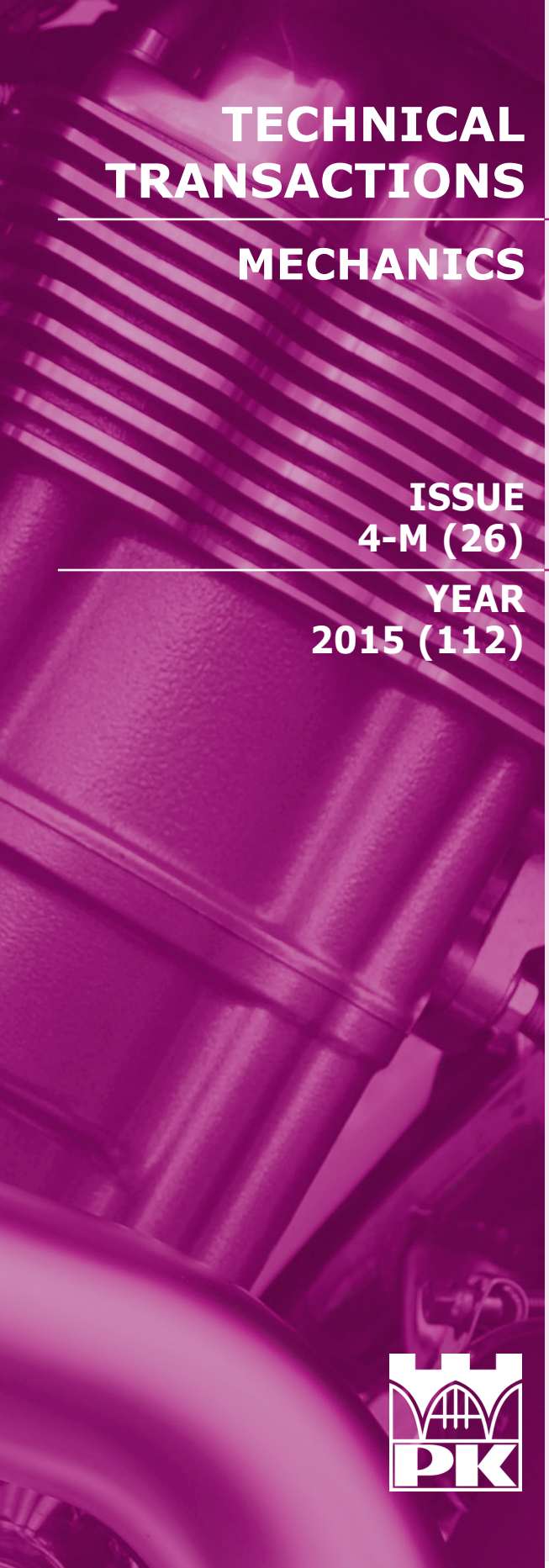

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ROBERT CIEŚLAK*, IRENEUSZ WYSOCKI**

THE ANALYSIS OF THE PRODUCT PLATFORM IN THE ELEKTROBUDOWA S.A. COMPANY

ANALIZA PLATFORMY MONTAŻOWEJ W FIRMIE ELEKTROBUDOWA S.A.

Abstract

The paper presents the development trends of modern assembly techniques. It focuses both on the significance of an assembly platform for the ELEKTROBUDOWA S.A. company and the analysis of technological processes of assembly, which costitutes a very important element in designing the structure of a production system. The work analyses the strengnts and weaknesses of assembly platforms. It also gives an overview of the five important stages in designing their structure.

Keywords: *assembly platforms*

Streszczenie

W artykule przedstawiono kierunki rozwoju współczesnych technik montażu. Omówiono znaczenie platformy montażowej dla firmy ELEKTROBUDOWA S.A., jak również bardzo ważny element w projektowaniu struktury systemu produkcyjnego, jakim jest analiza procesów technologicznych montażu. Opisano mocne i slabe strony oraz przedstawiono pięć ważnych etapów w opracowywaniu struktury platform montażowych.

Słowa kluczowe: *platformy montażowe*

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1. Introduction

Many of today's production companies take up the challenge of supplying the market with various products while simultaneously maintaining a small diversity among them. It means that the products vary but the level of difference between them (or their components) is always stable and not very high. To name such a trend, companies use the term 'product families' and develop end products based on a product platform in order to reduce both the development costs of a given product and its launch costs while simultaneously maintaining the diversity of the product and adapting it to market needs. A product family is a group of related products which share common components or subsystems, often described as a product platform, and fill so-called market niches. Therefore, developing a product family design involves typical challenges that we have to respond to while creating an end product and simultaneously taking into account the necessity and complexity of adapting it to a given product platform [8].

2. Product platform definition

Developing a product platform plays an important role for the final product as it shortens the time of its assembly and improves its quality. Such a product meets market needs and, at the same time, can be manufactured at the lowest possible production costs [7].

According to one definition, a product platform is a relatively large a set of subsystems, the components of which are connected with each other to form a stable subsystem and these components are common across different variations of the final product [7].

The main reason why product platforms are constructed is because they allow manufacturing the maximum possible number of final products by using standardised components and various production procedures. This is why adapting a product platform is a process that involves discovering common elements in a given product family such as common functions or operations, parameters, features, components, subsystems, or a sufficient amount of information related to manufacturing a given product family as well as the later adjustment and standardisation of the above mentioned common elements or parameters [10].

Once the usefulness of the platform in manufacturing a given set of final products is recognised, the company can take action which concerns:

a) developing a product family and an appropriate product platform architecture in such a way as to obtain the final product platform that stands out in comparison to others in terms of construction or virtual structure;
b) discovering the limitations to which the components manufactured by the most frequently used platforms are subjected – this also involves:
   – identifying both common modules/subsystems in a given product platform and the mutual dependence between their interfaces;
   – identifying both common components of a given end product developed on the product platform and the mutual dependence between them.

The standardisation of a product platform proceeds mainly thanks to recognising technical elements of a given product platform, its components and subsystems.

This process involves the standardisation of:

a) components of a product platform along with its structure and parameters;
b) subsystems and interfaces;
c) the production process and product platform management etc. [10].

Table 1 shows the strengths and weaknesses of product platforms.

Table 1

Strengths and weaknesses of product platforms, the authors' own compilation based on [4, 5, 9]

Product platforms	
Strengths	Weaknesses
Strategic phase – various products reaching the market faster – entering niche markets – implementing new technologies – lower technological risk Design phase – lower development costs – reusing previously designed components and systems – reusing tried and tested technologies Production management phase – possibility of using the same tools in the production of various products – economical manufacturing – possibility of bulk purchasing of the same subsystems used for manufacturing various products – reduction in warehouse stock – lower quality-related expenses – flexibility in the number of product variants Phase of testing and putting into operation – reduction in the time devoted to testing product launching – shared testing equipment for various products – reduction in the number of certifying tests Phase of operating and maintaining the product – reduction in fixed costs of maintaining products due to their shared functions – lowering costs of staff training – lowering variable costs due to more efficient logistics activities	Strategic phase – restrictions on future investment resulting from the limited range of products manufactured by one platform – risk of the market being monopolised by a company developing the product manufacturing strategy Design phase – the necessity to do research into the technical and economic feasibility of developing a product – extra costs connected with the necessity to design additional product-differentiating components of the product platform – overheads connected with commonality management of the product platform elements Production management phase – increased complexity of product configuration management on the assembly line – increased costs of subsystems and production Phase of testing and putting into operation – increased costs of developing the methods of verifying and validating the product and the product platform Phase of operating and maintaining the product – risk of failure in manufacturing common elements for a variety of end products – increased complexity of operating multi-purpose elements – increased costs of operating subsystems – increased costs of product platform management

3. The significance of effective planning when attempting to use a product platform in the manufacturing process

Plans to use product platforms are increasingly being implemented by companies which try to provide their customers with more tailor-made products while maximising the economic profits of companies. Doing the planning to use product platforms in the manufacturing process is proactively defined as an integrated set of capabilities and related architectural rules constituting the basis for a given group of products. The successful implementation of product platforms in the manufacturing process provides the distinct benefits of lower production costs and enables the appropriate balancing of market needs – this makes it possible for companies to be more competitive in the marketplace.

The benefits of using product platforms in the manufacturing process are most visible in the process of developing an end product. The process of developing an end product on a given product platform begins with defining the overall product strategy in which the elements of a potential new product or platform are also defined. At this stage, key market needs and customer requirements are combined and the underlying capabilities of a product platform give the greatest benefits in the process of balancing a given product platform [1].

Figure 1 below shows the phases of product development.

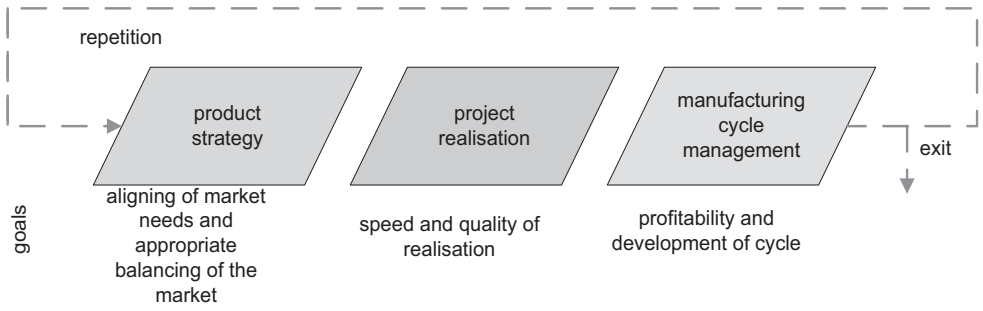

Fig. 1. Phases of product development [1]

Inappropriately planned product platforms result in a number of product development weaknesses in the manufacturing process, such as:

1) limited opportunities to plan the use of product platforms in the manufacturing process, which leads to product discards from a given platform;
2) failure to understand the technical feasibility and the operation of a product platform at a sufficiently early stage;
3) parallel development of both an end product and a product platform, which decreases the chances of balancing the product appropriately;
4) ineffective balancing of the platform see above note and the un-integrated architecture of the end product;
5) limited prospects of investments in product platforms, which is necessary for the future development of the end product;

6) compromise on the functionality of the end product due to the changes made to it, the features of the end product from a given platform are worse because the preset production schedules have to be maintained;
7) it is impossible to calibrate the infrastructure of a product platform which does not facilitate production growth [1].

Inappropriate planning by the company leads to higher capital costs, a slower pace in launching a product onto the market and a loss of opportunities to generate revenue. In order to minimise these weaknesses of the manufacturing process and maximise the value and importance of product platforms in the manufacturing process, a five-step methodology has been developed aimed at planning the use of product platforms in the manufacturing process effectively. This methodology relies upon:

1) a common language and terminology established in advance and used while developing product platforms;
2) specifying a product strategy and the value of it;
3) adapting product platforms to meet market needs;
4) identifying the vector of differentiation among various platforms;
4) developing matrixes of both end products and product platforms [1].

4. Research into product platforms

The research into product platforms was conducted in the ELEKTROBUDOWA S.A. company, which is a leader among Polish power engineering companies. ELEKTROBUDOWA S.A. provides comprehensive construction and installation services, implementing investments for the power sector, the petrochemical and mining industries as well as the turnkey construction of public utility facilities. The company manufactures electric power equipment including medium and low voltage switchgears, power substations and systems (Fig. 2). Being established over 60 years ago, the company has participated in the construction of almost all Polish power stations, thermal power plants and many other facilities all over the world [6].

The importance of using product platforms is becoming increasingly vital in various industry sectors and many companies have to take numerous decisions regarding this matter. The work is focussed on defining the basic architecture of the product platform.

1. **Stage One** – developing the platform as a physical structure of the product.
2. **Stage Two** – grouping operations in order to define the technological similarity or commonality of the manufactured products.
3. **Stage Three** – performing the cost analysis of a product platform.
4. **Stage Four** – defining the specifications of the given product platform. At this stage, an appropriate strategy should be adopted in order to find out about the goals as well as the limitations of a given product platform.
5. **Stage Five** – creating the product platform. This stage involves implementing the action strategy for the given product platform in the company.

The first three stages have already been completed. The authors of this paper are currently working on implementing stage four – this involves defining the specifications of the given product platform. The publications listed below [2–4] contain further information on the first stages of developing the product platform.

Fig. 2. Low and medium voltage switchgears produced by the ELEKTROBUDOWA S.A. company (images sourced from the company's catalogues)

5. Conclusion

In order to effectively utilise the benefits of the product platforms in the manufacturing process, we should start using them at the stage of product development. The five key stages of developing a product platform presented in this paper allow creating the plans of production lines which decrease the cost of developing an end product and give companies products that better satisfy customer requirements.

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ADAM DUŻYŃSKI*

POWER ENGINEERING – THE MINISTRY-COMMISSIONED COURSE OF STUDY CARRIED OUT AT CZESTOCHOWA UNIVERSITY OF TECHNOLOGY FROM 2012 TO 2015

KIERUNEK ZAMAWIANY ENERGETYKA, REALIZOWANY W POLITECHNICE CZĘSTOCHOWSKIEJ W LATACH 2012–2015

Abstract

This study discusses the progress of the engineers' studies in the Ministry-commissioned Power Engineering course conducted in the Faculty of Mechanical Engineering and Computer Science at Czestochowa University of Technology (FMECS, CUT) in the period 2012–2015.

Keywords: engineering studies, commissioned courses, power engineering

Streszczenie

W artykule omówiono dotychczasowy przebieg studiów inżynierskich na kierunku zamawianym Energetyka, realizowanych na Wydziale Inżynierii Mechanicznej i Informatyki Politechniki Częstochowskiej w latach 2012–2015.

Słowa kluczowe: studia inżynierskie, kierunki zamawiane, energetyka

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1. Introduction

Over the last twelve years or so, Poland has seen a disproportion between the number of graduates of liberal arts studies and people with scientific (technical, and mathematical and natural sciences) education. The labour market has become saturated with specialists in humanities, while the most desirable by employers have been science graduates, who could play a key role in stimulating the development of those branches of the economy which have a special influence on the improvement of the economic and social situation in Poland. A survey of the labour market has confirmed the growing demand for employees qualified in technical and scientific subjects. It is commonly known that the problem of the deficit of some professions and specialities is the consequence of the mismatch between the educational offer of the higher education institutions and the needs of the constantly changing labour market. In this situation, the Ministry of Science and Higher Education considered it necessary to take action aimed at enhancing the popularity of education in science and engineering faculties. This action was expected to contribute to a reduction of the existing mismatch – this was achieved by, for example, commissioning courses of academic studies essential for the development of a competitive and innovative economy. A pilot programme entitled 'Commissioning the Education in Technical, Mathematical and Natural Faculties' was carried out from 2007 to 2013. Its goal was to increase the number of graduates of commissioned courses of study up to 22% of the graduate population. The courses of study commissioned by the ministry have restored the social prestige to science and engineering courses of study, and it's now time for another quality step – better training of competencies and skills essential in the labour market [4, 5].

2. Power Engineering – the new course of study at the FMECS, CUT

In the academic year 2011/2012, a new course of study, Power Engineering, was launched at the Faculty of Mechanical Engineering and Computer Science of Czestochowa University of Technology (FMECS, CUT).

The faculty offers the following options to future students:

– full-time (7 semesters) and extramural (8 semesters) engineering studies for a first degree in the speciality 'Dispersed Power Engineering Systems';
– full-time (3 semesters) graduate studies for a second degree in the specialities 'Conventional Power Engineering' and 'Unconventional Power Engineering'.

Studies in the prestigious course Power Engineering, conducted in only a few universities in Poland, are intended to provide education corresponding to the needs of the sustainable development of the country and the growing role of issues relating to the ecological processing and distribution of energy. The graduates of this field of study acquire education based on the technical knowledge in the area of thermal engineering, electrical power engineering, computer science and economics. The students are given the opportunity to learn state-of-the-art technologies in the design and operation of both heating equipment and thermal machinery and engines (piston engines, steam and gas turbines, compressors, pumps), as well as modern technologies in the design and operation of refrigeration, air conditioning and ventilation equipment.

The University's unit holding the master's course in Power Engineering is the Institute of Thermal Machinery – a body that has been dealing with power engineering for over 50 years and has well-equipped specialised laboratories that help in the education of Power Engineering students.

Power Engineering graduates can be useful in the following areas: the diagnostics, safety and reliability of power engineering equipment and systems; stewardship in energy management; the control and automation of power engineering systems and equipment; the monitoring and supervision of companies' activity in environmental protection; waste disposal, etc. They can work in enterprises dealing with the operation of power engineering systems and in plants involved in the processing, transmission and distribution of energy. Municipal thermal-electric power stations, building companies and those involved in the manufacture and distribution of modern refrigeration, ventilation and air conditioning systems may also be interested in hiring Power Engineering graduates.

Those studying in the Power Engineering course at the FMECS, CUT, will have the opportunity to obtain 'Qualification Certificates' required by the 'Energy Law' for dealing with the operation of electrical power engineering, thermal and gas equipment, installations and networks on supervision and operation posts after completing an additional training course and passing an exam.

3. About the project

Wishing to make the studies in the Power Engineering course more attractive, the Faculty of Mechanical Engineering and Computer Science of Czestochowa University of Technology (FMECS, CUT) made an application to the National Research and Development Centre in Warsaw, and since 1st July 2012 the project POKL.04.01.02-00-149/12 'Take the key to success – commissioned courses at the Faculty of Mechanical Engineering and Computer Science' has been carried out at the FMECS, CUT. This project is co-financed by UE resources within the framework of the EUROPEAN SOCIAL FUND (EFC), Priority IV 'Higher Education and Science' of the Human Capital (HC) Operation Programme (OP), Measure 4.1 'Strengthening and development of didactic potential of universities and increasing the number of graduates from faculties of key importance for knowledge-based economy' Sub-Measure 4.1.2. 'Increasing the number of graduates from faculties of key importance for knowledge-based economy – competition projects' [3].

One of the courses which has obtained funding is Power Engineering. The project 'Take the key to success – commissioned courses at the Faculty of Mechanical Engineering and Computer Science' is addressed to the full-time, first degree students at the Faculty of Mechanical Engineering and Computer Science of Czestochowa University of Technology. The primary goal of the project was to strengthen and develop the didactic potential of the FMECS by expanding the syllabi and making them more attractive. By joining the commissioned course of study programme, Czestochowa University of Technology wished to compete for students in an innovative manner using European funds, by offering the students forms of didactic classes and the University's cooperation with potential employers, which had been practically unavailable to them before. Thus, the students were expected to acquire skills essential in the labour market. The implementation of the project was supposed to

contribute to an increase in the quality of the teaching of FMECS students in fields important to a modern, innovative economy.

The project concerned the students who started their studies in the academic year 2012/2013. The application for co-financing made by the FMECS, CUT to the National Research and Development Centre (Narodowe Centrum Badań i Rozwoju) took third place in the ranking list of positively assessed applications (with a score of 120 points) among 260 submitted applications (of 126 positively assessed applications, as many as 93 had not obtained co-financing). The overall project budget amounted to over 6.5 million zlotys.

Table 1

Basic project data according to the approved application [1]

Project duration	01.07.2012 – 31.12.2015
Commissioned courses of study (number of participants in given subject)	– Power Engineering (40) – Computer Science (166) – Mathematics (50) – Mechanics and Machine Building (102) – Mechatroniics (32)
Number of project participants	390
Number of project participants (Power Engineering)	40

Over the entire duration of their studies, the students of the commissioned courses took advantage of many attractions prepared by the FMECS, CUT, which included [1]:

- incentive scholarships – 50% of the best students will obtain scholarships of the amounts of 700, 800 or 1000 zlotys per *calendar* month;
- depending on their learning performance (over the 9 months of the academic year);
- compensatory courses in mathematics, physics and computer science for first year students;
- commissioned lectures delivered by invited outstanding domestic and foreign professors and national and international industry specialists;
- study visits to industrial partners;
- summer holiday international two- or three-month traineeships in renowned academic and scientific research centres and industrial plants;
- students' participation in national and international scientific and technical conferences;
- specialised training courses to obtain additional qualifications and competences, such as training courses in the AutoCAD, CATIA, SolidWorks, and Matlab-Simulink software programs;
- technical and business English courses;
- a training course for the 'Auditor of the Internal Integrated Management System' (ISO) – for TÜV, NORD certificates;
- support for disabled students, including psychological and professional counselling.

The awarding of scholarships and participation in optional classes is determined by ranking based on the scholarship indices (WS) from the previous semester – these are the sums of average marks (SRW) and the optional classes index (ZD).

4. How we carried out the Project

Table 2 summarises figures showing the implementation of the project so far.

Table 2

The Power Engineering commissioned course in numbers (what has been completed thus far)

Description	Dimension	Semester/ number of participants					
		1	2	3	4	5	6
The number of project participants (of which, the number of women)	–	77 20	50 10	47 10	41 10	41 10	39 10
Scholarships[1] (of which, the number of women)	–	22 6	25 8	21 7	20 8	20 9	20 8
COMPENSATORY CLASSES							
Mathematics	30 hrs	52	–	–	–	–	–
Physics	30 hrs	30	–	–	–	–	–
OPTIONAL LECTURE ON THE SUBJECT 'ENTREPRENEURSHIP AS A SOCIAL COMPETENCE – THE PROFESSIONAL CAREER OF A CZESTOCHOWA UNIVERSITY OF TECHNOLOGY STUDENT'							
MSc Ziemowit Słomczyński Remak Rozruch Opole	3 hrs	49	–	–	–	–	–
Prof. Włodzimierz Błasiak – Royal Institute of Technology (KTH), Stockholm	3 hrs	–	–	37	–	–	–
COMMISSIONED LECTURES GIVEN BY FOREIGN PROFESSORS							
Prof. Mirosław L. Wyszynski – University of Birmingham	10 hrs	–	–	–	–	33	–
Prof. Włodzimierz Błasiak – Royal Institute of Technology (KTH), Stockholm	10 hrs	–	–	–	–	–	31
COMMISSIONED LECTURES GIVEN BY DOMESTIC PROFESSORS							
Prof. Roman Domański – ITC, Warszawa University of Technology	6 hrs	–	40	–	–	–	–
Prof. Janusz Skorek – ITC, Silesian University of Technology	4 hrs	–	–	–	32	–	–
Prof. Wojciech Nowak – AGH, Kraków	4 hrs	–	–	–	–	28	–
COMMISSIONED LECTURES GIVEN BY FOREIGN INDUSTRY REPRESENTATIVES							
PhD Adam Luckos – Sasol Technology R&D (South Africa)	10 hrs	–	–	37	–	–	–
PhD Marek Sutkowski – Wärtsilä Finland Oy	10 hrs	–	–	–	33	–	–

Continue Table 2

Description	Dimension	Semester/ number of participants					
		1	2	3	4	5	6
COMMISSIONED LECTURES GIVEN BY DOMESTIC INDUSTRY REPRESENTATIVES							
MSc Kazimierz Gatnar – Jastrzębska Spółka Węglowa S.A.	4 hrs	–	39	–	–	–	–
PhD Jerzy Trzeszczyński Scientific & Technical Service Representative of PRO NOVUM Sp. z o.o. Katowice	4 hrs	–	–	–	–	29	–
STUDY VISITS AT THE DOMESTIC INDUSTRY PARTNER							
International Trade Fair of Environmental Protection Poleko 2012 in Poznań	–	22	–	–	–	–	–
P.P.U.H. Horus Energia at Sulejowek	–	–	23	–	–	–	–
PZL Sp.z o.o. in Mielec	–	–	4	–	–	–	–
PGE Górnictwo i Energetyka Konwencjonalna (Mining and Conventional Power Engineering) in Bełchatów	–	–	–	–	22	–	–
Oczyszczalnia Ścieków Warta S.A. (Warta S.A. Sewage Treatment Plant) in Czestochowa	–	–	–	–	23	–	–
Elektrownia Łagisza (Łagisza Power Plant) in Będzin	–	–	–	–	–	–	23
ENGLISH LANGUAGE COURSE							
Technical English	2 × 30 hrs	–	–	23	22	–	–
Business English	2 × 30 hrs	–	–	–	–	6	6
AUTOCAD TRAINING							
Basic	18 hrs	–	–	–	16	–	–
Advanced	18 hrs	–	–	–	–	14	–
CATIA SOFTWARE TRAINING							
For individuals starting working with the program	40 hrs	–	–	5	–	–	–
Hybrid programming training	16 hrs	–	–	5	–	–	–
SOLIDWORKS SOFTWARE TRAINING							
Basic – modelling of parts	12 hrs	–	–	–	–	8	–
MATLAB-SIMULINK SOFTWARE TRAINING							
Modelling of dynamic systems	10 hrs	–	–	–	–	2	–
TRAINING COURSE FOR THE INTERNAL AUDITOR OF THE INTEGRATED MANAGEMENT SYSTEM – ISO							
	32 hrs	–	–	–	–	–	5

Continue Table 2

Description	Dimension	Semester/ number of participants					
		1	2	3	4	5	6
NATIONAL SCIENTIFIC CONFERENCES (WITH A PAPER)							
The 18th International Scientific & Technical Conference on 'Preventing the pollution, transforma-tion and degradation of the environment' Szczyrk 2014	–	–	–	–	–	3	–
The 8th International Scientific & Technical Conference Power Engineering, Wrocław 2014	–	–	–	–	–	1	–
INTERNATIONAL SCIENTIFIC CONFERENCES (WITH A PAPER)							
'Topical Problems of Fluid Mechanics 2015', Prague, the Czech Republic	–	–	–	–	–	1	–
TRAINING IN NATURAL ENVIRONMENT PROTECTION AND PRO-ECOLOGICAL SOLUTIONS IN THE PRODUCTION PROCESS							
	6 hrs	–	–	36	–	–	–
PURCHASES OF TEACHING STANDS							
A DeltaOhm HD52.3D P147-R ultrasonic anemometer with accessories, designed for the measurement of wind velocity and direction, solar radiation, relative humidity, temperature and barometric pressure with a measurement recording and visualisation capability							
Purchasing of a G.U.N.T. testing stand for the examination of, for example, liquid stream properties and the visualisation of Bernoulli's law							
Purchasing of a system for the control and automatic adjustment of thermal machines							

[1] Eight project participants have obtained scholarships over all the semesters to date.

The number of project participants, i.e. Power Engineering commissioned course students, in successive semesters are illustrated in Figure 1.

When looking at Figure 1, one could be astonished by the fact that as many as twenty-seven students dropped out after Semester 1 – the explanation is very simple. Some of them, of course, did not pass the semester because of poor performance, but the majority of them were the students of another course of study – so called 'fictitious people', who, free of charge, additionally applied to the commissioned course of Power Engineering lured with the opportunity for winning a relatively high scholarship based on high marks of their secondary school-leaving examination, without any effort being made in the first semester. Because the regulations that were in force at that time allowed such behaviour, 'scholarship-seekers' eagerly used that opportunity and grew in number, and ultimately, they made up as many as one third of all students taking scholarships in Semester 1 – this was met with protest from the students who regularly attended the classes. After Semester 1, a group of very active students formed – this group survived practically intact until the end of the engineers' studies. The project assumed that forty students would study in Semester 7, and exactly this number of students reached this semester.

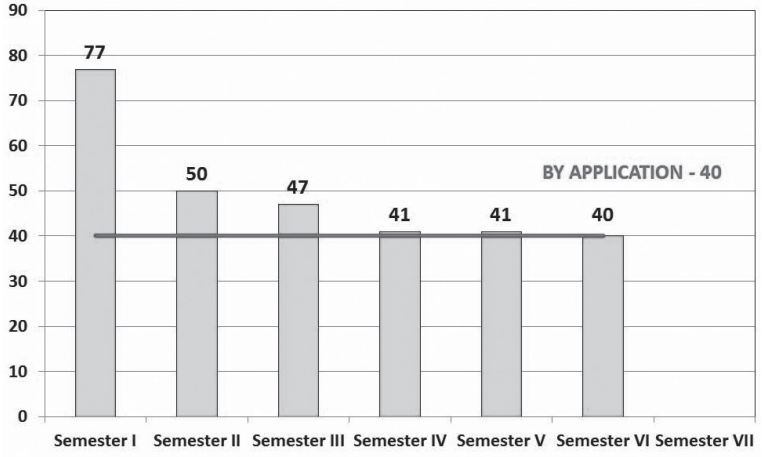

Fig. 1. The number of project participants, i.e. Power Engineering commissioned course students, in successive semesters

Fig. 2. Compensatory classes in physics and mathematics [2]

Fig. 3. The study visit at the International Trade Fair of Environmental Protection POLEKO 2012 in Poznań [2]

Figures 2–15 show some of the tasks already completed within Objective 3 ‘Implementation of new education forms for the students of the Power Engineering course’.

Fig. 4. The study visits at P.P.U.H. Horus Energia at Sulejówek and at the WARTA S.A. Waste Treatment Plant in Częstochowa [2]

Fig. 5. The study visit at PGE Górnictwo i Energetyka Konwencjonalna (Mining and Conventional Power Engineering) in Bełchatów [2]

Fig. 6. The study visit at Elektrownia Łagisza (Lagisza Power Plant) in Będzin [2]

At the end of Semester 5, the students were given the subjects for the engineers’ dissertations, the defences of which are planned for January 2016.

In the holiday break after Semester 6, two- and three-month industrial traineeships with potential employers were also conducted for twenty project participants. The basis for the traineeship qualification was the sum of average learning marks from five semesters (SRW).

Fig. 7. Optional lectures on 'Entrepreneurship as a social competence – the professional career of a Częstochowa University of Technology graduate': MSc Ziemowit Słomczyński and Prof. W. Błasiak [2]

Fig. 8. Commissioned lectures given by the foreign industry representative: PhD Adam Luckos and PhD Marek Sutkowski [2]

Fig. 9. Commissioned lectures given by the domestic industry representative: MSc Kazimierz Gatnar and PhD Jerzy Trzeszczyński [2]

Fig. 10. Commissioned lectures delivered by the visiting professors: Prof. Janusz Skorek and Prof. Wojciech Nowak [2]

Fig. 11. A commissioned lecture delivered by the visiting professor – Prof. Roman Domański [2]

Fig. 12. Commissioned lectures delivered by the foreign visiting professors:
Prof. Mirosław L. Wyszynski and Prof. Włodzimierz Błasiak [2]

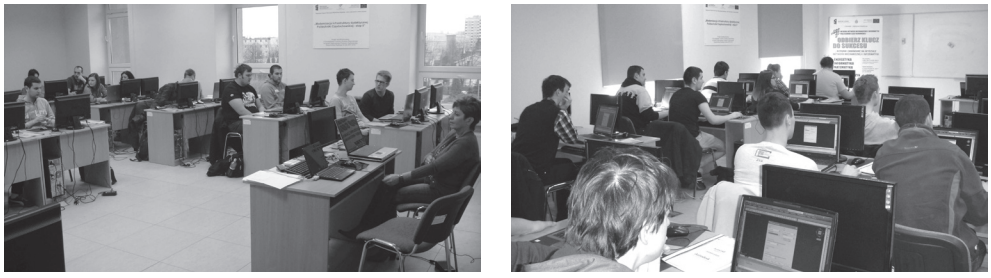

Fig. 13. Training in the AUTOCAD software program [2]

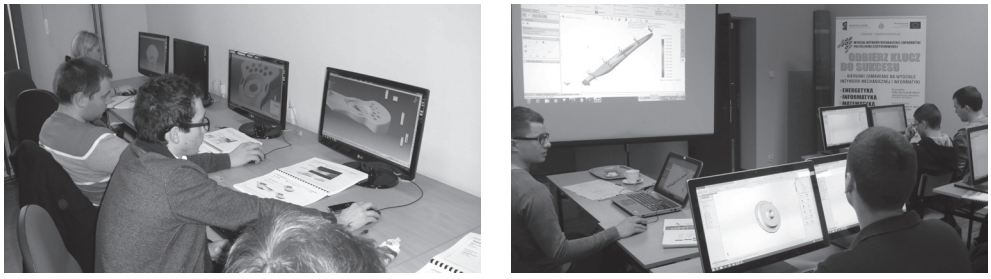

Fig. 14. Training in the CATIA and SOLIDWORKS software programs [2]

Fig. 15. The training course for the Internal Auditor of the Integrated Management System – ISO [2]

Table 3

Holiday industrial traineeships with potential employers

Traineeship	Number of trainees
MOTORTECH GmbH, Celle, Germany	4
The Institute for Thermomechanics, the Czech Republic	2
FOREIGN COUNTRIES	**6**
ENERGOMONTAŻ-PÓŁNOC BEŁCHATÓW Sp. z o.o., Rogowiec	2
Instytut Badań i Rozwoju Motoryzacji (Institute for Automotive Research and Development) BOSMAL Sp. z o.o., Bielsko-Biała	3
MOTORTECH Polska, Krzysztof Walicki i Wspólnicy Sp. Jawna, Charzyno	2
P.P.U.H. HORUS-ENERGIA Sp. z o.o., Sulejówek	1
Zakłady Remontowe Energetyki (Power Industry Repair Works) Katowice S.A., Katowice	2
Cementownia WARTA S.A. (WARTA S.A. Cement Mill), Działoszyn	1
Koksownia (Coking Plant) Częstochowa Nowa Sp. z o.o., Czestochowa	2
Oczyszczalnia Ścieków WARTA S.A. (WARTA S.A. Sewage Treatment Plant) in Czestochowa	1
POLAND	**14**
TOTAL (FOREIGN COUNTRIES AND POLAND)	**20**

5. Plans for Semester 7

For Semester 7, a Student Scientific Conference on Energetyka Przyszłości (The Power Engineering of the Future) was conducted for forty project participants, within the framework of which, a commissioned lecture will be delivered by Prof. dr. h.c. mult. T. Chmielniak from the Institute for Thermal Engineering of the Silesian University of Technology on

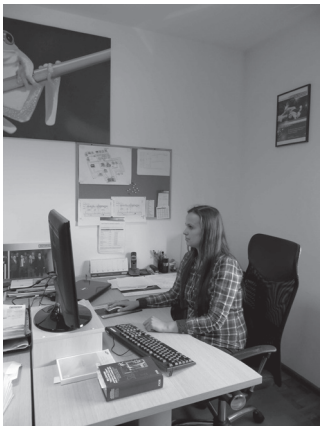

Fig. 16. Power Engineering commissioned course students at industrial traineeships with potential employers (MOTORTECH Polska) [2]

'Contemporary Energy Technologies' (the energy technologies of fossil fuels, the power engineering of renewable energy sources, the outline of nuclear power engineering) (Figs. 17–18).

Fig. 17. The proceedings of the Student Scientific Conference Energetyka Przyszłości (The Power Engineering of the Future)

Fig. 18. Student Scientific Conference on Energetyka Przyszłości (The Power Engineering of the Future) – Prof. T. Chmielniak and Students: K. Gajewska and K. Kaczyński [2]

The students of the Power Engineering commissioned course prepared 10 papers and presented them at the Student Scientific Conference 'Energetyka Przyszłości'. These papers have been included in the Conference proceedings, and are listed below:

- The Power Engineering commissioned course carried out at the Częstochowa University of Technology in the years 2012–2015;
- A review of solid fuel feeders for a single-family house water heater – energy consumption;
- The present state and the outlook for the development of the Polish wind power industry;
- The comparative analysis of the parameters of an engine performing the classic and extended-expansion cycles;
- Generator gas and its use for feeding internal combustion engines;
- The assessment of the potential of biomass for the generation of electric energy and heat in the coal co-combustion technology in Poland;
- Waste heat recovery from waste water;
- The methods of financing and the possibilities of investment return from the photovoltaic micro-system in the light of the new renewable energy sources law;
- The methane clathrate compound – a fuel of the future or a threat from the ocean depths?
- Algae as an energy fuel.

6. Summary

The curriculum on the commissioned course of Power Engineering enables a group of students to avail themselves to a more expensive, but better-quality course of engineering study, distinguished by a higher level, a variety of educational forms and greater emphasis on the practical aspects of education than before. As the coordinator of the course, the author of this paper has observed a smaller percentage of eliminations and resignations from the studies than before and higher average marks compared to other courses of study.

An undoubted strength of the implemented project was the possibility of enriching the engineers' studies through direct contact with industry through study visits to industrial partners, commissioned lectures delivered by outstanding domestic and foreign industry representatives, and two- and three-month industrial traineeships with potential employers. The students of the commissioned course of Power Engineering have highly valued the opportunity of obtaining various certificates confirming their participation at training – these were courses which were carried out, in their opinion, to a very high level. A confirmation of this fact can be the results of an evaluation survey summing up the engineers' studies in the commissioned course of Power Engineering given in Table 4 – these clearly show that the forms of education assessed highest by the polled students were those directly associated with practice, namely: laboratory and classroom lessons; study visits to industrial partners; industrial traineeships with potential employers; training courses; commissioned lectures delivered by domestic and foreign industry representatives.

Table 4

An evaluation survey summing up the studies on the Power Engineering commissioned course with a sample of the questions

For how many semesters did you take the commissioned course students' scholarship?	
Semester	Evaluation survey results [%]
1	15.8
2	7.9
3	5.3
4	2.6
5	5.3
6	15.8
7	18.4
Not applicable	28.2
Which form of teaching classes do you consider the most effective?	
Form of teaching	Evaluation survey results [%]
Lecture	5.3
Exercises	26.3
Labour	47.4
Seminar	18.4
How do you rate the organisation and scope of additional classes? (1 – very bad, 5 – very good)	
Rating	Evaluation survey results [%]
1	0
2	0
3	23.7
4	68.4
5	7.9
Which form of additional classes was the most interesting in your opinion?	
Form of teaching	Evaluation survey results [%]
Compensatory classes	0
Commissioned lectures by professors	5.3
Commissioned lectures by industry representatives	15.8
Courses, training	65.8
Study visits to industrial partners	18.4
Scientific conferences	13.2
Industrial traineeships	36.8
Would you make a decision to start studying in the Power Enginering course again?	
Decision	Evaluation survey results [%]
Yes	47.4
No	15.8
I don't know	36.8

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[1] The application for co-financing the Project Human Capital Operational Programme. Czestochowa University of Technology, version 8.6.4.
[2] www.ok.pl
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4-M/2015

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TESTING OF MECHANICAL AND ACOUSTICAL PARAMETERS OF POLYURETHANE MATERIALS WITH DESIRABLE PROPERTIES

BADANIA WŁAŚCIWOŚCI MECHANICZNYCH I AKUSTYCZNYCH MATERIAŁÓW POLIURETANOWYCH O WYMAGANYCH WŁAŚCIWOŚCIACH

Abstract

This paper summarises the results of the testing of the mechanical and acoustical behaviour of polyurethane materials with desirable properties. Testing was performed on several samples of materials which were modified during the manufacturing processes. Tests of mechanical parameters included, among other things, the Young modulus and the energy dissipation rate. Tests were conducted on the model 43 MTS Criterion hydraulic testing machine. In the framework of the acoustic research, sound absorption coefficient measurements were conducted. The sound absorption coefficient was measured with the type 4002 Bruel & Kjaer standing wave apparatus. Characteristics of the tested materials are provided.

Keywords: polyurethane materials, measurements mechanical and acoustical properties

Streszczenie

W artykule przedstawiono wyniki pomiarów właściwości mechanicznych i akustycznych materiałów poliuretanowych o oczekiwanych właściwościach. Badania przeprowadzono na kilku próbkach materiałów, które w procesie wytwarzania poddane zostały różnym modyfikacjom. Badania parametrów mechanicznych obejmowały m.in. określenie modułu Younga oraz zmian energii dyssypacji w pierwszych pętlach histerezy. Badania przeprowadzono na hydraulicznym urządzeniu MTS Criterion Model 43. W ramach badań akustycznych przeprowadzono pomiary współczynnika pochłaniania dźwięku. Pomiary przeprowadzono za pomocą rury impedancyjnej na stanowisku Bruel & Kjaer 4002. Przeprowadzono charakterystykę materiałów poddanych badaniom.

Słowa kluczowe: materiały poliuretanowe, pomiary właściwości mechanicznych i akustycznych

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1. Introduction

Elastomers have a number of engineering applications – some types of plastic materials are successfully used as energy damping elements. Porous materials, such as polyurethane foams, perform well in acoustical and mechanical energy dissipation processes.

The work by Domka, Malicka & Stachowiak [1] summarises the results of testing performed on a polyethylene-based composite material with kaolin fillers to determine its mechanical properties. This data can be further utilised to determine the acoustical properties of such structures. The paper by Dziechciowski [2] investigates methods to determine the sound insulation behaviour of multi-layered structures based on the mathematical model proposed by Sharp [3], which requires that mechanical parameters of component materials be first established. Reports in the literature provide the results of extensive testing conducted on polyurethane foams. More information about the composition of tested materials can be found in the paper by Gayathri, Vasanthakumari & Padmanabhan [4]. The research program summarised in this publication involved the measurements of the sound absorption coefficient. Acoustical measurements summarised in the work by Ekici, Kentli & Küçük [5] were taken on polyurethane foams filled with tea leaves as organic filler.

Cracow University of Technology has been engaged in research work relating to the design, manufacture and testing of polyurethane foams with predetermined parameters. It is expected that foams will soon be made from renewable materials, such as vegetable oils or natural fibres used as fillers.

2. The characterization of the research object

2.1. Applications of polyurethanes [6, 7]

Polyurethanes (PUR) are a group of polymers with versatile properties and thus have a wide range of industrial applications. They include foams, elastomers, coatings and adhesives, fibres and synthetic leather. Depending on their actual properties, they can be applied in many areas of life. Flexible polyurethane foams are used in the furniture industry, in automotive and aerospace engineering and in the manufacturing of air filters, liners, seals, packaging and toys. Rigid foams are used in the construction sector, in the manufacturing of walls, structure-reinforcing elements, and in heat insulating materials. Rigid polyurethane foam systems are also used in sealing and in the structural components of aircraft. Another group includes elastomers used to make shoe soles, heels and gears. Polyurethane systems are employed to provide excellent protective coatings for metal, wood and concrete as well as flexible coatings for leather, rubber or other materials. Polyurethane-based adhesives and fibres are another group of promising materials displaying specific properties which are demanded for many industrial applications.

2.2. Tested materials

Polyurethane foams were obtained using two component systems (A and B). Component A (so-called polyol premix) consist of polyols, catalysts, surfactant, water (as a chemical

blowing agent) and fillers. Component B was 4.4'-methylenediphenyl diisocyanate. Foams were formed in a closed mould measuring 120 mm × 100 mm × 20 mm by the one shot method. The final products were flexible foams. Their properties were similar to those displayed by visco-elastic materials. Such foams slowly return to their initial shape after deformation.

In order to estimate the influence of isocyanate on foam properties, 10 different foams were prepared. The quantitative ratio between components A and B and the apparent densities of the foams are shown in Table 1.

Table 1

Parameters of investigated foams (POL/ISO ratio and density ρ)

	Sample designations									
	POL/ISO ratio-fixed					POL/ISO ratio-varied				
	1n	5n	2n	4n	3n	1f	2f	3f	4f	5f
POL/IZO	2.67:1	2.67:1	2.67:1	2.67:1	2.67:1	2:1	2.25:1	2.5:1	2.75:1	3:1
ρ [kg/m^3]	126	142	156	170	197	166*	166*	166*	166*	166*

* Density range: 160–170 kg/m^3

The samples were divided into two groups – samples characterised by the constant ratio of polyol POL to isocyanate ISO (hereinafter designated as 'POL/ISO') and variable density (indicated by the letter 'n') and those having a constant density and variable POL/ISO ratio (indicated by the letter 'f').

In order to obtain porous materials with different apparent densities, varied amounts of component of polyurethane foam systems was poured into the mould. Tests described in this study were performed on polyurethane foams with apparent densities ranging from 126 to 197 kg/m^3. Measurements were taken of the acoustical and mechanical parameters of each foam. The density was determined by an approximate method involving weighing, measuring the foams' dimensions and computing their densities expressed as the ratio of the components' mass to the mould volume of the manufactured foam.

3. Testing the mechanical parameters and energy dissipation performance

3.1. Methodology

The procedure involved conducting static tension tests, compression tests and dynamic compression tests. The measurements were performed according to specifications laid out in documents PN-EN ISO 527-2 and PN-EN ISO 604 [8, 9]. Tests were conducted with the model 43 MTS Criterion electromechanical tester, supported by the TestWorks 4 software.

The application of time-variant loads lead to material wearing. There are two fundamental mechanisms leading to fatigue failure of polymer composites, these are crack propagation (being the consequence of micro-sized defects) and viscoelastic heating. On account of the

viscoelastic behaviour of polymer materials, during its deformation the compression and tension stresses acting on the material are not in phase, but they appear with a certain delay. In the consequence, a hysteresis loop is formed. A hysteresis loop is incurred through the heat energy dissipation. This process is responsible for the accumulation of internal energy and an increase of the self-excited temperature of the material leading to thermal fatigue failure.

To enable a preliminary assessment of the viscoelastic properties of foam materials, their energy dissipation capability and the effects of the loading rate on foam properties, the dynamic test involved fifty compression cycles with large amplitudes. Dynamic compression tests of polyurethane foams were performed at a sampling frequency of 0.14 Hz and a strain rate of 200 mm/min. A kinematic load was applied to the sample during the test (displacement control) and the maximal rate of applied displacement in the loops was 10 mm, which accounted for 50% displacement of the original sample thickness.

3.2. Measurement results

Table 2 summarises the results of elongation tests. The registered parameters included the maximal breaking force F_{max}, the modulus of elasticity E_e and the maximal elongation of foam samples. All foam samples subjected to elongation tests broke beside the clamps. The test proved the variety of foam properties. The module of elasticity of the investigated foams was in the range of 57 to 167 kPa – for samples indicated with 'n' and from 40 to 345 kPa for samples denoted by 'f'. It appears that there is no straightforward relationship between the modulus of elasticity and the value of breaking force, as we observe in the case of samples 2n and 5n. The sample elongation was in the range of 20 to 60 mm.

Table 2

Maximal breaking force F_{max}, modulus of elasticity E_e and elongation at break of tensioned samples Δl

	Sample designation									
	1n	5n	2n	4n	3n	1f	2f	3f	4f	5f
F_{max} [N]	33	43	101	123	71	188	116	90	73	60
E_e [kPa]	57	78	84	100	167	345	145	90	47	40
Δl [mm]	60	52	28	29	35	20	30	32	42	37
ρ [kg/m^3]	126	142	156	170	197	166*	166*	166*	166*	166*

* Density range: 160–170 kg/m^3

Table 3 summarises the force value registered during the sample displacement (25%) and the Young modulus E_c obtained from the static compression test. For the sake of comparison, the values of the elasticity modulus at elongation E_c are also provided. The compression test was interrupted when the displacement approached 50%. The values of the elasticity moduli of the investigated foams fell across a very broad range (34–870 kPa). Forces determined for a 5 mm displacement fall in the range of 9.7 N to 136.8 N. In the case of the compression tests, the relationship between the applied compression force and the modulus of elasticity is

fairly proportional and thus, easier to compare. The Young modulus in the samples subjected to larger compression loads also increased. The actual ratio POL/IZO was found to have a major influence on the mechanical behaviour of the investigated samples.

Table 3

Force registered during the sample 5 mm displacement (25%), ($F_{5\,mm}$) and Young modulus during the compression tests

	Sample designation									
	1n	5n	2n	4n	3n	1f	2f	3f	4f	5f
$F_{5\,mm}$ [N]	12.5	21.2	32	42.7	43.5	136.8	46.3	27.4	13.2	9.7
E_c [kPa]	34	76	83	103	155	870	170	114	51	35
E_e [kPa]	57	78	84	100	167	345	145	90	47	40
ρ [kg/m^3]	126	142	156	170	197	166*	166*	166*	166*	166*

* Density range: 160–170 kg/m^3

Figs. 1 and 2 illustrate the comparison of the first and last hysteresis loops for the investigated samples, the range of the displacement control is 2 to 10 mm.

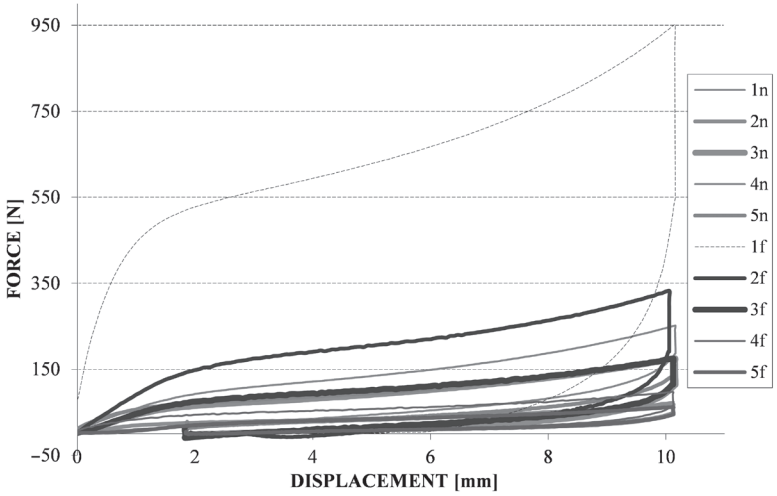

Fig. 1. Comparison of the hysteresis loops at the beginning of the testing of each foam sample – displacement control in the range of 2 to 10 mm

Dynamic loads applied at a rate of 200 mm/min in the form of kinematic excitations caused the hysteresis loop to change from linear (of fixed rigidity) to progressive (with increasing rigidity). Nevertheless, this rigidity tended to decrease in each subsequent cycle leading to the reduced capability of mechanical energy dissipation. The majority of the dissipated energy

is released in the second part of the cycle when the larger pressure is applied. It is apparent that the best energy dissipation performance was registered for sample 1f which featured the highest rigidity and the lowest polyol content (see Figs. 1, 2).

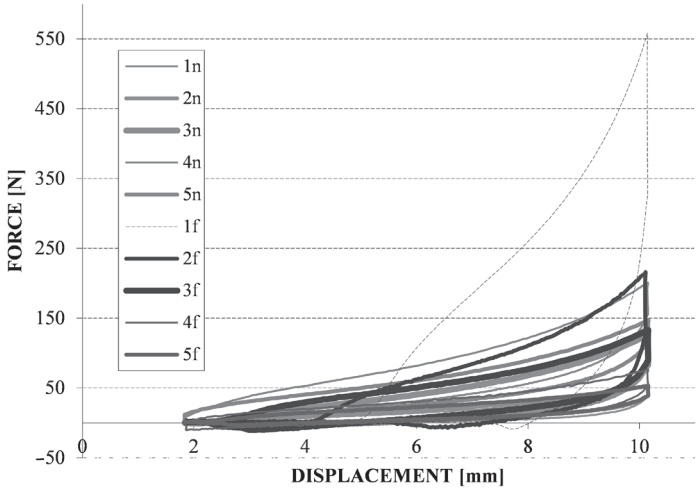

Fig. 2. Comparison of the hysteresis loops at the end of the testing of each foam sample (after 50 cycles) – displacement control in the range of 2 to 10 mm

The microstructures of the investigated materials (at 1000× magnification) were obtained using.

The microstructures of samples 2n and 1f, which were obtained using the JEOL JSN5510LV scanning microscope are shown in Figs. 3 and 4. They reveal the open pores and microstructure features most characteristic of polyurethane materials. Pores in foams indexed with ‘f’ contain spherical elements, those in samples denoted by ‘n’ are elongated with an

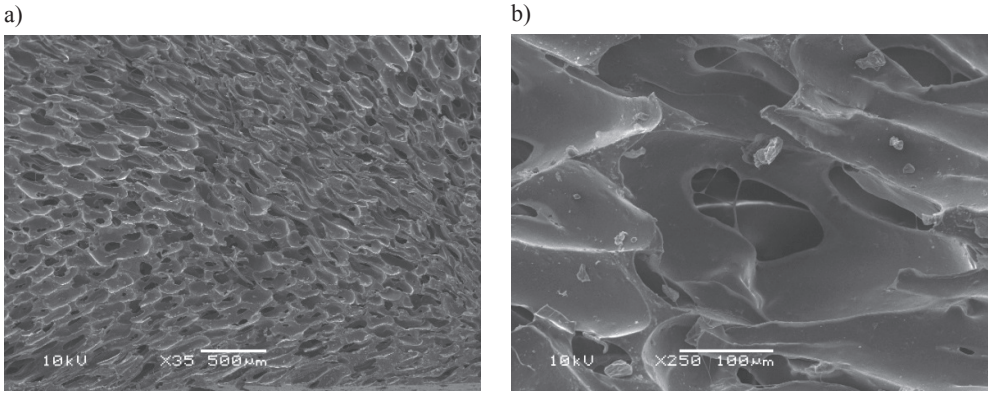

Fig. 3. SEM image of microstructure of polyurethane foam sample 2n (A – mag 35×, B – mag 250×)

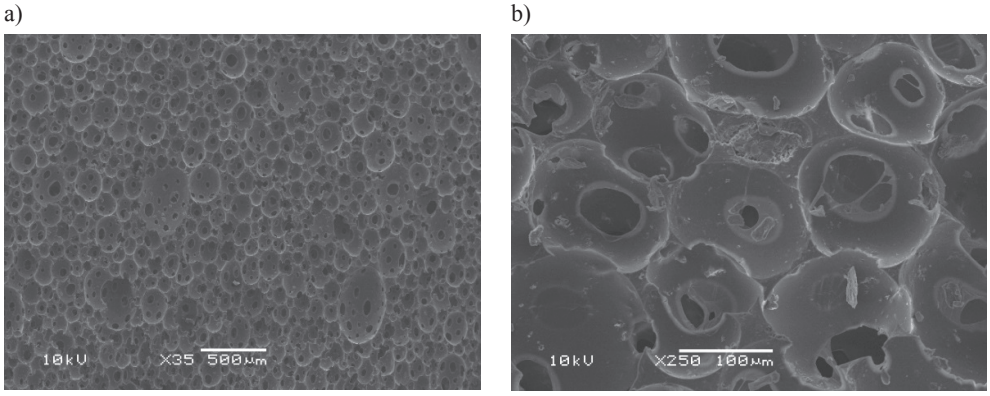

Fig. 4. SEM image of microstructure of polyurethane foam sample 1f (A – mag 35×, B – mag 250×)

irregular structure. In the case of sample 1f, the regular arrangement of pores and their fully-closed condition results in enhanced rigidity and anisotropy of the elasticity modulus.

4. Impedance tube and measurement method of absorption coefficient

4.1. Methodology

The normal incidence sound absorption coefficient of a material (α_n) is the fraction of normally incident sound energy absorbed by that material. The absorption coefficient will, in general, depend on both the structure of the material and its method of mounting. The normal absorption coefficients were measured in an impedance tube. The measuring technique employed here was that stipulated in document PN-EN ISO 10534-1 [10].

A schematic diagram of the impedance tube and measurement equipment used in testing is shown in Fig. 5. The translation from a set of angle-dependent free field absorption coefficients to random incidence values is normally carried out using Morse's formula [11]. Measurements were taken with the type 4002 standing wave apparatus by Bruel & Kjaer [12].

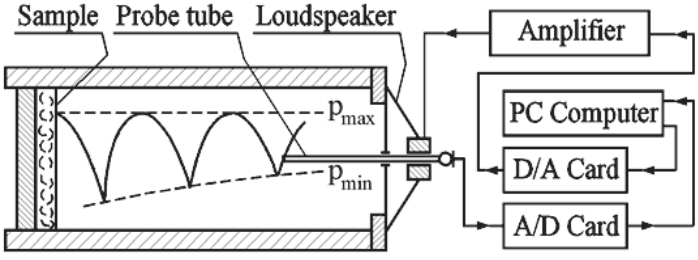

Fig. 5. The impedance tube and the measurement equipment

4.2. Measurement results

Fig. 6 plots the sound absorption coefficient determined in accordance with the procedure specified in the normative standard [13] for materials of different densities. It appears that the best sound absorption performance (in terms of the adopted criterion) is offered by materials whose densities range from 160 to 170 kg/m^3 whilst the materials with the density nearing the upper limit of the investigated range give the worst results.

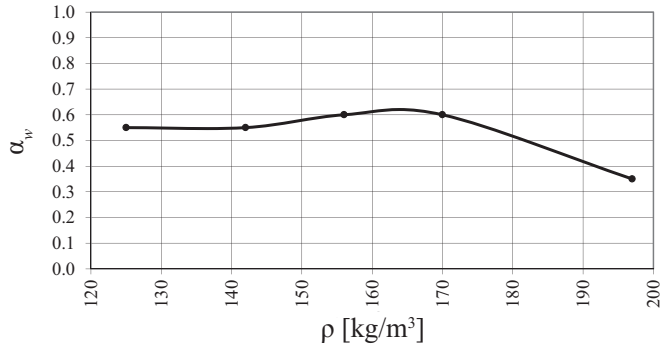

Fig. 6. Relationship between sound absorption factor and sample density

The influence of density on sound absorption behaviour in particular frequency ranges is illustrated in Fig. 7. In low frequency ranges (125 Hz, 250 Hz), the best sound absorption performance is observed for materials whose densities range from 160 to 170 kg/m^3. For frequencies of 500 Hz, 1 kHz and 2 kHz, and for densities up to 170 kg/m^3, the value of the sound absorption coefficient is scarcely affected by the density of the material. For higher densities, the value of the sound absorption coefficient tends to decrease. In the high frequency range (4 kHz), increased density is accompanied by a reduction of the sound absorption coefficient α across the entire investigated range.

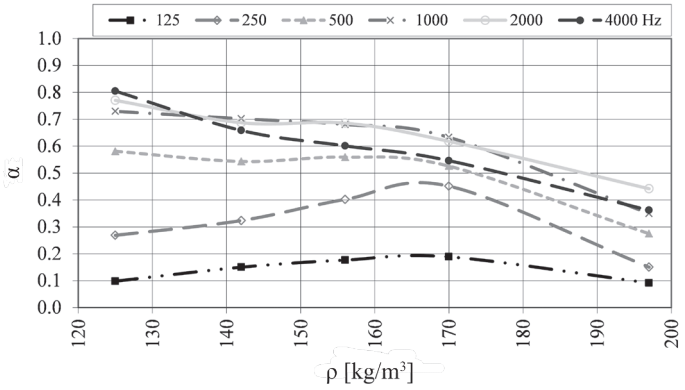

Fig. 7. Coefficient α verses density at the excitation frequencies

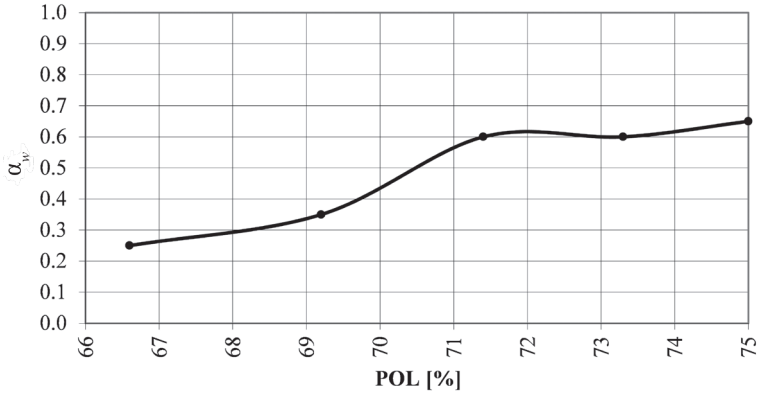

Fig. 8. Influence of the polyol content on sound absorption performance

Fig. 8 plots the values of the sound absorption coefficient determined in accordance with the procedure set forth in the normative standard [13] for materials with variable polyol contents. The percentage fraction expressing the polyol content in the sample mass is indicated on the x-axis. It appears that materials containing at least 71% of polyol exhibit the best sound absorption features.

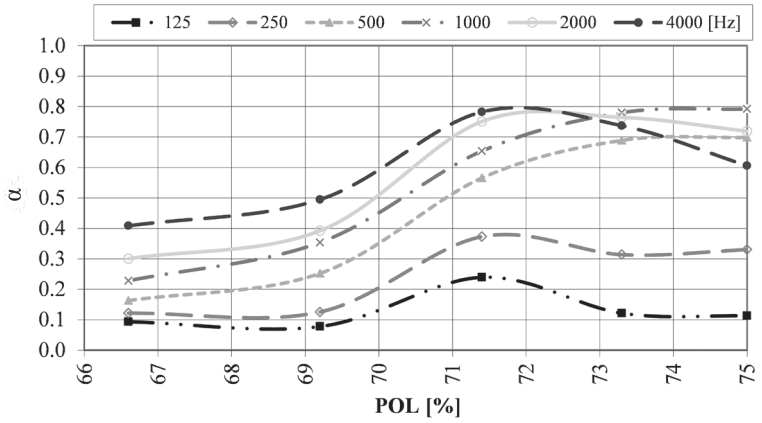

Fig. 9. Influence of polyol content on the coefficient α in specified frequency ranges

The influence of the polyol content on the sound absorption behaviour in specified frequency intervals is illustrated in Fig. 9. In the low (125 Hz, 250 Hz) and high (4 kHz) frequency ranges, the materials with the polyol content in the range of 71 to 72% shows the best sound absorption performance. In the frequency range 500 Hz and 1 kHz, the value of coefficient α increases with the increasing polyol content. At 2 kHz, the sound absorption coefficient α of materials with a polyol content in excess of 71% changed only to a minor degree.

5. Conclusions

The research investigation was undertaken to determine the mechanical and acoustical behaviour of polyurethane foams whose properties were predetermined at the stage of design. The behaviour of the investigated material can be modified by varying the weight proportions of the component mix and by varying the value of the POL/IZO ratio. The results of experimental tests lead us to the following conclusions:

- relationships are revealed between the ratio of polyols and isocyanate in the component mix and the mechanical and acoustical behaviour of the material, it is therefore reasonable to expect that the sound absorption and mechanical behaviour of polyurethane foams can be already modified at the stage of design;
- for samples characterised by the fixed ratio POL/IZO, the value of the sound absorption coefficient α varies with frequency and with sample density;
- tests results reveal the influence of the POL/IZO ratio on the acoustical parameters of samples; furthermore, the increased polyol content gives rise to improved sound absorption behaviour, particularly in the medium and high frequency ranges;
- measurements of the mechanical parameters revealed the dependence between density and the Young modulus – increased density gives rise to an increase of the Young modulus;
- the value of the Young modulus is found to decrease when the proportion of polyols in the component mix increases; however, an increased proportion of polyols does not lead to a significant enhancement of their rigidity or energy dissipation performance;
- the relationship is established between the sample density and the sound absorption coefficient α, the highest values of the coefficient are registered for densities in the range of 160 to 170 kg/m^3.

The results of this research investigation reveal a relationship between the values of selected mechanical and acoustical parameters. In particular, the improved mechanical energy dissipation behaviour goes alongside the reduced acoustic energy absorption performance, which may be attributable to the cell structure of investigated foams.

Further research should be undertaken to establish the relative importance of other factors – the mixing time and method, and their influence on the mechanical and acoustical behaviour of foam materials.

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EVALUATION OF THE SUITABILITY OF STUDY VISITS TO EXTERNAL COMPANIES AS A STRATEGY FOR FAMILIARISING STUDENTS WITH A BUSINESS ENVIRONMENT

EWALUACJA PRZYDATNOŚCI WIZYT STUDYJNYCH W PRZEDSIĘBIORSTWACH JAKO NARZĘDZIA WPROWADZAJĄCEGO STUDENTÓW W ŚRODOWISKO BIZNESOWE

Abstract

This paper presents the results of the evaluation of several study visits. On that basis, it discusses the issue of the suitability of study visits in external companies for the wider process of familiarising students with the business and market environment.

Keywords: study visits, evaluation

Streszczenie

W tym artykule przedstawiono wyniki ewaluacji kilku wizyt studyjnych. Na podstawie otrzymanych wyników omówiono kwestie przydatności wizyt studyjnych w firmach zewnętrznych jako narzędzia wprowadzającego studentów w środowisko biznesowe.

Słowa kluczowe: wizyty studyjne, ewaluacja

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1. Introduction

In recent decades, Cracow University of Technology has tried to provide the *sine qua non* condition for the successful transition from the purely scientific institution of academia to the knowledge-based economy – the early immersion of students of technical faculties into the business and market environment where they may find their potential employer and place of future self-fulfilment. An important element of the education policy relating to the technical faculties at Cracow University of Technology and the various programs run by the university under the EU Human Capital Operational Program are study visits to various companies in Poland and abroad. Such visits are very short in most cases and therefore one may ask if they actually contribute to maintaining the desirable link between the university and business and if they have a real impact on students' choices and attitudes towards their future career.

This paper presents the results of the evaluation of several study visits to companies in Poland and abroad. On that basis, it discusses the issue of the suitability of study visits in external companies for the wider process of familiarising students with the business and market environment. The evaluation covered post-graduate students studying fluid drives and fluid control systems as well as entrepreneurs who organised the study visits to their high-tech companies.

According to the obtained results, both the students and the entrepreneurs appreciated the essential role of study visits in the acquisition of highly-educated employers in innovative business and in shaping students' future careers through obtaining valuable personal contacts. Therefore, the study visits were found to be invaluable in establishing and maintaining the bond between the university and private companies. Aside from this, it was widely claimed that study visits may greatly contribute to honing students' skills by means of consolidating their technical knowledge with practice. On the other hand, it was revealed that the study visits were very often too short and sometimes not guided by specialists but by appointed workers whose technical knowledge was inadequate.

2. Methodology and Techniques

During the research, a CAWI method was employed. Computer assisted web interviews (CAWI) are a quantitative data acquisition technique in which respondents fill in the questionnaire on a website. The website provides its users with the necessary assistance. Therefore, the data may be acquired remotely from respondents and without the mediation of an interviewer who is not burdened with the time-consuming process of data entry typical of the PAPI method. Additionally, the data is analysed swiftly [1, 2]. In our research, the respondents of CAWI were:

- students studying fluid drives and fluid control systems;
- entrepreneurs who took part in organising the study visits.

3. Target group

3.1. The research

The research took place in May 2015. It covered the students studying fluid drives and fluid control systems who took part in study visits in companies and the entrepreneurs – people in charge in those companies involved in the study visits. Post-graduate studies in fluid drives and fluid control systems were study courses co-funded by the EU under the project POKL 'PIT Mobilne studia podyplomowe we współpracy z przemysłem' (OPHC 'PIT Mobile post-graduate studies in collaboration with the industry partners').

3.1.1. Students studying fluid drives and fluid control systems

The group consisted of fifteen men and no women. The respondents were mainly at the age of 25–30 (53%). See Fig. 1.

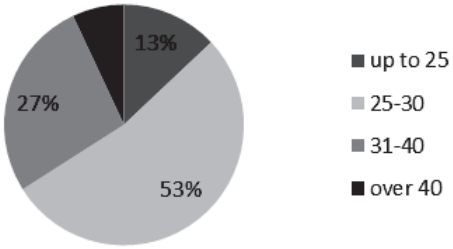

Fig. 1. Respondents' age. Source: Created by the authors, based on data from the CAWI interview with students studying fluid drives and fluid control systems, $N = 15$

Interviewed students studying fluid drives and fluid control systems were mostly (80%) employed within a branch of industry corresponding to the profile of postgraduate studies they had chosen (Fig. 2).

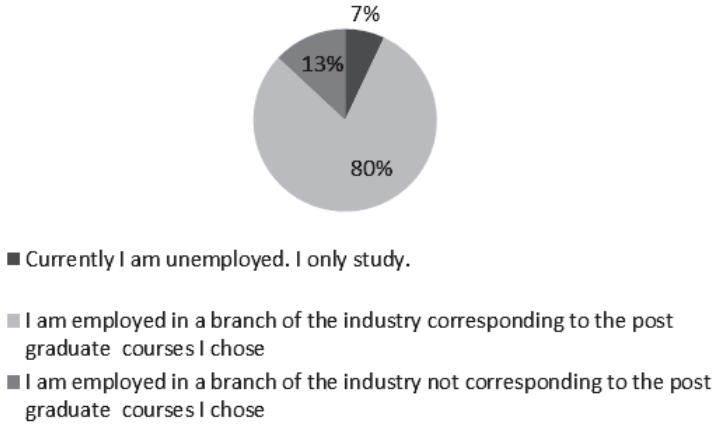

Fig. 2. Employment profile. Source: Created by the authors, based on data from the CAWI interview with students studying fluid drives and fluid control systems, $N = 15$

3.1.2. Entrepreneurs who took part in organising study visits for FDC students

The group of entrepreneurs who took part in organising study visits consisted of two directors and vice-directors, two specialists and one head of department (Fig. 3).

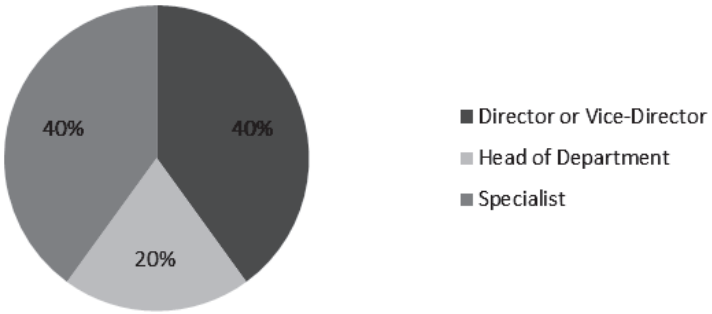

Fig. 3. Respondent's post. Source: Created by the authors, based on data from the CAWI interview with entrepreneurs, $N = 5$

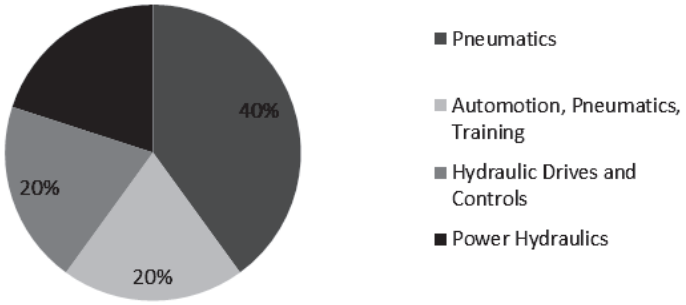

Fig. 4. Branches of industry represented by the respondents Source: Created by the authors, based on data from the CAWI interview with entrepreneurs, $N = 5$

Fig. 5. Size of enterprises. Source: Created by the authors, based on data from the CAWI interview with entrepreneurs, $N = 5$

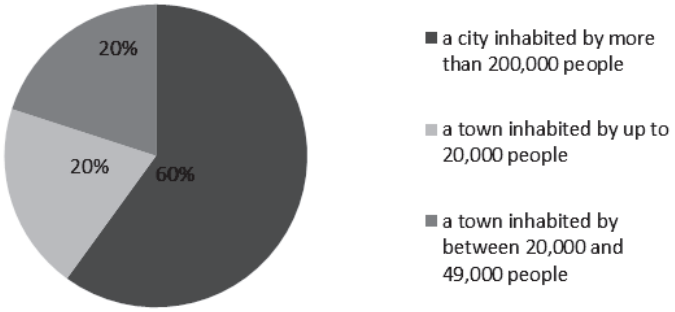

Fig. 6. Location of enterprises. Source: Created by the authors, based on data from the CAWI interview with entrepreneurs, $N = 5$

All the respondents represented enterprises involved in pneumatics or hydraulics (Fig. 4).

Four of those enterprises employed 50-249 people and one of them employed more than 249 people (Fig. 5).

Three enterprises were located in a city inhabited by more than 200,000 people, one in a town inhabited by up to 20,000 people and one in a town inhabited by between 20,000 and 49,000 people (Fig. 6).

4. Results

4.1. Students studying fluid drives and fluid control systems

According to the research, students studying fluid drives and fluid control systems evaluated the possibility of taking part in study visits under the project as very high (87%) or high (13%). As many as 93% of them declared they had been glad of the study visits. Moreover, 93% of students claimed that the study visits had met their expectations. 93% of respondents claimed that during study visits in companies, they had been involved in activities raising their level of knowledge and skills and therefore, also raising their market competitiveness. All of the respondents declared that study visits were in professionally organised and well-chosen companies i.e. in those whose profile was consistent with the visitors' field of study, see Fig. 7.

Among the strong points of study visits, the respondents mentioned:

- the possibility of getting acquainted with the practical issues encountered by companies all over the world and with the existing solutions;
- the possibility of gaining experience;
- the possibility of getting business contacts;
- the valuable insight into the real work of an industrial facility involved in hydraulics or pneumatics;
- meeting with specialists;
- the possibility of honing practical skills in production engineering and management;
- the possibility of gaining knowledge concerning the services available on the market.

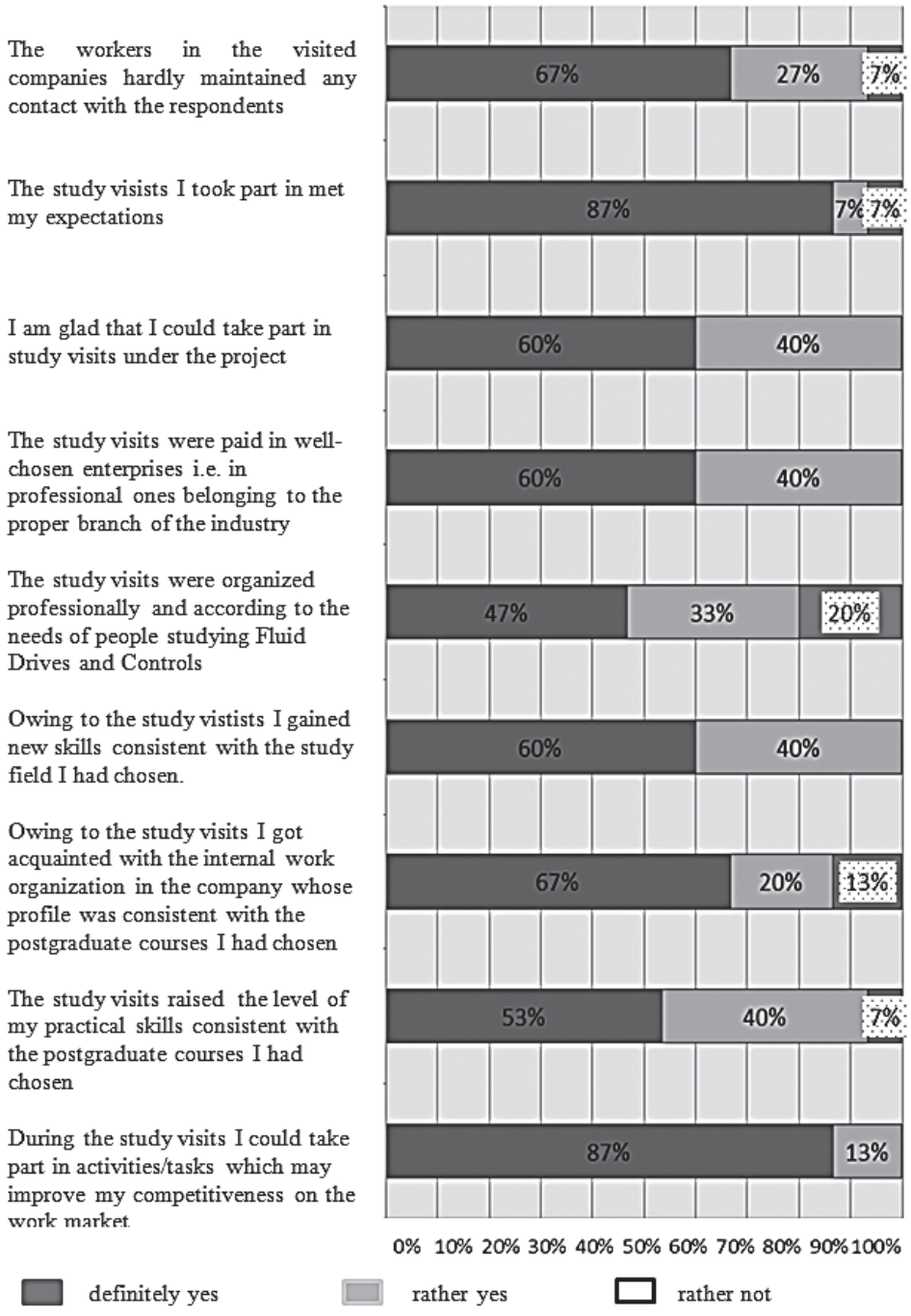

Fig. 7. Students' opinion on the aspects of study visits made during the PIT project: Source: Created by the authors, based on data from the CAWI interview with the students studying fluid drives and fluid control systems, $N = 15$

Among the weak points of study visits, the respondents mentioned the following issues:

– study visits were too short;
– the technical knowledge of some guides appointed by the company was inadequate.

According to the conducted research, the students and auditing students evaluated the possibility of taking part in study visits during the project as very good or good. The majority of students were satisfied with the visits and claimed that the visits met their expectations. According to the results, the majority of respondents were able to take part in activities/ tasks which may have improved their competitiveness on the work market. Almost all of the respondents declared that the visited companies were well-chosen i.e. professional and belonging to the proper branch of the industry, and that the visits were well-organised and were able to meet the students' needs.

4.2. Entrepreneurs who took part in organising study visits for FDC students

The representatives of the enterprises in which the study visits were, were asked to valued the reasons for their willingness to allow study visits during the project. They mentioned the following reasons:

– they had positive feelings about their previous collaborations with Cracow University of Technology;
– they were willing to acquaint the students studying fluid drives and fluid control systems with the techniques and products offered by their companies;
– they were willing to raise the students' interest in working within the company;
– they were willing to allow the students to consolidate their knowledge with practice.

All interviewed entrepreneurs claimed that the study visits met their expectations. 80% of them (four of five) declared that the study visits met their expectations to a very large extent, see Fig. 8.

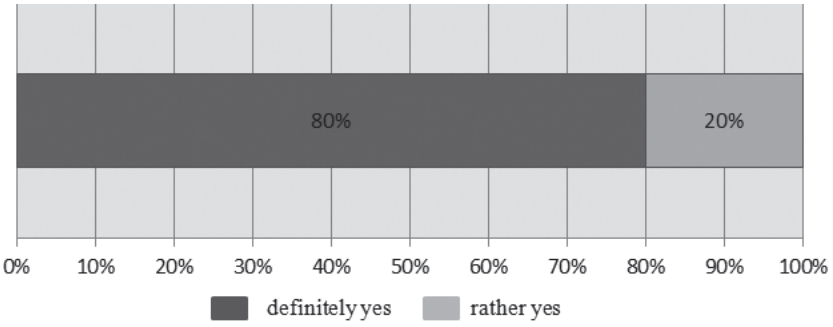

Fig. 8. Measurement of whether the study visit met entrepreneurs expectations. Source: Created by the authors, based on data from the CAWI interview with the entrepreneurs, $N = 5$

The respondents evaluated the positivity of the study visits as a type of collaboration between the university and their company as 'definitely' high (4 respondents, 80%) or 'rather' high (1 person, 20%), see Fig. 9.

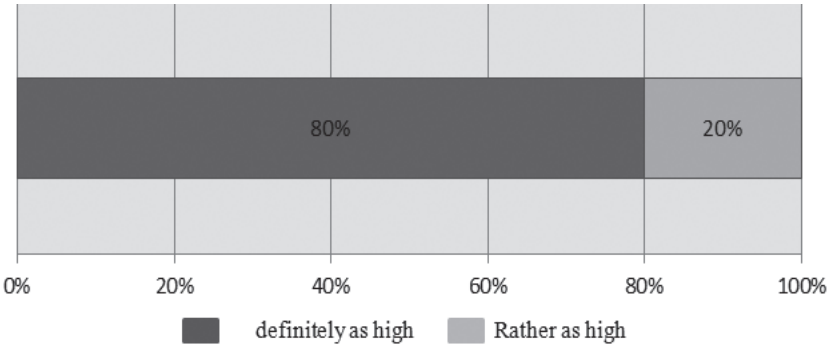

Fig. 9. How entrepreneurs evaluated the positivity of the study visits as a type of collaboration between the university and the company. Source: Created by the authors, based on data from the CAWI interview with the entrepreneurs, $N = 5$

All the representatives of the companies claimed that the project was either very highly innovative (3 respondents, 60%) or highly innovative, see Fig. 10.

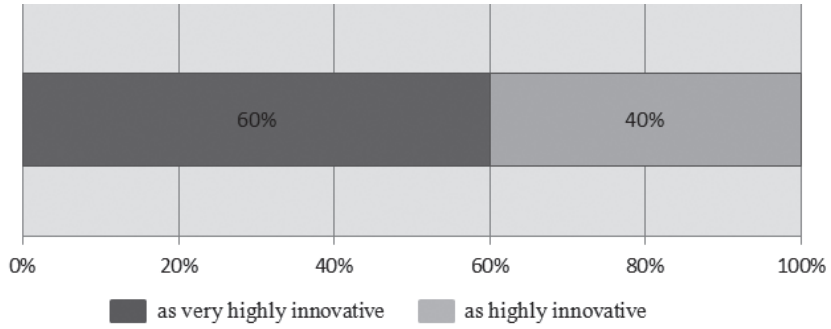

Fig. 10. How entrepreneurs evaluated the project with respect to the study visits (taking into account all the practical tasks, workshops and laboratory works conducted during the visits) Source: Created by the authors, based on data from the CAWI interview with the entrepreneurs, $N = 5$

According to the respondents, study visits were organised professionally and in a manner appropriate for the students' needs (see Fig. 11). The respondents claimed that such visits are beneficial for students for the following reasons:

- the visits gave students the opportunity to take part in task and activities which may raise their competitiveness on the labour market;
- the visits may provide students with more practical knowledge connected with the study field they chose;
- the visits may provide students with some practical knowledge connected with the organisation of work in the enterprise;

– the visits may provide students with knowledge and skills consistent with the profile of their chosen post-graduate courses.

Furthermore, the interviewees claimed that they were very glad to host the students in there companies.

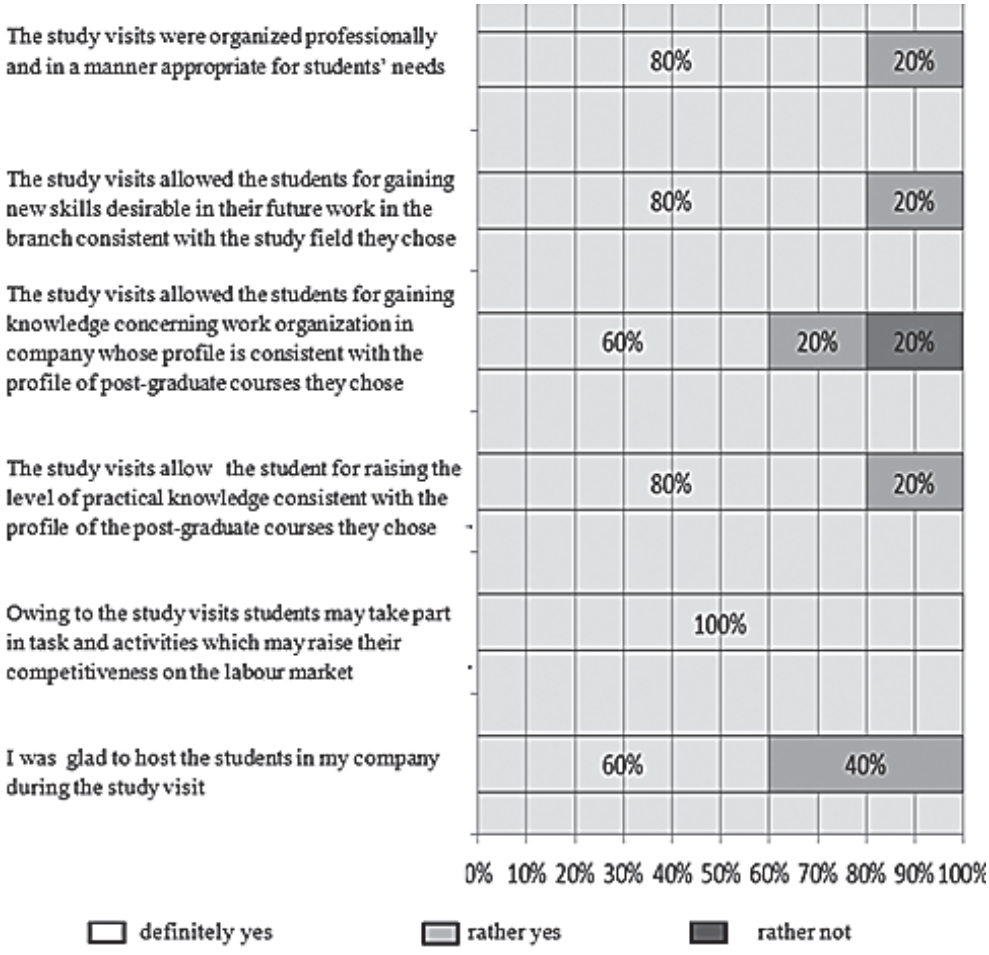

Fig. 11. Responses of the entrepreneurs to the statements connected with the study visits. Source: Created by the authors, based on data from the CAWI interview with the entrepreneurs, $N = 5$

According to the respondents, the main benefits of the study visits were their practical aspects and the possibility of the students gaining experience in this way. One respondent revealed that the university did not specify the topic of the study visit – this posed some difficulties during the visit. None of the respondents were able to indicate the aspects of study visits which should be modified. None of them made any suggestions concerning solving the issues which may possibly improve the quality of the visits. All of the respondents who

hosted the students claimed that their company was quite interested (60%) or definitely interested (40%) in organising such visits in the future, see Fig. 12.

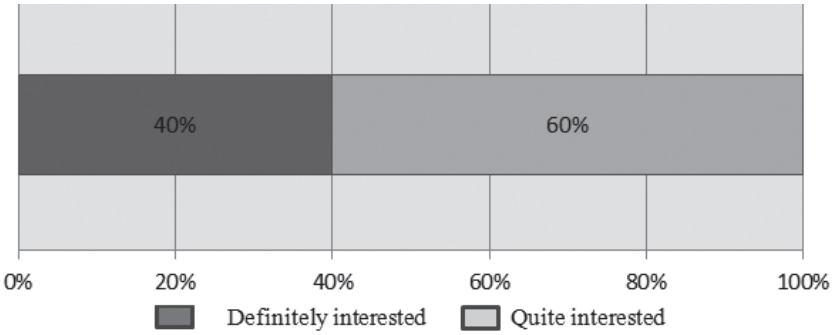

Fig. 12. The interest levels of entrepreneurs in organising study visits in the future. Source: Created by the authors, based on data from the CAWI interview with the entrepreneurs, $N = 5$

4.3. Conclusions

According to the research, students praised the study visits and declared that those visits were one of the highlights of the PIT project because the skills and knowledge gained during the study visits – including the contacts with branch specialists and employers – is quite unusual and cannot be acquired in any other manner. However, there were some remarks concerning some points of the study visit programmes, especially those which were purely theoretical. Furthermore, it was difficult to schedule the study visits as the companies preferred standard work days and claimed that between Monday and Friday, access to machines and employees is much easier. On the other hand, many students were already employed and would have therefore needed to take leave; thus, most of the study visits took place during the weekends.

The results of the interview with the entrepreneurs shed a light on the key role of study visits for students especially in gaining the practical experience which is the crucial issue during the recruitment process. Moreover, the study visits may contribute to the wider process of bonding the industrial and educational environments.

5. General conclusions

According to this research, the most important issue for the employers during the recruitment process is the experience of applicants. The first step towards gaining that experience may be study visits. By knowing the capabilities offered by the labour market, one could more sensibly shape their career path. Study visits are innovative tools which enable students to increase their level of knowledge and hone their practical skills. According to the obtained results, both the students and the entrepreneurs appreciated the essential role that study visits can play in the acquisition of highly-educated employees for innovative

businesses and in shaping students' future careers through obtaining valuable personal contacts. Therefore, the study visits were found to be indispensable in establishing and maintaining the bond between the university and private companies. Apart from that, it was widely claimed that study visits may greatly contribute to honing students' skills by means of consolidating their technical knowledge with practice. On the other hand, it was revealed that the study visits were very often too short, and sometimes guided not by the specialists but by the appointed workers whose technical knowledge was inadequate.

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SZYMON HERNIK*

THE MOODLE PLATFORM'S LESSON MODULE AS AN EXAMPLE OF EFFECTIVE E-LEARNING

MODUŁ „LEKCJA" PLATFORMY MOODLE JAKO PRZYKŁAD EFEKTYWNEGO NAUCZANIA NA ODLEGŁOŚĆ

Abstract

In the era of distance communication, areas such as education can try to find a place in the digital world. The possibility of distance learning, due to widespread access to the Internet, can provide valuable educational activities without the necessity for the student to leave their home. A perfect example of this approach is the module 'Lesson' contained within the Moodle platform. This allows not only the opportunity to present attractive knowledge but also the possibility for student evaluation on an ongoing basis whilst they are still learning. This functionality is one of the most dynamic components of the platform – it enables two-way interactivity between teacher and student.

Keywords: e-learning, Moodle platform, blended learning

Streszczenie

W dobie rozwoju komunikacji na odległość również taka dziedzina jak edukacja próbuje znaleźć swoje miejsce w cyfrowym świecie. Możliwości nauczania na odległość, ze względu na powszechny dostęp do Internetu, pozwalają na przeprowadzenie pełnowartościowych zajęć bez konieczności wychodzenia z domu. Idealnym przykładem takiego rozwiązania jest moduł „Lekcja" zawarty w platformie Moodle. Pozwala on nie tylko na przekazanie w sposób atrakcyjny wiedzy, ale również na jej weryfikowanie na bieżąco, w trakcie nauki. Opisywany moduł należy do dynamicznych składowych platformy – umożliwia dwukierunkową interaktywność pomiędzy nauczycielem a uczniem.

Słowa kluczowe: e-learning, platforma Moodle, blended learning

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1. Introduction

Nowadays, e-learning is one of the most popular forms of online education. Its popularity is mainly connected with the fact that it provides the opportunity for distance education thanks to the use of processes and software that create online courses. That is an important technique that meets the expectations of present day students who want to gain knowledge in an attractive manner and manage their learning time efficiently. Online courses allow achieving this aim, they also let students broaden their knowledge in a manner which might provide an alternative to traditional learning techniques.

The construction of online courses is based on the conviction that the interaction and collaboration between educators and students is continuous. The quality of the information exchange is determined by the efficiency of that exchange between teachers and students. In order to make online education professional and effective, it is necessary to employ the right processes and software designed especially for that purpose [1]. This means modern e-learning systems that have well developed IT tools which aid the educational process. The lack of unity of place, and very often time, is characteristic of the participants of online education.

Specialist literature provides various definitions of e-learning, generally, the problem can be described as "a set of instructions for digital tools, such as computers or portables, that aid learning" [12]. It is also emphasised that e-learning covers the whole scope of processes connected with teaching and learning within an environment that uses modern information technologies, especially the Internet. Interactivity is a characteristic feature of the whole process which utilises technological tools and allows for the creation of a relationship between a teacher (the broadcaster) and a student (the recipient) or students (the recipients). E-learning also provides an opportunity to make the educational process more flexible – this is possible due to available access to knowledge at any time and from any place in the world. What is more, a student can adjust the pace of learning according to his or her subjective abilities or individual needs. E-learning also provides access to state-of-the-art laboratories and virtual experiments [8].

However, disregarding some of the terminology, it is worth noting that the idea of e-learning or distance learning is currently an important educational alternative, mainly because of the constant necessity to broaden one's skills and professional competencies [6]. It is also extremely vital for enhancing the quality of education, primarily at the academic level. Involving the students in the educational process is the key to success in the case of online academic education. Students like the latest information technology, also learning platforms, designed to aid traditional classroom teaching [13]. Therefore, the quality of education is determined by the individualisation of the educational path. It is possible by the use of alternative online education.

2. Characteristics of the main e-learning platforms

Currently, common asynchronous teaching models are used in every day teaching practice. They lack the elements that are determined by the location and time of the classes carried out in the course of studies [5]. In that model, direct communication is replaced by electronic communication, e.g. creating newsgroups or exchanging e-mails. E-learning solutions, as

stated above, allow the learning place to be flexible and individual. In connection with the above, learning platforms (e.g. learning management system – LMS, or learning content management system – LCMS or virtual learning environment – VLE) give a chance not only to conduct classes and communicate with students within an online course but can also enhance regular classes run in university classrooms. This type of education is called blended learning [8] – it combines face-to-face education with e-learning. The system is typical for colleges and universities which more and more frequently begin to implement elements of online teaching and learning. Due to blended learning, it is possible to reduce the time spent by students at universities, and in this way, reduce the costs of studies as well as facilitate their organisation [9].

One of the solutions is the Moodle platform (modular object oriented distance learning environment) – the system that aids distance learning. It has over 65 million users all over the world and has been translated into 120 languages [11]. Martin Dougiamas, an Australian, is a founder and creator of Moodle who working on the platform believed in "(...) the importance of unrestricted education and empowered teaching, and Moodle is the main way I can contribute to the realisation of these ideals. I also know a lot of people in schools and smaller institutions (and some big ones!) who want to make better use of the Internet but don't know where to start in the maze of technologies and pedagogies that are out there. I've always hoped there would be a free alternative that such people could use to help them move their teaching skills into the online environment. It is crucial to me that this software be easy to use – in fact, it should be as intuitive as possible" [11].

Moodle enables creating educational pages that allow for distance teaching and learning. It is popular because it is widely available and free for use under the GNU GPL licence [4]. It offers an easy and user friendly interface that is characterised by customisable management features – this is possible thanks to setting the options that are connected with the following elements [7]:

- course availability – allows for attributing determined roles and authorisations (e.g. administrator, visitor, student, teacher, leader) and creating access for a particular group of users;
- course enrolment – users can enrol for courses unassisted (optional use of an access key – a password) or can be enrolled by the lecturer;
- course syllabus – the possibility of setting order, e.g. subject order or time order.

Moodle users have their own fully modifiable accounts which means that they have authorised access to the platform. It is also worth mentioning that Moodle is compatible with various software packages thus making it possible to publish educational materials in different formats, e.g. '.doc', '.ppt', or '.pdf'. It also has important features for use with other specific systems that allow educators to present learning materials to students and also check their knowledge using different testing tools (e.g. homework, quiz, survey) [7].

Other free learning platforms also exist, e.g. Caroline [2]. According to the platform's creators, it is used by over 500 organisations in 68 countries. It allows the management of documents and resources available to the learners. Collaboration among course participants is possible thanks to the use of the calendar and other tools designed for the purpose of cooperative work.

Apart from the free platforms, there are also commercial options – MS Windows Server Training [14] and Lotus Learning Space [10] are among the most common examples; however, their popularity is limited.

Bearing in mind the versatility, popularity and availability of Moodle, the following part of this article will focus on Moodle itself, or more precisely, one of its modules called The Moodle Lesson Activity. This is the basis for one of the dynamic elements of courses. It enables educators to provide information to learners and to simultaneously check their knowledge. The Lesson Activity consists some part called "lesson", built as a collection of HTML slides, designed by a course creator. All of them contains educational content and some questions tools to check the knowledge. Generally, there are two basic methods of content presentation, these are pages presenting educational content and pages designed for testing. What makes the Moodle Lesson Activity different is its ability to adapt to the learner's progress.

3. The use of The Lesson Activity in educational practice

In order to create a lesson, firstly click the 'Add an activity' drop-down menu and select 'Lesson', give the lesson a name and save it. You are then directed to a page with four tabs: 'Preview Lesson', 'Edit', 'Reports', 'Grade Essays'. The first tab enables students to view the lesson. The 'Edit' tab enables the creator to add new elements to the lesson, the 'Reports' tab shows statistical information about students' progress. The last tab enables the educator to grade students' essays. During the lesson creation process, the second tab is most important.

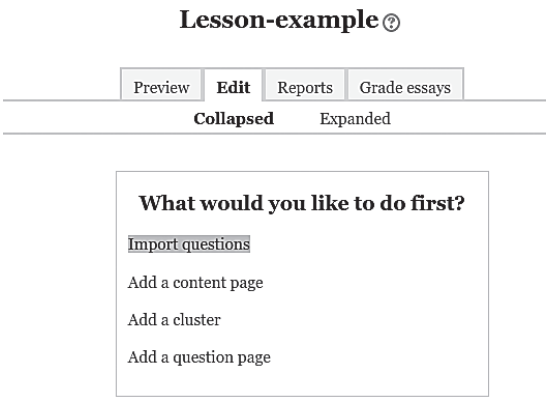


Fig. 1. Creating an example lesson

The easiest way of creating a lesson is by choosing the "Add a question page" option – this allows the insertion of teaching material and testing tools. Fig. 2 shows exemplary teaching content while Fig. 3 shows testing tools. Each question page should include a testing tools for checking students' progress. Exemplary multiple choice test (with only one correct answer) is presented in Fig. 3. It is possible to use other testing tools, of course.

A good example of multiple choice test is a strategy where the educator asks a question that has a number of possible correct answers and assign a different score to each one.

Methods based on the energy principle to calculate defiormation of beams

Castigliano theorem is the method based on the strain energy principle as follows:

The deformation at some point of linear elastic beam is equal the partial derivative of the strain energy with respect to an applied force at this point.

The angle of bending twist at some of linear elastic beam is equal the partial derivative of the strain energy with respect to an applied moment at this point.

Aforementioned theorem can be descibed by the equations as follows:

$$w_A = \frac{\partial L}{\partial H} = \int_{(l)} \frac{M_g(x)}{EI} \frac{\partial M_g(x)}{\partial H} \, \mathrm{d}x$$

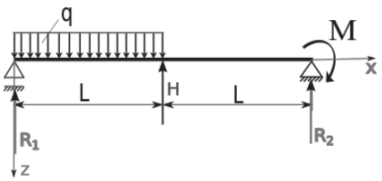
$$\varphi_A = \frac{\partial L}{\partial M_H} = \int_{(l)} \frac{M_g(x)}{EI} \frac{\partial M_g(x)}{\partial M_H} \, \mathrm{d}x$$

where:

- M_g is the bending moment
- EI is a stiffnes of beam
- symbol $\int_{(l)}$ means the integration along the beam.

Checking questions

Fig. 2. Example page with teaching content



The second part stands for: $L \leq x \leq 2L$. The equation describing the bending moment in this part of beam is as follows (checked the correct answer):

- $M_{g_2} = R_1 x - qL\left(x - \frac{L}{2}\right) + H(x-l)$
- $M_{g_2} = R_1 x + qL\left(x - \frac{L}{2}\right) + H(x-l)$
- $M_{g_2} = R_1 x - \frac{1}{2} qL^2 + H(x-l)$
- $M_{g_2} = R_1 x - qL\left(x - \frac{L}{2}\right) - H(x-l)$

Fig. 3. Example page with multiple choice question

A true or false quiz, as presented in Fig.4, is another testing tool – here, the learner has to answer ‘yes’ or ‘no’ to questions. In cases of choosing the option ‘Short answer’, the learner

needs to write the correct answer in an appropriate window. However, this should not be longer than a few words. ‘Match the answer’ is another type of question.

Fig. 4. A page with a ‘True’ or ‘False’ quiz

Here, the learner needs to pick one of the given answers and match it to the question asked, in such cases, more than one answer can be correct. There are also numerical questions where the answer is a number that has a certain tolerance. A short essay is another form of testing.

The student is informed about a correct answer (Fig. 5) and directed to the next page after pressing the ‘continue’ button.

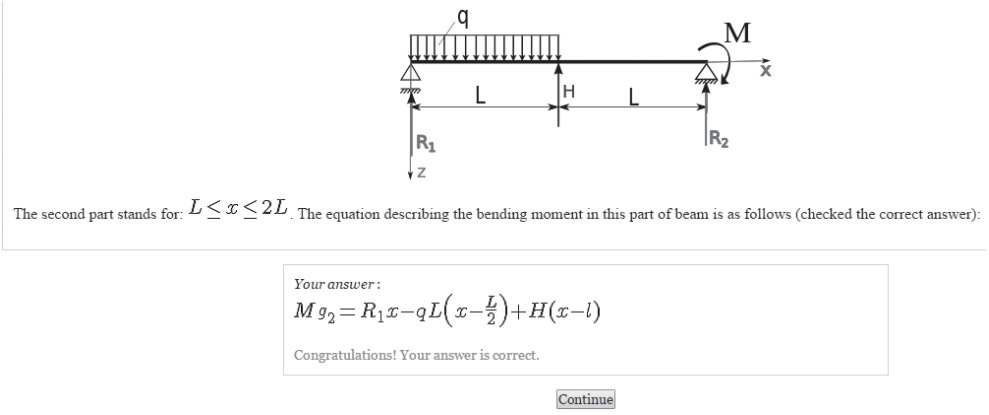


Fig. 5. Example question with choosing good answer

If the student answers the question incorrectly or gives no answer to the question, the educator can transfer the student to the content page for further study, or back to the question that was answered incorrectly. It is also possible to set an option where each additional answer has a lower score.

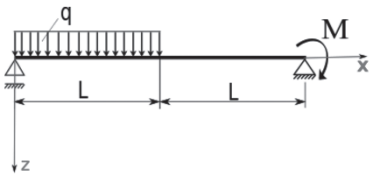
Branch tables and clusters are more advanced forms of lesson construction. Branch tables are used for dividing question pages into sections that create the basic structure of the page. Creating a branch starts with the insertion of a branch table, and finishes with the insertion of an ‘End of branch’ page; upon completion, you are directed to branch table page. Fig. 6 presents an example of a branch table page as seen by the course participant.

Clusters are groups of question pages that form is similar to the multiple questions test page. When we have a lots of lessons (lots of educational data) we can input one page with only educational content, and next input many pages with questions to check the knowledge

Exercise

Estimate the magnitude of the deflection at a half of length of the beam below and the value of bending angle at the end of beam.

Given: $q = 10$ kN/m, $L = 1$ m, $E = 210$ GPa, $I = 2 \cdot 10^{-7}$ m^4, $M = \frac{1}{2} q L^2$.



Estimate magnitude of deflection

Estimate value of bending angle

Fig. 6. Example branch table page where the student can divide next content

of learners. From the lists of questions, the Moodle system randomly select group of the questions to input on the question page. If the amount of questions are huge, it will possible that the same question are not select many times by the system. The parameters according to the question page are possible to choose on "End of cluster" page.

4. Conclusion

Using online courses in academic education can be a very attractive way of learning for students. Not only can e-learning enhance traditional education but can also be used as an individual course covering a particular subject. In that respect, The Moodle Lesson Activity is truly amazing as it allows the creation of engaging, interactive packages presented in an attractive form. It helps to make students more active and involved in the learning process, not only at the university but also in the home. The Moodle learning platform allows the use of non-standard educational procedures while embedding external media into Moodle makes it even more attractive. There is the option to add more dynamic content to lessons such as graphs, videos, animation, sound, or even have online tutorial sessions. Additionally, having the opportunity to not only present teaching content to students but also to test students' progress allows both parties to evaluate the time necessary to achieve learning goals. Due to the use of Moodle, students' grades improved and they found the Moodle learning experience to be very positive.

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MICHAŁ STOSIAK*

THE DIDACTIC AND SCIENTIFIC RESEARCH CAPABILITIES OF THE LABORATORY OF HYDRAULIC DRIVES & VIBROACOUSTICS OF MACHINES

MOŻLIWOŚCI NAUKOWO-DYDAKTYCZNE LABORATORIUM NAPĘDÓW HYDRAULICZNYCH I WIBROAKUSTYKI MASZYN

Abstract

This article presents a description of the equipment and the didactic and scientific research capabilities of the Laboratory of Hydraulic Drives & Vibroacoustics of Machines located at the Faculty of Mechanical Engineering of Wrocław University of Technology. In the article, the main areas of the laboratory activity are indicated as well as didactic offer including presentation of currently available test rigs.

Keywords: hydraulic drives, pneumatic drives, vibroacoustics of machines

Streszczenie

W artykule przedstawiono opis wyposażenia i możliwości dydaktyczne oraz naukowo-badawcze Laboratorium Napędów Hydraulicznych i Wibroakustyki Maszyn Wydziału Mechanicznego Politechniki Wrocławskiej. W artykule wskazano obszary działań Laboratorium, przedstawiono ofertę dydaktyczną, a także opisano stanowiska dydaktyczne i pomiarowe.

Słowa kluczowe: napędy hydrauliczne, napędy pneumatyczne, wibroakustyka maszyn

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1. Introduction

The Laboratory of Hydraulic Drives & Vibroacoustics of Machines is one of the most advanced laboratories in the field of hydraulics and vibroacoustic diagnostics on the national and continental level. In addition to delivering a wide range of courses dedicated to students of the Faculty of Mechanical Engineering of Wrocław University of Technology, much research is also conducted in the laboratory. This research is connected with master's theses, doctoral dissertations and projects as well as professional research from external orders including commissions from industry. The Laboratory is the only one in the country authorised for the attestation of hydraulic components and systems in terms of radiated noise. The laboratory equipment is mainly based on apparatus for testing vibration, noise, and mechanical and hydraulic parameters. A complete list of research equipment in the laboratory includes a total of over 200 entries. The acoustic reverberation chamber for NVH testing complies with the ANSI standard S1.21-1972 and PN-85/N-01334 and provides the ability to attest machines and devices for vibration and noise. In addition, the laboratory has a unique set of apparatus for measuring noise emission with energy methods – an acoustic probe and acoustic holography (STSF method) allow for the identification of sources of noise and sound power measurements according to ISO 9614. On a global scale, there is a total of approximately 50 systems for acoustic holography and this is the only facility of its kind in Poland. The interdisciplinary research team consists of experienced academics from Wrocław University of Technology who have been conducting scientific and development research in the field of hydrostatic drives for decades. As a result of numerous projects, the research team of the laboratory has done a lot of industrial implementations and has won important prizes and awards. The laboratory team continues to develop didactic and research offers, attempting to demonstrate the highest possible professionalism in the performance of tasks. One of the many activities of the laboratory is also conducting training sessions in hydraulic drives and control systems for the engineering staff of enterprises through the implementation of proprietary training programs.

2. A brief historical note

The research and didactic team in the field of hydraulics and pneumatics was established in 1964 under the leadership of Professor Stefan Stryczek. Since the year 1978, the head of the department was Associate Professor Wacław Kollek until his retirement in 2011, already as a professor organized all forms of research and didactics in the field of hydraulic drives as well as vibroacoustics of machines, ranging from the design stage to the industrial implementations of new solutions. In 2011 and 2012, the leadership of the Department of Hydraulic Drives & Automation was entrusted to Ph.D. Eng. Michał Stosiak, who continued to organise and coordinate the research and teaching activities of the department. The Department of Hydraulic Drives & Automation was included in the structures of the Department of Hydraulic Machines & Systems headed by Professor Jan Kulczyk in 2012 as a result of restructuring, and then in 2014, it became part of the Department of Maintenance & Operation of Logistics, Transportation & Hydraulic Systems managed by Professor

Tomasz Nowakowski. Currently, the activities of the department are being continued and developed in the Laboratory of Hydraulic Drives & Vibroacoustics of Machines, led by Ph.D. Eng. Piotr Osiński. Today, the laboratory is one of the leading research institutes in the field of vibroacoustic diagnostics of machinery and equipment, hydraulic drives and microhydraulics in the country and also acknowledged in Europe [6].

3. Fields of laboratory activities

In the field of hydraulic systems and vibroacoustics, the following research are carried out [6]:

- analysis and synthesis of hydraulic, microhydraulic and pneumatic structures;
- design and modernisation of hydraulic and electro-hydraulic systems;
- design and modernisation of hydraulic components;
- miniaturisation of hydraulic component design;
- automation of hydraulic systems control;
- durability testing of hydraulic components;
- identification of vibroacoustic energy propagation in the environment;
- use of vibroacoustic signals for diagnostic purposes;
- synthesis of vibroacoustic machinery and signals;
- location of vibration and noise sources in hydraulic components and systems, and noise reduction;
- passive and active methods to reduce noise and vibration of machines and equipment with hydraulic systems;
- simulation of dynamic phenomena in hydraulic components and systems;
- optimisation of hydraulic components and systems;
- identification of phenomena associated with the flow of fluid in hydraulic systems;
- modelling of viscous and compressible fluid flow with thermodynamic changes;
- calculation of multiphase flows, e.g. cavitation.

4. Equipment of the Laboratory

The laboratory is equipped with: a stand for testing hydraulic systems Hydro-Prax (Rexroth), a new generation of components controlled by electromagnetic coils, proportional elements – directional valves, throttle valves, pressure control valves, check valves, load-sensing valve, and actuators-hydraulic motors and cylinders [2]. Furthermore, pressure switches or inductive proximity sensors can be used in the system timers to implement sequential hydraulic circuits (Fig. 1).

The laboratory has extensive facilities for the design, construction and testing of components, pneumatic systems and controls enabling the creation of many individual hydraulic and pneumatic circuits for teaching and research in the field of pneumatic and electric automation, such as systems with timers, limit switches, pressure and logic elements (Fig. 2).

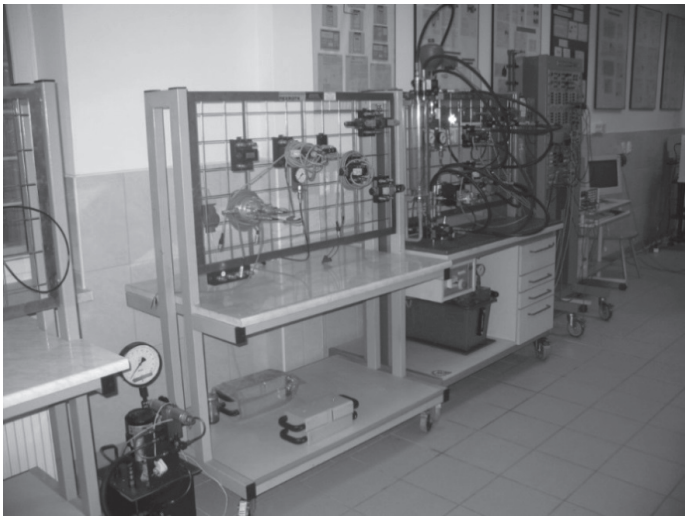

Fig. 1. Training stand with hydraulic components and electrical and proportional control panel

Fig. 2. Test rigs with the elements for pneumatic control systems

Additionally, in the laboratory of high powers, unique test rigs are dedicated for testing the following elements: seals, cylinders, valves, including proportional spool valves and servos. The test rigs enable studying various phenomena such as: cavitation, obliteration and to determine the type of flow. Moreover, a dedicated test rig enables dynamic testing of hydraulic components and systems. The acoustic reverberation chamber for vibroacoustic tests meets the requirements of ISO 9000 and enables attestation of machines and devices for vibration and noise, while a set of instruments for measuring noise emission with the use of energetic methods with a probe and acoustic holography allow the identification of the noise source and the measurement of sound power by ISO 9614 (Figs. 3, 4).

The Hydropax ZY25 linear hydrostatic drive simulator should also be described. It is a research unit of the propulsion system with reciprocating movement, which meets the actual conditions of devices with this kind of drive. The simulator consists of a hydraulic unit, control unit and the control program (Fig. 5).

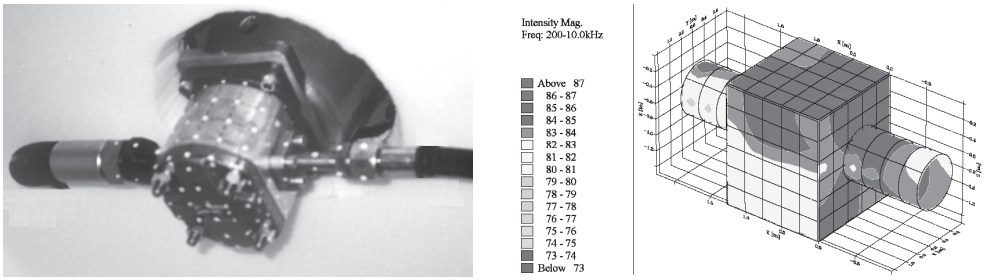

Fig. 3. Localisation of noise sources in the external gear pump (acoustic probe) [3]

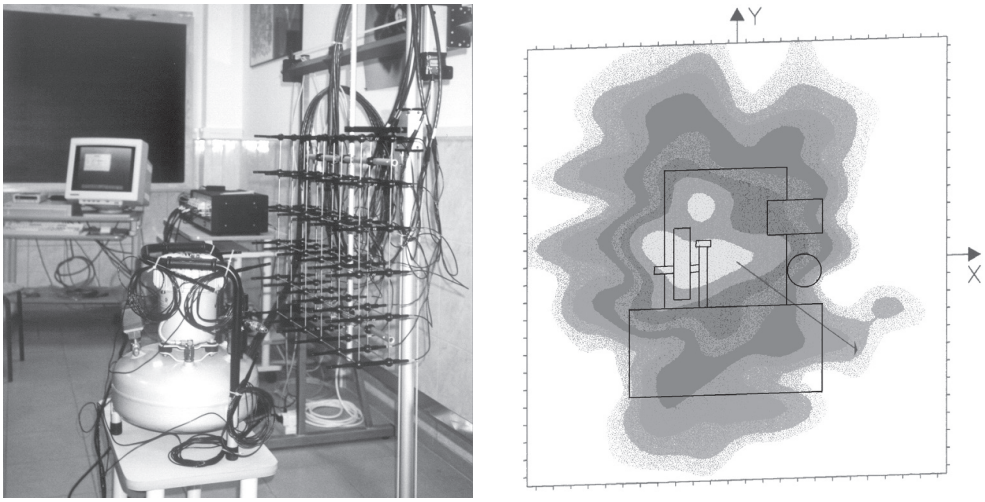

Fig. 4. Localisation of noise sources in the compressor (acoustic holography)

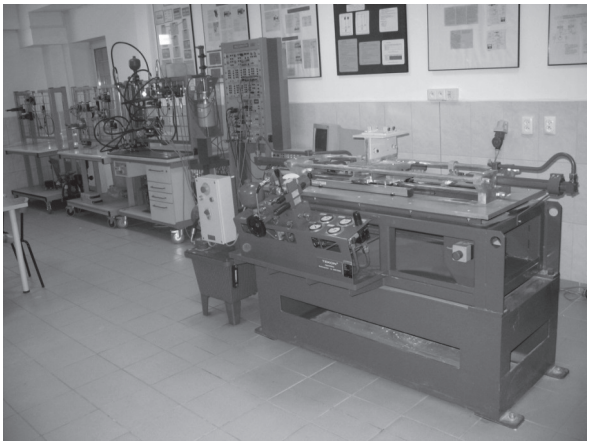

Fig. 5. Linear hydrostatic drive simulator

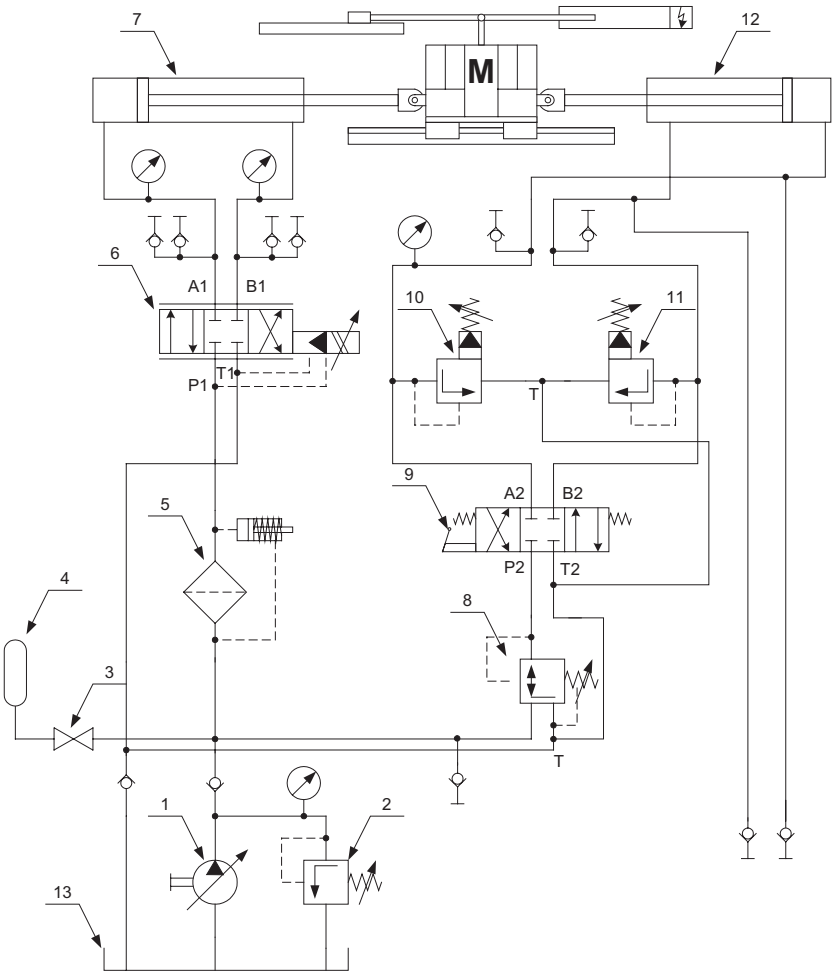

Fig. 6. Diagram of the HYDROPAX ZY25 hydraulic system simulator: 1 – displacement pump; 2 – safety valve; 3 – shut-off valve; 4 – accumulator; 5 – oil filter; 6 – electro-hydraulic amplifier; 7 – cylinder; 8 – differential valve; 9 – directional valve 4/3; 10, 11 – overflow valve; 12 – opposed acting cylinder; 13 – tank [5]

The hydraulic unit has the following specifications [1, 4, 5]:

- variable displacement vane pump PV7-16/20 with parameters p_{max} = 16 MPa, Q_{max} = = 29 dm^3/min, $n_{min} – n_{max}$ = 900 – 1800 rpm;
- electro-hydraulic amplifier 4WSE2EM10-45 – two-stage with integrated electronics in which the first stage is a flapper-nozzle type system, and the second stage is a control slider. This amplifier also has mechanical feedback;
- hydraulic cylinder CDE 160-32/22-500 – double-acting with single rod and cushioning on both sides. The diameters of the piston and rod are 32 mm and 22 mm respectively, the piston stroke is 500 mm;

– double-acting opposed cylinder CDE 160-32/22 – 400, the purpose of which is to produce forces resulting from movement resistances – friction etc. This force counteracts the force generated in the working cylinder;
– directional valve 4WMM 6 E53 – manually operated, 4 ways, 3 positions, for controlling the operation of the opposed cylinder;
– pressure reducing valve ZDR6DP1 – used to reduce the pressure in the chambers of the opposed cylinder, and thus determine the value of such forces as movement resistance.

A hydraulic schematic of the simulator is shown in Fig. 6.

The control device simulator (SYHCE 1) can be used to control, monitor and adjust the linear drives. It consists of the following elements [1, 4, 5]:

– BK1 measuring card for connecting external devices, e.g. an oscilloscope to observe (and registrate) analysed values, inputs and outputs;
– FERN1 remote control card and an FBOX transmitter allowing remote adjustment of the simulator. The FBOX transmitter is a potentiometer, which allows setting the position of the cylinder;
– BAS1 control device allowing the manual operation of the simulator, and choosing the type of operation by selecting the appropriate button;
– VR3D controller card, along with the BAS1 control device, allows access control to the electrohydraulic amplifier. This card is closely linked to the control program. Control parameters selected by VR3D are sent to the electrohydraulic amplifier, which performs specified tasks. The real value of the actual potentiometric sensor displacement is sent to the card in the form of an analogue signal. On this basis, it may be compared to the reference value of the input.

The HCE 1 control program allows choosing the type and parameter of regulation. The selection can be made between two main types of control – displacement and force regulation. After selecting the type of regulation, the parameters may be chosen from three controllers – proportional (P), integral (I) and derivative (D) [1, 4, 5].

5. Classes

Laboratory didactic equipment enables dozens of exercises taking into account electrohydraulic control, electropneumatic control and the proportional technique. Students carry out exercises based on laboratory instructions containing the theoretical basis. After every class, students prepare the short report with the results of measurements. The students assemble hydraulic or pneumatic circuits of the elements available at the test rig and connect the electrical circuit necessary for the proper control of previously assembled hydraulic or pneumatic circuit. The advantages of the module for hydraulic systems include the easy assembly of hydraulic elements with the use of hoses with quick release couplings, the quiet operation of the hydraulic power unit and the safety levels resulting from the low control voltage (24 V), insulated electrical wires and the presence of check valves and pressure relief valves.

In the case of hydraulic systems, after the assembly of the circuit and determining the measurement path, it is possible to perform measurements of hydraulic losses in the system, the flow rates, temperatures and linear or angular velocities, as well as voltage and current.

Some of the topics of exercises carried out during classes include topics related to volumetric and throttle control, sequential control, proportional technique, including load-sensing, as well as the realisation of measurements of pressure pulsation and other topics.

Students have the opportunity to use Automation Studio software intended for the design and simulation of complex mechatronic systems during the classes, which includes extensive groups of elements from the area of pneumatics, hydraulics, proportional hydraulics, electrical engineering and digital technology in its libraries. The program allows the simulation of processes by means of electrically controlled contactor-relay circuits, or programmable logic controllers (PLC). The program enables entering the parameters of individual hydraulic components and their characteristics, making the simulated system behave like a real one – composed of elements selected from manufacturers' catalogs. During the simulation, the plotting of specified variables in time is possible, e.g. pressure at the desired location of the system or flow through a particular element. The advantage of using the Automation Studio software is the ability to create documentation and carry out simulations and animations of system operation. With the software, it is possible to build a hydraulic system with different types of control, then test the operation of the system before proceeding with practical tasks.

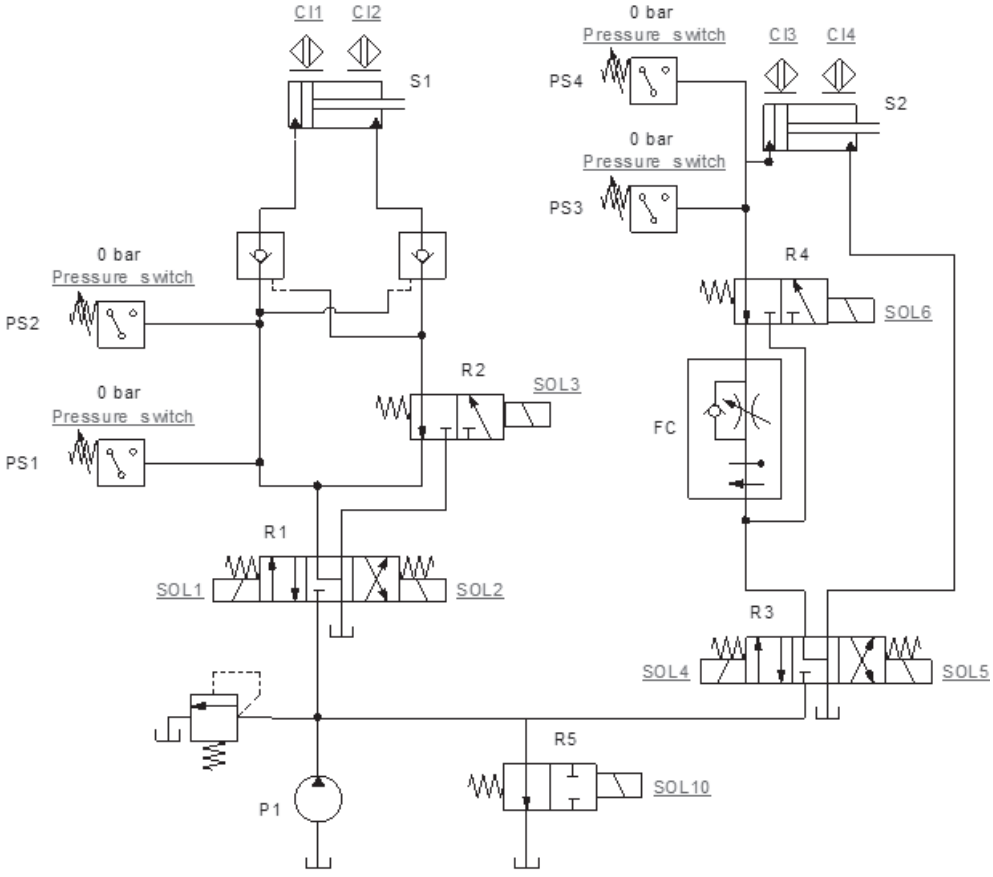

Fig. 7. A hydraulic circuit designed in the Automation Studio software

The design of the circuit in the Automation Studio program is made by dragging the specific symbols of desired elements from libraries to the project window and join them together in the desired way. The ability to use included symbols and the intuitive operation of the program greatly simplifies the complicated process of design; moreover, the option of monitoring the actual operation of the proposed system still allows finding errors in the design phase. Fig. 7 illustrates an exemplary hydraulic system made in the Automation Studio.

During the classes taking place in the laboratory, students acquire competences that are particularly relevant and sought after in the labour market. The most important of these include: the ability to draw appropriate conclusions; the ability to work in a group; the ability to achieve specified tasks; the ability to perform concise reporting.

6. Didactic offer

Currently, the Laboratory of Hydraulic Drives & Vibroacoustics of Machines hold classes for students of the Faculty of Mechanical Engineering, in the fields of automation and robotics (AIR), mechatronics (MTR), mechanical engineering (MBM). The teaching offer includes a range of bachelor's and master's courses, diversified in terms of the advancement of the participants, fields of study and specialisations. In addition, courses are conducted in Polish and English for foreign students.

The courses in the winter semester are: Hydrostatic Drive Systems (MBM, I level); Hydraulic, Hydrotronic & Pneumatic Systems (MBM, I level) – course conducted in English; Seals & Sealing Technique (MBM, specialisation in Construction and Operation of Machinery *KE*, II level); Hydraulic & Pneumatic Drive Systems, (AiR, I level); Drive Systems, Hydraulic & Pneumatic Components (MTR, I level), Dynamics of Electromechanical Systems (MTR, specialisation in Mechatronics in Factory Systems *MSP* and Mechatronics of Machines & Vehicles *MMP*, II level); Electrohydraulic Control (MTR – MMP, II level).

Moreover, in the summer semester the following courses are conducted: Hydraulic Drive (MBM, I level) in Polish and English; Machinery & Equipment Control (MBM, specialisation in Construction & Operation of Machinery *KE,* Engineering of Construction Materials *IMK*, Processes, Machines & Production Systems *PMS*, II level); Vibro-acoustic Diagnosis of Machinery & Equipment (MBM – KE, II level) – in Polish and English; Vibrations & Noise in Mechanical Engineering (AiR, specialisation in Automation of Machines & Processes *AMP*, II level), Systems of Hydrotronics & Pneumotronics (AiR – *AMP*, II level); Hydrotronic & Pneumotronic Systems (MTR – *MMP*, II level). The classes of hydraulic drive are also held for MBM students at the Faculty of Engineering & Natural Sciences in Legnica and the Faculty of Technology & Engineering in Wałbrzych.

7. Summary

The equipment and wide range of educational offers of the Laboratory of Hydraulic Drives & Vibroacoustics of Machines makes it the perfect base to put into practice the knowledge acquired during the academic lectures. The didactic offer is addressed to students

of various courses and specialisations in not only the field of vibroacoustics, hydraulic and pneumatic drive and control, but can also successfully serve the students of other fields such as those related to electronics. In addition, the laboratory provides the opportunity to conduct advanced research and measurements at the request of the industry. In the future, it is planned to further expand the laboratory with modern hydrotronic elements and systems, in particular controlled in proportional technique, load-sensing systems and systems controlled wirelessly. It is also planned to acquire new dedicated simulation programs for the purposes of teaching and training. Laboratory employees strive to continually improve the didactic and research offers in order to provide services at the highest possible level.

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THE POSSIBILITY OF USING MULTI-CRITERIA METHODS AS INNOVATIVE TOOLS FOR SUPPORTING POSTGRADUATE EDUCATION

MOŻLIWOŚCI ZASTOSOWANIA METOD WIELOKRYTERIALNYCH JAKO INNOWACYJNEGO NARZĘDZIA WSPARCIA W KSZTAŁCENIU NA STUDIACH PODYPLOMOWYCH

Abstract

The aim of the article is to analyse the possibility of using multi-criteria methods for support in planning the postgraduate program, their implementation and their evaluation. Multi-criteria methods, which are used to support the decision-making process, are a response to the complexity of contemporary problems, including uncertainty, incomplete data and changing environment. One of these issues is matching the postgraduate program to the current requirements of potential students. The research methods used in this article are a critical analysis of literary sources and a case study of the 'PIT Mobile postgraduate studies in collaboration with industry' project, financed by the European Social Fund.

Keywords: multi-criteria methods, analytical hierarchical process (AHP), postgraduate education

Streszczenie

Celem artykułu jest analiza możliwości wykorzystania metod wielokryterialnych jako narzędzia wsparcia w planowaniu programu studiów podyplomowych, ich realizacji oraz ewaluacji. Metody wielokryterialne, stosowane do wsparcia procesu decyzyjnego, są odpowiedzią na złożoność współczesnych problemów rozwiązywanych w warunkach niepewności, niepełnych danych oraz zmieniającego się otoczenia. Jednym z takich zagadnień jest właśnie dopasowanie programu studiów podyplomowych do aktualnych wymagań potencjalnych uczestników. Zastosowane metody badawcze to: analiza krytyczna źródeł literaturowych, *case study* na przykładzie projektu „PIT Mobilne studia podyplomowe we współpracy z przemysłem" finansowanego z Europejskiego Funduszu Społecznego.

Słowa kluczowe: metody wielokryterialne, analityczny proces hierarchiczny (AHP), kształcenie podyplomowe

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1. Introduction

The most important challenge for the educational system is to increase the productivity and efficiently the economy. Education, especially in the area of engineering, is crucial for the development and economic growth of each country. It is essential to develop a new, modern approach to supporting education, meeting the contemporary market requirements and predicting future trends. Despite the great importance of lifelong learning, relatively few people choose to undertake a programme of postgraduate study despite the potential future benefits [14, 22]. The data of the central statistical office of Poland [8–10] shows that there were approximately 163,628 postgraduate students in Poland during the 2013/2014 academic year – this is much lower than in 2009/10 when there were 194,212 students. Most people who undertake training at the postgraduate level are between 26 and 35 years old. Only 3% of Polish people have completed postgraduate studies.

There is a clear downward trend in postgraduate education, including studies in technical disciplines. Meeting the demand for highly skilled professionals and updating their skills in accordance with the changing ambient conditions can be problematic for the labour market. Despite the importance of postgraduate studies and the related personal benefits (statistically, higher remuneration), relatively few people choose this form of education. There are a variety of reasons for this [14, 22]:

- the programs of postgraduate studies were out-of-date;
- there is a lack of the implementation of modern tools in education, for example m-learning support;
- the lack of cooperation between science and business, and because of this, a lack of training programs tailored to the needs of the labour market;
- an overall decrease in the number of potential students due to a drop in the number of individuals fitting the typical demographic profile;
- relatively high unemployment among young people and low levels of income (graduates could not afford to fund attractive and expensive postgraduate courses).

The process of globalisation and the development of technology has caused the skills required in the professional arena to change. Nowadays, engineers should have not only technical knowledge, but also high levels of interpersonal competence, especially those related with communication (for example foreign languages), practical engineering, and business skills [21, 23]. Technical universities are facing an important challenge with regard to how to fulfil changeable requirements and predict future needs. Study programs that are suitable for meeting market needs are a crucial and urgent task for universities in order to improve their competitiveness; therefore, there is a necessity for all sector of higher education to develop new methods of academic support [14, 18].

2. The use of the multi-criteria methods in higher education sector

Nowadays, decision makers often face complicated dilemmas with tangible, intangible and sometimes conflicting criteria [20] – this certainly applies in the higher education sector. Numerous multi-criteria, decision-making methods are applied to various problems in universities such as resource allocation, performance measurement, budgeting and scheduling

[12]. These methods are used for solving general as well as specific problems. For example, this methods will have been successfully used for the assessment of the quality of higher education in different countries [1, 2, 24, 17]. The multi-criteria methods allow not only factors influenced the quality aspects for all education related services to be determined, but also optimise university (or faculty) performance evaluation in terms of research, teaching, university and community service [2], but also help manage effectively for example define strategies for the universities and to reach their pre-defined standards and goals [1]. It is possible to use the multi-criteria methods for restructuring and reforming higher education [1, 4]. The models, designed with using a multi-criteria methods such as Analytic Hierarchy Process (AHP), were analysed for different challenges in higher education, in several countries, for example, at the United Arab Emirates University [2], in Greece [24] and Italy [17]. Thanks to multi-criteria models, it is possible to compare different points of view.

Multi-criteria methods can be also used for some divisions of higher education exemplary to evaluate faculty performance in engineering education [1, 8] or in the specific area of higher education. Exemplary, AHP/DEA method was used for measurement of the efficiency of R&D management activities in universities [7] or identifying and ranking academic entrepreneurship [19]. Multi-criteria methods can be effective tools for the assessment of the management performance of research and development (R&D) activities in research-oriented universities – this application was investigated in twenty-nine universities in China where thanks to this method, the universities improved their management work which achieved a high level of efficiency. The method was also helpful in motivating the universities to keep on improving their R&D management [7]. Other examples include the use of AHP for identifying and ranking academic entrepreneurships in Iran. The methods help to determinate a clue factors of development the academic entrepreneurship and made easier decision in this area [19].

Multi-criteria methods can also be used in particular problems in higher education such as human resource management exemplary to rank faculty members within each discipline or major [2] or to make judgment on the qualification of candidates for such systems [2]. It is also possible to evaluate the criteria for human resources for science and technology as a whole [3] as well as for the department college or university level.

Another particular problem that can be solved by using multi-criteria methods is managing an intellectual capital. Multi-criteria methods have been successfully applied at universities in Taiwan for this purpose [16] – an evaluation model was created to facilitate the understanding of an intellectual capital contribution to the performance of the university. The AHP method was applied to formulate and prioritise the intellectual capital measurement indicators for constructing model. The model was used to evaluation as decision guidelines. Thanks to it was possible to develop and increase the productivity of investments in intangible assets [16].

Multi-criteria methods can be used during classes in higher education as a tool for solving real problems, for example, as a tool for simulations that can help students deal with complex real problems in the field of thermal engineering [5]. Exemplary this methods can be used as tools for education for undergraduate and postgraduate student projects to formalise the process of selection of `hard' and `soft' system components [6].

Multi-criteria methods can be applied to a wide range of important academic problems. These kinds of methods are especially valuable because:

– an application across the spectrum of decision-making activities, include evaluation, scheduling, budgeting;

– and possibilities decision-making problems in academia by committees or groups where a consensus must be reached.

Despite widespread use of this approach in other areas, there is a lack of use of this kind of method with the field of postgraduate education.

3. Case study of the 'PIT Mobile postgraduate studies in collaboration with industry' project

The 'PIT Mobile Postgraduate Studies in Collaboration with Industry' project ('PIT Mobilne studia podyplomowe we współpracy z przemysłem') is financed by the European Social Fund as part of the Human Capital Operational Program. The project is funded through a special programme for innovative ideas and based on research conducted on three groups made up of academic staff, future students and industry representatives. The project covers two technical postgraduate programmes realised in the form of blended learning at Cracow University of Technology Faculty of Mechanical Engineering over the years 2013 to 2015, these are:

– the International Welding Engineer programme (IWE),
– the Fluid Power Studies (hydraulic and pneumatic) programme (compliant with CETOP requirements).

The basic strategy was to identify the needs of both of these groups and combine them in one coherent program of postgraduate education. The main aim of the project is the design and implementation of various forms of learning support such as remote access tools for postgraduate studies which allow creating modern postgraduate studies tailored to the needs of students and the contemporary labour market [15]. For this purpose, an analytic hierarchy process (AHP) was applied in the project.

AHP is a multi-criteria method that was created and developed by Thomas L. Saaty in the nineteen-seventies. AHP was designed to incorporate both subjective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by the team, thus reducing bias in decision making [17]. This method is particularly useful in cases where there are the subjective judgments of different individuals that constitute an important part of the decision-making process [10].

The first step of AHP is to create a decision hierarchy by breaking down the problem into a hierarchy of decision elements. In the project the decision elements was chosen on the base of questionnaire made in expert group. A hierarchical tree was created with the following main criteria and sub-criteria:

– knowledge (sub-criteria: presentation of basic knowledge useful for performing basic tasks; a wide range of issues discussed in the field of study; knowledge showing different points of view for particular issues; linking theoretical knowledge with practical experience; teaching materials for students that aid the revision of knowledge; e-learning support; the presentation of the latest scientific knowledge);
– practice (sub-criteria: many practical classes; solving problems using software for simulation; industrial training; industrial internship – minimum of 3 months; internship opportunities in foreign organisations; organisation of study visits in companies; implementation of projects in cooperation with selected enterprise);

- the quality of the training staff (sub-criteria: teaching by people with experience in industrial companies; knowledge presented in available way for students; the high professionalism of the courses; constant development of professional staff; lectures by international authorities in the particular field od study; interpersonal features of the lecturers; assisting qualified technical personnel during laboratory classes);
- organisation of studies (sub-criteria: duration of study tailored to the needs of students; individual approach to the participant; small groups; reliability of the supply of information; good administrative services; possibility of remote administrative services; cooperation with other institutions (domestic and foreign) in the framework of study; organisation of postgraduate studies by the high prestige universities; providing opportunities for people with disabilities to participate in postgraduate courses);
- the level of knowledge of candidates (sub-criteria: entrance exams; the field of the previous study coherent with the profile of postgraduate studies; professional experience of the students; the motivation of candidates undertaking postgraduate studies; individual approach to student for example the division into groups by level);
- skills development (sub-criteria: obtaining a special license/certificate of competence; emphasis on mastering practical skills; development of professional qualifications; obtaining new professional skills (in a new field); develop the ability to act independently and solve problems; the development of social skills; the development of managerial skills);
- teaching facilities (sub-criteria: high quality reliable facilities; the use of information technology for support of the educational process; modern multimedia facilities; modern laboratory equipment; diversification of laboratory facilities – the opportunity to work on various types of equipment; the possibility of mobile/remote classes; access to the latest scientific literature/standards/databases; access to the latest software; proper teaching aids).

The second step is to collect input. It is made by a pair wise comparison of decision elements. The next step is to determine whether the input data satisfies a consistency test. The research involved twenty-three experts in the projects – most of them represented universities or research institutions (17) and business (6). The next step is to calculate the relative weights of the decision elements (cost and benefits). There were calculated so called global and local priorities. The local priorities are formulate for each group at each level (for sub-criteria with respect to main criterion). The global priorities are formulate for whole decision hierarchy (for sub-criteria with respect to general problem). Eventually, the researcher must aggregate the relative weights to obtain scores and therefore rankings for the decision alternatives (or elements).

For each sub-criteria, proper values for cost and benefits were calculated and these values were compared. The results of the comparison are presented in Table 1 [22].

The pairwise comparison were made for costs and benefits separately as well as taking into account both of them. As a results the most important criteria and sub-criteria was chosen. The most important criterion is knowledge, mainly because high benefits and low costs. Other important criteria are practice and skills development, because a similar levels (ranking points) of benefits and costs. According to benefits the highest notes has criterion the quality of the training staff, but it has also high level of cost and because of that it has not so high position in general rank. The same situation was for criterion the teaching facilities. The high costs (ranking points for this category) decided about low position this criterion in general rank. The criteria organization of studies and the level of knowledge of candidates are not so important according to the experts evaluation.

Table 1

The calculation of global priorities according to AHP [22]

Main criteria priorities P_{Si}	Local priorities of sub-criteria P_{Lij}	Global priorities of sub-criteria $P_{Gij} = P_{Si} \times P_{Lij}$
Knowledge P_{Lij}	Presentation of basic knowledge useful for performing basic tasks $P_{L11} = 0.19220$	$P_{G11} = 0.06847$
	A wide range of issues discussed in the field of study $P_{L12} = 0.13575$	$P_{G12} = 0.04836$
	Knowledge showing different points of view for particular issues $P_{L13} = 0.13575$	$P_{G13} = 0.04836$
	Linking the theoretical knowledge with experience $P_{L14} = 0.24713$	$P_{G14} = 0.08803$
	Teaching materials for students that aid the revision of knowledge $P_{L15} = 0.07788$	$P_{G15} = 0.02774$
	E-learning support $P_{L16} = 0.07949$	$P_{G16} = 0.02832$
	The presentation of the latest scientific knowledge $P_{L17} = 0.13181$	$P_{G17} = 0.04695$
Practice $P_{S2} = 0.15177$	Many practical classes $P_{L21} = 0.15126$	$P_{G21} = 0.02296$
	Solving problems using software for simulation $P_{L22} = 0.12851$	$P_{G22} = 0.01950$
	Industrial training $P_{L23} = 0.10090$	$P_{G23} = 0.01531$
	Industrial internship – minimum of 3 months $P_{L24} = 0.09087$	$P_{G24} = 0.01379$
	Internship opportunities in foreign organizations $P_{L25} = 0.08159$	$P_{G25} = 0.01238$
	Organisation of study visits in companies $P_{L26} = 0.16452$	$P_{G26} = 0.02497$
	Implementation of projects in cooperation with selected enterprise $P_{L27} = 0.28237$	$P_{G27} = 0.04285$

The quality of the training staff $P_{S3} = 0.13978$	Teaching from people with experience in industrial companies $P_{L31} = 0.10596$	$P_{G31} = 0.01481$
	Knowledge presented in available way for students $P_{L32} = 0.27246$	$P_{G32} = 0.03808$
	The high professionalism of the courses $P_{L33} = 0.18500$	$P_{G33} = 0.02586$
	Constant development of professional staff $P_{L34} = 0.09555$	$P_{G34} = 0.01336$
	Lectures by international authorities in the particular field of study $P_{L35} = 0.04591$	$P_{G35} = 0.00642$
	Interpersonal features of the lecturers $P_{L36} = 0.19418$	$P_{G36} = 0.02714$
	Assisting qualified technical personnel during laboratory classes $P_{L37} = 0.10094$	$P_{G37} = 0.01411$
Organization of studies $P_{S4} = 0.04628$	Duration of study tailored to the needs of students $P_{L41} = 0.09327$	$P_{G41} = 0.00432$
	Individual approach to the participant $P_{L42} = 0.15209$	$P_{G42} = 0.00704$
	Small groups $P_{L43} = 0.13692$	$P_{G43} = 0.00634$
	Reliability of the supply of information $P_{L44} = 0.14447$	$P_{G44} = 0.00669$
	Good administrative services $P_{L45} = 0.16441$	$P_{G45} = 0.00761$
	Possibility of remote administrative services $P_{L46} = 0.14259$	$P_{G46} = 0.00660$
	Cooperation with other institutions (domestic and foreign) in the framework of the study $P_{L47} = 0.06288$	$P_{G47} = 0.00291$
	Organisation of postgraduate studies by the high prestige universities $P_{L48} = 0.05600$	$P_{G48} = 0.00259$
	Providing people with disabilities opportunities to participate in postgraduate courses $P_{L49} = 0.04736$	$P_{G49} = 0.00219$

Continue Table 1

Main criteria priorities P_{Si}	Local priorities of sub-criteria P_{Lij}	Global priorities of sub-criteria $P_{Gij} = P_{Si} \times P_{Lij}$
The level of knowledge of candidates $P_{S5} = 0.11081$	Entrance exams $P_{L51} = 0.18310$	$P_{G51} = 0.02029$
	The field of the previous study coherent with the profile of postgraduate studies $P_{L52} = 0.25206$	$P_{G52} = 0.02793$
	Professional experience of the students $P_{L53} = 0.25563$	$P_{G53} = 0.02833$
	The motivation of candidates undertaking postgraduate studies $P_{L54} = 0.19464$	$P_{G54} = 0.02157$
	Individual approach to student for example the division into groups by level $P_{L55} = 0.11456$	$P_{G55} = 0.01269$
Skills development $P_{S6} = 0.14972$	Obtaining a special license/certificate of competences $P_{L61} = 0.07994$	$P_{G61} = 0.00886$
	Emphasis on mastering practical skills $P_{L62} = 0.22970$	$P_{G62} = 0.02545$
	Development of professional qualifications $P_{L63} = 0.10121$	$P_{G63} = 0.01122$
	Obtaining new professional skills (in a new field) $P_{L64} = 0.11464$	$P_{G64} = 0.01270$
	Develop the ability to act independently and solve problems $P_{L65} = 0.26530$	$P_{G65} = 0.02940$
	The development of social skills $P_{L66} = 0.13997$	$P_{G66} = 0.01551$
	The development of managerial skills $P_{L67} = 0.06924$	$P_{G67} = 0.00767$
Teaching facilities $P_{S7} = 0.04542$	High quality reliable facilities $P_{L71} = 0.09246$	$P_{G71} = 0.00420$
	The use of information technology for the support of the educational process $P_{L72} = 0.13370$	$P_{G72} = 0.00607$
	Modern multimedia facilities $P_{L73} = 0.08321$	$P_{G73} = 0.00378$

Teaching facilities $P_{S7} = 0.04542$	Modern laboratory equipment $P_{L74} = 0.06932$	$P_{G74} = 0.00315$
	Diversification of laboratory facilities – the opportunity to work on various types of equipment $P_{L75} = 0.07790$	$P_{G75} = 0.00354$
	The possibility of mobile/remote classes $P_{L76} = 0.17663$	$P_{G76} = 0.00802$
	Access to the latest scientific literature/standards/ databases $P_{L77} = 0.14759$	$P_{G77} = 0.00670$
	Access to the latest software $P_{L78} = 0.11534$	$P_{G78} = 0.00524$
	Proper teaching aids $P_{L79} = 0.10385$	$P_{G79} = 0.00472$

The comparison of the sub-criteria according to local priorities allow the determination of their position in every category and next determine a value of global priorities. Thanks to the global priorities, it is possible to compare sub-criteria between categories. The determination of global priorities give a possibility of choice the factors that are the most important for the model of postgraduate studies. In the model, the following sub-criteria were included [22]:

- interpersonal features of the lecturers;
- professional experience of the students;
- many practical classes;
- entrance exams;
- e-learning support;
- the field of the previous study coherent with the profile of postgraduate studies;
- the motivation of candidates undertaking postgraduate studies;
- internship opportunities in foreign organizations;
- emphasis on mastering practical skills;
- industrial training;
- industrial internship – minimum of 3 months;
- organization of study visits in companies;
- linking the theoretical knowledge with experience;
- presentation of basic knowledge useful for performing basic tasks;
- knowledge presented in available way for students;
- implementation of projects in cooperation with selected enterprise;
- develop the ability to act independently and solve problems;
- teaching materials for students that aid the revision of knowledge;
- a wide range of issues discussed in the field of study;
- the presentation of the latest scientific knowledge;
- knowledge showing different points of view for particular issues;
- the high professionalism of the courses.

The sub-criteria were taken into account during the development of programs of study and the selection of tools that support the learning process. It has not been possible to include all elements in the scope of the model, but the most important elements were included in curricula and lecture notes for two postgraduate curses (international welding engineer and fluid power studies). The sub-criteria were also taken into consideration during the design of tools for postgraduate studies. New tools for teaching such as a mobile platform, the remote control laboratories and mobile software were designed and implemented [13, 17]. The solutions proposed in the project were mainly based on mobile technologies, because of the growing prevalence of m-technologies (access to the Internet is more often provided by equipment other than a computer, e.g. smartphones, tablets). M-technology is also convenient for students, because they carry mobile devices rather than computers with them at all times – this provides easy access to the accumulated knowledge, this also applies in the workplace [13, 14].

4. Conclusions

Multi-criteria methods were successfully applied in different fields of higher education, but there is a lack of use of this method in postgraduate education. The case study of the 'PIT Mobile Postgraduate Studies in Collaboration with Industry' project shows that it may be a valuable tool for supporting postgraduate study especially during the design of programmes that require the consideration of a lot of elements. These kinds of methods are especially valuable for complex decision-making activities and decisions made by academic groups.

The model described above is general and can be used in different fields of engineering. Thanks to support from external funds, the model as well as each of the designed components is widely available to other organisations interested in its use. Developed elements can be used by all the institutions (mainly universities) that offer postgraduate education in the field of technical sciences. The model can also be used in education at the second stage of technical studies, due to the similarity of expectations and previous experience of undergraduate students which should guarantee an adequate level of knowledge. The postgraduate students as well as MSc candidates should have a similar knowledge, because they have ended BSc course. In addition, the particular tools based on the model can be used for: courses in the field of welding; hydraulics and pneumatics; BSc degree courses in engineering; MSc degree courses, especially in the field of technical education; PhD studies in engineering sciences; education provided in the workplace.

The project provided an opportunity to create a new conception of innovative studies and gives valuable tools for futures teaching – it also made for a stronger collaboration between companies and the university.

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TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
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STANISŁAW KUCIEL*, PAULINA KUŹNIAR*

MODERN METHODS OF TEACHING ENGINEERS STUDYING ENVIRONMENTALLY FRIENDLY COMPOSITES

NOWOCZESNE METODY KSZTAŁCENIA INŻYNIERÓW Z ZAKRESU EKOLOGICZNYCH MATERIAŁÓW KOMPOZYTOWYCH

Abstract

This paper explains why and how to teach engineering students studying structural materials obtained from renewable sources. It describes modern approaches in the education of materials science including focussing on design strategies, sustainability and the use of modern educational tools.

Keywords: academic education, sustainability, biobased materials

Streszczenie

W artykule wyjaśniono w jakim celu i jak uczyć przyszłych inżynierów o konstrukcyjnych materiałach pozyskiwanych z odnawialnych surowców. Opisano nowoczesne podejście do nauki o materiałach, uwzględniając proces projektowania i zrównoważony rozwój oraz korzystanie z nowoczesnych narzędzi edukacyjnych.

Słowa kluczowe: edukacja akademicka, zrównoważony rozwój, biopochodne materiały

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1. Introduction

Being used to traditional forms of the teaching of the major material groups (*metals, ceramics and polymers*), academic teachers, and as a consequence, their students and future engineers, often forget or even do not realise that the world of materials science and the materials market is huge, diverse and developing and has much to offer for those who are looking for new solutions that lead to the sustainable development of products and technologies. One of the directions of the current and strong development of materials science is the field of materials obtained fully or partially from renewable sources including engineering structural materials, mainly biocomposites. Although this topic has been explored extensively over the last two decades not just in most academic institutions in Poland, but also by scientists all over the world, it rarely enters the educational and training programs of universities. This, however, is supposed to change in the near future because of the market trends and needs of our society.

At the Institute of Materials Engineering of Cracow University of Technology, new curricula entitled 'Materials made from renewable sources' (comprising teaching materials, draft materials of the curricula, 'master classes' etc.) is being prepared as a part of the project entitled 'Modernisation of two cycles (MA, BA) of competence-based curricula in Material Engineering according to the best experience of Bologna Process', 543994-TEMPUS-1-2013-1-BE-TEMPUS-JPCR ('MMATENG') funded with support from the European Commission. The course is going to be implemented in targeted partner universities in Israel, the Ukraine and Russia in accordance with local requirements and the market [13]. As a renewable source of engineering material, we understand biomass in its various forms as being defined in EU law as 'the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste' [1]. Materials such as natural fibre reinforced composites (NFCs), wood plastic composites (WPCs), polyamides and polyurethanes obtained from plant oils, starch-based and bacterial plastics, polymers and fillers (powders) made from animal shells and many other biomass-based materials already exist out there, not only in the pages of scientific journals but also in the market and in various industry sectors – primarily within the automotive industry, construction, electrical and electronic industries, medicine and sport.

Issues connected to modern educational methods and tools suitable for use in materials science are further discussed in this paper. The authors would like to share their experience and insights gathered from their work on the 'Materials from renewable sources' curricula preparation and implementation as well as their scientific work on biobased materials [6–10].

2. The need for teaching engineers of biobased structural materials

In recent years, new legal, social, environmental and economic aspects (which are all integrally related) of the life cycles of materials and products connected with a broad concept of sustainable development are being considered. This is particularly true for plastics and

polymer composites, which form a relatively young and developing group compared to such material groups as metals and metal alloys or ceramics.

In the case of conventional materials obtained from non-renewable sources, several important aspects are raised nowadays that show their weaknesses and motivate us to seek improvements in the following areas:

- the depletion of finite resources (those with a long-term life cycle, including raw materials for metals and most ceramics and petroleum-based polymers) is the most obvious and serious threat. Our dependence on fossil fuels and their rapid consumption especially gives reasons for concern;
- the location of large deposits of non-renewable resources being in countries that are known to be political unstable and of low levels of development may result in rising tensions between the major global consumers and the regions playing the role of the suppliers of raw material – these tensions may easily affect the market;
- recycling is commonly expected to prevent the depletion of natural resources, but this too has some limitations. Loss of quality and material during product usage and recycling needs to be taken into consideration. While for precious metals, recycling can be very effective (high quality and low susceptibility to oxidation), it leads to serious problems in the case of plastics as these are prone to various ageing processes and thermo-oxidative degradation during processing;
- the acquisition and processing of some non-renewable resources is connected with the emission of significant quantities of substances considered as negatively influencing the environment. A common example is the use of fossil fuel-based by-products responsible for the emission of carbon dioxide;
- the degradation of the most non-renewable resource-based materials deposited in the natural environment usually takes a long time. The situation is different with regard to biomass and some biomass-based materials prone to biodegradation and suitable for composting (e.g.: polylactide, thermoplastic starch, natural fibers). This rapid degradation rate is an advantage especially for short-life products, disposable items. This is, however, irrelevant for materials synthesised from renewable sources which are not biodegradable, such as biobased polyethylene for example.

Obviously, these issues listed as the disadvantages of non-renewable sources at the same time show the advantages of renewable sources. However, there are still more reasons why interest in 'green' solutions in fact already exists – these are important more for scientists, designers and manufacturers of a material or a finished product than for standard consumers or for humanity in general:

- eco-politics – legal regulations regarding the use of resources or restrictions of emissions of hazard substances, for packaging, the automotive industry, E&E sectors etc., favour the use of renewable resources and/or biodegradable materials – this is also true when one looks for the possibility to receive funds, realise research projects etc.;
- eco-fashion – green-minded consumers generate a demand for various environmentally friendly products. This has led to the rapid development of 'green marketing';
- rising prices of raw materials resulting in increases in the total material cost.

Even if these points do not convince someone of the importance of biobased materials and the need for their development, the fact is that such new material types are now entering the market with some degree of success (see examples of such commercial biocomposite compounds in Fig. 1). Biocomposites in particular are worthy of inclusion in the academic

course on engineering materials as these are gaining serious interest in the biggest industry sectors as structural materials. These materials are gaining prominence during international trade fairs, they receive important awards, find common as well as sophisticated applications in various industry sectors and the most well-known world brands invest in their development; however, many of them are sadly completely unknown to many material engineers, including academic teachers and graduate students.

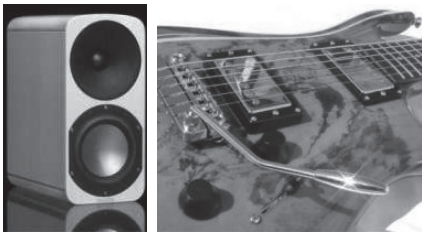
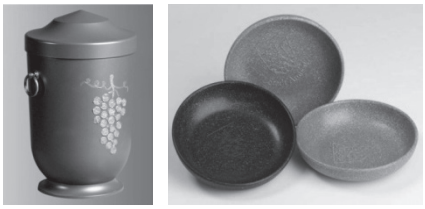
UPM ForMi® – man-made cellulose fibre reinforced plastic composite with a high level of renewable material content (up to 50%)	
Tecnaro Arboform® – made from 100% renewable materials (lignin, natural fibres and additives), Abroblends® (containing biopolymers e.g.: PHA, polyester, Ingeo TM, lignin, starch, cellulose, organic additives, natural resins or waxes and natural reinforcing fibres)	
Kareline® – natural fibre reinforced composite granulates available based on PP, ABS, PS, POM and PLA matrix	
Fibrolon®, FKuR – PP, polyolefine blends or PLA filled with wood flour	

Fig. 1. Examples of ready-to-use biocomposite blends with some potential applications [9]

New standards for biobased and/or biodegradable materials are being developed, especially for biocomposites and biodegradable packaging [4, 5]. Additionally, where novel materials are developed, new terms and definitions are formed which, because of a lack

of knowledge, are often misused or misunderstood. For example, it is often believed that the terms 'biobased' and 'biodegradable' can be used interchangeably to describe the same material, while these features do not always go hand in hand. Such engineering materials as biobased polyethylene, polyamides, polyurethanes and others are not biodegradable and some biodegradable materials are synthesised from fossil fuel feedstock (e.g. polybutylene succinate).

One must remember that it is the new generation of engineers who are, in many cases, expected by their employers to be the individuals who propose new ideas that would increase competitiveness, gain new customers, provide a green corporate image and/or product, and find a promising field for research and development. To help students, academic teachers should provide inspiration by showing recently introduced innovative solutions and motivate them to keep track of such news. To quote well-known research engineer Theodore von Kármán 'the scientist describes what is; the engineer creates what never was' [12] it must be clear that honest knowledge on 'what is' is not to be underestimated in attempts to 'create what never was' – otherwise it may also happen that one preaches to the converted.

3. Approaches towards teaching about materials, design and potential applications

The implementation of a new academic course is always connected with some challenges which need to be addressed. The subject of biobased materials which is discussed in this study is current and developing, designed to keep students up-to-date with important novelties on the materials market. Obviously, to deliver a course on such a topic also requires a teacher to be up-to-date. Information has to be frequently supplemented. In teaching such new and developing materials, one should follow the latest literature, standards and trends in legislation. This need is even more important for courses of biobased materials as topics arise which can be disputable and even controversial – a teacher should prepare themselves to discuss these with students. For example, there are many contentious issues surrounding the use of renewable plant feedstock as a technical material source:

- using land and food crops to produce biopolymers (e.g. to produce thermoplastic starch or polylactide from potatoes, corn or wheat) when there is a global deficiency in food crops;
- overharvesting and genetic modifications of plants in order to obtain useful material properties;
- biomass material inhomogeneity, dependence upon climate, weather conditions, insects and plagues, all of which may result in an unstable supply of plant-based materials.

The task of the teacher here is not only to transfer knowledge but also to provide students with the basis to form their own opinions and reasonably assess facts.

Academic courses on biobased materials should provide students with general information on the materials' division, applications, advantages and disadvantages. Traditional materials should be described in addition to modern materials which also show some future trends regarding the biomaterials market. It would focus on biopolymers and, even more importantly, biocomposites (the most sophisticated biobased materials nowadays) obtained from different kinds of biomass feedstock. From the course, students should acquire useful knowledge on

basic definitions and classifications connected to materials obtained from renewable sources and should also be able to identify the advantages and disadvantages of using renewable and non-renewable sources in the synthesis, processing and use of such materials. There is, however, still more to accomplish with students than that. The goal of courses on materials obtained from renewable sources is to help the students to develop knowledge and skills in the field of environmentally-friendly engineering materials competitive with conventional non-biobased materials. To accomplish this goal, a fresh look at materials science is needed. When introducing novel materials into university curricula, one should take the opportunity to update conventional schemes: the teaching of materials usually starts with their physics and chemistry, structure and general properties, then it covers the most important manufacturing techniques and finishes by presenting a list of some common applications. This is basic and crucial knowledge for material engineers, but there is a lack of discussion on the role of material in the design process, on factors that influence the selection of materials, on the process of the introduction of material to the market, on innovations in this field and on sustainability (these are all connected).

3.1. Material selection in a design process

Teaching students of biobased materials the basic information (definitions, divisions, features etc.) should be supported with examples and exercises on its practical use in the designing process – this is much more efficient in showing the feasibility of the use of such materials than a list of properties or pros and cons. A task that requires students to look for proper material/materials for a specific application by comparing availability, prices, processing, selected phisico-chemical properties among other factors (see section 3.2 on sustainability) and justify their choice is a good idea. However, it remains important to specify what the place of material selection is in the design process. Is a given material of the product a consequence of the chosen shape, processing, function etc.? Or may it be the other way around? The first strategy is more common, but the other is also used and it is called ‘design for materials’ or ‘materials driven design’ [15]. ‘Materials driven design is all about bringing materials at the beginning of the design process (even before deciding on the function and shape of the product or its manufacturing method). This can be by using material samples to broaden the idea generation or by using a single material as a starting point to explore possible applications’ [17]. This kind of design process is important for innovative materials without an established position in the market as well as for the purposes of green marketing. Biocomposites, primarily those filled with wood flour/chips or natural fibres, are well suited to the purpose of materials driven design having an interesting ‘eco-appearance’ and textures. Let us take the polymer composites in general and NFCs in particular as an example. They have low densities and thus, their specific tensile properties are very interesting compared to other engineering materials. In fact, many NFCs show similar or even better specific properties compared to some metals and their alloys or glass-fibre reinforced composites. This encouraged car part manufacturers looking for ‘green’ light-weight solutions to redesign some car panels and to adapt them for production with the use of biocomposites.

The possibility of finding new applications for old materials is also inspiring and worth mentioning. Wood and natural fibres, being traditional materials, are undergoing a revival again and are being applied in new forms in technical applications. Some traditional and newer applications of natural fibres are presented in Fig. 2.

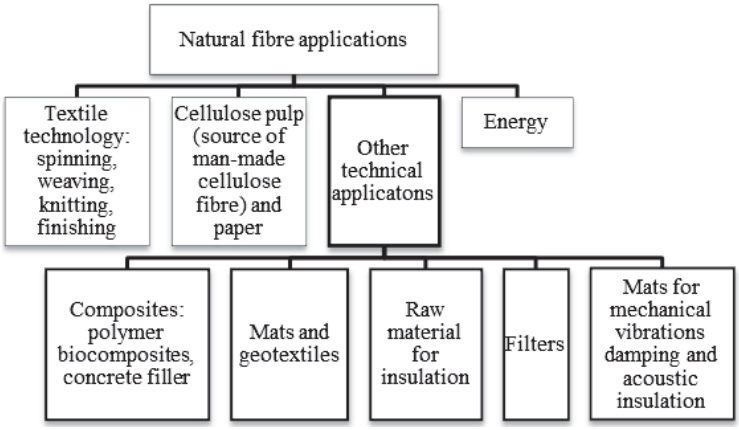


Fig. 2. Applications of natural fibres [9]

Wood is also applied in new forms, for example, as a filler of thermoplastic composites (WPC) or as a fibrous material for isolation. Another example is CLT (cross laminated timber) used to built a wind turbine in Hannover (Fig. 3).

Fig. 3. CLT wind turbine in Hannover (Timber Tower Research Project) [9]

3.2. Sustainability

A lot of scientists working on biobased materials who publish their journal papers tend to emphasise the advantages of such materials, write of their bright future and explain their superiority over the materials obtained from non-renewable feedstock – companies advertising their green products on their websites and during trade fares do just the same. Their purpose is to promote these materials rather than to give cool judgments on them; this

is understandable. However, this strategy is not the best one for teaching future engineers. Is it our purpose to compliment biobased materials and deplore non-renewable materials in the eyes of our students? Can we declare that these materials are, in general, 'better' or 'worse' than materials based on non-renewable feedstock? It is preferable to make students consider when a given material may be beneficial for a clearly specified product whilst taking various factors into consideration. Students should evaluate when to use one material over and above another, or even more importantly, explain the complexity of this choice and provide accessible tools that can be used to make the decision less complex. In fact, this is the question of what can be called sustainable and on what basis.

Sustainability should be considered as an integral part of the design process among all engineering students [11]. The World Commission on Environment and Development defines sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs. According to the Union of Conservation Scientists (IUCN), the United Nations Environment Programme (UNEP) and the Worldwide Fund for Nature (WWF), sustainability is improving the quality of human life while living within the carrying capacity of the Earth's supporting eco-systems.

In general, what we are trying to accomplish in sustainable development is meeting the functional and hedonic needs of certain groups of customers as well as the minimisation of hazardous emissions, energy and material consumption or land use. Clearly, the assessment of product sustainability is not a simple task and it requires deep analysis of various aspects connected to all the stages of the life cycle of a product. In general, these aspects include: raw sources and their acquisition, manufacturing and product use, and, finally, waste management. A useful tool that can be applied here is a life cycle assessment (LCA). LCA is one of several environmental management techniques that are used to study the environmental aspects and potential impact on the environment connected to a given product or material. The technique has been performed mainly on engineering materials and products since the nineteen-nineties.

It is a good idea to not just present it to students, but also, to make them realise its limitations. Often, LCA does not consider real-world infrastructure and costs which fluctuate. For example, in the plastics industry, price changes tend to determine whether oil-based or natural-gas-based feedstock is used in polyolefin production. The prices of natural fibres, as another example, depend on their quality, which is related to their growing conditions. Furthermore, LCA generally do not consider the availability, consistency, and stability of the various raw sources under consideration. Even if an LCA indicates a certain biopolymer as the most sustainable choice for a product, its use may not be possible at the required quantities. Another issue which is not taken into consideration in LCA is the consumers' willingness or unwillingness to pay more for what is found to be a lower-impact product. In many cases, there is also difficulty in defining what level of emissions or waste is acceptably sustainable for a given type of product [16].

Sometimes, a variety of factors, including those mentioned above, may be the source of serious disagreement, conflicts and accusations between the authors of different LCA reports on the same material, product or process, especially if the results of the analysis have a negative effect on a certain company or industry sector, for example, [2]. Prof. Ramani Narayan, working on developing the LCA method said in one of the interviews that '...LCA shines a spotlight on a single product and identifies the areas where it could/should be improved... However, LCA's are increasingly used as a comparative marketing tool using,

for example, selecting parameters and impact categories favourable to one's product, which cannot and should not be the intent of an LCA.' [3].

By preparing a task with different scenarios for simple LCA analysis of selected biobased and non-biobased materials, a teacher can make the student realise the need for its responsible and careful use.

3.3. Thinking regionally

'Thinking regionally', defined here as using native, regional resources in materials and product manufacturing processes is actually connected to 'thinking sustainably'. This concept assumes economic and environmental benefits for both the manufacturer and for the region itself taken from savings on the transportation of the resources and on building competitiveness. To promote this idea among students, one should motivate them to look for possibilities to manufacture green products that take advantage of the following local factors:

- the cultivation of plants which can be used to produce biopolymers or as components of biocomposites – especially those specific for a region because of climate, soil etc.;
- the existence of chemical industry involved in the production of biobased materials or interested in sustainable development;
- the existence of manufacturers of products made with biopolymers, biocomposites and other biobased materials.

Students may analyse global and local market potential focusing on materials and products that exist on the market and that use market projections.

3.4. The diversity of materials and the force of habits

To be truly honest with the students about the process of material selection or finding applications for materials, one should make them realise that usually, when a manufacturer look for the possible improvements in his products portfolio, a change in the type of material used is less common than changes made in the manufacturing process and/or geometry of the product. This is especially true with regard to switches from traditional materials into more innovative materials – the consequences of such a decision may be very complex. Force of habit also plays an important role here. For traditional materials, methods of manufacturing and the consequences of their application are generally known; however, for new materials, what is unknown seems suspicious and difficult. The variety of engineering materials present on the market within different material groups is huge, as is the competition among them.

4. Modern tools in the teaching of innovative materials

In educating about materials which are developing every day, the use of modern educational tools accompanying traditional ways of teaching (known as 'b-learning' or 'blended learning') should enable them, in a motivating and inspiring manner, to responsibly seek and use different sources of knowledge and to apply that knowledge to solving real-life problems.

These modern educational tools generally require access to the Internet and certain software with the use of a desktop computer or a personal electronic device (in the case of m-learning [mobile learning]). When designing e-learning and m-learning courses, the teacher has numerous possibilities to provide students with access to knowledge and important data, as well as to develop their skills. Some examples are given below which focus on the needs of education in the field of materials science and biobased materials:

- material databases – there are many material databases accessible on-line. Some of these require payment and some are free of charge. The 'Materials Data Center' offers a free biopolymer database which can be successfully used during work with students, e.g. for an exercise on the selection of materials;
- news from the market – important sources useful in teaching about innovative materials include trade journals and websites (e.g. www.news.bio-based.eu, www.compositesworld.com, www.en.european-bioplastics.org, www.bc.bangor.ac.uk) as well as market reports. To supplement this information, it is useful to enable students to take part in trade fares connected with the course when such opportunities arise;
- scientific publications – full-text databases including the university repository should be used as a source of current journal papers or textbooks (many books on biocomposites and other materials from renewable sources are available via the Knovel database);
- computer software – for the purpose of the academic course on biocomposites and other biobased materials, the use of software dedicated for life cycle assessment would be most beneficial as it would help students to identify various factors affecting material selection and connected to sustainable development as well as to observe some of the limitations of LCA method;
- online lectures and other educational films, animations, audio recordings or virtual laboratories – using e-learning platforms, teachers may direct students towards useful sources;
- self-prepared, interactive educational materials – including recorded lectures, textbooks, but also virtual labs – these are useful for teaching about the properties of biobased materials which are less accessible and often more expensive than materials usually used for the preparation of specimens for conventional laboratory work. It is also possible for a teacher to prepare smartphone applications, for example, in the form of quiz or a simple game (a lot of tutorials that demonstrate how to accomplish this are easy to access on the Internet) [14].

Using a Moodle e-learning platform, a teacher can share information with students and redirect them to useful websites, prepare and evaluate tasks, provide feedback and grades, and communicate with student in various ways.

5. Conclusions

Materials obtained fully or partially from renewable sources, especially those suitable for technical applications like biocomposites (mainly wood plastic composites and natural fibre composites) are becoming more and more important on the materials market. They

are competitive options in comparison with commonly used materials obtained from non-renewable feedstock – mainly with conventional plastics and polymer-matrix composites. They have been intensively tested for over two decades and they are now a part of the portfolios of the biggest chemical producers as well as smaller companies all over the world. There is a need to introduce these materials into the university curricula and the opportunity to make it in active learning environment using various verified up-to-date online sources of knowledge and tools which make learning more interesting and more accessible.

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PERSPECTIVES ON AVATION TRAINING IN POLISH UNIVERSITIES

PERSPEKTYWY POLSKICH UCZELNI W ZAKRESIE KSZTAŁCENIA NA RZECZ TRANSPORTU LOTNICZEGO

Abstract

This article presents the potential for development of aviation education at Polish Universities with a focus on aircraft mechanics training certified by the Civil Aviation Authority in Warsaw and the European Aviation Safety Agency (EASA). An engineering graduate who obtains such a licence in addition to having a diploma would have no problems with finding a suitable employment.

Keywords: aviation training, aircraft engineering, polytechnic education

Streszczenie

W artykule przedstawiono potencjalne możliwości rozwoju kształcenia lotniczego na polskich uczelniach, z naciskiem na szkolenie mechaników lotniczych certyfikowanych przez Urząd Lotnictwa Cywilnego w Warszawie oraz Europejską Agencję Bezpieczeństwa Lotnictwa EASA. Absolwent studiów inżynierskich, który obok dyplomu, miałby tego rodzaju licencje, nie powinien mieć problemów ze znalezieniem dobrej pracy.

Słowa kluczowe: szkolenie lotnicze, inżynieria lotnicza, kształcenie politechniczne

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1. Introduction

As is clear from the practice of recent decades in the labour market, the greatest demand is for technical experts in various fields. On the other hand, graduates of secondary and higher technical schools, often complain about the lack of work or lack of adequately paid employment – they tend to work below their level of education, often abroad. In the nineteen-nineties, many technical secondary schools were closed in Poland. One of the areas where technicians are still needed is aeronautics.

In the politics of the European Union, regional development is highly prised. These 'little homelands' are very diverse in terms of development and living standards. A key factor in determining the degree of alignment between developed and less developed regions is investment in infrastructure, logistics, transport and its sub categories including air transport. One of such branches is air transport. In this respect, Poland unfortunately still lags behind Western countries where aviation is commonly used. Unfortunately, in Poland, where the process of economic change is still ongoing, air transport is still limited; however, some developments in this field can be seen in Poland.

This concerns not only the airlines, but also General Aviation (GA) – light transport and air services performed without permanent schedule, usually by light aircraft. The concept of general aviation has not yet been clearly defined – it includes light recreational and biusness aircraft fleet., which perform non-scheduled flights that are, as a rule, usually non-commercial. This definition is not complete because GA also often includes heavy private planes (eg. Business jet Boeing 737BBJ), gliders and ultralight aircraft (including trikes/ microlight aircraft). In other words, general aviation refers to a wide variety of aircraft usually carrying from 2 to 15 persons, a small load (up to several tons) and used to patrol forested areas and roads, or for medical or postal services etc. Interestingly, GA accounts for about 90% of civil aviation in terms of the number of aircraft and the number of flight operations [1]. The remaining 10% is made up of aviation transport – airlines. This, however, relates to the number of flights and not the number of passengers or volume of cargo. Most passengers are carried by traditional aviation carrying not just a few passengers but a few hundred.

This article provides a general description of the proposed vision of a modern aviation school, providing staff for both general aviation and communication, and to some extent, also for the military. This may be for a technical high school, a component of higher university education (e.g. BSc) or vocational training. The mission of such a school should be to produce highly qualified middle and senior technical personnel for industry, military, general aviation and air transport.

In recent years the European labour market, has suffered from a lack of qualified aircraft mechanics [3]. This is also true in Poland, where trained aviation technical school graduates, or those who have an engineering degree with a licence in aircraft mechanics are almost guaranteed a good job. Unfortunately, there is no such school in western Poland, yet. A modern aviation centre of learning could be created as an aviation mechanical technical works or university offering a degree in engineering, logistics and transport.

A requirement of the job market nowadays, however, is that such school certificates are issued by the Civil Aviation Authority in Warsaw and the European Aviation Safety Agency EASA, so that graduates can obtain national and international (EU) aircraft mechanics

licences. Possessing a technician or engineering diploma at university is often considered insufficient by present standards and must be supported by obtaining the EASA licence. This could be overcome by cooperation with another aviation training centre or MTO – Mechanic Training Organisation (MTO), which can confer such certification.

For example, the centre in Mielec, MTO Royal Star is willing to work with schools and is even prepared to apply for EU grants for this purpose. In this way, the graduate would receive professional training in elite professions which are in demand on the labour market, as well as the knowledge required to undertake further technical studies (especially on the aviation profile). Ultimately, the school can later obtain all certificates and begin conducting their own training without the need for participation from external organizations.

Table 1

The types of international aircraft mechanic licenses [9]

Categories of 'maintenance' licenses according to Part-66	Type of certified operation
A Line Maintenance Certifying Mechanic	Simple, scheduled line maintenance and rectifying basic faults within the limits of the tasks specified in the mandate. Work done in person at the Part-145 organisation
B1 Maintenance Certifying Technician – Mechanical	Technical support of aircraft structure, powerplant and mechanical and electrical systems, as well as replacement of blocks within avionics line maintenance, requiring simple tests to verify the correctness of the blocks'actions Category B1 shall automatically include the appropriate A subcategory
B2 Maintenance Certifying Technician – Avionic	Technical support for avionics and electrical systems (certifies a simple, scheduled line maintenance – possible if possessing a category 'A' licence
C Base Maintenance Certifying Engineer	The base (hangar) maintenance of whole aircraft in the organisation Part-145

The biggest problem in organising technical courses may be attracting teaching staff and organising basic practical training classes. There would be a requirement for supply of technical staff and teachers from outside, as well as the purchase of new literature for the library. The best solution would be to work with polytechnics and possibly other schools and universities. The practical part of the course could take place outside the school, in airports or in other educational centres. Professional practices should be conducted only in centres with modern technology and aircraft engaged in training technical staff – to achieve this end, schools could collaborate with technical training centres listed with the Civil Aviation Authority.

An aviation mechanic is a highly skilled person, authorised to certify activities performed on aircraft that comply with applicable European Standards Part-66 (European legislation on aviation technical staff certifying the operation of aircraft).

Under the law, a person under training in this profession can gain the necessary knowledge through the following routes:

– high school or university;
– learning in aviation training centre MTO;
– studying at a Part-147 training organisation;
– self-study (supported by state exams).

Currently, there are legal opportunities for trainee aircraft mechanics to obtain Polish and European licensed aircraft mechanic certification through a curriculum in secondary or higher technical school. The provision regulating this issue can be found in Poland as the Report Recognition of Knowledge (appendix to regulation No. 15 of the President of the Civil Aviation Authority dated 30/11/2007). In Poland, this document is known as the RUW (Raport Uznania Wiedzy) [5].

During the preparation of the above-mentioned document, an analysis approved by the Ministry of Education core curricula of teaching in schools and curricula provided by universities. The RUW has proven itself in practice, as evidenced at schools that have already received related accreditation.

Table 2

Examples of courses (modules) for obtaining the aviation mechanics licence which may be classified under evaluation of technical school in conjunction with the RUW [5, 9]

No.	Name of course (module)
1	Maths
2	Physics
3	Electrotechnics
4	Electronics
5	Digital techniques
6	Hardware
7	Aviation equipment maintenance
8	Basic Aerodynamics
9	Human factors in aircraft maintenance
10	Aviation regulations
11	Aerodynamics, structure and systems of planes (A1, A2, B1.1, B1.2)
12	Aerodynamics, structure and systems for helicopters (A3, A4, B1.3, B1.4)
13	Aerodynamics, structure and systems of aircraft (B2 only)
14	Aviation powerplant (B2 only)
15	Aviation turbine engines (A1, A3, B1.1, B1.3)
16	Aviation piston engines (A2, A4, B1.2, B1.4)
17	Propellers (A1, A2, B1.1, B1.2)

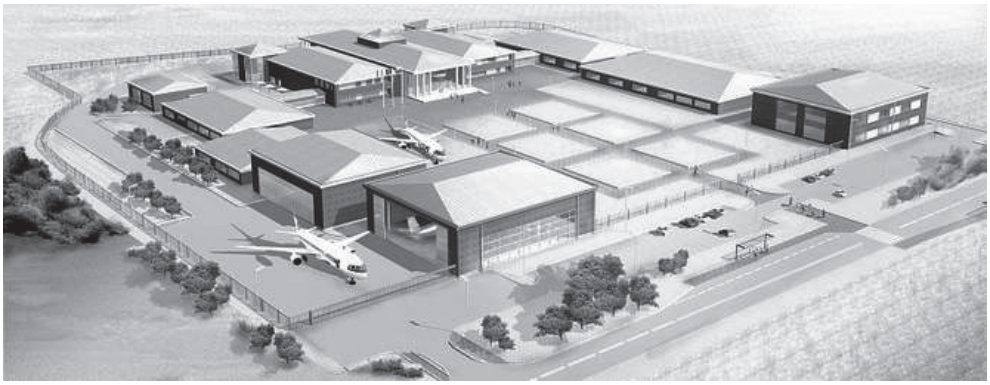

Fig. 1. Design of the PWSZ university at Chelm with hangars and aviation laboratories [10]

Looking into the future, schools could become major centres for comprehensive training for aviation and not only in mechanical contexts. Aviation is not only about pilots and technicians – safety in aviation also relies upon other specialists, e.g. controllers, dispatchers, managers and logisticians.

Today, many wonder whether it makes sense, whether technical or engineering studies about the profile of mechanical and aerospace have a raison d'etre in the current market? The author of this paper thinks they do, as evidenced by examples of new flight schools in Poland, which prosper – one of these is the European Aviation Technical College (Europejskie Technikum Lotnicze ETL) at Powodowo (Wielkopolska province), which was created from scratch over the last decade. The school is dynamically developing and has its own sport aerodrome recently built from scratch.

An example of a university for this profile was founded in the early twenty-first century, this is The State Higher Vocational School in Chelm, where degrees in aeronautical engineering and piloting can be obtained. The school was built from scratch and even includes its own airport in Depułtycze Królewskie. The website of PWSZ-Chelm reads: "From the moment of registration, flight training for students of mechanics and mechanical engineering is continuously carried out, there are trained aeroplane pilots, helicopter pilots and also aviation mechanics. The airport plays an important role in the region, in addition to the training activities carried out there, public order agencies and aviation enthusiasts enjoy it".

Today's modern society must be based on knowledge. The famous expression 'learning for life' implies continuous development, not only of students, but also teachers. To achieve this, it is important to ensure that school staff have easy access to courses and postgraduate improvement. It is worth noting especially that postgraduate studies funded by the EU (European Social Fund). The school could theoretically help students to obtain the following certification for the pilot*:*

- Private pilot licence PPL (A),
- Professional pilot licence CPL (A).

A large part of the knowledge required to obtain a pilot's licence coincides with the curriculum on technical studies in university.

A school should seek the broadest possible ways to obtain external funding (national and EU programs/ESF) for the development of schools and educational projects. For example, several schools in Poland have already obtained the funding to equip a computer lab for flight training. The introduction of technology-based learning and e-learning may be extremely useful – this is a specific embodiment of the training method in absentia through extensive use of online technology.

2. The potential implementation and development of aeronautical engineering at Polish technical universities

Aviation technology and mechanics can be one of the very attractive faculties for studying in modern Europe. The student would attend classes in fields of both design and aircraft operation. Training in the operation, in addition to the engineering program, could include software modules provided for the licensed aircraft mechanic category A or B.

In addition, each of the fields of engineering and aviation should also include a module of general knowledge in the field of aviation. The author proposes that it should consist of the following items:

- air traffic management (perhaps using a computer air traffic control simulator);
- geography and air navigation;
- principles of aeronautical radio communication (phraseology, methods of maintaining communication);
- construction of aircraft;
- construction of radar and radio navigational equipment;
- aviation flight instruments;
- basic knowledge about piloting aircraft (including use of computerised flight simulators);
- international aviation and airlines;
- Air Force;
- aviation law and flight rules;
- human factors in aviation and aero medical grounds;
- the history of aviation.

At the end of this paper, the author has added some digressions on contemporary engineer-graduate technical studies. We are often unsure about who should be an engineer. Once, in the communist era, Poland had a producer market and almost everything that was produced could be sold. This has forged with us the false notion that a task for an engineer is to build something that just needs to work well, and questions regarding the need for such a product are deposited on the back burner. Meanwhile, the product, in addition to having to work, must also be able to sell. Which is why all producers need to execute thorough market research and consumer needs assessments, concepts which are already is in the field, and not only in scientific disciplines and sometimes can reach beyond science. Itis impossible to compute what the recipients will need mathematically. For example, we can consider the Polish historical case of the PZL M-26 Iskierka trainer aircraft (known also as Airwolf) which was designed on the basis of the Piper PA-34 Seneca. As a technical object, she acted flawlessly,

this aircraft was safe and pleasant to fly, but almost no one bought it. The M-26 proved to be too light for the army (the armies of the world prefer to train in heavier aircraft, of the PZL-130 Orlik or PC-9 Tucano class) and it was too heavy for civilian flying clubs (the cost of flying hours on the M-26 would be much higher than the Cessna and Piper aircraft used for training). Besides, for civilian pilot training, it is preferable for the trainee and the instructor to be sitting next to each other rather than one in front of the other as is the case with the M-26.

Fig. 2. Beechcraft Starship – very modern aircraft, but its vanguard design probably discouraged many potential customers [7]

The failure of the M-26 project lies largely in a failure by the producer of that aircraft to correctly qualify market demand. When it comes to foreign manufacturers, an interesting example is the American Beechcraft Starship aircraft. Despite its modern design and good performance, this aircraft also lacked buyers. In this case, the vanguard silhouette with a canard presumably discouraged customers. Although this layout can enhance performance (both wings and stabilizers produce lift), it is quite different from traditional aircraft. Potential buyers prefer to buy something known and proven, rather than risk investment in new vanguard designs.

Within three years of certification, only eleven examples of the Starship aircraft were sold. The low sales were caused by the economic slowdown of the late eighties and the careful approach of customers to technical innovations (of which the Starship was undoubtedly one) and the high tax on luxury goods which was in force then in the United States. In 2003, the Beechcraft producer announced that it would not maintain technical support for such a small fleet of Straship aircraft, and started scrapping aircraft owned by the factory. The manufacturer failed to adequately characterise the market before commencing work on this vanguard design, though the Starship itself was technically well built and flew properly.

As is clear, engineering today cannot be based only on maths, it must also take into account variables determined by many other factors, the hooking of sociology, psychology, issues of fashion, as well as the usual intuitions [6, 4].

Fig. 3. The PZL M-26 Iskierka (Airwolf) trainer aircraft [8]

A Polish lecturer at the famous Massachusetts Institute of Technology (MIT), a specialist in complex mathematical calculations, Prof. Eng. Arch. Wacław Zalewski, designer, among others of the 'Spodek' building in Katowice, says outright that in Poland, engineering puts too much emphasis on strict thinking (based mainly on maths), rather than teaching independent thinking and creativity. He explains [6]: "sketching for me has always been more important than the calculation (...). Such work can be performed by computer. But your computer can not create the design of Spodek (...). The engineer makes decisions that are approximate (...). Therefore, you must use intuition, and this is not a scientific concept".

3. Summary

The modern education of flight engineers must flexibly respond to the needs of the labour. It is therefore proposed here to the program of studies included both part of the construction of aircraft, as well as modules for their maintenance (training for licensed mechanic) demands of the potential recipients of our services (customers) should be the main determinant of changes in the education process. This also applies to the construction and design of academic courses where students are taught to realise that the implementation appropriate theme for activities ought to go beyond traditional engineering.

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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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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].

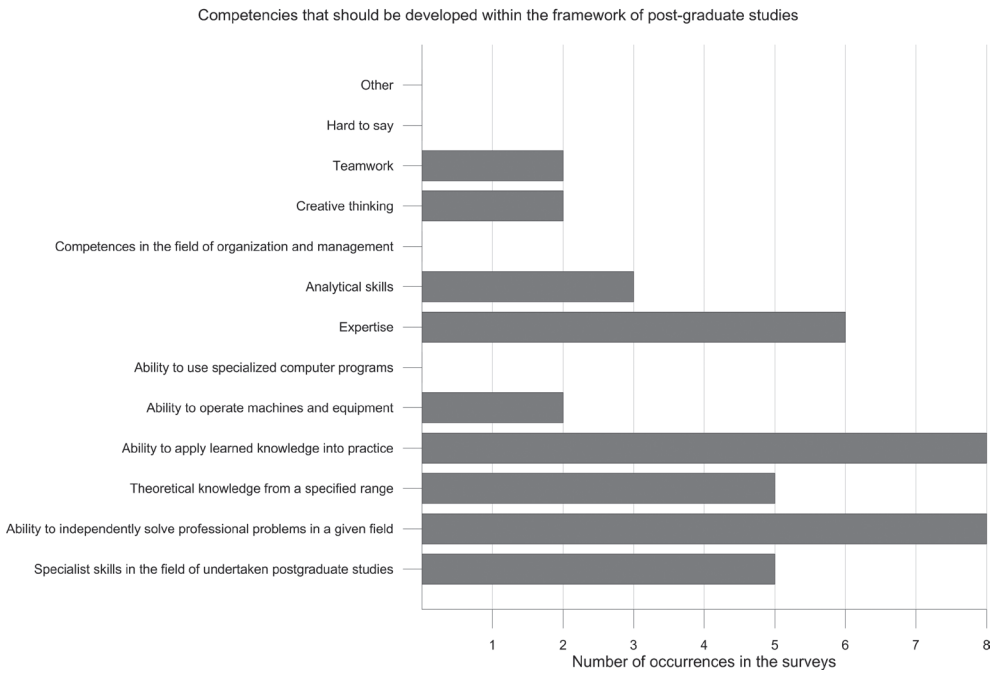

Fig. 1. Competences of post-graduate students identified in the survey [13]

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.

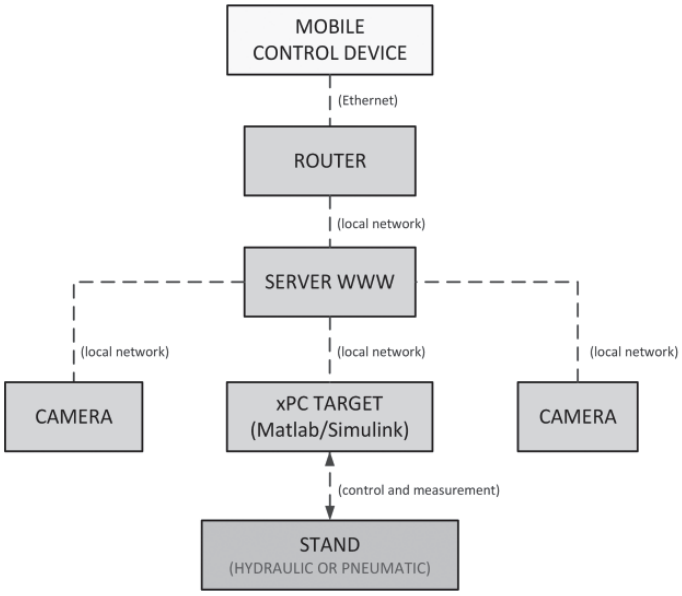

Fig. 2. Diagram of the remote control system of laboratory stand

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.

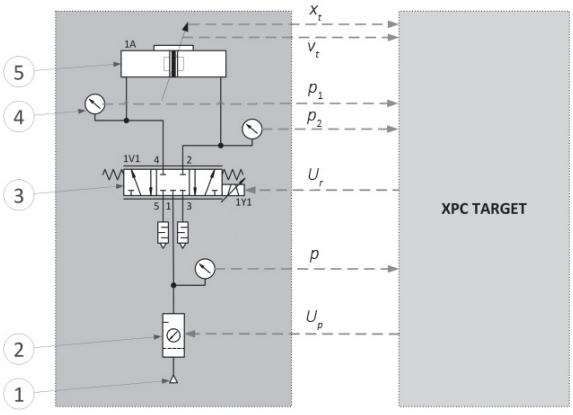

Fig. 3. Diagram of a remote-controlled pneumatic stand: 1 – compressed air connection, 2 – pneumatic service unit, 3 – proportional valve, 4 – pressure transducer, 5 – cylinder

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.

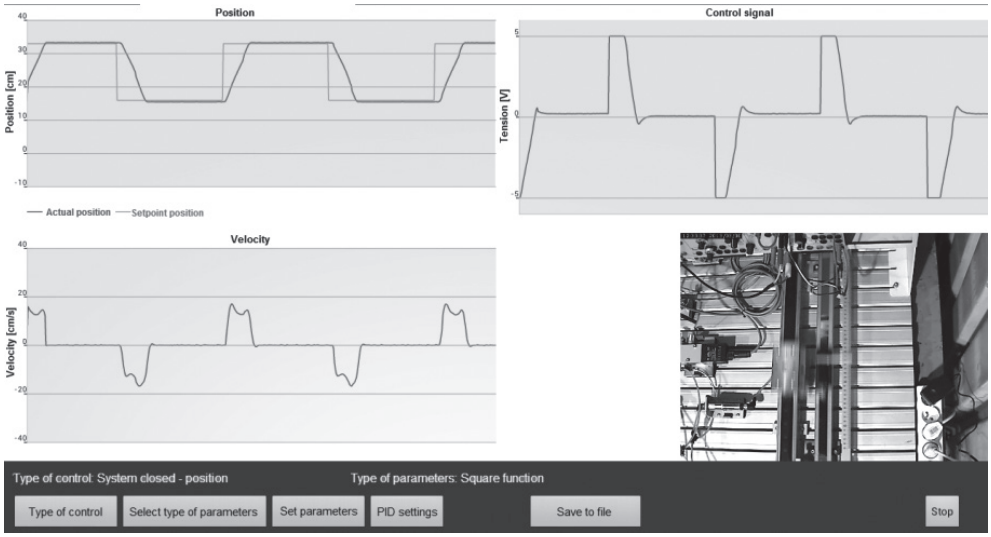

Fig. 4. A view of the tablet display during the lab exercise using the mobile platform

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*).

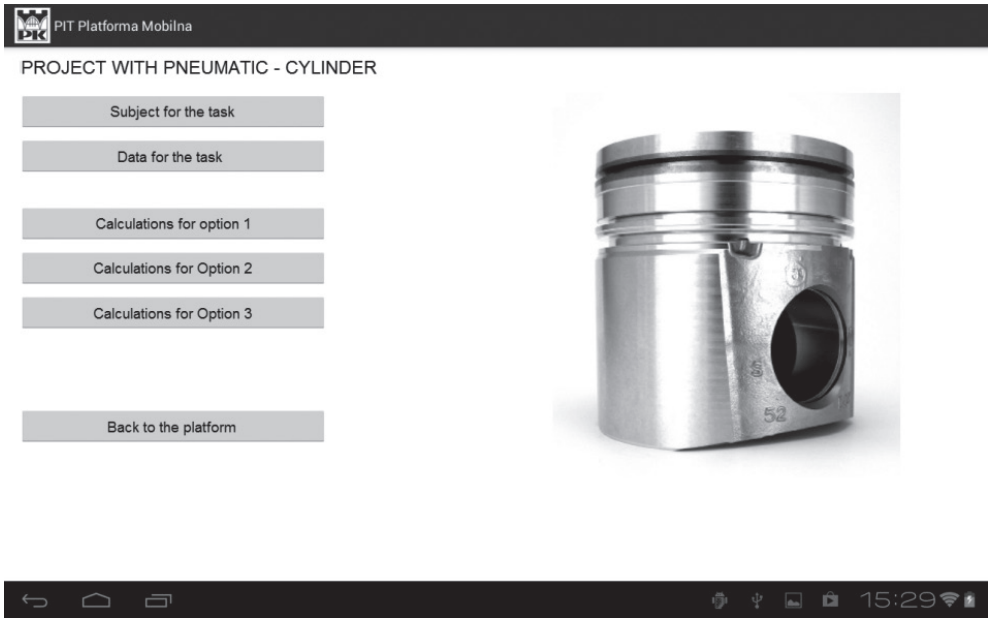

Fig. 5. A sample screenshot of the interactive "pneumatic cylinder" project

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.

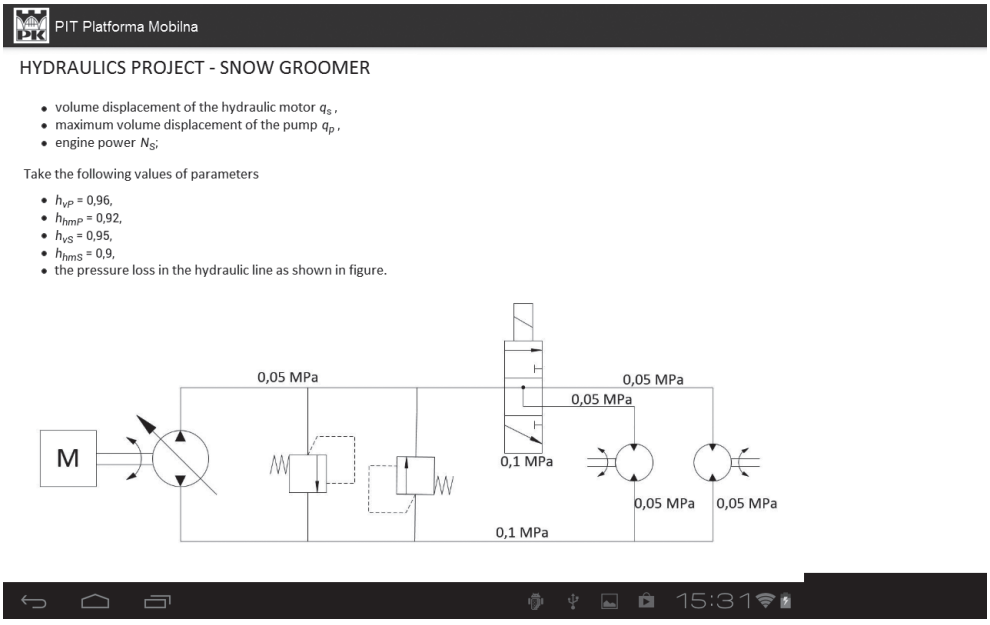

Fig. 6. A sample screenshot of the interactive hydraulic project

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

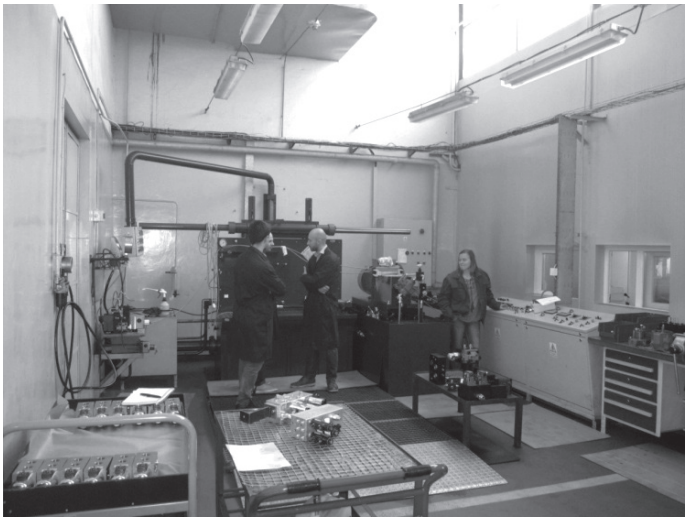

Fig. 8. Post-graduate students visiting the diagnostic test bench in PONAR Wadowice

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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MACIEJ SIWCZYNSKI*, MARCIN JARACZEWSKI*

THE POLES METHOD FOR HIGHER-ORDER LINEAR TIME-VARYING SYSTEMS

METODA BIEGUNÓW DLA UKŁADÓW LINIOWYCH WYŻSZEGO RZĘDU O CZASOWO ZALEŻNYCH WSPÓŁCZYNNIKACH

Abstract

In dynamic linear systems described by differential equations with constant parameters, the poles of the rational function (transfer function of the system) play an important role. This article attempts to expand the poles concept in a situation where the system is described by the *N*-th order linear system with time-varying parameters. It then introduces the concept of characteristic equations and time-dependent poles.

Keywords: linear systems, time-varying systems

Streszczenie

W opisie liniowych systemów dynamicznych opisanych przez równania różniczkowe o stałych parametrach ważną rolę odgrywają bieguny funkcji wymiernej (transmitancji systemu). Ten artykuł rozszerza koncepcję biegunów na przypadek, gdy system jest opisany równaniem liniowym *N*-tego rzędu o zmiennych w czasie parametrach. Pojawia się tu pojęcie zależnego od czasu równania charakterystycznego i zależnych od czasu biegunów transmitancji.

Słowa kluczowe: równania różniczkowe liniowe, równania różniczkowe parametryczne

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1. Introduction

In the field of linear systems analysis with constant coefficients, the well-known and functioning method is the factorisation method – this consists of transforming complex systems to *a* commutative cascade of the first-order systems.

This requires finding the poles of the transfer function – these are also the zeros of the characteristic polynomial called the eigenvalues of the system which are generally complex. For a stable system, they lie in the open left half-plane. It turns out that this method also works in the case of linear systems with time-variable coefficients [3, 6, 7].

Linear systems of the first and second order can be described by a differential equation, or by a block diagram.

First-order ODE:

$$\frac{dy}{dt} - \alpha y = x(t)$$

and its corresponding block diagram:

$$x(t) \rightarrow \boxed{\left(\frac{d}{dt} - \alpha\right)^{-1}} \rightarrow y(t)$$

The second-order ODE:

$$\frac{d}{dt}\left(\frac{dy}{dt} - \alpha y\right) - \beta\left(\frac{dy}{dt} - \alpha y\right) = x(\mathrm{t})$$

and its corresponding block diagram:

$$x(t) \rightarrow \boxed{\left(\frac{d}{dt} - \beta\right)^{-1}} u(t) \rightarrow \boxed{\left(\frac{d}{dt} - \alpha\right)^{-1}} \rightarrow y(t)$$

Such cascade factorisation of the second-order system can be called the time-dependent 'Vieta's formulas' with time-dependent poles.

For the first-order systems, a closed-form analytical solution may be available. However, for the higher-order system with time varying parameters, the finding of poles must be carried out numerically or some special methods must be used [1, 2, 4, 5, 8–10].

2. Separation of time-dependent poles in the higher-order linear systems

The differential equation of the higher order:

$$\frac{d^n}{dt^n} y + a_{n-1} \frac{d^{n-1}}{dt^{n-1}} y + \ldots + a_1 \frac{d}{dt} y + a_0 y = x \tag{1}$$

is subjected to the following transformations:

$$\begin{aligned} &\frac{d}{dt}\Bigg(\overbrace{\frac{d^{n-1}}{dt^{n-1}}y+\alpha_{n-2}\frac{d^{n-2}}{dt^{n-2}}y\ +\ldots+\ \alpha_1\frac{d}{dt}y\ +\ \alpha_0 y}^{u(t)}\Bigg) \\ &-\alpha\Bigg(\overbrace{\frac{d^{n-1}}{dt^{n-1}}y+\alpha_{n-2}\frac{d^{n-2}}{dt^{n-2}}y\ +\ldots+\ \alpha_1\frac{d}{dt}y\ +\ \alpha_0 y}^{u(t)}\Bigg)=x \end{aligned} \tag{2}$$

where:

α – unknown time-dependent pole,

$\alpha_{n-2}, \ldots, \alpha_1, \alpha_0$ – unknown coefficients of the differential equation of reduced order (also time-dependent).

In the flowchart convention, this operation involves replacing the single block:

$$x(t) \rightarrow \boxed{\left(\frac{d^n}{dt^n}+a_{n-1}\frac{d^{n-1}}{dt^{n-1}}+\ldots+a_1\frac{d}{dt}+a_0\right)^{-1}} \rightarrow y(t)$$

by the cascade:

$$x(t) \rightarrow \boxed{\left(\frac{d}{dt}-\alpha\right)^{-1}} \rightarrow \boxed{\left(\frac{d^{n-1}}{dt^{n-1}}+\alpha_{n-2}\frac{d^{n-2}}{dt^{n-2}}+\ldots+\alpha_1\frac{d}{dt}+\alpha_0\right)^{-1}} \rightarrow y(t)$$

One can call this operation the separation of the time-dependent pole α.
From (2), we get:

$$\begin{aligned} &\frac{d^n y}{dt^n}+\alpha_{n-2}\frac{d^{n-1}y}{dt^{n-1}}+\ldots+\alpha_1\frac{d^2 y}{dt^2}+\alpha_0\frac{dy}{dt} \\ &-\alpha\frac{d^{n-1}y}{dt^{n-1}}-\alpha\alpha_{n-2}\frac{d^{n-2}y}{dt^{n-2}}-\ldots-\alpha\alpha_1\frac{dy}{dt}-\alpha\alpha_0 y \\ &+\frac{d}{dt}\alpha_{n-2}\frac{d^{n-2}}{dt^{n-2}}y+\ldots+\frac{d}{dt}\alpha_1\frac{d}{dt}y+y\frac{d}{dt}\alpha_0=x \end{aligned} \tag{3}$$

equivalence of (1) and (3) gives us the system of differential equations:

$$\alpha_{n-2} - \alpha = a_{n-1}$$
$$\alpha_{n-3} - \alpha\alpha_{n-2} + \frac{d\alpha_{n-2}}{dt} = a_{n-2}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$\alpha_1 - \alpha\alpha_2 + \frac{d\alpha_2}{dt} = a_2$$
$$\alpha_0 - \alpha\alpha_1 + \frac{d\alpha_1}{dt} = a_1$$
$$-\alpha\alpha_0 + \frac{d\alpha_0}{dt} = a_0$$

or:

$$\alpha_{n-2} = \alpha + a_{n-1}$$
$$\alpha_{n-3} = \alpha\alpha_{n-2} + a_{n-2} - \frac{d\alpha_{n-2}}{dt}$$
$$\alpha_{n-4} = \alpha\alpha_{n-3} + a_{n-3} - \frac{d\alpha_{n-3}}{dt}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \qquad (4)$$
$$\alpha_1 = \alpha\alpha_2 + a_2 - \frac{d\alpha_2}{dt}$$
$$\alpha_0 - \alpha\alpha_1 + a_1 - \frac{d\alpha_1}{dt}$$
$$0 = \alpha\alpha_0 + a_0 - \frac{d\alpha_0}{dt}$$

The system of equations (4) in the dynamic state can be transformed to the normal Cauchy form:

$$\frac{d\alpha_{n-2}}{dt} = \alpha\alpha_{n-2} - \alpha_{n-3} + a_{n-2}$$
$$\frac{d\alpha_{n-3}}{dt} = \alpha\alpha_{n-3} - \alpha_{n-4} + a_{n-3}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \qquad (5)$$
$$\frac{d\alpha_1}{dt} = \alpha\alpha_1 - \alpha_0 + a_1$$
$$\frac{d\alpha_0}{dt} = \alpha\alpha_0 + a_0$$
$$\alpha = \alpha_{n-2} - a_{n-1}$$

While in the static state, for systems with constant coefficients, it evolves to the following form:

$$\alpha_{n-3} = \alpha(\alpha + a_{n-1}) + a_{n-2} = \alpha^2 + a_{n-1}\alpha + a_{n-2}$$

$$\alpha_{n-4} = \alpha(\alpha^2 + a_{n-1}\alpha + a_{n-2}) + a_{n-3} = \alpha^3 + a_{n-1}\alpha^2 + a_{n-2}\alpha + a_{n-3}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{6}$$

$$\alpha_0 = \alpha^{n-1} + a_{n-1}\alpha^{n-2} + \ldots + a_3\alpha^2 + a_2\alpha + a_1$$

$$0 = \alpha^n + a_{n-1}\alpha^{n-1} + \ldots + a_2\alpha^2 + a_1\alpha + a_0$$

At the end of the process, it leads to the classical characteristic equation for the constant- coefficient equation (1). In contrast, the system of equations (4) can be called 'distributed time-dependent characteristic equation' of the variable parameter system and function $\alpha(t)$ is its 'time-dependent eigenvalue'. By solving the differential equation (5), we get the time-dependent coefficients α_{n-2}, ..., α_1, α_0 of the subsystem of reduced order and time-dependent pole α. The resulting algorithm that reduces degree of the polynomial, classically is called the Horner scheme. Therefore, it could be called a 'time-dependent Horner's scheme'.

For $n = 2$, it transforms to Vieta's formulas.

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MACIEJ SIWCZYNSKI*, MARCIN JARACZEWSKI*

THE POLES METHOD FOR SECOND-ORDER LINEAR TIME-VARYING SYSTEMS

METODA BIEGUNÓW DLA UKŁADÓW LINIOWYCH DRUGIEGO RZĘDU O CZASOWO ZALEŻNYCH WSPÓŁCZYNNIKACH

Abstract

In dynamic linear systems described by differential equations with constant parameters, the poles of the rational function (transfer function of the system) play an important role. This article attempts to expand the poles concept in a situation where the system is described by the second-order linear system with time-varying parameters. It then introduces the concept of characteristic equations and time-dependent poles.

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Słowa kluczowe: równania różniczkowe liniowe, równania różniczkowe parametryczne

DOI: 10.4467/2353737XCT.15.343.4864

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Linear systems of the first order can be described by a differential equation, or by a block diagram:

$$\frac{dy}{dt} - \alpha y = x(t)$$

$$x(t) \rightarrow \boxed{\left(\frac{d}{dt} - \alpha\right)^{-1}} \rightarrow y(t)$$

The operator of the transfer function of the system can be written down using a so-called Green's function in the following form:

$$\left(\frac{d}{dt} - \alpha\right)^{-1} x(t) = \int_{-\infty}^{\infty} e^{\alpha(t-t')} 1(t-t') x(t') dt'$$

where:

α = const.

When α is a time-depended function, its general form is:

$$\left(\frac{d}{dt} - \alpha\right)^{-1} x(t) = \int_{-\infty}^{\infty} e^{\int_{t'}^{t} \alpha(\tau) d\tau} 1(t-t') x(t') dt'$$

where:

$1(t)$ – unit step:

2. Cascade factorisation of the second-order system. The time-dependent 'Vieta's formulas'

The differential equation describing the second-order system is:

$$\frac{dy^2}{dt^2} + a(t)\frac{dy}{dt} + b(t)y(t) = x(t) \tag{1}$$

and it can be written as:

$$\frac{d}{dt}\left(\frac{dy}{dt}-\alpha y\right)-\beta\left(\frac{dy}{dt}-\alpha y\right)=x(\mathrm{t}) \tag{2}$$

where:

$\alpha(t)$, $\beta(t)$ – unknown functions,

or as a sequence of the 1st-order equations:

$$\frac{du}{dt}-\beta u=x; \qquad \frac{dy}{dt}-\alpha y=u$$

or by using the inverse operator:

$$u=\left(\frac{d}{dt}-\beta\right)^{-1}x; \qquad y=\left(\frac{d}{dt}-\alpha\right)^{-1}u$$

It corresponds to the cascade:

$$x(t)\rightarrow\boxed{\left(\frac{d}{dt}-\beta\right)^{-1}}\,u(t)\rightarrow\boxed{\left(\frac{d}{dt}-\alpha\right)^{-1}}\rightarrow y(t)$$

which, however, is generally not commutative.

Differential equation (2) can be written as:

$$\frac{dy^2}{dt^2}-(\alpha+\beta)\frac{dy}{dt}+\left(\alpha\beta-\frac{d\alpha}{dt}\right)y=x \tag{3}$$

The equivalence of equations (1) and (3) requires that:

$$\begin{aligned}-(\alpha+\beta)&=a & \qquad a+\alpha+\beta&=0\\ \alpha\beta-\frac{d\alpha}{dt}&=b & \text{or} \qquad \alpha\beta-b&=\frac{d\alpha}{dt}\end{aligned} \tag{4}$$

This result could be called ‘time-dependent Vieta’s formulas’. For systems with constant coefficients, they become classic Vieta’s formulas.

From the Vieta’s formula (4), it follows the differential equation:

$$b+a\alpha+\alpha^2=-\frac{d\alpha}{dt} \tag{5}$$

which is a generalised characteristic equation of the differential equation (1) and for the constant coefficients, it becomes the classical characteristic equation. Therefore β, α coefficients, which could be called 'time-dependent poles' of the parametric differential equation, are determined from equations (5) and (4) [1–4].

The figures below illustrate the problem of the pole stability in the static (*a*, *b* = const) and dynamic (*a*, *b* = var) state.

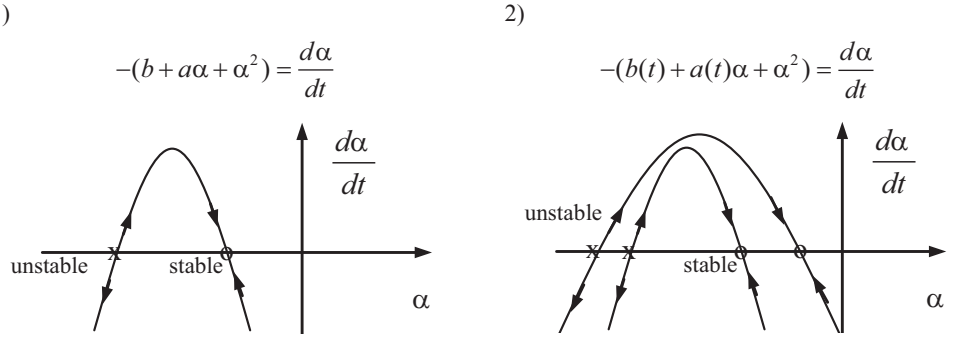

Fig. 1. The pole stability in the 1) static (*a*, *b* = const) and 2) dynamic (*a*, *b* = var) state

This is for the real poles, whereas for the complex ones the differential equation (5) can be rewritten into the form:

$$\frac{d\,\backslash\,\alpha^2}{dt}=-2\,\mathrm{Re}(\alpha)\left(b+\left(\frac{a}{\mathrm{Re}(\alpha)}+1\right)|\,\alpha\,|^2\right)\Bigg|_{\mathrm{Re}(\alpha)\to\,-\alpha/2}\to a\left(b-|\,\alpha\,|^2\right)$$

This guarantees the numerical stability of the complex root [5–10] (Fig. 2).

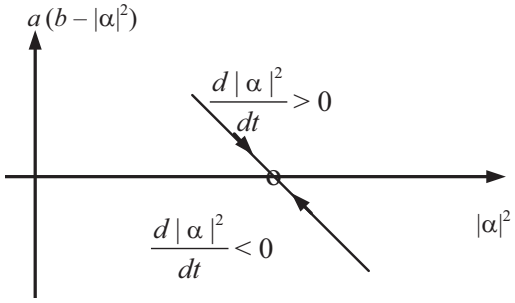

Fig. 2. The complex pole stability condition

3. The inverse problem – synthesis of poles

The inverse problem for the system of the second order is to find the coefficients $a(t)$, $b(t)$ of the differential equation at the pre-set time-variation of the poles $\alpha(t)$ i $\beta(t)$. The case of complex poles and the real equation coefficients will be considered here.

The coefficients $a(t)$, $b(t)$ are obtained from the Vieta's formulas:

$$a = -(\alpha + \beta)$$

$$b = \alpha\beta - \frac{d\alpha}{dt}$$

if they are real, they must satisfy the following equations:

$$\alpha = \alpha_R + j\alpha_I$$

$$\beta = \beta_R - j\alpha_I$$

where:

α_R, α_I, β_R – real-valued functions.

Thus, there is the relationship:

$$b = \alpha_R\beta_R + (\alpha_I)^2 - \frac{d\alpha_R}{dt} + j\left[\alpha_I(\beta_R - \alpha_R) - \frac{d\alpha_I}{dt}\right]$$

and therefore, coefficients of the differential equation are determined by the formulas:

$$a = -(\alpha_R + \beta_R)$$

$$b = \alpha_R\beta_R + (\alpha_I)^2 - \frac{d\alpha_R}{dt}$$

under the condition that:

$$\alpha_I(\beta_R - \alpha_R) - \frac{d\alpha_I}{dt} = 0 \qquad \text{or} \qquad \frac{d\alpha_I}{dt} = \alpha_I(\beta_R - \alpha_R)$$

Finally, a differential equation with separated variables can be solved analytically:

$$\alpha_I(t) = Ke^{\int(\beta_R(t) - \alpha_R(t))dt}, \quad K = \text{const}$$

The resulting formula defines the relationship between the real part and the imaginary part of the poles. In particular, for systems with constant coefficients, α and β must be adjoint to each other , thus $\beta_R = \alpha_R$ which results in $\alpha_I = \text{const}$.

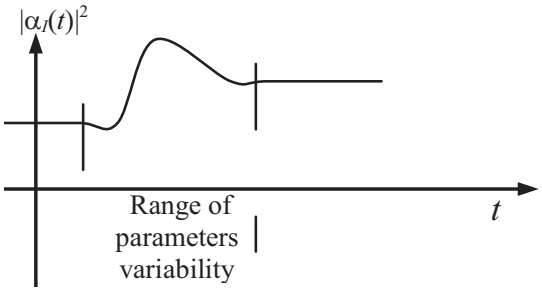

Fig. 3. The function $(\alpha_I(t))^2$ in the range of system parameters variation and outside this interval

Figure 3 shows an example of the function $(\alpha_I(t))^2$ in the range of the variation of the system parameters and outside this interval.

4. The homogeneous differential equation of the second-order and time-dependent Vieta's formulas

For the defined operators:

$$A = \frac{d}{dt} - \alpha; \qquad B = \frac{d}{dt} - \beta$$

the 1st-order homogeneous differential equations have the form:

$$Ay = 0; \qquad By = 0$$

and their solutions are:

$$y_A(t) Ke^{\int \alpha(t)dt}; \qquad y_B(t) Ke^{\int \beta(t)dt}$$

where:

α, β – time-dependent eigenvalues.

The sequences of the operators are:

$$ABy = \frac{dy}{dt}\left(\frac{dy}{dt} - \beta y\right) - \alpha\left(\frac{dy}{dt} - \beta y\right) = \frac{d^2y}{dt^2} - (\alpha + \beta)\frac{dy}{dt} + \left(\alpha\beta - \frac{d\beta}{dt}\right)y$$

and:

$$BAy = \frac{d^2y}{dt^2} - (\alpha + \beta)\frac{dy}{dt} + \left(\alpha\beta - \frac{d\alpha}{dt}\right)y$$

This allows writing a formula for the operator commutator:

$$[A, B] = AB - BA = \frac{d}{dt}(\alpha - \beta)$$

and to express the 2nd-order homogeneous differential equation as:

$$\left(\frac{dy}{dt}\right)^2 + a(t)\frac{dy}{dt} + b(t)y(t) = \left(\frac{d}{dt} - \alpha\right)\left(\frac{d}{dt} - \beta\right) = 0 \rightarrow ABY = 0$$

where:

$\alpha + \beta + a = 0$,

$\alpha\beta - b - \frac{d\beta}{dt} = 0$ – 'Vieta's formulas'.

Theorem:
If:

$$y_A: \; Ay_A = 0$$

$$y_B: \; Ay_B = 0$$

then:

$$AB(y_A + y_B) = AB\, y_A = (BA + [A, B])y_A = [A, B]\, y_A$$

or:

$$\frac{d^2}{dt^2}(y_A + y_B) + a\frac{d}{dt}(y_A + y_B) + b(y_A + y_B) = y_A\frac{d}{dt}(\alpha - \beta)$$

where:

$\alpha + \beta + a = 0$,

$\alpha\beta - b - \frac{d\beta}{dt} = 0$,

therefore:

$$b + a\beta + \beta^2 = -\frac{d\beta}{dt}$$

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ANETA SZEWCZYK-NYKIEL*

THE INFLUENCE OF MOLIBDENUM ON CORROSION RESISTANCE OF SINTERED AUSTENITIC STAINLESS STEELS

WPŁYW MOLIBDENU NA ODPORNOŚĆ NA KOROZJĘ SPIEKANYCH AUSTENITYCZNYCH STALI NIERDZEWNYCH

Abstract

Molybdenum was introduced into sintered austenitic stainless steels to improve their corrosion resistance. The influence of different Mo contents on the pitting corrosion resistance of AISI 304L and 316L steels in 0.1 M sodium chloride solution has been investigated. The corrosion behaviour was evaluated by potentiodynamic polarisation method. Sintered Mo-containing 304L steel is less prone to pitting corrosion in environment containing chlorides than 316L with Mo addition. The introduction of molybdenum to 304L steel resulted in an improvement of corrosion resistance. This steel exhibits the highest value of polarisation resistance as well as the lowest value of corrosion rate.

Keywords: *sintered austenitic stainless steel, molybdenum addition, pitting corrosion, potentiodynamic polarization*

Streszczenie

Molibden wprowadzono do austenitycznych stali nierdzewnych w celu poprawy ich odporności na korozję. Badano wpływ różnej zawartości molibdenu na odporność na korozję wżerową stali AISI 304L i 316L w 0.1 M roztworze chlorku sodu. Zachowanie korozyjne oceniano metodą polaryzacji potencjodynamicznej. Spiekana stal 304L zawierająca molibden jest mniej podatna na korozję wżerową w środowisku zawierającym chlorki niż 316L z dodatkiem Mo. Wprowadzenie molibdenu do stali 304L spowodowało poprawę odporności na korozję. Stal ta wykazuje najwyższą wartość oporu polaryzacji, jak i najniższą wartość szybkości korozji.

Słowa kluczowe: *spiekana austenityczna stal nierdzewna, dodatek molibdenu, korozja wżerowa, polaryzacja potencjodynamiczna*

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1. Introduction

Stainless steel is the common name of a large family of steels that are resistant to destruction under the influence of chemical or electrochemical reaction with the surrounding environment. Corrosion resistance of stainless steels is the result of the passive state. In order to ensure corrosion resistance, the content of chromium should be at least about 11% wt. [1–5]. Due to presence of this element in chemical composition of stainless steel, a thin, chemically stable, invisible, durable, extremely adherent, self-healing, and passive film of chromium oxide is formed on the surface of steel [3, 5–8]. This film is formed in oxidising environments, whereas steel may be subjected to corrosion in anaerobic environments and in the presence of aggressive ingredients (chlorides, sulphur compounds). Then corrosion can lead to perforation, reduction in mechanical strength, deterioration of the surface appearance or contaminant of the manufactured products [7]. When steels contain chromium in an amount of more than 13 weight %, they are resistant to corrosion in oxidising environments, such as nitric acid. These steels are definitely less resistant in reducing environments, such as hydrochloric acid or sulphuric acid. It is well known that higher content of chromium must be added to protect against pitting and rusting in more hostile environments than, for instance, relatively pure and dry air [3, 7]. Because of austenitic phase stability considerations, the content of chromium in austenitic stainless steels is generally kept in the range of 17–18 weight % [3–4].

Besides chromium and nickel, modern austenitic stainless steels contain other alloying elements. For example, the introduction of molybdenum addition to stainless steel improves the corrosion resistance of the passive layer in the presence of chloride ions (derived from chemicals, road salt, sea water, etc.), so steels with the addition of this element have a higher resistance to pitting and crevice corrosion than conventional chromium-nickel steels [3].

The AISI 300 series includes austenitic stainless steels containing chromium and nickel. The chromium-nickel steels are mostly resistant to electrochemical corrosion in an environment of inorganic and organic acids, nitrogen compounds, salt solutions and aggressive food products. They have excellent corrosion resistance in diverse environments, but their mechanical properties are not satisfactory in some applications. Moreover, their tribological properties are rather poor. Chromium-nickel steels exhibit a high coefficient of friction and low wear resistance. Austenitic stainless steels are non-magnetic [2–4, 7]. The most commonly used steels are 304L and 316L. They belong to the group of austenitic stainless steels. The chemical composition of both these grades is similar. It should be pointed that the main difference between them is the absence of molybdenum in 304L. Thanks to the content of molybdenum, corrosion resistance of 316L steel is increased compared to 304L steel (especially pitting corrosion in the presence of chlorides) [7]. Generally, the addition of molybdenum increases corrosion resistance of wrought austenitic stainless steels. It lowers the critical passivation current and the current in the area of passive, shifts pitting potential towards positive values, raises the temperature of the critical pitting, and also reduces the number and size of pitting [7, 9–12]. Because of excellent corrosion resistance, 316L steel is used for equipment in the food industry and marine industry, for surgical implants, the nuclear fuel processing installations [4, 7].

Sintered austenitic stainless steels are increasingly used in many industrial branches, for instance, in the automotive industry, electromechanical industry or in medicine. They are used

as components of engines, drive systems, braking systems, exhaust systems or suspensions (for example, fuel pumps, self-lubricating bearings, brake pads, oxygen concentration sensors or ABS sensors). In medicine, they are used as bone implants and elements of the hocks endoprostheses [13].

P/M stainless steels are usually solid-state sintered and have usually worse mechanical properties and corrosion resistance as compared to their wrought counterparts. This is mainly due to inherent porosity [4, 8, 14–16]. The austenitic stainless steels fabricated by powder metallurgy are economically attractive because there are no metal losses during machining and finishing [17].

Corrosion behaviour of sintered stainless steels is dependent on many factors, such as: their chemical composition (effect on the durability and quality of the passive layer, assurance of corrosion protection); the state of the surface; the interconnected pores (which considerably increase the total reactive surface); the morphology of the pores; and others [6, 13, 17–19]. It is known that low porosity and the presence of intermetallic precipitation, compounds, or phases, do not favour the corrosion resistance of stainless steels. It has been reported that precipitation of undesired phases may cause drastic decrease of mechanical properties as well as corrosion resistance [3, 4, 13, 14].

In recent years, it can be seen the development of sintered austenitic stainless steels towards an improvement of corrosion resistance through variation in the compacting pressure, sintering parameters (temperature, time, atmosphere), heating mode (conventional, microwave) or use of alloying additions (such as copper, boron, phosphorus), which favour liquid phase sintering [13–19]. Besides corrosion resistance, the attention has been directed towards improvement of density, the hardness and mechanical properties of these steels.

It has been reported that the increase of sintering time caused slight improvement of strength, however, it led in grain growth and particle coarsening [17]. Whereas the higher sintering temperature, the greater corrosion resistance. Steels sintered in a hydrogen atmosphere avoid any chromium depletion phenomena.

Many studies have investigated on the corrosion behaviour of austenitic stainless steels [4, 6, 7, 9–22]. The effect of reduction of anodic area on the surface of the modified sintered austenitic stainless steel in neutral media (with and without chlorides) has been observed. It caused a decrease in the i_{corr} and an increase in E_{corr} [17].

Pardo et al. [9, 12] investigated the effect of introduction of Mo and Mn additions to AISI 304 and AISI 316 on the pitting corrosion resistance in chloride-containing media. They found out that Mo additions slightly shifted the corrosion potential to more noble values and increased the pitting corrosion resistance. It has been reported that the presence of Mo modified the passive film on the surface of steel. This film rendered more stable against breakdown because of the attack of aggressive Cl^- ions. The Mo addition significantly improved the repassivation behaviour [9–12].

The austenitic stainless steel type Cr18Ni10 with different molybdenum content (in the range up to 0.13 to 6.1 wt. %) was investigated to determine the effect of molybdenum on the corrosion and passivation of this steel. The author has proposed the synergistic mechanism of nitrogen-molybdenum interaction [7].

In this study, molybdenum was introduced into austenitic stainless steels (AISI 304L and AISI 316L) to improve their corrosion resistance. These steels were obtained through conventional pressing and sintering. The corrosion behaviour of austenitic stainless steels (with and without molybdenum addition) were investigated. The influence of different Mo

contents on the pitting corrosion resistance of AISI 304L and AISI 316L steels in 0.1 M sodium chloride solution has been investigated. The corrosion behaviour was evaluated by potentiodynamic polarization method. The electrochemical behaviour has been correlated with the densification.

2. Materials for research

Commercially available AISI 316L and AISI 304L (corresponding with standard UNS S31603 and S30403, respectively) stainless steel powders (provided by Höganäs) were used in the study. These powder grades were produced by water atomisation. The chemical compositions of these powders are listed in Table I. The physical properties of used powders are given in Table 2. The powders of both grades had a nominal particle size of < 150 μm.

Table 1

Chemical composition (% wt.) of tested powders

Powder grade	Cr	Ni	Mo	Si	Mn	C	Fe
AISI 316L	16.8	12.3	2.2	0.8	0.12	0.02	bal.
AISI 304L	18.5	11.2	–	0.8	0.14	0.02	bal.

Table 2

Properties of stainless steels powders (according Höganäs)

Powder grade	Flow [s/50g]	Apparent density [g/cm^3]
AISI 316L	31	2.67
AISI 304L	31	2.88

Molybdenum in the form of elemental powder (product of Sigma-Aldrich, average particle size of 10 μm, purity of 99.95%) was used. The powders mixtures of the austenitic stainless steels with different molybdenum content in the range from 0 to 4.4% were prepared using the powders of AISI 304L, AISI 316L and molybdenum (Table 3).

Table 3

Components of powder mixtures used in this research work

Designation	304L	304L/316L	316L	304L Mo	316L Mo
Base powder	AISI 304L	AISI 304L, AISI 316L	AISI 316L	AISI 304L	AISI 316L
Mo additive	no	no	no	yes	yes
Mo [%]	0	1.1	2.2	4.4	4.4

3. Experimental procedure

All powder mixtures were prepared by mixing in Turbula. The time of mixing was 120 minutes. Then, the powders were uniaxial pressed in a rigid matrix at a pressure of 600 MPa. In this way, the cylindrical samples of ∅20×5 mm size were obtained. The zinc stearate was used to minimise the friction along the walls of die. These samples were sintered in Nabertherm furnace in pure (99.9992%), dry (dew point below –60°C) hydrogen atmosphere. The temperature of isothermal sintering was 1240°C. The sintering time was 45 minutes. The samples were slowly heated to the sintering temperature at a rate of 10°C/min. The same rate was applied during cooling from the sintering temperature to the ambient temperature.

Green and sintered densities of investigated steels were determined. For compacted specimens, the density measurements were carried out by geometrical method. Whereas the density and porosity of sintered samples were measured by the water-displacement method, in accordance with Standard PN-EN ISO 2738:2001.

To estimate the sinterability, the densification parameter (DP) was used. The DP is calculated as follows [16]:

$$\text{DP} = (\text{sintered density} - \text{green density})/(\text{theoretical density} - \text{green density}) \quad (1)$$

Metallographic cross sections were prepared. The microstructural study of the sintered steels was done with Nikon Eclipse ME 600P Light Optical Microscopy and SEM microscope JSM550LV produced by Joel.

Corrosion resistance test of investigated stainless included open-circuit potential and potentiodynamic polarization measurements. They were performed using the ATLAS 0531 Electrochemical Unit (ATLAS – SOLLICH), controlled by AtlasCorr05 software. During the electrochemical measurements, platinum was used as the counter electrode, saturated calomel electrode (SCE), as the reference electrode, and austenitic stainless steels samples as the working electrode. All potentials were measured versus SCE. Before starting the measurement, the surface of the working electrode was grinded (600 grade of silicon carbide paper), then washed by distilled water, degreased in acetone and dried in air. Corrosion behaviour of the sintered steels was investigated in 0.1 M NaCl solution at room temperature. The open circuit potential was measured in function of immersion time (about 3 hours). When the open circuit potential became stabilised, the potentiodynamic polarisation was performed. A polarisation curve was obtained at a potential scan rate of 1.0 mV/s from – 0.8 V to + 1 V. The corrosion current density (i_{corr}), corrosion potential (E_{corr}), cathodic Tafel slope (b_c), and anodic Tafel slope (b_a) were determined from the Tafel plot (potential versus logarithm of corrosion current density). The electrochemical parameters such as, polarisation resistance (R_{pol}) and corrosion rate were determined based on polarisation curve. The polarisation resistance was evaluated using Stern method as well as Stern-Geary method. According to standard ASTM G 102, the polarisation measurements can be used to calculate the corrosion rate, either in terms of penetration rate (*CR*) or mass loss rate (*MR*).

PREN (pitting resistance equivalent number) is commonly used to compare the corrosion resistance of various types of stainless steels in a chloride-containing environment. The pitting corrosion resistance of stainless steel depends on its chemical composition. Because

elements such as chromium, molybdenum, and nitrogen have significant influence on pitting resistance, the most frequently used formula of PREN is following:

$$PREN = 1\%Cr + 3.3\%Mo + 16\%N \quad (2)$$

It is well known that the higher value of PREN, the greater corrosion resistance of stainless steel.

4. Results and discussion

The calculated values of densification parameter and relative density of sintered austenitic steels are presented in Fig. 1. Fig. 2 shows the results of measurements of an open and closed porosity obtained for all investigated steels.

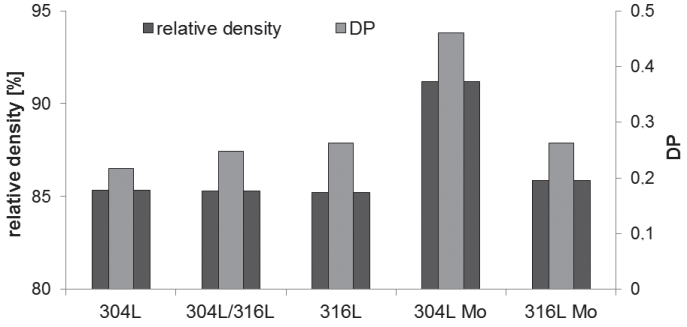

Fig. 1. Relative density and densification parameter (DP) of tested stainless steels

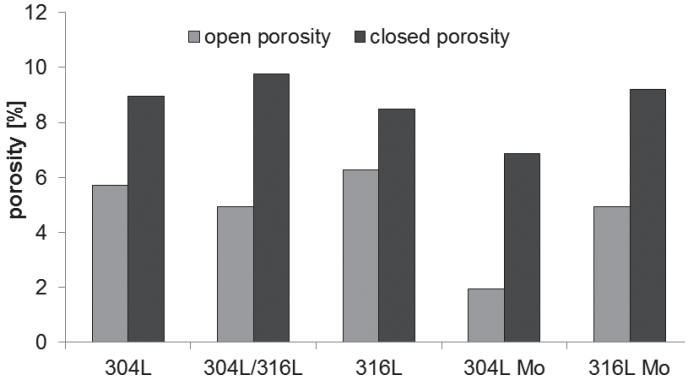

Fig. 2. Open and closed porosity of tested stainless steels

It can be generally seen that the value of densification parameter increases with increasing of molybdenum content in investigated steels. Furthermore, the DP value of 316L Mo steel is significantly lower than 304L Mo for the same amount of molybdenum in chemical composition. It should be pointed that the compressibility of 316L is lower than 304L. It was similar when molybdenum was added to these powders of steel. The highest relative density and the lowest values of open and closed porosity were obtained in the case of 304L with molybdenum addition. The relative density of 304L/316L steel (made with the mixture of 304L and 316L powders) remained at a similar level as sintered 304L and 316L steels.

The variations in the open circuit potential were monitored for all investigated steels (immersed in 0.1 M NaCl solution). The obtained results are presented in Fig. 3. Based on these results, values of open circuit potential were determined at the beginning of the test as well as after 3 hours of immersion in 0.1 M NaCl solution. They are presented in Table 4.

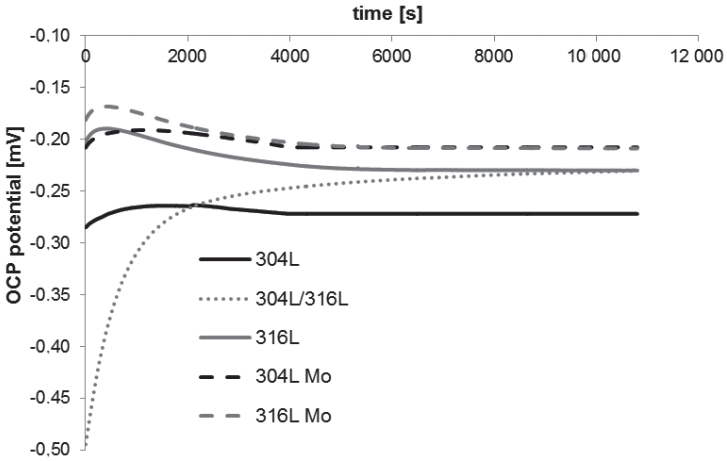

Fig. 3. Variation of OCP for investigated stainless steels immersed for 3 hours in 0.1 M NaCl solution

Table 4

OCP values of the investigated steels: initially and after 3 hours of immersion in 0.1M NaCl solution

Designation of samples	OCP [V vs. SCE]	
	Initial	After 3 hours
304L	–0.285	–0.272
304L/316L	–0.484	–0.231
316L	–0.191	–0.229
304L Mo	–0.208	–0.208
316L Mo	–0.181	–0.209

It can be observed that the evolution of the OCP with time is virtually the same for tested steels. At the beginning, the OCP showed a tendency to slightly reduce with time. After a few minutes of exposure in 0.1 M NaCl solution, it started to shift towards the lower values, and then it stabilised. Only for 304L/316L steel the evolution of the OCP with time is different. Namely, potential increases all the time during measurement. When OCP potential is shifted with time towards more positive value, it indicates the formation of a protective passivation layer on the surfaces. The steel without molybdenum had the lowest value of OCP. It might suggest that 304L steel has the highest tendency to corrode in the studied medium. The OCP potential of 316L steel is more positive. From the analysis of presented characteristic, it can be generally concluded that higher molybdenum content in steel leads to potential increase (shift to more positive values).

In order to estimate the pitting corrosion behaviour of the sintered stainless steels, potentiodynamic polarisation study in 0.1 M NaCl solution was performed. Fig. 4 shows the registered potentiodynamic curves for the tested steels.

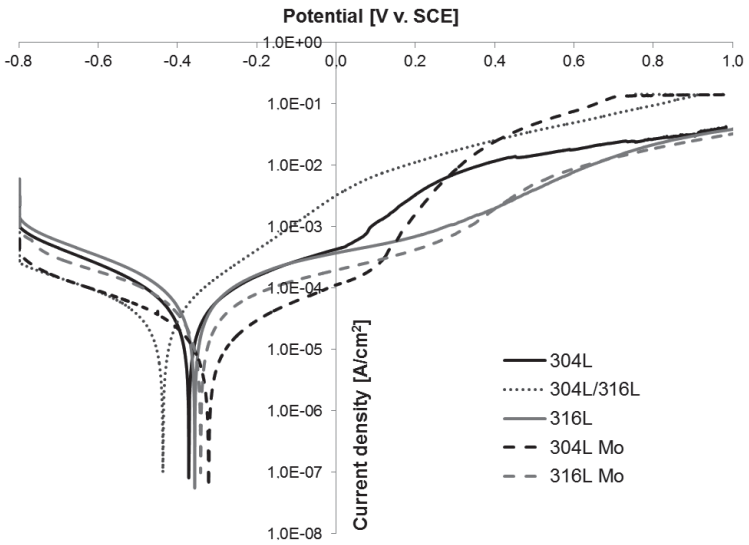

Fig. 4. Potentiodynamic polarisation curves of investigated stainless steels in 0.1 M NaCl solution

The parameters such as corrosion potential (E_{corr}), corrosion current density (i_{corr}), polarization resistance (R_{pol}) as well as corrosion rate (*CR* and *MR*) have been calculated for all investigated steels. The values of these corrosion parameters are summarized in Table 5.

Figure 5 shows the values of polarisation resistance and corrosion rate for the sintered austenitic steels with different Mo contents in sodium chloride solution.

As expected, the corrosion parameters are dependent on the chemical composition of investigated steels. It should be pointed out that there is no linear dependence between molybdenum content in alloy and polarisation resistance (or other corrosion parameters).

Table 5

The values of the corrosion parameters of investigated stainless steels

Designation	Corrosion parameters					
	E_{corr} [V vs. SCE]	i_{corr} [A/cm^2]	R_{pol} [Ω·cm^2]		*CR* [mm/y]	*MR* [g/m^{2}d]
			Stern method	Stern-Geary method		
304L	–0.371	$4.39 \cdot 10^{-5}$	1520	1549	0.539	9.701
304L/316L	–0.437	$3.36 \cdot 10^{-5}$	1834	1936	0.414	7.507
316L	–0.359	$6.87 \cdot 10^{-5}$	1185	1186	0.851	15.359
304L Mo	–0.322	$1.35 \cdot 10^{-5}$	5072	5276	0.157	3.022
316L Mo	–0.342	$2.95 \cdot 10^{-5}$	2065	2104	0.365	6.633

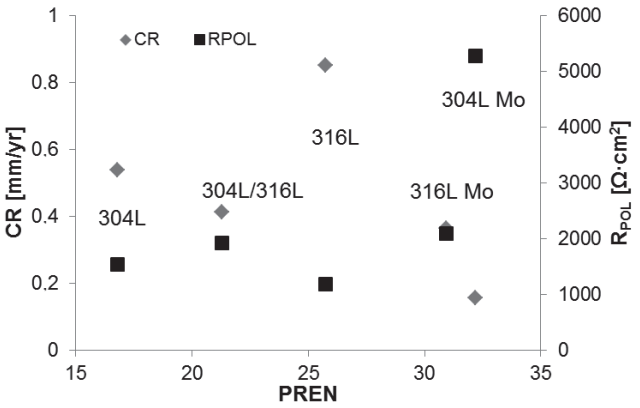

Fig. 5. The dependence of corrosion rate and polarisation resistance on PREN for investigated stainless steels

Generally, the highest value of polarisation resistance as well as the lowest values of *CR* and *MR* parameters were obtained for 304L Mo steel. This alloy is characterised by the highest molybdenum content (4.4% wt.) as well as the total content of elements such as Cr, Ni and Mo. It is no surprise that among all investigated steels 304L Mo has the highest value of the PREN. Therefore, greater corrosion resistance can be obtained in the case of this stainless steel. Although 316L Mo steel exhibits the same molybdenum content, the total content of Cr and Mo is lower in comparison to 304L Mo steel. And therefore, the value of PREN as well as polarisation resistance of this steel is lower while the corrosion rate is higher. As already stated, the introduction of molybdenum to 316L steel did not result in an improvement of the corrosion behaviour as significant as that for 304L with Mo. Although both steels contain molybdenum (in amount of 4.4% wt.) and total content of chromium and nickel is almost the same, they differ in regards to alone chromium content as well as nickel content in chemical composition. It seems that higher chromium content in 304L Mo steel has contributed towards its better corrosion resistance in comparison to 316L Mo.

The obtained results pointed out that the pitting resistance of Mo-containing 304L stainless steel is superior to that of non-Mo-containing one. It can be seen that 316L steel exhibits the lowest polarisation resistance and the highest values of corrosion rate although it contains molybdenum in chemical composition.

Taking into account the corrosion resistance in chloride-containing environment (0.1 M NaCl solution), 304L steel modified molybdenum (4.4% wt.) has turned out to be the best steel.

5. Conclusions

The pitting corrosion resistance plays an essential role in the properties of stainless steels. In this study, the pitting corrosion resistance of austenitic stainless steels with different Mo contents was investigated in 0.1 M sodium chloride solution. Electrochemical corrosion measurement (OCP and potentiodynamic polarisation) have been performed. The influence of molybdenum addition on pitting corrosion resistance of austenitic steels has been studied.

It is generally known that in the case of sintered materials corrosion pits initially are formed in open pores and then proceed into interior of them. That is why the open porosity is an important parameter. In regards to the effect of chemical composition of steel on properties, such as density and open porosity, it can be concluded that 304L and 316L steels with introduced molybdenum addition exhibit higher relative density and lower open porosity than Mo-containing ones. The steel designated as 304L Mo shows the highest density and lowest open porosity.

Considering the influence of molybdenum addition on the pitting behaviour of austenitic steels, it can be concluded that:

- sintered 304L Mo steel is less prone to pitting corrosion than 316L Mo in environment containing chlorides,
- sintered steels (304L, 316L) containing molybdenum behaves better than the steel without Mo. It can be stated that molybdenum additive with presence of chromium and nickel improves corrosion resistance of investigated austenitic steels,
- steel designated as 304L Mo exhibits the highest corrosion resistance in 0.1 M NaCl solution (the lowest values of corrosion rate (*CR* and *MR*) and corrosion current density, the highest values of PREN and polarisation resistance).

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INVESTIGATIONS OF STRENGTH AND LEAK TIGHTNESS OF WAVE-RING GASKETS

BADANIA WYTRZYMAŁOŚCI I SZCZELNOŚCI USZCZELEK DWUFALISTYCH

Abstract

The paper deals with stress-strain analysis and estimation of leak tightness of *wave-ring* gaskets. The investigations are carried out using the simplified analytical approach. A cylindrical shell of constant mean thickness is introduced to simulate the gasket. It is assumed that the shell is simply supported at the inner surface of the seat. The influence of certain geometric and assembly parameters on the strength and leak tightness of the closure is analytically investigated. The results are presented in dimensionless variables in order to generalise the conclusions. The analytical solution is verified by FEM calculations and compared with the experimental results.

Keywords: high-pressure closures, wave-ring gasket, stress-strain analysis

Streszczenie

W artykule przedstawiono analizę wytrzymałościową oraz ocenę szczelności uszczelek *dwufalistych* (typu „B"). W rozważaniach wykorzystano uproszczone podejście analityczne. Uszczelka została zamodelowana powłoką cylindryczną o stałej grubości, podpartą obwodowo na wewnętrznej powierzchni gniazda. Badano wpływ niektórych geometrycznych i montażowych parametrów złącza na wytrzymałość uszczelki oraz szczelność połączenia. W celu uogólnienia wyników zostały one przedstawione w funkcji zmiennych bezwymiarowych. Wyniki rozwiązania analitycznego zostały zweryfikowane za pomocą MES i porównane z wynikami badań doświadczalnych.

Słowa kluczowe: uszczelki wysokociśnieniowe, uszczelka typu "B", analiza wytrzymałościowa

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1. Introduction

Modern power installations and advanced chemical equipment, usually operating at extremely high pressures, require reliable and hard-wearing sealing systems. Metal gaskets are sometimes used to seal the heads of reactors or boilers and pipe connections [1]. Metal gaskets give satisfactory sealing service, and additionally, they are chemically resistant, moisture-proof and heat stable. Temporary closures with self-sealing metal *wave-ring* gaskets are applied in heavy-duty systems, in particular in these of great diameter.

The paper follows earlier contributions of the authors devoted to the sealing systems with metal gaskets for the high-pressure applications. Several computational models of the wave-ring gasket were investigated [5] with the aim of selecting the simplest and most effective one, but also sufficiently precise to be applied in the engineering approach. The results of the analysis confirm that the shell model of constant thickness simply supported at both ends at the inner surface of the seat is appropriate to describe the wave-ring gasket and leads to good agreement with FEM modelling. However, the seat must be considered as a thick-walled cylinder loaded by shear forces and internal operating pressure. The created analytical model was used to determine the influence of several gasket parameters on its strength and sealing properties [12]. The results of analysis were compared with FEM (ANSYS®) calculations and were verified by experimental results obtained under assembly conditions in the gasket installation state [7–10].

2. Engineering example and service conditions of the sealing

The wave-ring gasket is a certain type of self-sealing gaskets for very high-pressure equipment. An engineering example of the joint with wave-ring gasket between the vessel wall and reactor head is shown in Fig. 1. The closure is successfully applied [18] in the heavy-duty chemical installation working at the pressure of 200 MPa.

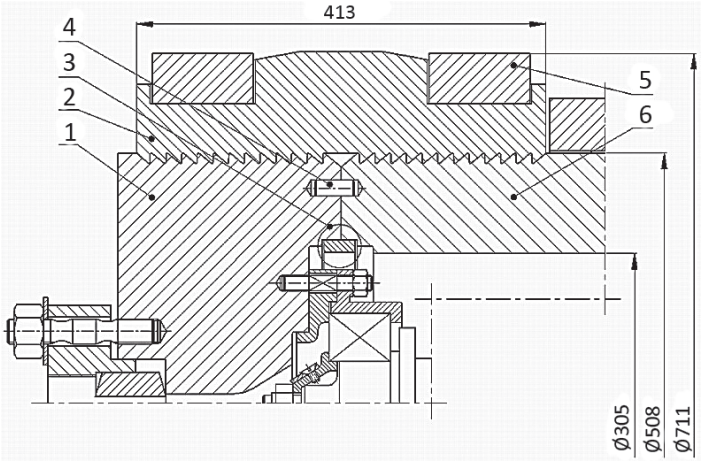

Fig. 1. Engineering example of the joint between the vessel wall and reactor head: 1 – head, 2 – sectional clamping rings, 3 – wave-ring gasket, 4 – locating pin, 5 – grips, 6 – cylindrical shell

The yield stress of the wave-ring gasket material must be significantly lower than the yield stress of the seat material to ensure the proper effectiveness of the joint. The gasket is usually made of low-carbon soft steel subjected to heat refining to the yield limit of approximately 400 MPa. Sometimes, the gasket is manufactured out of copper, brass, or some other moderately soft metal. The high-quality chromium-nickel-molybdenum steel hardened to the yield limit of minimum 750 MPa is mostly used for the seats. The gasket must be made slightly oversized, so that an interference fit is obtained in the seat. The experience gained from testing of existing and properly running closures leads to the conclusion that the degree of the preferred radial interference between the external wave surface of the gasket and the cylindrical internal surface of the seat may vary from 0.5‰ to 2.5‰, and it depends on both the yield limit of the gasket material and the operating pressure.

Under assembly conditions, the initial contact pressure q appears at the portion e of a wave surface due to the assembly interference, thus making the initial seal just before the operating pressure p is applied to the closure (Fig. 2). The working pressure is exerted on the entire inner surface, forcing a seal on the two outer radii. The initial assembly pressure q increases as the stiffness of the gasket is much less than that of the seat. Because of its specific features, such a sealing can be applied in equipment working at extremely high pressure, far exceeding 100 MPa.

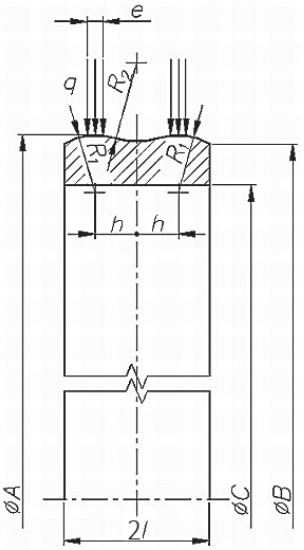

Fig. 2. Distribution of initial load at the contact region of the gasket

The difference in the yield limits of materials of the gasketed members and the value of the radial interference fit are the key parameters of the closure. They have an essential influence on the width of the contact zone of required size and on the related contact pressure value, which provides the leak tightness of the connection under the operating pressure p. In simple preliminary calculations of practical engineering applications of wave-ring gaskets, the non-leakage condition is usually formulated as:

$$q_{m\,opr} > R_{0.2g} \geq 2p \tag{1}$$

where the average contact pressure $q_{m\,opr} = 2q_{\max\,opr}/3$ as for the parabolic elastic distribution due to the Hertz theory. Because of highly approximate estimation of the contact stress distribution, the average value of the distribution is introduced into equation (1). It means that the average contact pressure $q_{m\,opr}$ in the contact zone under operating conditions must be greater than the yield limit $R_{0.2\,g}$ of the gasket material and should exceed the operating pressure p at least twice. The magnitude of the yield limit of the gasket material and the size of the radial interference fit are related and strongly depend on the applied operating pressure. The influence of several parameters of the connection on its sealing properties in the operating conditions was investigated in dimensionless variables [12]. The dimensionless non-leakage parameter was defined as $\psi = q_{m\,opr}/2p$ and the simplified analytical approach was applied to obtain the solution.

Wave-ring gaskets give satisfactory service where the vessel, or piping, does not need to be opened very often. Otherwise, they are somewhat impractical as they sometimes become so tightly wedged that the vessel head can be removed only with extreme difficulty. When this jamming occurs, the gasket usually must be discarded, as the crests have been flattened and scarred. Where the closure must be opened and closed fairly often, the gasket is sometimes made of hardened steel.

In conclusion, it should be noted that there are no design objectives and constraints collected, which can be recommended in the design procedures of the closures with wave-ring gaskets. The parameters of the new connections are selected basing on the experience gained during operation and improvements of the existing sealing systems. Moreover, in each individual case of technical application, a set of expensive and time-consuming calculations and experimental tests should be carried out to confirm the accuracy of the choice. A sudden unexpected decrease of the leak tightness of very high-pressure installation operating with caustic dangerous packing may cause serious damages.

3. Simplified analytical solution

The geometry of the investigated closure is presented in Fig. 3. For the analytical calculations, the gasket is replaced with a cylindrical shell of constant thickness t and mean radius r, where t is defined as an arithmetic average of three extreme values of gasket thickness. The analytical investigations of a gasket are then based on a simple shell model of length $2l$ simply supported around the circumference at contact with the seat. The hinges are selected at the top points of the wave surface where the contact with the seat occurs.

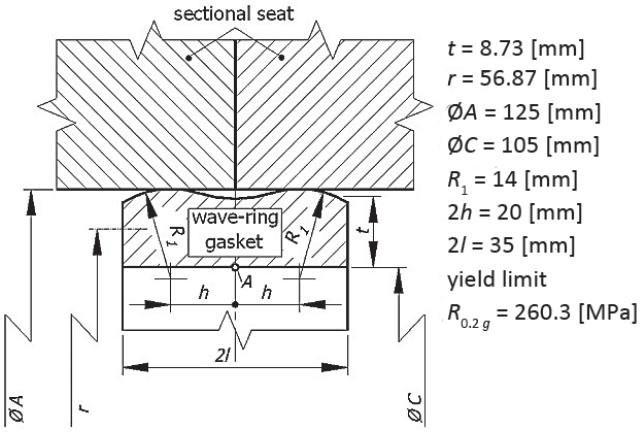

Fig. 3. Geometry of the closure with wave-ring gasket in assembly conditions (operating pressure $p = 0$)

The spacing of the supports is $2h$ (Fig. 4). It is assumed that, except a small region in the vicinity of supports, the shell is purely elastic. The analytical calculations verified by FEM

modelling lead to the conclusion that the influence of external parts of the gasket outside of the supports (broken line in Fig. 4) is negligible. The relative difference in maximum equivalent stress σ_{eq} at the inner surface of the gasket is less than 2% for this simplified model, with respect to the complete shell model with attached external segments. The results of the analysis confirm that the shell model of constant thickness simply supported at both ends at the inner surface of the seat in the cross-sections of coordinates $x = -h$ and $x = h$ is appropriate for the description of the wave-ring gasket and leads to a good agreement with FEM modelling. At the assembly conditions, the shell is loaded by shear forces Q_x at the supports only. Under service conditions, the shell is additionally loaded by an operating pressure p acting at the inner cylindrical surface and at the edge plain surfaces. The seat must be considered as a thick-walled cylinder loaded by shear forces and by the internal pressure p.

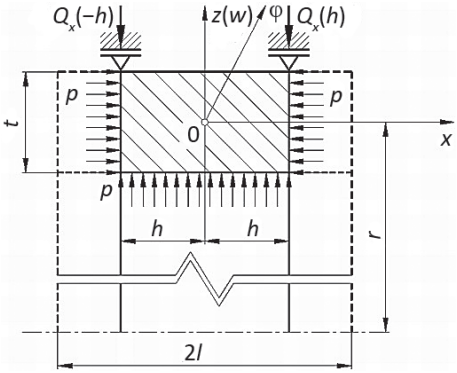

Fig. 4. Simplified computational model of the wave-ring gasket in service conditions

The applied approach, together with the permissible simplifications, depends in the shell theory on the geometric proportions of an element [14, 16]. In this case, the gasket must be solved on the basis of the bending shell theory and some terms in the differential equation of deflection could not be neglected. Under the assumptions as for the cylindrical axisymmetric shell of mean thickness t, mean radius r and small radial deflections w with respect to the thickness t, the differential equation of deflection takes the well-known form [2, 11]:

$$\frac{d^4w}{dx^4} + \alpha\frac{d^2w}{dx^2} + \beta^4 w = \delta \tag{2}$$

where:

$\alpha = \nu/r^2$,

$\beta = \sqrt[4]{12(1-\nu^2)/r^2t^2}$,

$\delta = 12p(1-\nu^2)/Et^3$,

ν and E – Poisson's ratio and Young's modulus, respectively.

The constants of integration can be determined from the boundary conditions as for the simply supported shell, and eventually, the shell model of the gasket can be easily solved. The principal stresses σ_z, σ_φ and σ_x can be expressed in terms of the shell parameters and operating pressure p. The maximum equivalent von Mises stress σ_{eq} occurs at the inner surface at the gasket's midpoint and is:

$$\sigma_{eq} = \sqrt{\sigma_z^2 + \sigma_\varphi^2 + \sigma_x^2 - \sigma_z\sigma_\varphi - \sigma_\varphi\sigma_x - \sigma_x\sigma_z} \tag{3}$$

The sectional seats (Fig. 3) are usually executed directly in thick vessel walls like in the example of closure shown in Fig. 1. These walls are designed for very high pressure and their thickness ratio is of great value. Nevertheless, the resultant displacement w_h (negative) at the support after assembly is different from the designed radial interference δ. The resultant displacement w_h was finally determined basing on the thick-walled cylinders theory applied to the shell model of the gasket and to the seat, respectively [13]:

$$|w_h| = \frac{\delta}{2}\frac{\kappa_2^2 - 1}{\kappa^2 - 1}\left[\kappa_1^2(1-\nu) + 1 + \nu\right] \tag{4}$$

where $\kappa_1 = (2r + t)/(2r - t)$ is the ratio between the outer and inner radii of the shell, κ_2 is the ratio between the outer and inner radii of the seat and κ stands for the thickness ratio of the entire unit. The pressure q at the contact surface of the cylinders corresponding to the interference δ is:

$$q = \frac{E\delta}{2r+t}\frac{\left(\kappa_1^2 - 1\right)\left(\kappa_2^2 - 1\right)}{\kappa^2 - 1} \tag{5}$$

and can be additionally used to estimate the shear force at the support:

$$Q_x = \frac{1}{2}2ql \tag{6}$$

Special attention must be paid to the interaction conditions between the wave working surface of the gasket and the cylindrical surface of the seat (Fig. 2). Initial assembly interference Δ is usually of a high value (more than 0.5‰), and the difference in mechanical properties of the materials may cause the plastic process in the gasket. For this reason, the Hertz theory cannot be used directly to calculate the width of the contact region, where the sealing is obtained.

Hypothetical elastic distribution of the contact stress $q(x)$ under operating pressure p is shown in Fig. 5a. In the regions where stress q calculated from the initial elastic Hertz distribution is considerably beyond the yield limit $R_{0.2\,g}$ of the gasket material, the plastic process must appear. As a result, redistribution of the initial elastic stress $q(x)$ must occur and finally resultant stress distribution $q_{pl}(x)$ must appear, which allows for plastic deformations (Fig. 5b).

Simple and rough estimation of width e of the contact region is derived on the assumption that the gasket material satisfies pure elastic-plastic stress-strain relationship and that the seat material is perfectly rigid. Moreover, it is assumed that plastic deformation begins when the gasket is subjected to load $Q_x(h)$, which produces stress $q_{max} = R_{0.2\,g}$. Under the load that produces stress q_{max}, which is n – times greater than the yield limit $R_{0.2\,g}$ ($q_{max} = nR_{0.2\,g}$), the elastic parabolic distribution $q_{el}(x)$ corresponding to the load $Q_{x\,el}(h) \le Q_x(h)$ will exist in the contact surface, for which the maximum stress equals $q_{max\,el}$. The width of the contact region satisfying this elastic Hertz distribution $q_{el}(x)$, with respect to the distribution $q(x)$ is:

$$e_{el} = \frac{1}{n}e \tag{7}$$

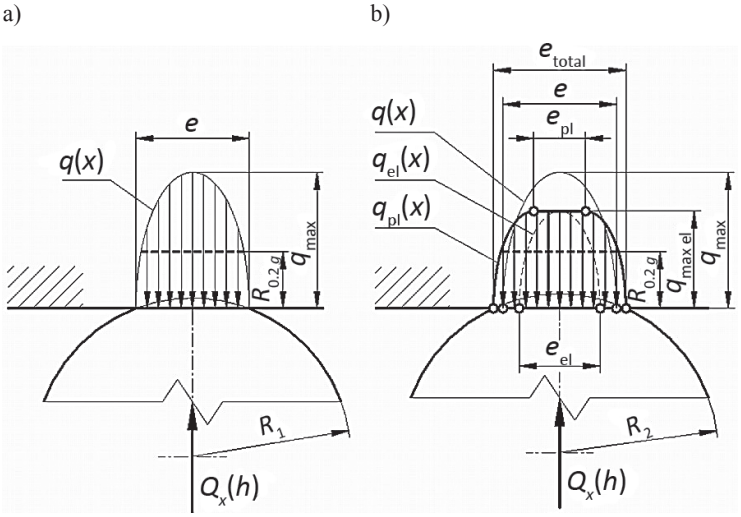

Fig. 5. Distribution of stress at the contact region of gasket and seat: a) hypothetical elastic (parabolic) with respect to the Hertz theory, b) changed (partially-linear) with respect to plastic deformation

The surplus shear load $\Delta Q_x(h) = Q_x(h) - Q_{x\,\mathrm{el}}(h)$ produces a plastic process, which leads, on the applied assumptions, to plastic deformation. A new partially-linear stress distribution $q_{\mathrm{pl}}(x)$ is introduced to model the problem (Fig. 5b). The width of the additional plastic zone is determined from the condition that the entire shear force $Q_x(h)$ does not change:

$$e_{\mathrm{pl}} = \frac{2}{3}\left(n - \frac{1}{n}\right)e \tag{8}$$

The total width of the contact region is then a sum of the elastic contact e_{el} (7) and plastic contact e_{pl} (8):

$$e_{\mathrm{total}} = \left(2n + \frac{1}{n}\right)\frac{e}{3} \tag{9}$$

The suggested simplified distribution of the contact stress $q_{\mathrm{pl}}(x)$ must be treated as a highly approximate one. The assumption of the pure elastic-plastic stress-strain curve of the gasket material leads to the overestimation of the total width of the contact region.

4. Numerical modelling (FEM)

Three parts of the investigated structure are assembled with an interference fit between the external wave surface of the gasket and the inner cylindrical surface of both seats. The

shape of the structure and relatively high radial interference, which should preserve the leak tightness of the junction under operating pressure, result in high stresses and stress gradients distributed over the small zones in the vicinity of contacting areas. The problem considered in the paper concerns the contact of two deformable bodies and belongs to the class of *flexible-to-flexible* contact, for which the analytical solutions are known only in a limited number of simple cases. Nowadays, the contact tasks are solved numerically, by means of the finite element approximation. The ANSYS® code [17] was used to solve the problem in the present paper and to get the strain and stress distributions in all contacting bodies. Also, the contact pressure distribution and the width of the contact zone were the results of this analysis.

The gaskets were made of soft 25CrMo4 (1.7218) chromium-molybdenum normalised steel and the seats were made of 42CrMo4 (1.7225) high-carbon chromium-molybdenum steel toughened to R_m = 1000 MPa. The mechanical properties of 25CrMo4 and 42CrMo4 steels were verified experimentally. Two cylindrical specimens were subjected to the same heat treatment as the corresponding elements, and prepared for the static tensile tests. The obtained real load-displacement curves $F = f(\Delta l)$ for both materials are shown in Fig. 6. The strength properties of both materials, calculated as arithmetic means of the two tests, are given in Table 1. The experimentally verified Brinell hardness number of the sealing surfaces of the gaskets was of 250–280 BHN and Rocwell hardness number of the seats was of 45–48.

Table 1

Uniaxial tension test results

Steel	E [MPa]	$R_{0.05}$ [MPa]	$R_{0.2}$ [MPa]	R_m [MPa]	$\varepsilon_{0.05}$ [%]	$\varepsilon_{0.2}$ [%]	ε_{max} [%]
25CrMo4 (N)	2.014×10^5	253.59	260.30	523.38	0.185	0.359	15.338
42CrMo4 (T)	2.064×10^5	809.12	812.46	918.50	0.460	0.711	8.802

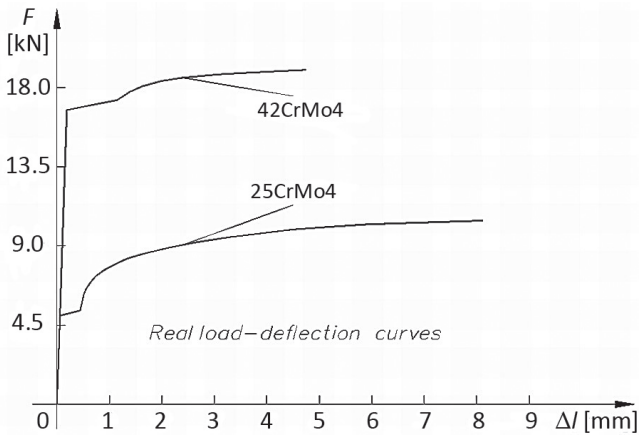

Fig. 6. Results of static tensile tests of 25CrMo4 (N) and 42CrMo4 (T) materials – real load-displacement curves $F = f(\Delta l)$ (not to scale)

Two approximations of the real stress-strain curves $\sigma = f(\varepsilon)$ of the materials used for the gasket and the seats were adopted in the paper. The parameters of the first multi-linear approximation (Fig. 7a) were calculated from the set of equations (10):

$$\begin{aligned} R_m - R_{0.2} - E_{t2}\left(\varepsilon_{\max} - \varepsilon_{0.2}\right) &= 0 \\ R_{0.2} - R_{0.05} - E_{t1}\left(\varepsilon_{0.2} - \varepsilon_{0.05}\right) &= 0 \\ R_{0.05} - E\varepsilon'_s - E_{t1}(\varepsilon_{0.05} - \varepsilon'_s) &= 0 \\ S_c - E\varepsilon'_s &= 0 \end{aligned} \tag{10}$$

and are given in Table 2. The parabolic modelling was suggested beyond the yield limit in the second approximation (Fig. 7b). The parabola containing the point of coordinates $\varepsilon_{0.2}$, $R_{0.2}$ and reaching the maximum value at the point $\varepsilon_{\max}$, R_m was applied to describe the tensile behaviour of the material. For the numerical calculations, the parabola was replaced by several (twenty) segments of different slope, but of equal length in the orthogonal projection at the ε axis. Such approximation enables direct introduction of the nonlinear material properties in the software module ANSYS®, which was used in the paper. Both approximations are conservative beyond the yield limit, although the second one is more precise. The similar approximation was proposed for the material used for the seats. However, plastic deformations were present in the softer part of the junction, namely in the gasket only.

Table 2

Parameters of the stress-strain curves approximation of the materials

	Steel	S_c [MPa]	ε'_s [%]	ε_s [%]	E_{t1} [MPa]	E_{t2} [MPa]
Gasket	25CrMo4 (N)	251.35	0.1248	0.159	3854.02	1756.37
Seat	42CrMo4 (T)	808.26	0.3916	0.511	1329.88	1310.63

Moreover, it was assumed that the relationship between equivalent stress σ_{eq} and equivalent strain ε_{eq} under complex stress states $\sigma_{eq} = f(\varepsilon_{eq})$ is the same as the stress-strain relationship under uniaxial tensile loading $\sigma = f(\varepsilon)$. The stress intensity is derived from the von Mises yield criterion, and the strain intensity is defined as [16]:

$$\varepsilon_{eq} = \frac{2}{\sqrt{3}}\sqrt{\left(\varepsilon_z - \varepsilon_\varphi\right)^2 + \left(\varepsilon_\varphi - \varepsilon_x\right)^2 + \left(\varepsilon_x - \varepsilon_z\right)^2} \tag{11}$$

where ε_z, ε_φ and ε_x are the principal strains at a certain point of the cross-section.

The so-called *surface-to-surface* contact elements are recommended to be used in the case of contact of deformable bodies, which are assembled with certain interference. Such elements can be of higher order approximation with inside nodes introduced. This provides

better results for many engineering applications and enables modelling complex, curved shapes of bodies that are in contact. The above contact elements are defined on the surface geometry and need several constants and options to set prior to the analysis. The augmented Lagrangian method was used with contact detection points localised in nodal points in the considered problem. Also, the contact stiffness updated at each iteration step, based on the current mean stress, was applied. The Coulomb friction law was used in the analysis.

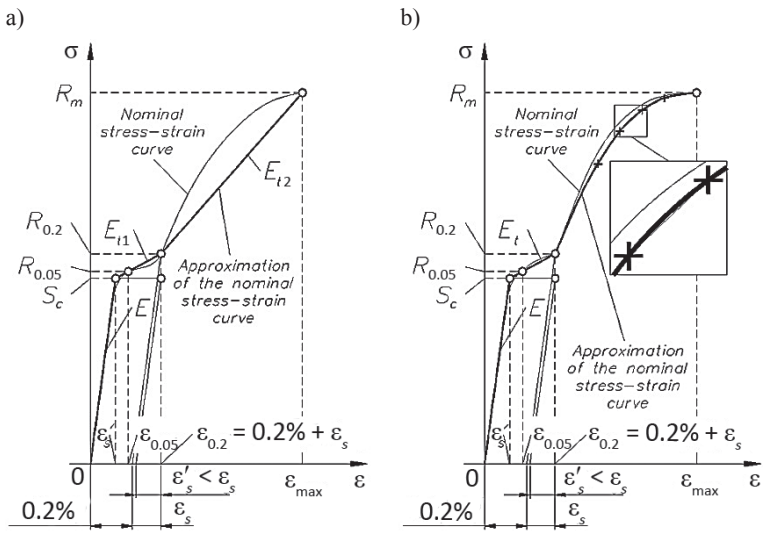

Fig. 7. Approximations of the real stress-strain curves $\sigma = f(\varepsilon)$ (displayed in stretched scale)

In general, the analyzed structure should be modelled as a 3D object, which results in a very big numerical model and demands a lot of time to get the solution. The size of the task can be reduced when the ideal geometry of the junction is presumed. Then, the structure is assumed to be axially symmetric and only a half-part of the cross-section is considered. The high accuracy of numerical results is provided by the application of 8-node quadrilateral axisymmetrical finite elements, which are well-suited for irregular meshes and tasks with elastic and plastic deformations. The finite elements are accompanied with the contact elements introduced on the lines where the contact is expected. Like in the majority of nonlinear problems, the number of applied finite elements should be rather high and the dense meshes should be used in order to keep the solution error within the acceptable range, in particular in the vicinity of the contact zones. The mesh in this area should be dense enough to give satisfying results, while the mesh on the outer unloaded surfaces can be rather rough [15].

In the first numerical approach (FEM 1), the interferences between the gasket and both sectional seats were arranged by means of the thermal method. For the calculation purpose, the gasket was first cooled down and after inserting into the seats and expanding the appropriate interference fits were obtained in the closure. The thermal simulation of the assembly process leads to the same (symmetric) results in displacements, stresses and contact pressure in both half-parts of the axial cross-section.

The second numerical approach (FEM 2) follows the assembly process performed on the stand during the experiment. The nonlinear contact analysis was divided into two steps. In the first step, the gasket was pressed into the bottom sectional seat (supported vertically), while in the second one the upper seat was pressed down until the edges of both seats were in contact. In the second step, the bottom edge of the bottom seat and the bottom edge of the gasket were blocked against the vertical displacement. The symmetry of results, with respect to the middle surface, disappears in this case.

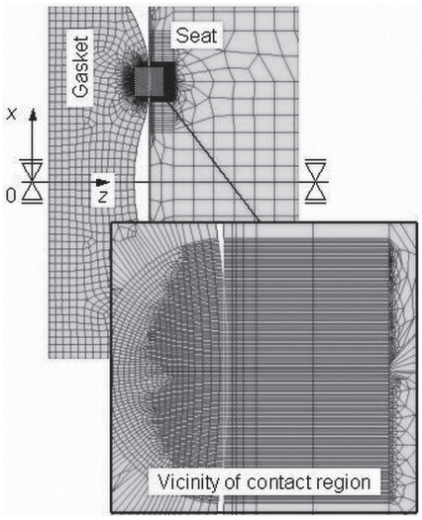

Fig. 8. Example of the mesh of finite elements, division of the closure into parts and illustration of the boundary conditions

Even with the introduced simplifying assumptions and restrictions concerning the geometry and loading, the numerical solution is time consuming and difficult to obtain due to the numerical instability. The size of the finite elements in the anticipated contact zone and the size of the load step should be chosen with particular care in order to avoid convergence problems. Several numerical trials have been carried out to get the final mesh, which is shown in Fig. 8. As a final criterion for the choice of the element size, a compromise between the calculation time and approximation error has been established. The criterion used for the approximation error Δ is based on the comparison between the maximum absolute value of the radial stress $\sigma_{z\,\max}$ and the maximum contact pressure $q_{\max}$ and accepts the mesh for which the discrepancy is less than 5% for each load step [6]:

$$\Delta = \frac{\left|\left|\sigma_{z\max}\right| - q_{\max}\right|}{q_{\max}} 100\% \le 5\% \tag{12}$$

Distribution of equivalent stress σ_{eq} for the initial interference δ = = 1.0‰ under the load p = 100 MPa at the contact surfaces of the gasket and the seat is shown in Fig. 9.

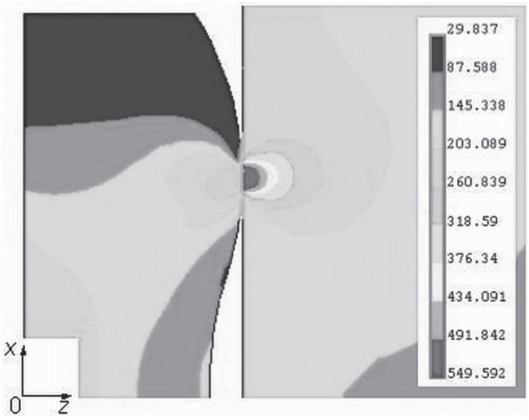

Fig. 9. Distribution of equivalent stress σ_{eq} for the initial interference δ = 1.0‰ under load p = 100 MPa at the gasket-seat contact surfaces

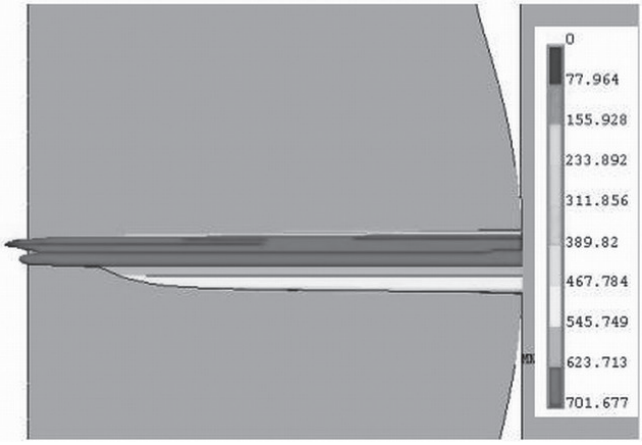

Fig. 10. Example of distribution of contact pressure q in the closure for the initial interference $\delta = 1.0‰$ under load $p = 100$ MPa

An example of the distribution of contact pressure q in the closure is presented in Fig. 10 for the same interference δ and the same operating pressure p. The numerical results are obtained applying FEM 2 procedure for the upper part of the wave-ring gasket, which is assembled in the second step. The friction in contact zones was included in the proposed finite element model with the coefficient of friction assumed $\mu = 0.25$ [3].

5. Definition of gasket dimensionless parameters

The dimensionless variables were applied to investigate the strength and operating properties of wave-ring gaskets. The calculations were based on the simplified analytical shell model of the gasket. The critical section of the gasket is placed at its centre of symmetry, where the equivalent stress σ_{eq} is maximal at the inner radius under the operating pressure (point A in Fig. 3). The strength of the gasket was estimated using the dimensionless parameter σ defined as:

$$\sigma = \sigma_{eq}/R_{0.2\,g} \text{ – dimensionless strength parameter}$$

where $R_{0.2\,g}$ MPa stands for the yield point of the gasket material. The leak tightness of the closure depends on stress q acting at the toroidal wave working surface of the gasket (Fig. 2). The recommendations verified in practice used in the design projects of high-pressure chemical equipment were applied to investigate the leak tightness of the joint. It was assumed that the closure is leak-proof if the average contact pressure $q_{m\,opr}$ satisfies condition (1). The dimensionless parameter ψ:

$$\psi = q_{m\,opr}/2p \text{ – dimensionless leak tightness parameter}$$

was introduced to estimate the functional quality of the closure with respect to non-leakage condition. Dimensionless operating pressure was defined as:

$$\tau = p/R_{0.2\,g} \text{ – dimensionless operating pressure}$$

Another dimensionless variables subjected to change during the analysis were introduced as:

$$\chi = t/h \text{ – dimensionless geometry ratio of the gasket}$$

$$\delta \text{ – relative radial interference (in per milles)}$$

$$\gamma = t/r \text{ – dimensionless average thickness of the gasket}$$

$$\rho = R_1/t \text{ – dimensionless radius of the working wave surface}$$

where all quantities are defined in Figs. 3 and 4. The geometry of the real gasket is presented in Fig. 3 and the dimensions of the analytical model of the gasket used in the analytical approach are shown in Fig. 4.

6. Analysis of gasket strength and operating properties

Detailed analytical calculations were carried out for the dimensions of the gasket, which were applied in the earlier investigations [10], i.e. t = 8.73 mm, r = 56.87 mm, R_1 = 14 mm, $2h$ = 20 mm, $2l$ = 35 mm and $R_{0.2\,g}$ = 260.30 MPa like for the normalised 25CrMo4 material. The average thickness t of the gasket was calculated as the arithmetic mean of its three extreme values, and the average radius r was a result of the assumed thickness t and of the inner radius $ØA$ of the seat (Fig. 3). The thickness coefficient of the seats was set at the maximum admissible value $\beta = 2.00$.

The strength of the gasket and its leak tightness were investigated versus dimensionless operating pressure τ in the range [0, 1], i.e. the maximum operating pressure was assumed to be equal to the yield limit of the gasket material. The analysis was based on the variation of one of the earlier defined geometric or assembly dimensionless parameters of the gasket χ, δ, γ and ρ in the technical acceptable range, while the remaining parameters were kept at a constant mean level. Dimensionless geometry ratio of the gasket was changed in the range χ = 0.06–1.60, relative radial interference was changed in the range δ = 0.5–3.0‰, dimensionless average thickness of the gasket was modified in the range γ = 0.05–0.30 and dimensionless radius of the working wave surface was subjected to variation in the range ρ = 0.5–3.0. The mean values of dimensionless parameters refer to the geometry of the closure used in the experimental investigations χ = 0.8730, δ = 1.0‰, γ = 0.1535 and ρ = 1.6037.

Initial analytical calculations based on the standard thin-walled shell theory [2, 11], and preliminary FEM simulation, lead to the conclusion that the maximum stress appears at the cross-section placed at the gasket's centre of symmetry. The maximum equivalent stress

σ_{eq} appears at this cross-section, which can be seen in Fig. 11. The dimensionless strength parameter σ is presented at four characteristic points versus the dimensionless operating pressure τ: at the inner (σ_i) and at the outer (σ_o) radii of the gasket, in the central cross-section ($x = 0$) and in the extreme cross-section ($x = h$).

Special attention must be paid to the strength of the gasket in assembly conditions and for relatively low pressure τ which occurs during starting of high-pressure equipment. In assembly conditions, the gasket is loaded by shear forces Q_x which are only acting at the supports (Fig. 4). The shear forces are usually of high value as they are caused by the initial radial assembly interference δ. The interference δ must also be of high value because it should ensure the initial leak tightness of the closure necessary while the installation is being filled with the working medium. During the assembly, local plasticity processes occur at the wave surfaces of the gasket. It should be noted that, when the contribution of shear forces Q_x in the loading of the gasket is large and the contribution of the operating pressure τ is small, the maximum strength parameter σ appears at the central cross-section at the outer radius – $\sigma_o(0)$. The above effect can be seen in Fig. 11, where the maximum strength is moving to the inner radius $\sigma_i(0)$ only for the pressure $\tau > 0.08$.

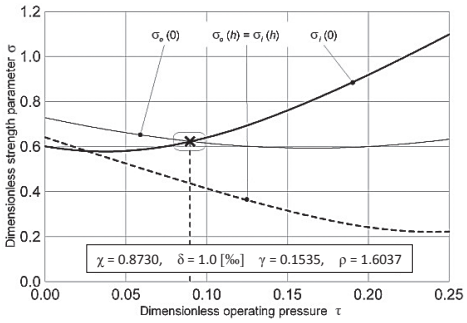

Fig. 11. Dimensionless strength σ at four characteristic points of the gasket versus dimensionless operating pressure τ. Dimensionless parameters χ, δ, γ and ρ fixed at average values

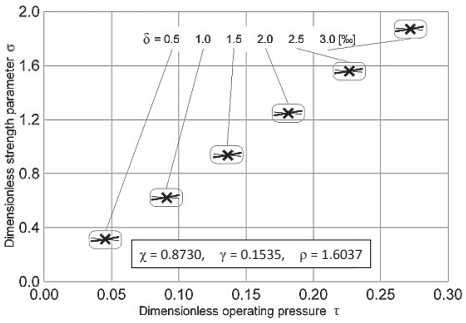

Fig. 12. Dimensionless strength σ of the gasket at the outermost radii versus dimensionless operating pressure τ for different dimensionless parameters δ. Dimensionless parameters χ, γ and ρ fixed at average values

The magnitude of pressure τ, for which the maximum strength parameter σ changes its localisation, depends strongly on the applied initial assembly interference fit δ. The relationship between the strength parameter at the inner radius $\sigma_i(0)$ (bold lines) and the strength parameter at the outer radius $\sigma_o(0)$ (fine lines) and the pressure τ is fragmentarily presented in Fig. 12 for several interference fits. It appears, however, that even for the maximum practical value of the interference fit of the order of 2.5‰ the maximum strength parameter σ shifts from the outer to the inner radius for pressure $\tau > 0.23$. For this reason, the equivalent stress acting at the inner radius was used to estimate the gasket strength.

Dimensionless strength σ at this point for different values of the dimensionless average thickness γ of the gasket and fixed values of χ, δ, and ρ versus pressure τ is shown in Fig. 13.

Permissible range of parameters is for $\sigma \leq 1$ because the loading of the gasket must be lower as the yield limit $R_{0.2\,g}$ of its material. It appears that the influence of the investigated parameter γ on the gasket strength σ is small in the adopted range of other parameters. The closure may be loaded with the pressure $\tau < 0.25$ for which the condition $\sigma \leq 1$ is satisfied.

The influence of the initial assembly interference fit δ on the strength of the gasket is illustrated in Fig. 14. An increase of the interference fit δ produces a simultaneous decrease of the operating pressure τ for which $\sigma \leq 1$. The negative interference fit has an unloading partial effect on the stress distribution caused by pressure τ. The large magnitude of the interference fit δ together with the large value of the thickness coefficient β of the seats cause that for $\delta = 2.0‰$ the strength of the gasket exceeds $\sigma = 1$ in certain places already during the mounting process of the closure.

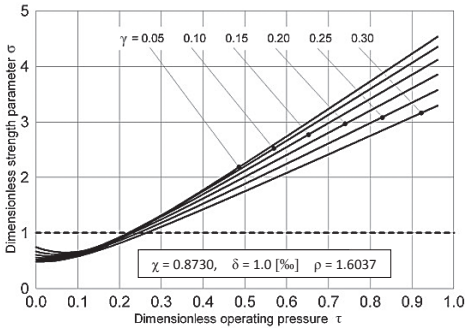

Fig. 13. Dimensionless maximum strength σ of the gasket versus dimensionless operating pressure τ for different dimensionless parameters γ. Dimensionless parameters χ, δ and ρ fixed at average values

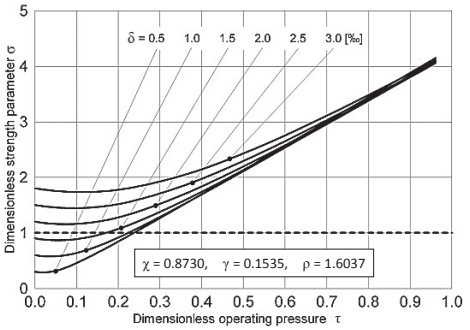

Fig. 14. Dimensionless maximum strength σ of the gasket versus dimensionless operating pressure τ for different dimensionless parameters δ. Dimensionless parameters χ, γ and ρ fixed at average values

The ratio of cross-sectional dimensions χ has a distinct influence on the strength of the gasket. The examination of the relationships in Fig. 15 leads to the conclusion that an increase of the parameter χ from 0.6 to 1.6 results in a significant increase of the gasket load capacity τ.

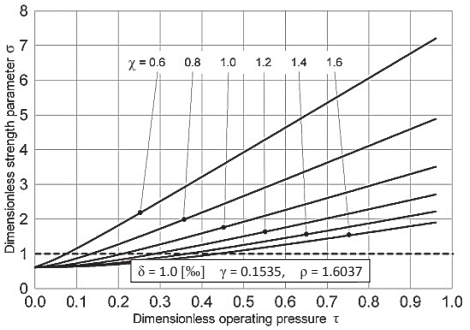

Fig. 15. Dimensionless maximum strength σ of the gasket versus dimensionless operating pressure τ for different dimensionless parameters χ. Dimensionless parameters δ, γ and ρ fixed at average values

It is assumed that because of the highly approximate assumption of the stress distribution in the contact region, leak tightness is preserved for the parameter $\psi \geq 2$. The average stress q_m calculated on the basis of purely elastic Hertz approach is in this case four times greater than the applied operating pressure p. The influence of the dimensionless parameters χ, δ, γ and ρ on leak tightness parameter ψ is presented in Figs. 16–19. The general tendency of leak tightness is to decrease, with an increase of the operating pressure.

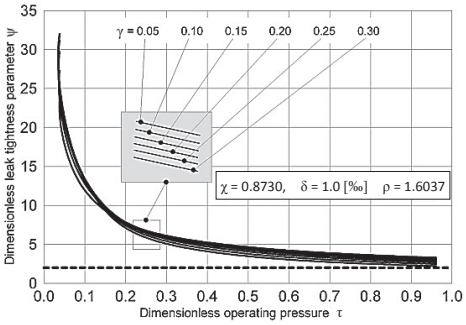

Fig. 16. Dimensionless leak tightness parameter ψ versus dimensionless operating pressure τ for different dimensionless parameters γ. Dimensionless parameters χ, δ and ρ fixed at average values

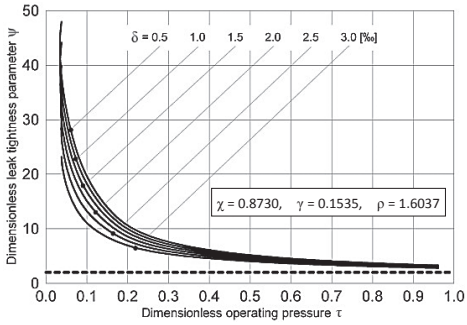

Fig. 17. Dimensionless leak tightness parameter ψ versus dimensionless operating pressure τ for different dimensionless parameters δ. Dimensionless parameters χ, γ and ρ fixed at average values

An increase of parameter γ (an increase of the gasket thickness) has a negative effect (Fig. 16). The examination of the relationships in Figs. 17 and 18 indicates that the variation of parameters δ and χ change distinctly the leak tightness parameter ψ of the joint.

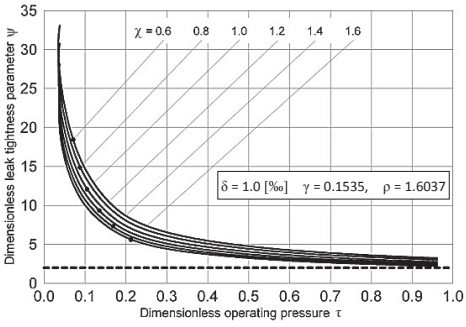

Fig. 18. Dimensionless leak tightness parameter ψ versus dimensionless operating pressure τ for different dimensionless parameters χ. Dimensionless parameters δ, γ and ρ fixed at average values

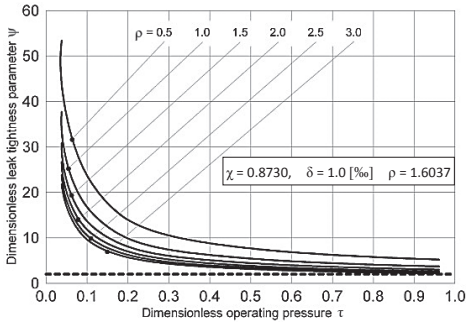

Fig. 19. Dimensionless leak tightness parameter ψ versus dimensionless operating pressure τ for different dimensionless parameters ρ. Dimensionless parameters χ, δ and γ fixed at average values

The variation of parameter ρ connected with the wavy working surface of the gasket produces significant changes in leak tightness (Fig. 19). Too high value of this parameter ($\rho > 3.0$) may be the cause of a loss of leak tightness, in particular for greater values of the operating pressure τ.

All distributions of the dimensionless leak tightness parameter ψ versus dimensionless operating pressure τ presented in Figs. 16–19 are placed considerably beyond the admissible value $\psi = 2$ in the adopted range of the closure parameters. It appears that the non-leakage condition (1) of the joint is satisfied and leak tightness is preserved, in particular for low values of the operating pressure τ.

7. Comparison of the analytical approach with FEM simulation and test results

The experimental results were obtained in the installation state with no operating pressure applied to the joint. The dimensions of the investigated closure are presented in Fig. 3. The gaskets were pressed into their seats and the circumferential and axial strains were measured at the inner surfaces of the gaskets. This is why the comparison of the analytical approach with FEM modelling and test results may be carried out in the assembly conditions only.

Examination of the dimensionless strength parameter σ distributed along the gasket width (Fig. 20) confirms that a change of loading of the gaskets and application of the numerical model FEM 2, similar to real test conditions, makes the numerical results closer to the test results, in particular for small nominal radial interference $\delta = 0.5‰$.

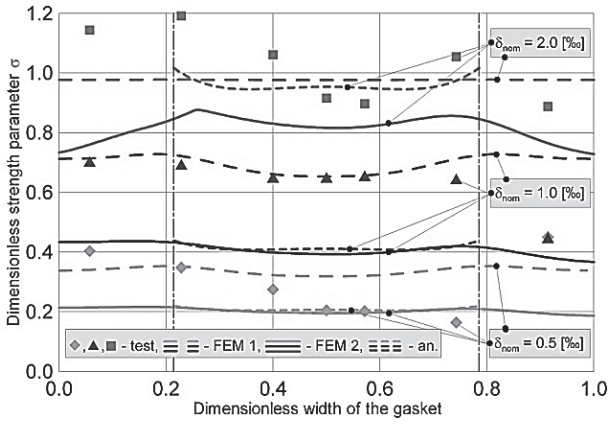

Fig. 20. Dimensionless strength parameter σ at the inner surface of the gaskets versus dimensionless width in assembly conditions ($\tau = 0$). Labels: ♦, ▲, ■ – test results for nominal interferences $\delta = 0.5‰$, 1.0‰ and 2.0‰, respectively. Wide dashed lines – FEM 1 results for nominal interferences, solid lines – FEM 2 results for nominal interferences, narrow dashed lines – analytical results for nominal interferences

Most of the test results are placed in the vicinity of the range received by FEM 2 method and the analytical approach. The greater interferences δ (1.0‰ and 2.0‰) result in respectively

greater differences between FEM 1 and FEM 2 methods and analytical solutions, whereas the test results are located between FEM 1 and analytical results. Investigation of experimental and theoretical strength distributions shown in Fig. 20 leads to the conclusion that FEM 1 method is overestimated and analytical calculations are underestimated with respect to the experiment. The difference increases with the increase of the initial interference.

The dimensionless maximum strength parameter σ at point *A* (Fig. 3) versus dimensionless operating pressure τ is compared in Fig. 21 for the analytical approach and FEM 2 simulation. The numerical calculations were carried out for the thickness coefficient of the seats β = 2.00. For loading τ < 0.3, the nature of both relationships is similar, although analytical results are considerably greater. Above the yield limit (σ > 1), the difference rapidly increases, with an increase of the loading. The width of the contact region *e* versus the dimensionless operating pressure τ for the above solutions is presented in Fig. 22. In this case, the relative difference is even greater.

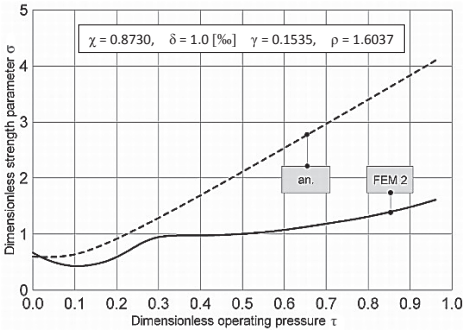

Fig. 21. Dimensionless maximum strength σ of the gasket versus dimensionless operating pressure τ. Comparison of the analytical approach with FEM simulation

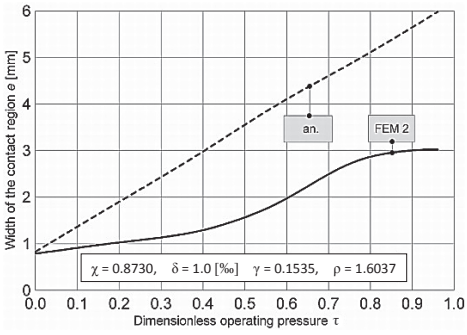

Fig. 22. Width of the contact region versus dimensionless operating pressure τ. Comparison of the analytical approach with FEM simulation

The leak tightness of the joint depends, in particular, on the applied initial assembly interference δ. Visual inspection of the gaskets (Fig. 23) after disassembly indicates that the designed interference must be less than 2.0‰ for the unchanged other parameters of the investigated closure. Too close radial interference fit with respect to the yield limit $R_{0.2\,g}$ of the gasket material was probably the main cause of the serious damage of the working surface. In this case, during the assembly (and disassembly), operation under load in the absence of adequate lubricant the applied interference fit together with a large value of the friction coefficient lead to adhesive wear [4]. The original adhesion theory postulated that all asperity contacts would result in yielding and adhesion due to the high stresses present.

When clean surfaces are pressed against one another under load, some of the asperities in contact will tend to adhere to one another due to the attractive forces between the surface atoms of the two materials. As sliding between the surfaces is introduced, these adhesions are broken, either along the original interface, or along a new plane through the material of the asperity peak. In the latter case, a piece of one part is transferred to another part, causing

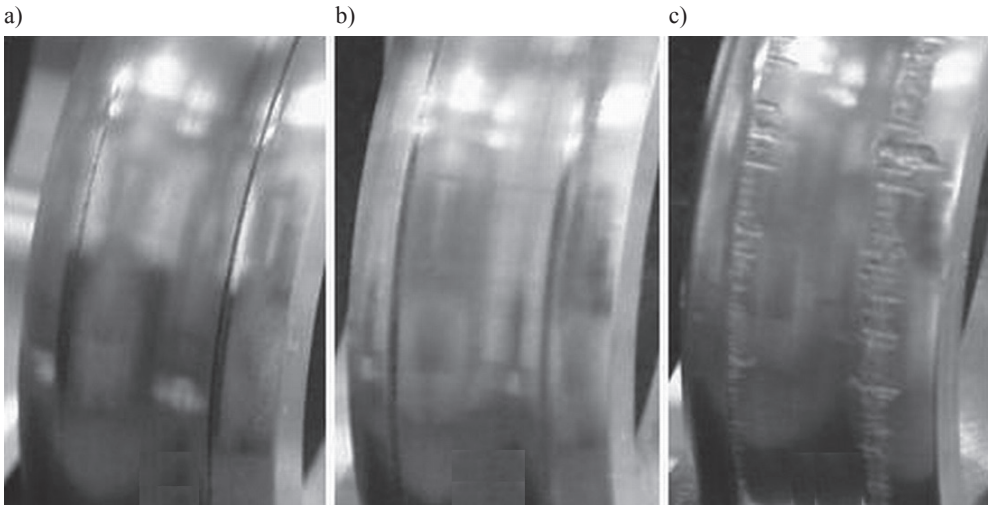

Fig. 23. The gaskets after disassembly. Interferences δ: a) 0.5‰; b) 1.0‰; c) 2.0‰. Note the contact traces

surface disruption and damage. Sometimes, a particle of one material will be broken free and become debris in the interface, which can then scratch the surface and plough furrows in both parts. This damage is called scoring or scuffing of the surface.

8. Final remarks

The simplified analytical approach, based on the shell theory, was applied to investigate the influence of certain geometric, material and assembly parameters on the strength and leak properties of high-pressure closure with a wave-ring gasket. The analytical solution was verified by FEM modelling and by an experiment. On the basis of the obtained results, certain general conclusions and recommendations may be formulated with respect to the safety of the joint.

Because of specific working features of the wave-ring gasket, the yield point of its material must be relatively lower than that of the seat. Reactor vessel walls and its heads, as well as the pipelines designed for high-pressure applications, are manufactured out of high-carbon chromium-nickel-molybdenum steel. The yield stress of such material usually exceeds $R_{0.2\,g} > 750$ MPa and possible Rockwell hardness number is of the order of 45–48. The corresponding wave-ring gasket should be made of a material of which Brinell hardness number is less than 250–280 BHN and the yield stress is approximately $R_{0.2\,g} = 400$ MPa. Acceptable operating pressure should be of the order of $p = 250$–300 MPa. Application of a higher operating pressure must be preceded with a detailed stress-strain analysis of the gasket and earlier considerations with respect to leak tightness.

The strength of a wave-ring gasket cannot be improved significantly through the change of the dimensionless parameter γ, however, greater loading capacity may be obtained through

an increase of parameter χ. The increase of parameter χ to 1.6 produces an increase of the parameter τ to 0.43.

Special attention should be paid to the magnitude of the initial assembly interference fit δ. The interference fit less than 0.5‰ may cause leakage of installation at the start, in particular for the joints of large diameters for which it is hard to provide precise dimensional accuracy. On the other hand, the interference fit exceeding 2.5‰ appears too large because it insignificantly improves leak tightness, but it produces significant damage of the working surface during the assembly of the joint. The interference fit δ = 1.0–2.0‰ is recommended to the closures with wave-ring gaskets for the adopted data.

The analytical computational model of the closure may be convenient to proceed an initial analysis. A large number of simple calculations can be carried out for different geometry of the gasket, different material properties and assembly requirements. It should be noted that a comparison of experimental and theoretical results reveals that the analytical calculations are underestimated with respect to the tests. The final parameters of the closure may then be determined in the detailed FEM verification, which is closer to the experimental results.

The experimental investigations indicate that gasket installation and replacement operations should be carried out with extreme precision. Attention must be paid to the exact alignment of the gasket with respect to the seat, and above all, in closures with a large diameter. As a conclusion of the experimental investigations, it should be noted that the assembly process realised by means of the expanding technique (thermal method) is advantageous with respect to the mounting process in which the gasket is pressed into the seat. Inaccurate sliding process may result in scoring of the wave surface of the gasket.

Moreover, the manufacturing process of wave-ring gaskets must ensure high dimensional accuracy, in particular with respect to the wave working surface, as the effective interference fit depends on this accuracy. The average nominal diameters of approximately 200 mm require the IT6–IT7 grade of tolerance and the roughness number of R_a = 0.16 μm seems to be sufficient.

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RAPID E-LEARNING TOOLS ON THE MOODLE PLATFORM

NARZĘDZIA DO SZYBKIEGO PRZYGOTOWYWANIA E-MATERIAŁÓW NA PLATFORMIE MOODLE

Abstract

One of the most frequently highlighted problems regarding online teaching reported by teachers is the time and effort required to prepare and regularly update attractive e-content. This is particularly true for multimedia content. On the other hand, the problem often reported by students is the low aesthetic value and teachers' failure to produce materials that students deem to be aesthetically attractive. This article presents some suggestions on possible ways to control and manage the visual side of e-content.

Keywords: e-learning, rapid authoring tools, moodle

Streszczenie

Jednym z problemów w e-learningu jest zgłaszana przez nauczycieli czasochłonność i pracochłonność przygotowania e-zawartości i jej aktualizacji. W szczególności dotyczy to multimediów. Problemem często zgłaszanym przez studentów jest z kolei niska wartość estetyczna i brak dbałości o stronę wizualną projektu. W artykule zaprezentowano kilka porad dotyczących sposobów pozwalających zapanować nad wizualną stroną kursów.

Słowa kluczowe: e-learning, narzędzia do szybkiego autoringu, moodle

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1. Introduction

The development of the Internet and the ongoing diffusion of such phenomena as electronic media, mobile and wearable technologies, and "the Internet of things" into our lives makes education as we know it a matter of the past. Today, no one doubts that e-learning is a fully legitimate teaching and learning medium in Polish universities.

Distance learning or e-learning is no longer a set of electronic presentations made available for students, nor is it providing merely pdf files or links to recommended websites. Nowadays, e-learning, e-teaching or e-education is an interactive method of tutoring which comprises: delivering teaching materials; managing the didactic process; monitoring and assessing progress; ensuring student-teacher as well as student-student communication; interaction by means of information technologies, particularly Internet communication tools [5].

The Sloan Consortium Report, published in 2010 [1], claims that in the USA alone, over 4.6 million students participated at least once in an online course offered in the previous semester. Interestingly, the figure increased by 17% in comparison to the year before and it is estimated that the increase is ongoing. The latest report indicates a growth of 3.7% year on year in the autumn of 2013. The year-on-year gain in the number of distance students (189,187) represents 73.7% of the increase in overall enrollments for this time period (256,650) [2].

To the authors' knowledge there is no similar data available for Poland. The findings of a survey conducted at Czestochowa University of Technology show that 14% of the polled students (464 persons) have experience in distance learning while 45% of students do not know what e-learning means in practice. However, it seems encouraging that nearly 80% of respondents voiced their readiness to enrol in an online course – this leads to the belief that there is a huge demand for such education [5]. The university should be urged to implement elements of distance learning, which ought to be preceded by a publicity campaign and a series of training sessions.

Distance learning is becoming a new way of gaining knowledge as an alternative to traditional education and the existing educational structures. Although technology plays a significant role in the process, it shouldn't dominate the didactics. The focus should be put on including properly designed, implemented and delivered e-courses.

Despite the many benefits of using the tools and techniques of distance learning in education, there has been a significant number of critical voices, complaints and problems lately. Preparing attractive e-content (teaching materials) has been seen as a laborious, time-consuming and costly process.

The present paper discusses some good practices in the field of developing attractive teaching materials that are rich in multimedia. Tools and methods used for developing such content are presented.

2. Background information – E-courses

In this paper, the solutions to improve the appeal of e-courses and creative ideas used in the 2014/2015 academic year in two e-courses at the Mechanical Engineering and Computer Sciences Department of the Technical University of Częstochowa are presented.

Fig. 1. Screenshot of the Quality Tools e-course. Example of the use of visual elements – pictures and word map

The first course was a thirty-hour project entitled Quality Tools delivered mainly over the Internet (26 hours online, 4 hours face to face) to students of three fields of regular and extramural studies: mechanics and machinery building, mechatronics, and biomedical engineering.

The second subject, Basic Manufacturing Technologies – Metal Working, was carried out entirely in the real world laboratory and the e-course was only used as an electronic repository (a hub) for the information concerning the issues presented in the laboratory and a virtual location for submitting reports and publishing the results of tests and exercises.

3. Why Moodle

Dedicated computer systems called virtual learning environments (VLE), learning management systems (LMS) or learning content management systems (LCMS) are used to organise and manage e-learning. These systems allow the user to create dynamic online services, either public or for a particular group of students. They offer a wide variety of tools supporting and facilitating the publication of the service content, in text or graphic form or as ready-made documents or usable applications. The systems make it possible to manage groups of users (students, teachers) as well as the resources created for them. They help organise the work of teams and individuals by offering tools which enable monitoring of the learning process. An attempt to incorporate e-learning into the traditional system of education at the Faculty of Mechanical Engineering and Computer Science was made as early as in 2001 at the Institute of Metal Forming, Quality Engineering and Bioengineering, when an e-learning platform was installed on the institute's server. With time, the scope of the tool application was extended to cover new areas, for example, to enhance student mobility [7]. When the decision was taken to support traditional classes with online teaching, an analysis was performed to compare the software available on the market. All the necessary requirements were defined and after studying the existing solutions, the Moodle platform was selected. Drawing on the literature review, the platform also appears to be popular in Poland [3, 4, 8].

We have used Google Trends Analysis to assess the search volume of selected e-learning platforms to analyse the popularity of Moodle, Blackboard, Fronter and Claroline in both Poland and the world over the previous ten years. The results, shown in Figure 2, prove that Moodle is definitely and unquestionably the number one LCMS in Poland while it is one of the two most popular learning content management systems in the world.

The reasons the Technical University of Częstochowa has chosen Moodle are:

- Moodle is an open source solution,
- uses free server solutions,
- enables the publication of e-content and advanced content management,
- allows the advanced management of users,
- ensures security for teachers and students,
- contains basic tools for authoring,
- it is intuitive, clear, legible,
- Moodle is a recognised standard in Poland and Europe,
- it is a developing platform with good and efficient support.

Having used the platform for several years, it seems that the decision was right and Moodle proves to be no worse than the existing commercial products while definitely surpassing other open source platforms.

The Moodle platform is also widely used as a workspace in European projects to exchange experience and know-how as well as to supplement various forms of education.

Figure 2 shows that the search-term 'Moodle' is much more popular in Poland then all the other platforms. This is a permanent trend. In the world, Moodle has a great competitor – a commercial platform called Blackboard. Due to the financial issues, the Blackboard platform has always been out of reach for the authors' University.

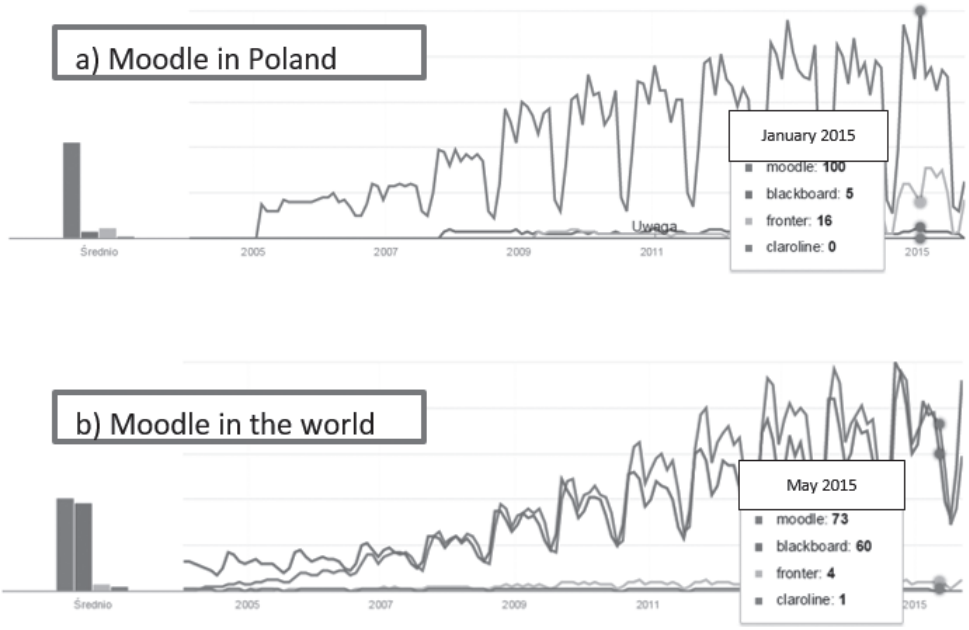

Fig. 2. Google Trends Analysis of the search volume of some e-learning platforms – Moodle, Blackboard, Fronter and Claroline in a) Poland, b) the world [9]

The Moodle platform provides a suitable and reliable system of logging, securing and managing its users – which in this case are teachers and students. It also offers a variety of authoring tools which enable an online didactic process. Thus we can develop, organise, deliver and manage didactic materials (in any text, graphic or even multimedia rich format), monitor the way in which these materials are used by students and teachers, and assess the effectiveness of online education with tests, surveys or assignments. The platform also makes it possible to run interactive classes by means of discussion forums (asynchronic communication) and chats (synchronic communication). Furthermore, it provides tools to run statistics and analyses of the didactic process.

Moodle was developed by Martin Dougiamas from the Curtin University of Technology, Perth, Australia in 1999. Currently, the platform, similarly to other open source solutions, is being further improved by its creator and hundreds of voluntary programmers all around the world. At the MoodleMoot Polska 2010 conference [10], Martin Dougiamas presented the latest version of Moodle, which assures us that the LCMS is constantly being developed, tested, and refined.

The Moodle platform undergoes continuous alterations so as to meet the demands of the constructivist model of learning. A range of tools have been developed to enable student/student and student/teacher interaction. These encompass over 35 activities, e.g. lessons, choices, surveys, chats, journals, forums, assignments, standard and Hot Potatoes quizzes, SCORM, glossaries, workshops, and Wiki. The tools offered by Moodle can be used to provide and/or test knowledge as well as to encourage interaction and/or collaboration among course participants.

The ability to integrate communication tools such as forums or chats with the content of lectures and tutorials and to supplement those with quizzes and tests assessing the progress of education can allow the teacher to develop and conduct an effective online course.

3.1. Tips for Moodle

1. To split the area of the course, or even a single topic into sections, you can use banners, collages or simply photographs that have been prepared earlier in another application, as shown in Fig. 3.

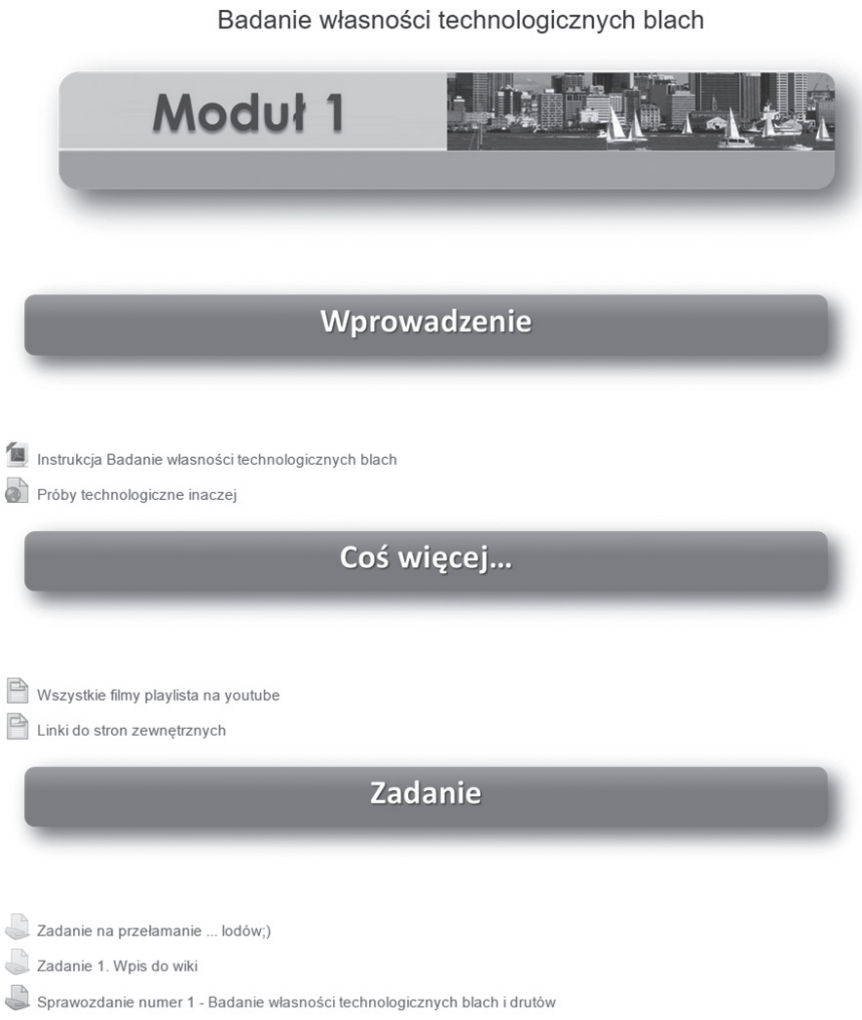

Fig. 3. One of the Moodle courses where banners and photograps were used to divide the topic into smaller areas: Introduction (Wprowadzenie), More... (Coś więcej), and Assignement (Zadanie). The scheme was copied into all topics

Fig. 4. Menu created in a course together with the **show one section per page** option of the **course layout**. All the cells in the menu are hyperlinks

2. One of the main disadvantages of learning with Moodle is the fact that courses are usually very long. It is quite frustrating to scroll down all the topics to get to the one that the student is currently working on. In one of the courses, we used the 'show one section per page' option in the course layout menu and created the table type menu to make all the topics available from the opening screen of the course. As a result, students can see the menu of the course and one topic only. They can still access other topics from the menu or the navigation toolbar. Our courses usually have the organisation and communication topics consistent for the entire course. The menu used in the course allows students to immediately access both of these (Fig. 4). The course was divided into the following modules:
   – Organisation (Organizacja),
   – Communication (Komunikacja),
   – Module 1. Tests of the technological properties of metal sheet (Moduł 1. Badanie własności technologicznych blach),
   – Module 2. Tests of the technological properties of wire (Moduł 2. Badanie własności technologicznych drutu),
   – Module 3. Cutting (Moduł 3. Cięcie),
   – Module 4. Blanking (Moduł 4. Wykrawanie),
   – Module 5. Powder metallurgy (Moduł 5. Wytwarzanie wyrobów z proszków metali),
   – Module 6. Stamping (Moduł 6. Tłoczenie),
   – Module 7. Rolling (Moduł. 7. Walcowanie),
   – Module 8. Extrusion (Moduł 8. Wyciskanie),
   – Module 9. Open-die forging (Moduł 9. Kucie swobodne),
   – Module 10. Impression-die forging (Moduł. 10 Kucie matrycowe).
3. We strongly advise our fellow authors to use styles and fonts proposed by the CSS designers. They are usually people who know trends, golden rules, best practices and they have the relevant aesthetic knowledge. Moreover, changing the Moodle themes (which can be done for a separate course) will result in an appropriate change of fonts, headings, and colours.
4. Moodle offers quite advanced ways to publish multimedia in the e-course area. We widely use images (available on creative commons licences or at the public domain), word maps, tag clouds (i.e. Wordle.net), or videos (Youtube.com, Vimeo.

com, TeacherTube.com, WikiVid.pl etc.). The main page of the Quality Tools course with graphic elements is presented in Figure 1 – this shows the tags cloud, also called a word map. Moreover, there are some nicely arranged images (e.g. the banner, which was prepared in PowerPoint).

3.2. Rapid Authoring Tools

Although Moodle is more than sufficient for the development, implementation, delievering and evaluation of an e-learning course, it is difficult to use in order to create multimedia, which would make the course visually attractive.

It is good if developers use built-in styles of the Moodle theme, using professionaly designed cascade style sheets (CSS).

It is usually much worse when the authors experiment with colors, fonts, and the layout of course elements. It is not the intention of the authors of the article to discuss tastes, trends and people's personal aesthetic preferences; neither do they intend to recall any customer satisfaction examinations regarding the visual attractiveness of e-courses as it seems not to be the main aim of academic education. However, we will present a few selected tools and tips that allow teachers to 'spice up' their e-content, with virtually no additional work.

4. Review of the tools

All the problems discussed in the first part of this paper made the authors look for solutions which would allow them to swiftly publish e-content in a safe format. The conducted research revealed a wide variety of software known as Rapid E-learning Tools. The most user-friendly tools are able to convert content created in Microsoft PowerPoint (Open Office Impress), which is regarded by many teachers and academics as a standard tool, to the format appropriate for e-learning course.

The list below shows examples of such programs (free and commercial):

- Articulate Rapid e-Learning Studio (Articulate Presenter);
- Adobe Presenter;
- ProForm (Flashform) Rapid e-Learning Studio;
- AuthorPOINT;
- QuickLesson;
- FlashPoint;
- Wondershare PPT2Flash;
- Camtasia Studio;
- Impatica;
- PresentationPro PowerConverter;
- PowerPoint;
- OpenOffice.

Characteristic features of Rapid e-Learning Tools are as follows [6]:

- the time needed to prepare a resource is significantly reduced;
- e-content is prepared by experts in a given field, not a specialist in computer sciences, graphics or distance learning;

- preparation of an e-course takes place in the well-known and user-friendly environment of Microsoft PowerPoint (OpenOffice Impress) or with the help of ready-made templates;
- it is easy to monitor and assess progress as well as to provide feedback;
- they can supplement the course with simple multimedia elements (audio, video, animation) which enhance the process of learning, but do not create technological barriers;
- the course consists of reusable learning objects where each object constitutes an almost self-contained unit;
- learning objects can be used in various configurations which take from 20 to 60 minutes;
- synchronous (live) or asynchronous models of e-learning can be employed.

After the experience of developing multimedia lectures with Adobe Flash and testing trial versions of various programmes, a decision was taken to purchase Articulate Presenter and Adobe Presenter. The programs proved to be excellent tools for the rapid conversion to the SWF format of lectures prepared with Power Point or Open Office Impress; they also make it possible to add audio and video. Apart from the obvious fact that the time needed to prepare materials is decreased to just a few minutes, the application also offers a very interesting and functional interface for ready presentations (Fig. 5, 6).

5. Examples of the application

It has become routine and standard for academics and teachers to prepare all their lectures and other materials as PowerPoint presentations. Although PowerPoint presentations are very useful to use in the classroom where they can be presented using a multimedia projector and with the audience looking at a large screen, it is also very inconvenient to publish them in an e-learning course on the Internet. Therefore, we had looked for programmes capable of converting PPT files into SWF files. We have discussed in this paper why we chose the Flash format for our e-learning courses. From the review, we found two of the programmes to be most interesting: Articulate Presenter and Adobe Presenter. It is not the subject of this paper to review or describe them in detail. We have used both of them and found both to be very easy to use, the results were quite similar and very satisfactory. Below, one can see the results of the conversion of ppt presentations into .swf Flash files performed by Articulate Presenter (Fig. 5) and Adobe Presenter (Fig. 6).

The bar on the left in Fig. 5 and on the right in Fig. 6 shows a photo of the author and a brief note about him. Underneath, there are four links: table of contents (outline of the lecture), miniature slides (thumbnails), notes and a search tool. Below the main window (presentation area) there is a navigation menu with buttons for viewing, pausing, and fast-forwarding the presentation etc. Additional options are also available so that we can view notes prepared by the lecturer, see a slide without the side menu or enlarge the main slide with no menu in view. It is worth noting that the program is intuitive and retains all the animations and recordings that were included in the original PowerPoint document.

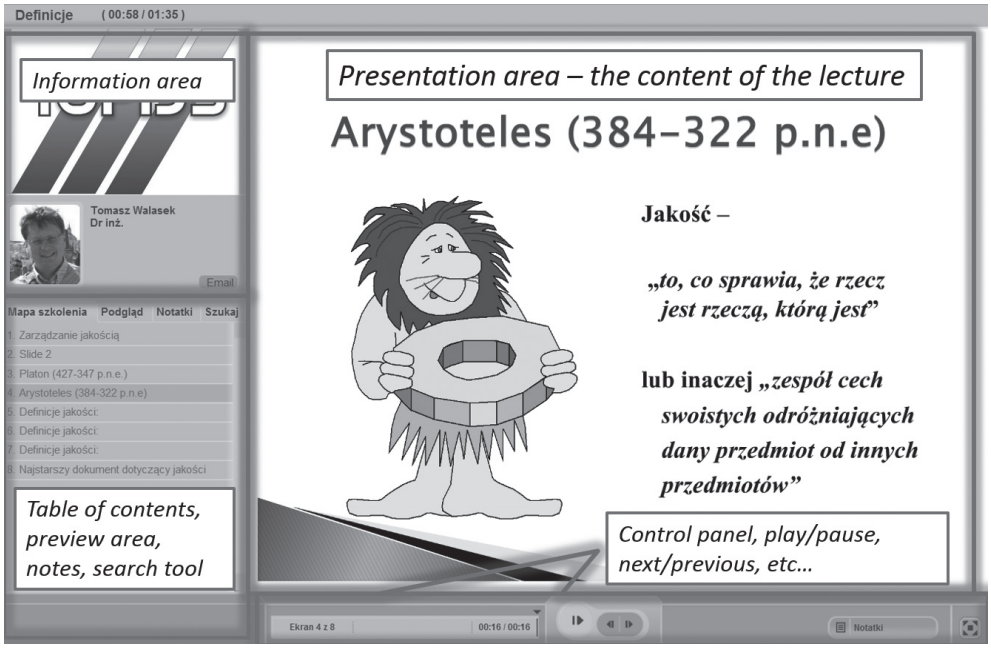

Fig. 5. One of the screens prepared in PowerPoint and converted into a multimedia presentation in Articulate Presenter

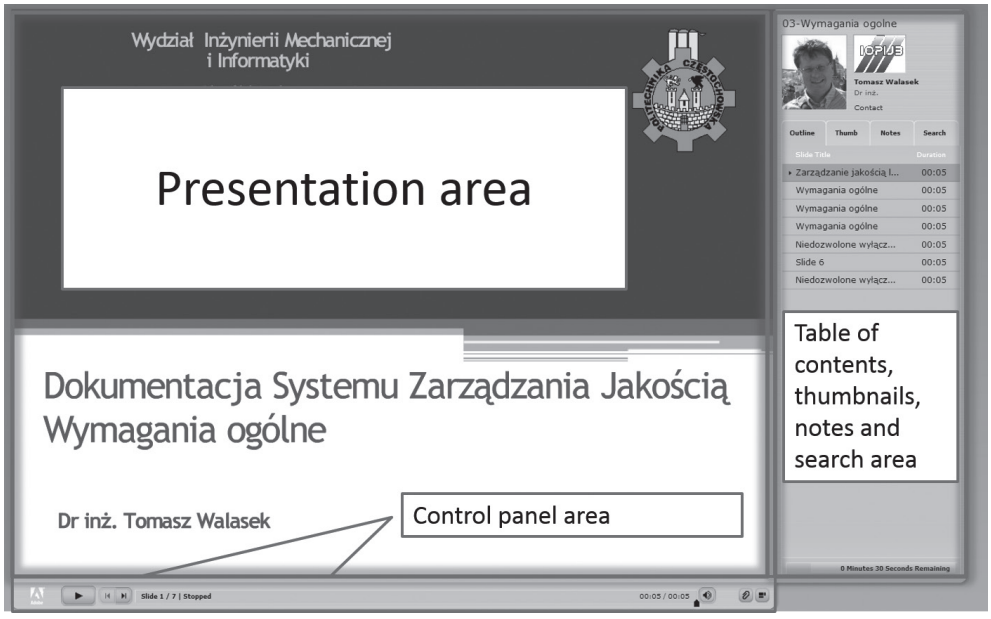

Fig. 6. The result of the conversion of the PowerPoint presentation performed by Adobe Presenter

Bearing in mind that the most common complaint voiced by e-teachers is the huge amount of time spent on preparing e-content, the authors can make assurances that the use of rapid e-learning tools significantly saves a significant amount of time. Most contemporary teachers are able to create, without any difficulties, a multimedia presentation in one of the two most popular programs (Microsoft PowerPoint or OpenOffice Impress) and they usually already have their lectures and teaching materials prepared in this way. Thanks to the tools discussed in the present paper, the conversion to the flash format and, consequently, making the materials more attractive and suitable for distance learning takes only a few moments, and this should be highly appreciated by all interested teachers.

6. Conclusion

The most problematic element of the e-learning process from the teacher's point of view is time management. The workload to prepare and conduct a course (which is annually updated and often refined with new teaching materials) as well as to assess and grade students' work is much greater compared to preparing and running traditional classes. The use of Rapid e-Learning Tools reduces the time needed to prepare an e-course to a significant extent and makes it possible to provide quick tutorials and other learning aids for students enrolled in the course.

The surveyed students appraised such a way of conducting classes very favourably and appreciated the availability of electronic lectures as well as the opportunity to complete tasks at times that are most convenient to them.

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