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JANUSZ POBĘDZA*, ARTUR GUZOWSKI*

INNOVATIVE APPROACH TO POSTGRADUATE EDUCATION IN THE FIELD OF FLUID POWER TECHNOLOGY

INNOWACYJNE PODEJŚCIE DO KSZTAŁCENIA PODYPLOMOWEGO W DZIEDZINIE TECHNOLOGII NAPĘDU HYDRAULICZNEGO I PNEUMATYCZNEGO

Abstract

The article presents the developed, innovative model of postgraduate education in the area of fluid drive and control technology, launched in the Cracow University of Technology. The program of postgraduate studies was elaborated in accordance with the CETOP guidelines. Characteristics of education on hydraulic and pneumatic systems are presented together with the proposed model of studies and its innovative components.

Keywords: education, fluid power systems, CETOP

Streszczenie

W artykule przedstawiono opracowany i uruchomiony na Politechnice Krakowskiej innowacyjny model kształcenia podyplomowego z napędów i sterowania płynowego zgodny z wytycznymi CETOP. Pokazano charakterystykę kierunku, zaproponowany model studiów oraz jego innowacyjne elementy, zweryfikowane w zrealizowanych już dwóch edycjach zajęć.

Słowa kluczowe: kształcenie, napędy i sterowanie płynowe, CETOP

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* PhD. Janusz Pobędza, MSc. Artur Guzowski, Institute of Machine Design, Faculty of Mechanical Engineering, Cracow University of Technology.

1. Description of post-graduate courses

Fluid drives and fluid power control systems are an important group of devices used in machines, vehicles and installations. They include both hydraulic and pneumatic drive systems and are widely used in numerous installations in various branches of the industry: from metallurgy, mining, manufacturing systems, materials handling, civil engineering and road construction, through extractive industry, fire-fighting installations, to mobile machines and vehicles, robots, manipulators, tools, ships, aeroplanes, as well as in agriculture, forestry, in food processing, pharmaceutics, right to hospital, rehab and recreational facilities.

This wide diversity of industries that use hydraulic and pneumatic systems means a wide range of service conditions and responsibilities of personnel operating those drives and control systems. A relatively small group are those employed in companies engaged in the design and manufacturing of hydraulic and pneumatic elements. More people are involved in the design or upgrading or retrofitting of complete systems using fluid power drives, whilst the largest group will be responsible for operation, maintenance and servicing of those systems.

The need arose, therefore, to develop specialist courses for technical university graduates [6, 16], who encounter fluid drives and control systems in the course of their engineering career because the knowledge of their structure, operating principles, work characteristics and troubleshooting are necessary so that processes and mobile machines and vehicles remain operational. The need of continuous learning to acquire new expertise in novel technologies is of particular importance, creating new potentials in the field of design and operation of drive systems based on fluid drives and fluid power control systems.

Hence, we offer mobile degree courses in the field of fluid drives and fluid power control systems, which are intended to cater for the needs of operating engineers, design engineers, servicing personnel or other specialists, consultants and those selling elements.

Prior to development of the course syllabus and throughout the process, several panel consultations were held with representatives of companies that manufacture and sell hydraulic and pneumatic system components as well as people entering the labour market: students and technical university graduates. During those consultations the fact that was emphasised was the need for extensive practical training alongside theoretical backgrounds and for the thorough study of operating principles of particular elements and systems such that those attending the course should be able to assemble, set and adjust, take measurements and regulate the investigated systems.

The developed syllabus and teaching materials provide the background for a 1-year post-graduate course in the field of fluid drives and fluid power control systems, though they may also be used during the 2-cycle courses or even at senior years of the 1-st cycle degree programmes. Alongside the issues included in the syllabus, extensively discussed with the representatives of industry, the curriculum contains novel forms of classes involving the development of mobile course subjects and incorporating practical training through visits in factories and plants associated with manufacturing of hydraulic and pneumatic system components [4].

Present-day hydraulic and pneumatic drive system components are equipped with automatic control systems of which complexity and technological level are constantly improving. Hydraulic and pneumatic elements with electromagnetic control features are of particular importance, which allow for the design and construction of mixed systems:

electro-hydraulic and electro-pneumatic systems. Integration of these techniques gives us systems featuring high precision, fast response and offering the possibility to implement most intricate and complicated functions. It is required, therefore, that the syllabi of the post-graduate programmes in the field of fluid drives should incorporate those aspects and hence they include such subjects as electro-hydraulics and electro-pneumatics.

The post-graduate course includes lectures and lab classes, where, after receiving instructions, students perform the assigned tasks, process the results and prepare the reports. During the lab classes, a major focus is put on practical expertise in the field of design and construction of hydraulic and pneumatic system components, and the students are encouraged to disassemble and assemble the components, describe their operating principles, design and configure the basic electro-hydraulic and electro-pneumatic control systems. When presenting the proposed lab classes, we considered their universality and possibility of implementing similar solutions by other institutions offering the post-graduate degree courses in this area [14, 15].

"Mobile" course subjects, incorporated in the syllabus, are of particular importance, involving the designed and engineered unique system for remote experimenting through the available mobile devices: laptops, tablets, ipads, smartphones [6, 7]. Students who learnt about the system components during the regular class are encouraged to complete selected laboratory exercises by the remote technique, thanks to the mobile platform and using the Internet. They are able to cover such aspects as activating, experiment planning, experimental procedure, visual observation via an installed camera, importing the saved operational parameters and, on that basis, they work out the characteristic of the investigated object and the drive system and prepare a report on the completed laboratory task. Alongside the innovative form of class, the mobile platform allows for access to the database of teaching materials and control tests, using the portable devices available to students.

A further argument for this format of studies is the possibility of students' obtaining their competence and professional certificates in the field of fluid drives and control systems on the European market because the contents of theoretical and practical classes cover all aspects stipulated in the CETOP (European Oil Hydraulic and Pneumatic Committee) standards [2, 9], enabling them to apply for the certificate of competence CETOP passport, proving the given level of competence in the field of hydraulics and pneumatics.

2. Post-graduate study plan

With a view to developing a program of postgraduate education in the field of fluid power technology, four discussion panels, dedicated to this subject, have been carried out. The participants of those meetings were representatives of various social groups, representing both the technical universities, manufacturing plants and potential study participants. In addition to the presentations and discussions, in the framework of completed panels, a survey has been carried out, which allowed us to define the scope of knowledge and competencies identified to be achieved during the planned postgraduate studies. To obtain representative results, a survey was conducted among people with different professional experience, education, and in different age groups. In formulating the survey questions and in the data processing, the AHP (Analytic Hierarchy Process) method was used [1, 3, 11].

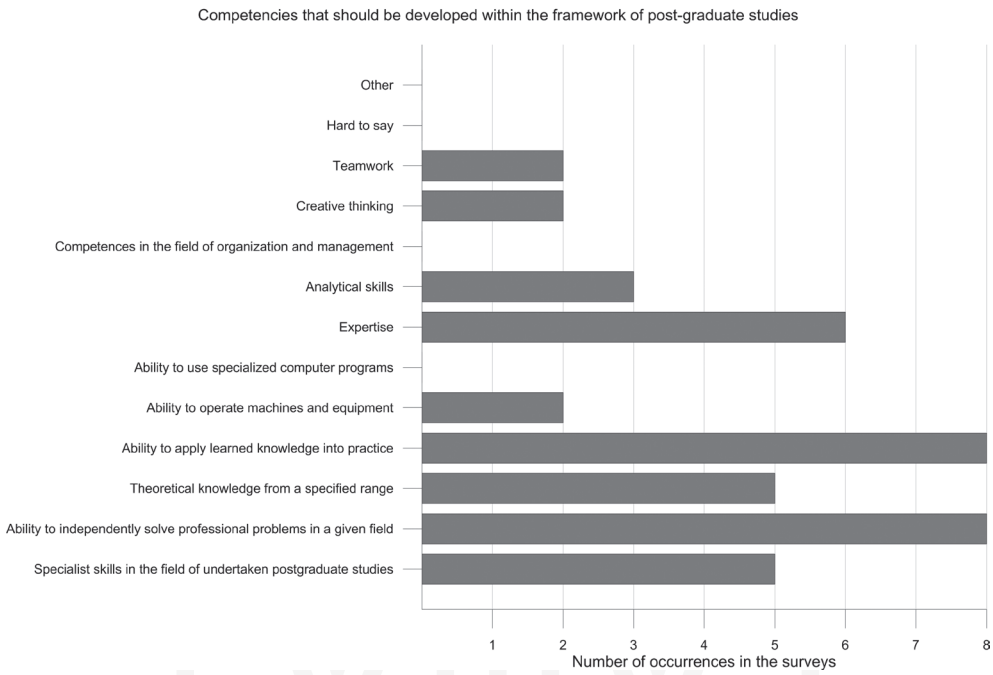

Fig. 1. Competences of post-graduate students identified in the survey [13]

Fig. 1 shows exemplary survey results, specifying the expected competencies, acquired during postgraduate studies in fluid power.

In developing the program and the schedule of postgraduate studies in fluid power drives technology, the following topics have been taken into consideration:

- defining group of recipients for whom post-graduate studies are planned,
- elaboration of questionnaires for candidates, allowing the determination of their expertise and expectations,
- a reference to the practical experience of current technical graduates,
- determination of significance of postgraduate studies for people already working in the hydraulic or pneumatic industries and wishing to expand their knowledge,
- great emphasis on the important skills sought by the industry: the ability to selection of components and subsystems, knowledge of methods of systems design and their assembling and maintaining,
- taking into account the level and the minimum knowledge needed for a participants of mobile postgraduate studies, which will achieve the goal of CETOP certification.

Basing on the requirements of the Minister of Higher Education, the framework plan of the post-graduate course "Fluid drives and control" was developed and approved by the Board of the Faculty of Mechanical Engineering of the Cracow University of Technology on 26th June 2013 [5]. The post-graduate course takes two semesters and covers the following modules:

- Hydraulics,
- Pneumatics,

– Electro-hydraulics,
– Electro-pneumatics.

Alongside theoretical classes, practical training is provided in the form of study visits in four companies, covering 12 teaching hours per one course subject. The course provides instruction in the form of:

– Lectures supported by multi-media presentations,
– Study visits to companies and plants,
– Lab classes and projects using the mobile platform,
– Practical lab classes with the technical support provided by university staff members.

3. Innovative features

3.1. Mobile facility

When developing the plan of studies, special effort was made to make the course innovative. Such elements as collaboration with the industry and experimenting using the remote techniques were most welcome by the post-graduate course students and candidates.

Study visits to companies and plants, provided in the curriculum, are an attractive form of contact with well-prospering companies in the fluid control branch. Students are able to learn about the manufacturing technologies of system components, quality control and customer service. They will then reproduce the management and production patterns in their own companies or at their workplace. It is worthwhile to mention that such visits are impossible to arrange by individuals or average businessmen because most companies are focused on maximising their efficiency and performance and the need to spare one employee so that he could take care of the visitors is an unwelcome interruption. On the other hand, organised groups of students, having studied the subject and acquired the expertise, are acceptable to most companies. That is so because communication with people knowing the specificity of products manufactured by the company is much easier, besides, there is a strong belief that amongst those students might be potential customers and users of the manufactured components.

An innovative feature is the option of remote experimenting via the mobile platform, within the framework of the course. This form of class ensures the involvement of each course participant. The time required by an individual student to complete the task is not limited, hence, the student is able to complete the lab exercise no matter what his level of expertise and professional experience. This form of class does not restrict the user, they can do more than merely test the predetermined inputs or settings of control parameters, and they are able to observe the system's behaviour over a wide spectrum of parameters [10].

The structure of the remote control system of the laboratory stands is presented in Fig. 2. The user, via a remote control device (tablet, laptop, PC) with specially designed software, can connect to the web server. This server, in addition to managing all functions of the educational platform, communicates with all devices (xPC computers and cameras) directly correlated with laboratory stands. The main role, in the control of the research

station, performs computer (xPC Target), working in the real-time system. Multifunction analogue I/O board, installed in this computer, allows both to send control signals to the stand components as well as a collection of measuring data from system transducers.

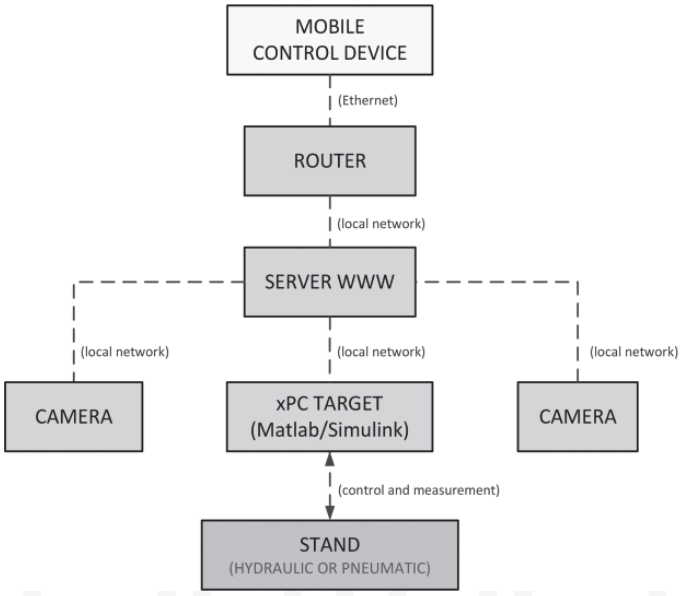

Fig. 2. Diagram of the remote control system of laboratory stand

Within the framework of existing activities developed and launched two stands with remote operation, one of the load-sensing hydrostatic drives, the second with pneumatic rodless cylinder positioning system. For each of the stand, an array of variables has been formulated, which is used to exchange information between used devices in two directions, whereas cameras give the user a continuous preview of stand operation.

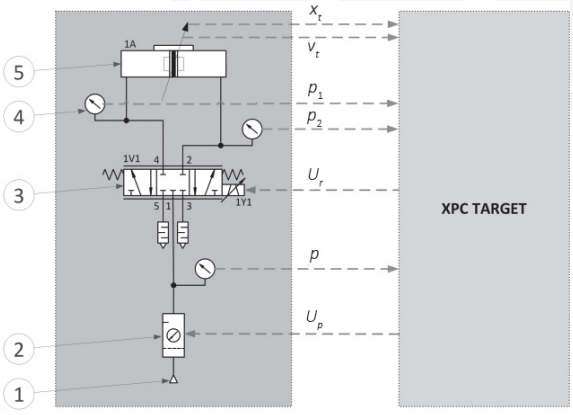

Fig. 3. Diagram of a remote-controlled pneumatic stand: 1 – compressed air connection, 2 – pneumatic service unit, 3 – proportional valve, 4 – pressure transducer, 5 – cylinder

Fig. 3 shows a pneumatic stand with rodless cylinder controlled by proportional directional valve. In this system, control signals are: U_r and U_p – control voltage for proportional valves (directional valve and reducing valve), while the measured values are: x_t, v_t – cylinder displacement and velocity respectively, p, p_1, p_2 – pressure in different points of the system.

Exercise can be implemented both in the open loop control system and close loop control system. In the open loop control system, the student can study the system response to various input signals: step, sinusoidal, rectangular, sawtooth. In turn, for the close loop control system, cylinder positioning or velocity regulation could be tested.

Fig. 4 shows the tablet display used in taking measurements in the laboratory facility. Basing on the camera images, the user is able to observe the real-time behaviour of the actuator and to monitor the impacts of changes in control on the registered operating parameters.

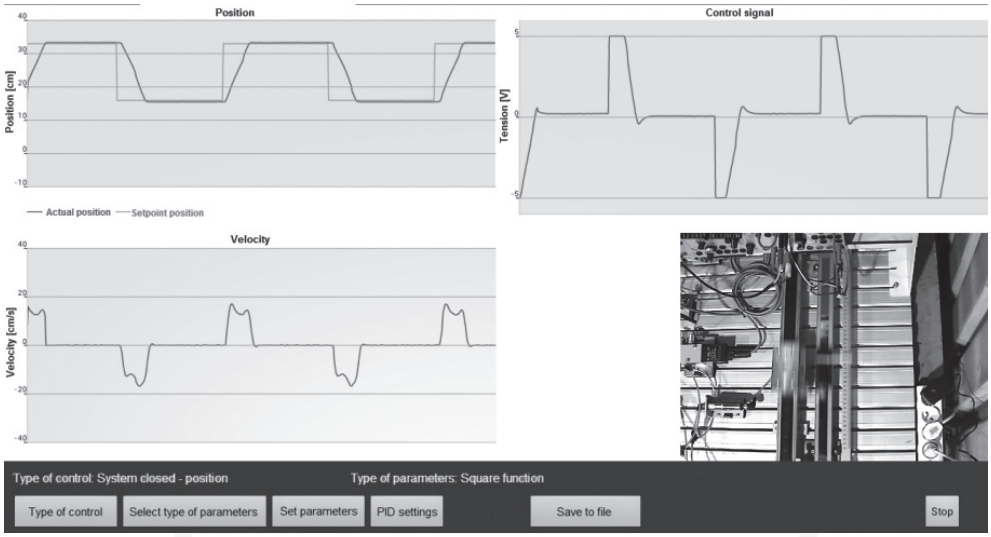

Fig. 4. A view of the tablet display during the lab exercise using the mobile platform

Lab classes in this format, supported by theoretical backgrounds, are easy to assimilate and can be implemented from any place whatsoever, provided there is an access to the global network. The aspects taught to the students can be modified to a certain extent and adjusted to the students' needs. A discussion of real problems involved in operation and maintenance of those systems, which the students have encountered, makes the class more attractive, catering for the needs of both course students and their employers.

A portion of the lab course involves the task of solving problems to be completed in small groups, using the available fluid system components. That inspirits team work, encouraging students to formulate the results based on joint work.

3.2. Mini-projects

The objective of mini projects, placed on a mobile platform, is to acquaint the participants of postgraduate studies with the methods of designing hydraulic and pneumatic systems. In these projects, students use both the calculation formulas of fluid drives and also knowledge available on web pages. A selection of the elements needed to construct a hydraulic or pneumatic system is implemented on the basis of catalogues of components and subassemblies

manufacturers. Tool implemented on a mobile platform allow for assessing the performance of the project and making modifications. In addition, mini projects are intended to prepare the participants of postgraduate studies to more accurate and sophisticated calculations of hydraulic and pneumatic systems containing determination of efficiency, flow resistance in pipes, pressure losses on the valves [12]. For the realisation of mini projects, a special application for Android and Windows systems has been developed.

The proposed tasks include some examples of calculation, which take into account the working conditions and the physical parameters of linear and rotary motors used in both hydraulic and pneumatic drives. In the pneumatic design, the selection of cylinder is presented, as an actuator that converts the energy of the compressed gas into mechanical energy of linear motion. While the design of hydraulic system includes two motors that convert energy of the liquid into mechanical energy of the snowmobile's wheel rotation.

Mini-project – Pneumatics

The aim of the projects is to acquaint the students with the subject matter of system design, including the selection of an actuator- a hydraulic cylinder (a power drive) of which operating parameters must be such that it should behave in the prescribed manner (Fig. 5). The course attendant, as a user of the application, is expected to calculate the following parameters:

- effective force induced on the piston rod Fc,
- theoretical force on the piston rod Ft,
- supply pressure *p*,
- piston velocity in both directions *v*,
- selection of the piston and rod diameters (*D* and *d*).

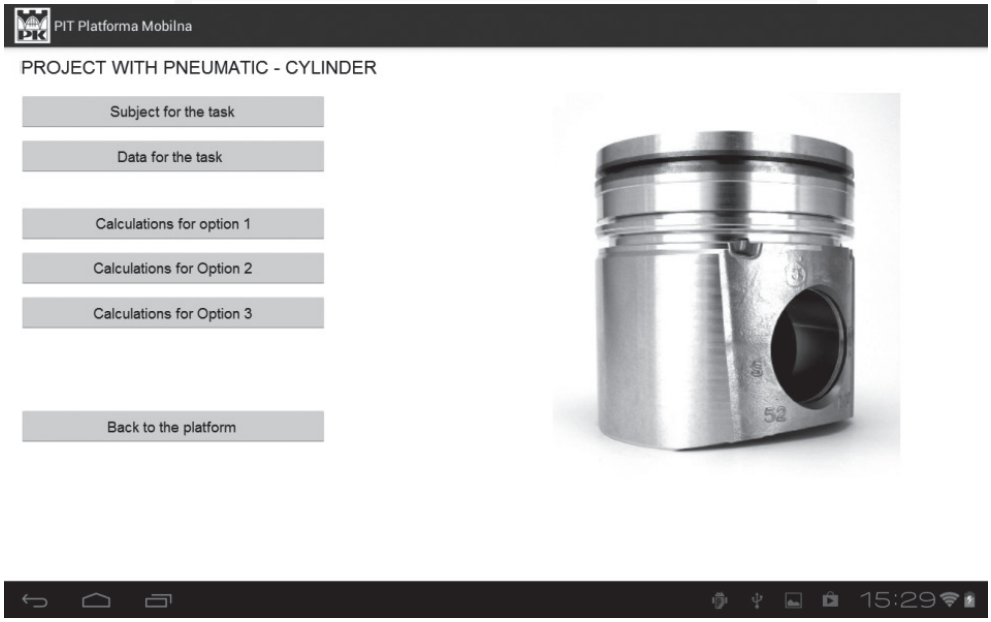

Fig. 5. A sample screenshot of the interactive "pneumatic cylinder" project

The project can involve the design calculations for three various variants of generating the motion of the cylinder:

– on the piston end only – rod protruding,
– on the rod end only – rod return,
– two ends connected – rod protrusion (dependent on the difference in surface areas).

Mini-project – Hydraulics

The aim of the second mini-project is to acquaint the app users with the calculation procedures and to provide backgrounds for calculations required during the design and selection of components of a newly designed hydraulic system (Fig. 6). The calculation procedure covers two variants:

– the ideal variant in which the losses due to flow and efficiency of hydraulic system components in the drive system of a field vehicle are neglected;
– the real variant in which correcting terms are introduced to account for energy loss during the system's operation.

In the context of those objectives, the users have to find a method to compute the following parameters:

– hydraulic engine displacement q_s;
– maximal displacement volume of a pump q_p;
– power rating of a combustion engine N_S.

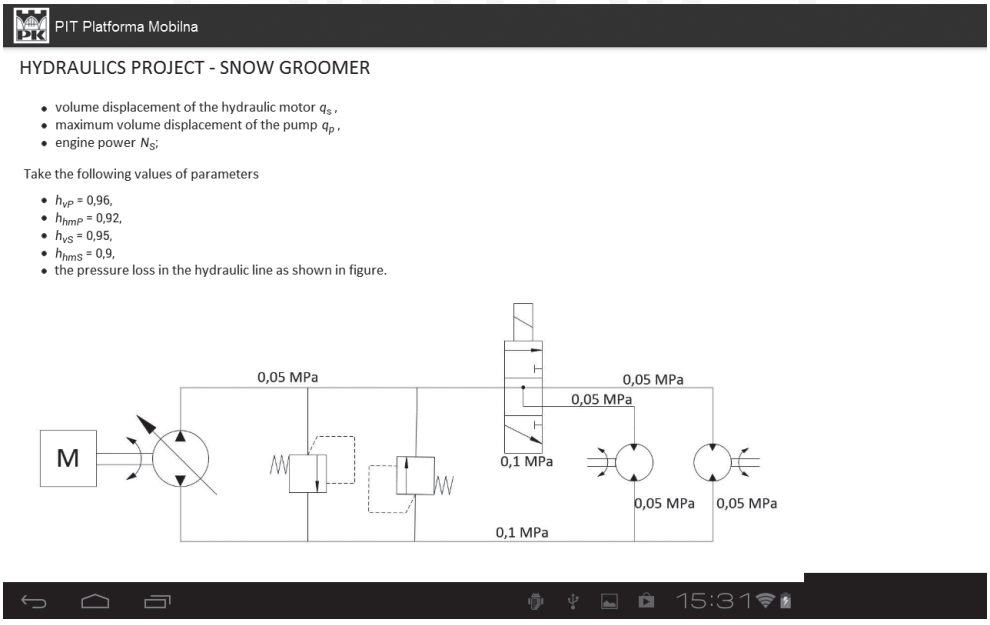

Fig. 6. A sample screenshot of the interactive hydraulic project

Each student does the calculations whilst the specific data, such as vehicle mass, slope inclination, are provided by the instructor. Users can enter their own data and on the basis that they check and verify the correctness of their calculations. The app gives the users step-

by-step instruction through subsequent stages of the calculation procedure required for the system design. When the users come up against difficulties, are not able to work out the results, or when the results they give are incorrect, they will be informed about the fact and given a further clue. The procedure of giving the clues involves several steps, giving more and more specific information to enable the student to find the appropriate formula and start the design calculation of the whole system.

These projects demonstrate a simple way to determine the main operating parameters of the engines. Selected problems and the considered variants allow the students to investigate the system operation using units widely used in hydraulic and pneumatic drives in machines and installations. The completed calculation procedure may be the starting point for more advanced calculations required in design of new fluid power drives and control systems.

4. Collaboration with industry

When developing the curricula for the 1-st and 2-nd degree programs and, mostly, for post-graduate courses, it is necessary to consider the specificity of the labour market and the competences and skills that the graduates should acquire, which would enable them to develop abilities and skills useful in their present or future employment, and to satisfy the employers' requirements. It is worthwhile to mention that the branch of hydraulic and pneumatic drives has considerably changed in the last few years, and refers particularly to the engineers' responsibilities and competences that are required from them. In the 1980s and 90s, the demand for workers involved in design and manufacturing of new systems and system components declined significantly. Most workers were engaged in sales, distribution or operation and maintenance of systems and system components offered by multinational companies. Luckily, towards the end of the 20th century, there was a rapid growth of small and middle-sized enterprises, which designed and launched a variety of specialist machines and installations equipped with hydraulic or pneumatic drive systems, giving employment to a large group of fluid control engineers. This tendency is still continuing, and at the same time, a number of companies operating on the Polish market have strengthened their position and continue to manufacture systems and system components. Besides, major investments of such worldwide concerns as Sauer Danfoss have created a number of jobs for fluid control engineers.

In order to further the links with the industry, the post-graduate degree programs include study visits to companies specialising in the design, manufacturing, operation and maintenance of hydraulic and pneumatic systems. For example, in the academic year 2014/2015, there were study visits to the following companies: Ponar Wadowice, Ponar Silesia, Bosch Rexroth, Sauera Danfoss, Pneumat System, Festo. Some of these companies are world-leading corporations, which guarantee the post-graduate students the exposure to the novel and most-advanced technologies and systems.

Study visits covered various problems, starting from design of new fluid systems or system components, manufacturing and acceptance tests, right through to operation, maintenance and diagnosing of their working condition (Fig. 7).

Fig. 7. Post-graduate students visiting the valve testing bench during their visit to PONAR Wadowice

A visit to the factories of Ponar Wadowice and Ponar Silesia companies took place on 10–11 May 2014. First, there was a meeting with the representatives of the company, who presented a brief history of the enterprise and the range of products and services provided by PONAR Wadowice and PONAR Silesia. After the discussion, the visitors were shown round and learnt about the manufacturing processes, especially the production technologies using state-of-the-art machinery. In the context of getting the practical expertise, the visit to the

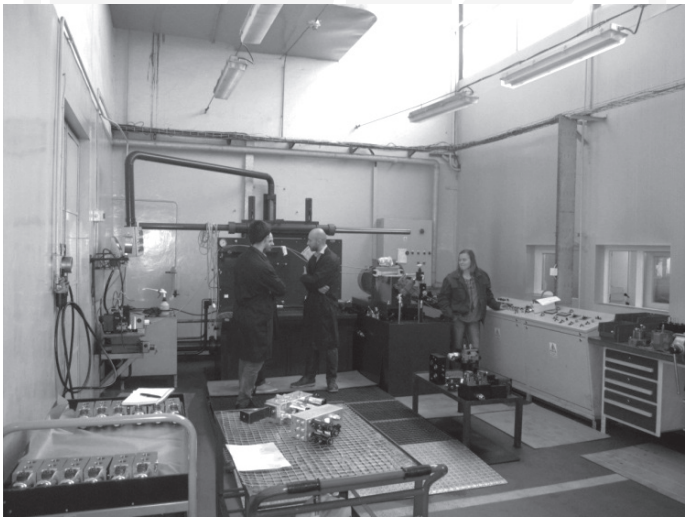

Fig. 8. Post-graduate students visiting the diagnostic test bench in PONAR Wadowice

laboratory was of particular importance, where the students were divided into three groups, 5 students in each, and took part in the following activities:

- servicing of overflow distributing and electro-hydraulic valves;
- assembly of spark-safe distributor valves and sandwich valves;
- bench tests aimed to determine the flow characteristics of throttling valves and force characteristics of electromagnets.

The students had a unique opportunity to get acquainted with the quality control procedures, diagnostics or acceptance testing of hydraulic supply units (PONAR Silesia). The instructors were expert specialists in the field, able and willing to share their expertise and experience in the field of design, operation, maintenance and diagnostics of hydraulic systems and system components (Fig. 8).

5. Conclusions

When the post-graduate degree programmes in the field of hydraulic and pneumatic drives and control systems were being launched, efforts were made to make the course innovative. The first step involved the development of the curriculum, preceded by extensive consultations with potential employers, students and graduates of technical universities, potential candidates for post-graduate courses. While developing the curriculum contents for individual subjects, the particular needs of the previously mentioned groups were considered. Practical instruction is of particular importance, which is why the plan of studies involves lab classes attended by small groups of students, so that each student has access to laboratory facilities and real machines and installations with hydraulic and fluid control systems. One has to bear in mind that modern fluid drives implement various functions associated with automation of equipment, which is achieved by using electromagnetic control; hence, the syllabus includes electro-hydraulics and electro-pneumatics as well.

One of the major undertakings in the project, adding a novel feature to the post-graduate study plan, is opening the possibility of remote experimenting using communication via the Internet. It is a novel solution, giving the students the opportunity to execute the control and take measurements of the investigated system and to prolong the time required for tests. The developed system for remote control of laboratory facilities, involving both hardware and software solutions, has proved its adequacy throughout the post-graduate course.

Another novel feature was the incorporation of study visits to selected companies in the branch of hydraulics and pneumatics. One has to emphasise that those responsible for the course were met with good understanding on the side of host companies, which enhanced further collaboration and the programs of students' visits became more attractive and inspiring.

Two editions of postgraduate studies in the field of fluid power have been completed for 35 participants with an average final grade "good" (C). These students have completed a survey, which found that the completed studies met their personal and professional expectations. Highly rated: the value of study in terms of obtained knowledge and skills; organisation of study; course schedule; the quality of teaching materials and laboratory equipment. Also, high scores were obtained through content and functionality of the mobile platform. In the opinion of the audience, remote work allowed for greater

flexibility in performing tasks, better assimilation of new knowledge and skills. The survey confirmed that listeners highly evaluated the participation in study visits carried out in hydraulic and pneumatic companies. The completed postgraduate studies raised the level of participants' qualifications and helped them to improve their professional competence and competitiveness in the labour market.

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