, links and principles.

In the most general case, the life cycle of training a mechanical engineer can be represented as the consequent increment of professional competence through stages of origin, formation, growth, stabilization and recession over the entirety of their time employed within the industry. The stage of origin is characterized by professional self-determination and choice of direction of activity or education. During this period, a person can change across several types of activity or educational institutions in order to choose a more suitable course that allows for self-determination in the range of future works. After determination of the area of professional activity, the subsequent stage of formation involves mastery of profession and acquisition of basic necessary professional competences. An expert achieves a certain level of professional competences, which is determined with regard to the developed indices based on individual assessment of the employee. With regard to the individual abilities of the expert, different versions of passing through stages to achieve a certain level are possible. The following stage is characterized by the growth of qualification, accumulation of experience, and both acquisition of new and consolidation of previously acquired knowledge and skills. A certain limit for improving the skills at a definite level is reached, thus leading to uniform stable work characterized by the stabilization stage. In the case of an absence of positive assessment results for improving the professional level, the regression period occurs, characterized by a freeing of the expert [16].

The process of the consequent passing of different stages of the life cycle implies an assessment of the employees to reveal the potential for development of their professional competences. At the stage of formation of the mechanical engineer at each level, the performed assessment allows for determining the level of starting potential; and in a case of possibility for its increment, it is reasonable to continue the formation process on the next level up. Otherwise, an engineer is passing to the next stage purely by consequence. Similar processes are considered at stages of growth and stabilization and, in the case of the potentials being revealed, passage to the stage of formation of an employee of the next higher level takes place. If the assessment does not give a positive result, the consequent transition to the next stage of the life cycle takes place. At the stage of origin, we deal with the professional self-determination of the future mechanical engineer and the primary study of the specific character of gears. At this stage, the enterprise needs to unmask the presence of the professional affection of pretenders and to choose possible candidates for training. During the formation process, the choice of the most suitable candidates takes place on the basis of assessment. Adaptation and accumulation of experience at the stage of growth gradually lead to stable work; the performed assessment will allow for revealing the potential possibilities of making decisions about promotions and the circulation of employees. The proposed approach of considering the employee within the stages of the life cycle implies determination of possible professional levels and the development of requirements for each level with respect to the stages of the lifecycle within the model of professional competences.

For each stage of accumulation and formation of professional competences of the mechanical engineer, it is necessary to make up a list of courses of fundamental, humanitarian, practical and profile (special) cycles. At different stages, the education should involve both basic chapters of these courses and specially developed "advanced" chapters of the educational process. In certain cases, special educational modules consisting of several inter-related courses are developed. The practical cycle should be related to the real design of gears, and it should encourage the development of business, designing and manufacturing activity. When investigating the issue of the formation of professional competences within the study of basic skills at the university, the activity that will further turn into production creativity, possibility and a desire to develop innovative production must be determined.

3 Studying "Advanced Gears" Within MMS and Machine Design Courses for Future Mechanical Engineers

Let us consider the content of courses that include the study of gear through the example of one of the most sought-after majors at Kalashnikov ISTU related to the training of mechanical engineers. This major within the Bachelor program is called "Design and manufacturing preparation of mechanical engineering production" (DMPMEP). The professional activity of the graduates of this major is often related to the design and manufacture of various gears and gear mechanisms.

The typical structure of the **Theory of machines and mechanisms (TMM)** course, as a rule, includes two parts related to the design of gear mechanisms: the geometric synthesis of toothed gearing, and analysis and synthesis of gear trains. Gear train force analysis is included in the investigation of dynamics of a whole mechanism made by Assur groups. Some University course syllabi contain the issues related to Wildhaber-Novikov tooth profile design, bevel gears, worm gears, gears with cycloidal profiles, and strain wave gearing [4, 8, 14].

The introductory part of the corresponding section provides basic definitions and a classification of the simple gears according to various criteria, such as: type of gear ratio, location of the gear axes in space, shape of a tooth profile, shape of a tooth line, shape of a generating gear tooth surface, and others.

Within the study of the *geometric synthesis of toothed gearing*, the fundamental law of gear-tooth action is derived from the basis of the higher kinematic pair theory. The law has its two statements, one for analysis and one for the synthesis of a gearing. The courses mostly focus on the involute gearing, when each mating profile is generated as the involute of a circle. The mathematical equation of the involute, as well as the properties of the involute curve and the involute gearing, is investigated in detail.

During the practical lessons, students learn to identify the basic dimensions of the teeth and the qualitative parameters of gearing in the course of solving problems associated with tooth thickness along the arc of a circle of arbitrary radius, the lengths of the arc of contact and the path of contact, the contact ratio, and the relative sliding ratio.

The geometry of the teeth and all gear parameters are defined by the gear manufacturing process. The TMM course considers two principle machining manufacturing processes, including gear forming (form milling, broaching) and gear generation (milling with a hob, gear shaping with a pinion-shaped cutter, gear shaping with a rack-shaped cutter). By virtue of clarity, the gear shaping with a rack-shaped cutter is the most popular in the study of manufacturing processes. In this case, generation commences by aligning the rack's reference line with the pitch circle of the gear blank about to be cut. A cutting rack may be displaced transverse to its reference line from the pitch diameter of the gear in order to avoid teeth undercutting in the course of generation.

During the practical lessons and labs, students explore a way to eliminate the possible undercutting of a tooth due to the profile shift of a cutting tool. After doing this, students are expected to be able to calculate the parameters of engagement of modified (corrected) gears, such as the operating pressure angle α_w and center-to-center distance a_w with zero backlash, tooth thickness along the arc of the pitch circle, the diameter of dedendum circle d_f, the diameter of addendum circle d_a, and others. During calculations carried out for the purpose of learning, it is necessary to verify the correctness of selecting the profile shift coefficient x so as not to let the tooth crest thickness become too thin. Students are given an idea of how to calculate coefficients suitable for a range of operating criteria, including the use of graphical methods.

The profile shift coefficient x, as one of the most important geometrical parameters, must be controlled when cutting teeth. For the indirect (and quite accurate) measurement of the shift coefficient, the instrumentally controlled dimensions can be used, which depend on x and, at the same time, allow for direct measurement through the use of standard or special tools, such as the vernier caliper, the gear-tooth caliper, or special templates. Wherein, depending on the method used, it is controlled, those dimensions are: the tooth height to the chord $\bar{h}_{ay}$, tooth thickness along the chord $\bar{S}_y$ (both used to determine the actual values of s, or x); constant chord $\bar{S}_c$, span measurement W.

Thus, in the process of studying the theory and applying the relevant knowledge in practice, students acquire skills related to the design of involute gears cut by a standard tool rack. When making the project, the students also learn to make drawings of the involute gearing.

The aim of the *kinematic analysis of toothed gearing* is to determine the angular velocities of gears and gear ratios. The first topic of the corresponding section is to examine the kinematics of simple and compound gear trains with gears rotating about fixed axes. In a multi-stage gear train, the number of stages is equal to the number of meshings, its overall gear ratio being defined as the product of the ratios of series-connected stages.

Gear ratio i is defined both algebraically and graphically. In the latter case, a method of calculation is based on the construction of the velocity triangles. This method is also used for kinematic analysis of epicyclic mechanisms, for which angular velocity diagrams are built to scale.

To determine the gear ratios of planetary and differential gear trains, Russian courses mostly employ a method of motion inversion (an analog of tabular method) and formula method (R. Willis's method).

Students apply the Willis formula in two alternative forms. The general formula view is useful for describing the kinematics of almost any planetary gear:

$$i_{ab}^{H} = \frac{\omega_a - \omega_H}{\omega_b - \omega_H}$$

In the particular case in which, for example $\omega_b = 0$, the Willis formula takes the form: $i_{aH}^{b} = 1 - i_{ab}^{H}$. The first formula is more versatile and is suitable for any planetary or differential gear trains, while the second is used only for the stages that include fixed-axis gears.

The study material focuses on the kinematic analysis of closed-loop gear trains in which members of the differential gear train form a rigid kinematic constraint in the form of a circuit, closing the differential stage. Some courses pay attention to the complex combined mechanisms, in particular, bi-planetary gearboxes.

A *gear mechanism design* comprises the choice of its kinematic scheme and selection of its parameters. The main condition for the design of a gear mechanism is to provide a predetermined gear ratio. A typical TMM tutorial focuses on the problem of selecting the number of teeth.

When selecting the number of teeth in the planetary and differential mechanisms, one must take into account the conditions of alignment, assembly condition, and some others. To avoid getting too large or too small a number of teeth, the design conditions are shaped as proportions. Formulae expressing design conditions form a closed non-homogeneous linear system of algebraic equations that can be solved for the numbers of teeth according to Cramer's Rule or by other means.

Analysis of the results of all kinds of TMM-relevant learning activity of students allows for identifying the most common difficulties and errors. These include, in particular, errors in counting the number of moving bodies within a complex gear train; determining the number of two-degrees-of-freedom kinematic pairs; identifying idle degrees of freedom; determining the number of one-degree-of-freedom kinematic pairs; kinematic analysis of the gear train and finding the angular velocity of the gears and the linear velocity vectors of teeth points; sign detection for gear ratios; determining the gear ratio of the differential stages of gear trains (for example, using the Willis method); determining the sizes of the tooth; analyzing the geometry of the involute gearing; determining qualitative parameters of gearing, and others [9]. A properly planned educational process helps to reduce the number and frequency of these errors.

The successful acquisition of competences by students, related to the analysis and design of gear trains in the course of TMM, becomes possible provided that the syllabus contains practical lessons, labs and a course project, the latter being one of the most important types of learning activity, giving students the possibility of applying the knowledge acquired in a practice problem.

The syllabus of a **Machine Design** course also provides implementation by the students of a course project to design a drive unit with a gearbox as its most important component. At the initial step of calculation, the kinematics and force parameters of a drive unit are determined. Then, the material for the gears is selected, including determination of the hardness and heat treatments and of the allowable contact and bending stresses. Thereafter, the design calculation of the gear train geometric parameters is performed; the results are tested according to the determining calculation. This allows for calculating the loading of the gear shafts and making a drawing of the gearbox. Furthermore, the design scheme is established for the gear shafts and a determining calculation for bearings is carried out. Typically, in the course of the project, the largest amount of computational and other operations falls on the gear train design.

In general, the scope of knowledge related to gears obtained within the professionally-oriented courses is wide enough, which is why its versatile analysis is beyond the area of the present paper and deserves its own thorough individual study.

Gears in this or that form are studied within several other courses, for instance, Material Science, Strength of Materials, Advanced Techniques in Mechanical Engineering, etc. When finishing the Bachelor program, the mechanical engineering graduate should possess a clear understanding of the place and role of gear mechanisms within advanced manufacturing and mastery of definite skills for designing and analyzing various gear-based mechanisms.

Let us consider another aspect which is no less important within the training of an in-demand mechanical engineer given the present state of international and manufacturing activity—knowledge of a foreign language (English) [6, 7].

In 2001–2002, ten leading world engineering universities took part in a research (SPINE—Successful Practices in International Engineering Education) [5]. Partner universities in this research were, in particular, the Massachusetts Institute of Technology (USA), Queen Technical University (Sweden), Imperial College (Great Britain), and the Federal Polytechnic School in Lausanne (Switzerland). The purpose of the SPINE project was a comparative analysis of courses of engineering education in different countries, assessment of their quality, and revelation of the concepts, methodologies and means of education proving their efficiency in accordance with the chosen criteria. The review was proposed to 543 professors, 1517 engineers and managers, and 66 rectors, deans, and other supervisory personnel. Means of quality and quantity analysis were applied to study: the structure of universities, the educational process, international collaboration, collaboration with industry, the competences of an engineer, and the authority of universities. An engineer should possess the following common professional competences:

- presentation skills,
- leadership abilities,
- skills of project management,
- capability for teamwork,

- capability for acquiring common (general culture) education,
- language competence (not English),
- language competence (English),
- communicative competence,
- social competence,
- competence in the field of finance,
- marketing competence,
- legal competence.

Emphasis was on a high rank of communicative and language competences—experts of all categories gave the rating 5.4 out of a possible 6 for these competences. Assessment of the real situation gave 4.0–4.5 for communicative competence and 4.4–4.7 for language (English) competence out of a possible 6. It was concluded in the project that communicative and language (English) competences, along with the capability for teamwork, presentation skills and the development of leadership characteristics, are related to the most important general professional competences [5].

In accordance with the review of 100 engineers employed in Australian industry, more than 70% of their working time was spent dealing with documents [15]. The real object is preceded by its ideal image represented by explanatory notes, schemes, drawings, and mathematical calculations. Globalization of markets requires that all the developed documentation (including drawings) be made understandable and easily translated into any language.

The portions of course syllabi that relate to gears are among the most difficult to learn and require significant classroom time. A significant reduction in contact hours during the transition from the Russian higher school to a two-level model will, in our opinion, have an effect on the categorization of the students' team into two unequal groups. The first one is represented by the conditionally average and weak students who, without going deeply into the essential questions, will acquire receptive skills only.

The more talented and, most importantly, motivated students will form a second, smaller group. To acquire the relevant competences, they will have to make additional efforts in the process of learning, self-study, attending electives, performing research projects, participating in competitions at various levels, and participating in professional societies. The objective of the Technical University is to provide conditions for implementing the potential of this category of students. Its positive examples are considered to be of student participation in international competitions in MMS (with the obligatory inclusion of the tasks related to the gearing) [9, 10] and in the activities of the IFToMM [3].

The most active students comprising the second group are more likely to dedicate their professional activity to scientific research and project engineering directly related to gears at advanced manufacturing mechanical engineering enterprises.

4 Analysis of Agreement on Valid Syllabi for Mechanical Engineering Students and Requirements Specified for Graduates by the Manufacturing Industry

One of the most sought-after majors for mechanical engineering graduates is the above-mentioned "Design and manufacturing preparation of mechanical engineering production." Bachelors for this major are successfully trained at Kalashnikov ISTU.

Analysis of types of professional activity allowed for identifying five variable blocks of professional training with the necessary professional competences for the workplace: project design, manufacturing, operation and maintenance, scientific research, and management and control; it also facilitated grouping them into two main blocks of training: project design and innovation manufacturing [13].

Such identification provides an opportunity to define the courses within a syllabus in accordance with the professional competences necessary for the workplace; their set is chosen by the university, together with an employer with regard to the advanced object-oriented training of Bachelors.

The syllabus for training the experts in the above-mentioned major implies various types of education (lectures, practical and laboratory works, term papers and term projects, etc.) for more than 30 courses within all five blocks.

One of the methods for evaluation of an agreement on syllabi and requirements specified for graduate-engineers by manufacturing enterprises is the survey of graduates who now successfully work for modern mechanical engineering enterprises. The review involved graduates who obtained the B.S. degree in the considered major in 2004–2015 and whose professional activity is in one way or another related to investigation, development, production, testing and operation of gears and gear-based mechanisms.

70% of respondents found their job related to their major as far back as in their time studying at the university. All the rest found their job immediately after graduation from the university. None of the respondents answered that they had had difficulties in finding a job or that it took any significant amount of time to find a good job.

Respondents related their professional activity to one or several of five blocks:

- A project design—53%
- B manufacturing—46%
- C operation and maintenance—7%
- D scientific research—30%
- E management and control—15%

46% of respondents emphasized that the knowledge obtained during their study in the Bachelor program was enough to commence professional activity successfully. 54% said that it was not enough, and that that was why they had decided to start their MS programs in the same major immediately after graduation from the Bachelor program.

In general, the level of training offered by the experts in the "Mechanical engineer" major at the DMPMEP Department of Kalashnikov ISTU satisfied 85% of the respondent graduates.

One of the questions posed to the graduates was: What theoretical knowledge and practical skills did you lack at the beginning of your professional activity? Almost all of them answered that theoretical knowledge was enough, but they lacked a significant number of certain practical skills in the development of manufacturing processes, in work with engineering and design documentation, in work with metal working equipment, and in practice writing down the programs for CNC machine-tools.

Knowledge in the field of gears obtained when studying for the Bachelor program was enough to commence professional activity for 77% of the respondents. 11% answered that the insufficient volume of knowledge was completely replenished during their further study in the Master's Degree program; and another 12% noted that their professional activity was not so closely related to gears, so it was hard for them to answer this question for sure.

After that, the graduates were offered the opportunity to assess the quality of teaching for practically all professionally-oriented courses from the point of view of their validity and applicability within their professional activity on a scale from one to ten (0 was for unsatisfactory, 10 was for maximum useful courses). Results of this assessment are given in Table 2.

Among all of the above-enumerated courses, the most important ones from the point of view of becoming an engineer and an expert in the field of gears proved to be (in descending order of priority):

1 Machine parts (Fundamentals of machine design)
2 Theory of mechanisms and machines
3 Mechanical engineering technology
4 Accuracy rating. Metrology, standardization and certification
5 Strength of materials
6 Material science
7 Methods for computer-aided design.

In general, the results of the review showed a good agreement on the syllabus for training mechanical engineers at the "Design and manufacturing preparation of mechanical engineering production" Department. However, the results given in Table 2 indicate the necessity for continuous monitoring of the validity of these aspects of those courses, and the necessity of paying greater attention to acquiring practical skills for future professional activity.

Table 2 Results of assessment for the quality of the obtained knowledge from the point of view of their validity and applicability within real manufacturing conditions

Name of the course	Average value
Methods for computer-aided design	9.57
Metrology, standardization and certification	9.43
Accuracy rating	8.86
Mechanical engineering technology	8.64
Machine parts (Fundamentals of machine design)	8.57
Advanced techniques of machining and assembly	8.46
Manufacturing tooling	8.46
Computer science	8.43
CAD of manufacturing processes	8.42
Systems of computer-aided engineering analysis	8.31
Fundamentals of mechanical engineering	8.29
Design of blanks in mechanical engineering	8.29
Material science	8.21
Introduction to professional field of work	8.17
Computer-aided methods for solving engineering problems	8.09
Computer-aided practice of mechanical engineering	8.00
Techniques for manufacturing processes	8.00
Theory of mechanisms and machines	7.86
Quality management	7.73
Programming languages	7.64
Strength of materials	7.57
Algorithm development and applied programming	7.38
Automation of manufacturing processes	7.36
Fundamentals of logic control	7.33
Mathematical modeling of processes in mechanical engineering	7.14
Theory of computer-aided control	7.00
Microprocessor systems in control of manufacturing objects	6.90
System analysis and decision-making	6.25
Electronics and microprocessor engineering	6.22
Control of objects and systems	6.13
Control of discrete systems	6.00

5 Conclusions

Nowadays, gear experts should continuously improve the machinery, and develop new mechanisms on the basis of already-existing gears, accounting for the rapid appearance of new methods of design, analysis, production and testing of gears and gear mechanisms. Within the advanced innovative development of gear production, strict requirements are specified for graduate engineers who plan to devote their professional activity to gears; these requirements imply the development of high skills and abilities, innovative knowledge, and communicative capabilities by the time of their graduation.

Obvious contradictions between the necessity to increase the efficiency of activity of an innovative manufacturing system, insufficient rates of reformation of the educational system and a low-performing level of professional competences of engineering experts allow for stating the urgency for the development of innovative mechanisms for forming professional competences as applied to requirements for training an expert engineer.

Analysis of the contents of different courses related to gears within the training of mechanical engineers in the Bachelor program shows a good fundamental theoretical preparation of future gear engineers.

Results of the review carried out for graduates of one of the most sought-after majors, "Design and manufacturing preparation of mechanical engineering production" at Kalashnikov ISTU, indicate good agreement on the valid syllabi for mechanical engineers and requirements specified for graduates by the present manufacturing industry. Nevertheless, results of the review revealed the necessity for continuous monitoring of the validity of aspects of those courses, and the necessity of paying greater attention to acquiring practical skills for future professional activity.

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