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REALIGNING OF HYDRAULIC ENGINEERING EDUCATION TO ACTUAL INDUSTRIAL REQUIREMENTS

Peter HEIDRICH[1], Niklas WEISS[1], Mirko ROTHHAAR[1]

[1] University of Applied Sciences Kaiserslautern, Schoenstraße 11, 67659 Kaiserslautern, Germany, peter.heidrich@hs-kl.de; niklasweiss1@gmx.de; mirko.rothhaar@hs-kl.de

Abstract: *Fluid technology is an ever-changing technology influenced by actual trends like up-and-coming mechatronics or digitization of signals. Further influence is given by occurring new technologies like augmented and/or virtual reality as well as artificial intelligence. Hence, engineering education has to be adapted to these new requirements continuously. In this work we report on redesigning hydraulic lab exercises according to different curricula. Widespread hardware was purchased to cover all necessary technologies like solenoid valve circuits, servo valve operation with externally given velocity profiles and finally closed loop controller circuits. Based on included short hydraulic exercises comprehensive lab exercises of 30 to 60 minutes duration were developed and tested. Focus was here to involve knowledge of other course contents with adherence to the different curricula of Bachelor and Master studies. Finally, templates for all lab exercises were written and tested by ourselves. Future step will be to test new lab exercises with appropriate groups of students. Based on their feedback and additional feedback of supervising lab staff optimisation should be carried out – if necessary.*

Keywords: *Hydraulic engineering, hydraulic education, basic lab exercises, enhanced lab exercises*

1. Introduction

Fluid technology, including hydraulics as well as pneumatics, remains one of the most used drive train system in automation technology and automotive applications. Since its beginnings around 250 B.C. by Greek people like Archimedes or Heron of Alexandria [1, 2] continuous improvements led from simple machinery of the early days to today's high-tech applications of hydraulics and pneumatics.
Current trends are including fluid technology into mechatronics, digitization of signals and signal processing, integration into Industry 4.0 philosophy as well as testing of environmentally friendly pressure media like water-based liquids and using renewable energy sources like solar power to support hydraulic power trains [3, 4, 5]. Another topical field of interest is combining fluid technology with Augmented Reality (AR) and/or Virtual Reality (VR) [6, 7, 8]. Hence, it is possible to replace – especially for teaching and training purposes – expensive hardware by simulation tools embedded into augmented and/or virtual surroundings. Newly, benefits of linking fluid technology with Artificial Intelligence (AI) are researched and implemented to first industrial applications [9, 10].
Based on this awareness it is obviously, that hydraulic engineering education has to be realigned to these new requirements. Here it is important to find a proper balancing between basic understanding of hydraulics and introducing new technologies in lectures as well as in lab exercises. Otherwise students are not well prepared for professional life. Hence, in this paper we report on our experience in developing new lab exercises that would fulfill both specifications – train basic hydraulics and introduce new technologies.

2. Related Work

The first step was to carry out a comprehensive literature review regarding actual trends and opportunities in fluid technology education.
Generally, there is a constant need to adapt and enhance training systems and training methods of fluid technology to new and future requirements. Very important in this content is, that all improvements has to be specific to the target audience. For example, learning goals of future design

engineers are completely different to those who will work in maintenance or close to production [11, 12, 13].
A big challenge every now and then is, that commercially available training systems with appropriate technology are often either not available or only at tremendous cost. A simple relief could be to develop and design lab scale equipment in student work projects. As an example, miniature excavator arms were constructed and operated by electro-pneumatics or electro-hydraulics [14, 15]. Here, pneumatics is less dangerous and less oily compared to hydraulics. On the other side, hydraulics is more realistic to excavators. Additionally, controller based operation and even remote control by an app via blue tooth connection is possible [15].
Regarding teaching philosophy there seems to be a turning away from the classic fragmentation of lecture and lab exercises, at least for all fields of teaching, where theory is supported by practical contents. It begins with introducing active and cooperative teaching and learning methods to train soft skills along with knowledge, too [11, 16, 17, 18]. All references mention that student's abilities to cooperate, to solve problems and to be creative are promoted. Hence, students are better prepared for today's competitive working world. This trend continuous with Outcome Based Education (OBE) [19] and could finally result in gamification of lab exercises to catch student's attention [20]. Another possibility is to replace the classic written exam by project based workload with periodic self-assessment in combination with assessment by teaching staff [21]. Here students will train their self-reflection and their self-criticism, two important soft skills in today's working world. Finally, with all options there should always be an adaption of levels of difficulty to the level of studies, e.g. Bachelor versus Master [13, 22]. During the first semesters of Bachelor studies students need more guidance at lab time. At higher semesters of Bachelor studies the guidance should be replaced by space for development of own ideas. Additionally, tasks like planning, preparing and critical assessment should be taken into account. At Master studies students should get just problem descriptions and information on available lab equipment. Then, they should be able to solve the problem – with help from supervisors if necessary.
For several years there was a strong interest in developing and establishing remote and/or virtual lab exercises. One reason therefore is that training system hardware is not available with actual functionality, especially regarding needs of Industry 4.0 like electronical control of valves and digital data acquisition units [23]. Another reason is that more students could participate in virtual labs at any time – even at night or at the weekends – and with less cost for training equipment [24]. Especially due to COVID pandemic in 2020 there was need to offer non-contact lab exercises as well as non-contact assessment of lab activities. Hence, remote lab exercises were the one and only option to continue with education [25, 26].
Some lecturers integrate lab exercises like demonstrations into their lectures to replace boring slides and/or videos. Their experience shows more interest of students and hence, better marks [27, 28]. However, here the hardware must be transportable from lab to lecture hall or lectures has to take place directly in the lab. Sometimes special light weight equipment, in the referenced case even enhanced by augmented reality, has to be designed and produced [28].
A last conclusion is that in addition to academic fluid technology education the training of industrial people should be taken into account, too [11, 29]. Here training equipment as well as content of training courses should be adapted to the different knowledge base of industrial participants.

3. Hardware Selection

Based on all information of the literature review a requirement specification of the new hydraulic training system was finalised. The main items are:

- Exercises with manual operated valves – as basic hydraulics – should be performed with the actual training system;
- Exercises with solenoid operated valves should be performed with the new training system. Hence, appropriate operation units with low voltage power supply, a sufficient amount of push buttons, switches, electromagnetic relays (including switch-on delay and dropout delay) as well as audible alarms and visual displays must be available;

- Exercises with servohydraulic valves should be performed with the new training system. Therefore, actual controller units with features like zero balancing, slope time adjustment and test jacks of given value and actual value must be available;
- For all controller units the option of external generated given values – like sinusoidal wave, square wave or even sawtooth waveform – must be available;
- A hydraulic accumulator must be part of training system;
- Measurement equipment for pressure and flowrate must be part of training system;
- The hydraulic pump unit must be integrated into to training system;
- Due to safety reasons maximum system pressure should be 50 bar;
- All electrical equipment has to fulfil CE and GS mark requirements;
- For further enhancement of the system in future, an appropriate computer interface must be either integrated or could be upgraded easily.

With these items a noncommitted specification was created. After an open competitive bidding and an accurate assessment of all submitted proposals the new training system as shown in Figure 1 was purchased.

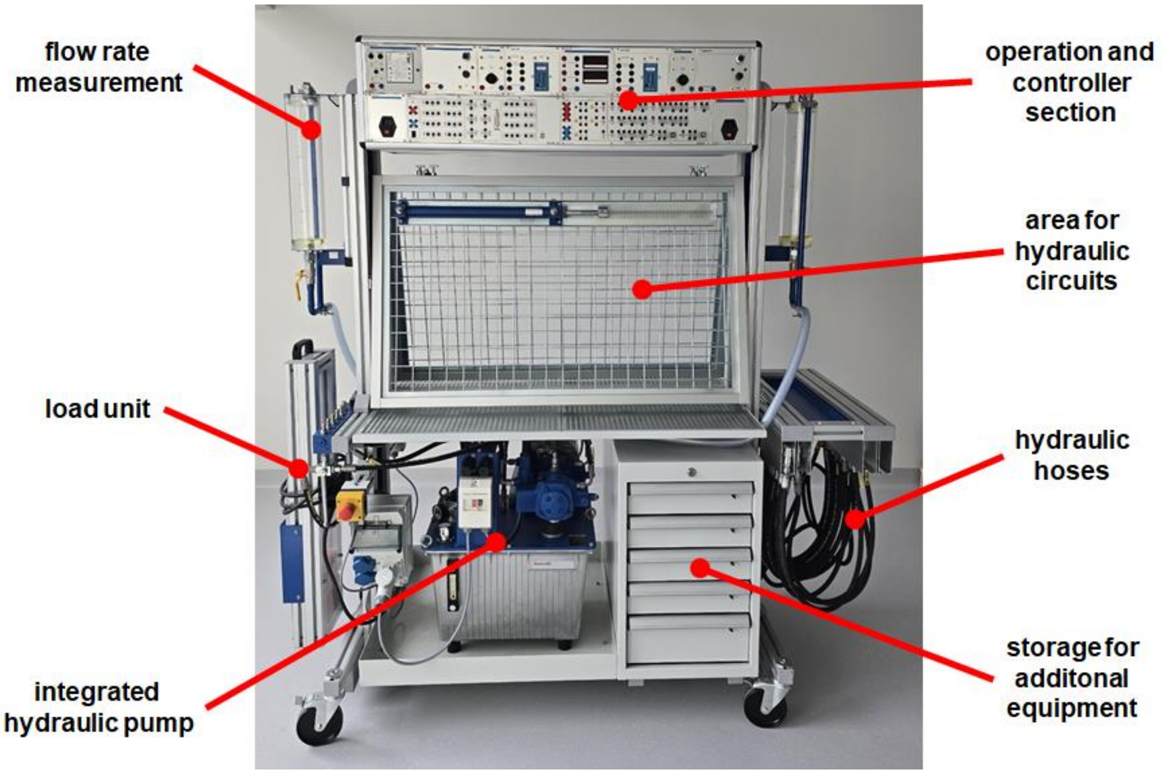

Fig. 1. New hydraulic training system at UAS Kaiserslautern

4. Testing, Validation and Assessment of Included Exercises

Together with the hardware of the new training system three folders with hydraulic exercises corresponding to technical apprenticeship requirements of Federal Institute of Vocational Training (Bundesinstitut für Berufsbildung, BIBB) were delivered. These folders cover the fields of “basic circuits with solenoid valves (24 exercises)”, “electro hydraulic servo valves (13 exercises)” and “closed loop controller circuits (6 exercises)”. The test record for each exercise consists of a basic introduction, explanations to all components used, the hydraulic and wiring diagram including parts lists and finally prepared templates for results documentation. Additionally most exercises contain information on typical risks and on prevention of accidents.

Hence, the next step was to conduct all 43 exercises, recognise content and duration as well as level of difficulty and correlate these results to requirements of related curricula. In Table 1 the assessment of suitability of all 43 exercises is shown in compressed form.

Table 1: Assessment of exercises regarding related curricula

Description	**Assessment**
Basic circuits with solenoid valves:	
Familiarize oneself with equipment (1 exercise)	yes
Operate hydraulic pump (1 exercise)	no
Operate hydraulic actors (3 exercises)	yes
Operate different hydraulic valves (8 exercises)	yes
Operate hydraulic accumulator (1 exercise)	yes
Assemble and operate basic circuits (2 exercises)	yes
Operate manometric switch (1 exercise)	yes
Operate rarely used and/or very special valves (1 exercise)	no
Operate very special circuits (4 exercises)	no
Commissioning and error diagnostics (1 exercise)	no
Electro hydraulic servo valves:	
Operate cylinder with preselected target value (4 exercises)	yes
Influence braking distance of cylinder (2 exercises)	yes
Velocity control of differential cylinder (1 exercise)	yes
Velocity profile control by proximity switch (2 exercises)	yes
Influence of operation pressure (2 exercises)	yes
Four-quadrant operation (2 exercises)	no
Closed-loop controller circuits	
Basic circuits of exact positioning (3 exercises)	yes
Positioning by limit switches (2 exercises)	no
Set-up operation (1 exercise)	no

All exercises assessed with “yes” are adequate to engineering education. All others are not suitable. They either are covered by other modules – like pump operation is part of fluid flow engine lab – or don’t fit to content of this module – like commissioning and error detection or very special circuits with rarely used valves.

5. Classification of Exercises Corresponding to Curricula

As most exercises assessed with “yes” in Table 1 are of short duration like 5 to 10 minutes and introduce just one single hydraulic component and its typical function, it was decided to group some of these exercises together with the goal of getting challenging exercises on Bachelor respectively Master level with a minimum of 30 minutes and up to 60 minutes duration.
Together with grouping the exercises, it was necessary to take the previous knowledge of the different curricula of mechanical engineering and mechatronics on Bachelor level as well as those on Master level into account. Main focus is here lectures and exercises in control theory and their relative position in curricula, as knowledge of this topic is absolutely necessary to participate in exercises with closed-loop controller circuits. Results are shown in Table 2.

Table 2: Extraction of Bachelor and Master curricula regarding control theory

Curriculum	Control theory	Hydraulics	Closed-loop controller circuits
Bachelor "Mechanical Engineering"	6th semester	5th semester	not suitable
Bachelor "Mechatronics"	4th semester	5th semester	suitable
Master "Mechanical Engineering and Mechatronics"	unconstrained	unconstrained	student's responsibility

Hence, lab exercises with closed-loop controller circuit are only suitable for Bachelor students of mechatronics. With Master students it is in their own responsibility to have appropriate previous knowledge if they want to participate in corresponding hydraulic Master modules.
Furthermore, technical skills regarding measurement technology should be integrated into the exercises. Usually with hydraulics this is pressure and flow rate measurement. These options are implemented in the training system a priori. In addition, rotational speed measurement was taken into account. Here, a simple measurement application consisting of power supply, speed sensor and oscilloscope has to set up by the students (see Figure 2). Hence, students learn to create measurement systems on their own instead of using just plug-and-play technology.

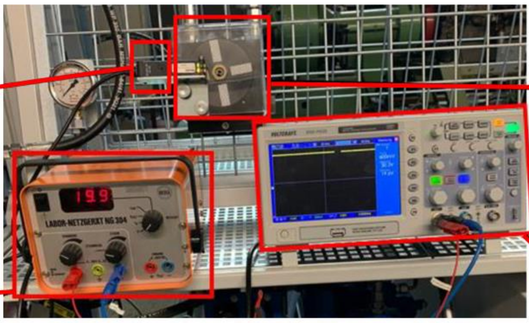

Fig. 2. Setup of speed measurement

As the rotating disk of hydro motor has 4 reflectors as visible in Figure 2, the frequency of the measured signal is four times the rotation frequency (see Figure 3). This has to be taken into account while evaluating.

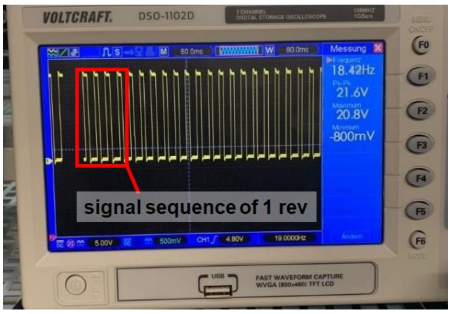

Fig. 3. Frequency signal of speed measurement

Further options for training measurement skills could be analysis of controller signals like given values and actual values via oscilloscope. Here students will learn to set proper sampling rates, scaling of display axis and to operate with trigger signals to start/stop data collection. Experience confirms that especially these skills could only be learned "do it yourself".

Based on all these requirements a set of 12 challenging exercises was defined as shown in Table 3. Additionally, the classification to the different curricula is included.

Table 3: Challenging exercises and classification

<table>
<tr><th rowspan="2">Exercise</th><th rowspan="2">Duration (min)</th><th colspan="3">classification</th></tr>
<tr><th>Bachelor Mech. Eng.</th><th>Bachelor Mechatron.</th><th>Master</th></tr>
<tr><td>Manual hydraulics (old training system)</td><td>30</td><td>yes</td><td>yes</td><td>no</td></tr>
<tr><td>Simple circuit with solenoid valves (hydraulic and electric installation)</td><td>40</td><td>yes</td><td>yes</td><td>no</td></tr>
<tr><td>Basic circuit with servohydraulics (connection of valve and controller as well as measurement of valve characteristic)</td><td>60</td><td>yes</td><td>yes</td><td>yes (introduction)</td></tr>
<tr><td>BIBB-exercise differential cylinder</td><td>20</td><td rowspan="2">yes (option)</td><td rowspan="2">yes (option)</td><td>no</td></tr>
<tr><td>BIBB-exercise homokinetic cylinder</td><td>20</td><td>no</td></tr>
<tr><td>BIBB-exercise hydro accumulator</td><td>30</td><td rowspan="2">yes (option)</td><td rowspan="2">yes (option)</td><td>no</td></tr>
<tr><td>BIBB-exercise load unit</td><td>30</td><td>no</td></tr>
<tr><td>Circuit with two cylinders in parallel/serial arrangement</td><td>40</td><td rowspan="2">yes (option)</td><td>no</td><td rowspan="2">yes (option if no previous knowledge)</td></tr>
<tr><td>Circuit with electrical pressure control</td><td>30</td><td>no</td></tr>
<tr><td>Analysis of hydro motor (pressure, pressure difference and flow rate including appropriate diagrams)</td><td>60</td><td>(perhaps option)</td><td rowspan="3">yes (option)</td><td>yes</td></tr>
<tr><td>Control of hydraulic cylinder with external sinus curve as given value (combination of microcontroller, servo controller, servo valve and cylinder)</td><td>40</td><td>(perhaps option)</td><td>yes</td></tr>
<tr><td>Automatic sequence of cylinder operation with velocity profile (fast motion, braking, slope timing)</td><td>50</td><td>no</td><td>yes</td></tr>
<tr><td>Closed loop controller circuit with load dependent positioning accuracy</td><td>80</td><td>no</td><td>no</td><td>yes</td></tr>
<tr><td>Approximate total lab time</td><td>---</td><td>210 - 220
(250 - 280)</td><td>220 - 240</td><td>290
(360)</td></tr>
</table>

For the two Bachelor studies total lab time results in 210 to 240 minutes. According to 1 ECTS for the whole lab exercises this duration for just the hydraulic part is reasonable. Hence, hydraulic lab exercises could be done in one part, e.g. one afternoon from 2 to 6 PM. On the other hand splitting lab exercises into two shorter sessions of about 2 hours is possible, too. This gives the student more flexibility in matching the lab exercises to their individual schedules.
For Master studies at minimum lab time of nearly 5 hours is necessary. As Master students do the more complex lab exercises combined with project work as examination type this longer time is absolutely necessary and appropriate. Master students should merge deeper into the hydraulic matter driven by a higher fraction of intrinsic motivation.
For all exercises a first version of single instruction manuals were prepared. Single instruction manuals were chosen as this gives more flexibility regarding varying lab exercises between different

studies and/or consecutive years. The content and structure are very alike the delivered manuals. However, all information regarding safety at work and avoidance of accidents are summarized in one common document to safe space and if printed out to safe paper.

6. Conclusion and Future Work

New technologies intruding into fluid technology made it necessary to adapt the hydraulic engineering education. Based on a comprehensive literature review of nearly 30 actual scientific publications requirements for a new training system were defined. Finally a new training system was purchased. Together with the training system a set of more than 40 basic lab exercises covering solenoid valves, servo valves and closed loop controller circuits were delivered. Out of this pool of exercises 12 enhanced lab exercises were developed to cover needs of different curricula involved into hydraulic engineering education. For all enhanced lab exercises appropriate hand-outs were prepared.
Future steps will be to test all the enhanced exercises with corresponding student groups. All student groups have to fill out feedback questionnaires. Additionally, the supervising staff members have to give feedback, too. After at maximum of two optimization loops of mentioned kind, a final set of lab exercises for all curricula involved should be established. Nevertheless, if necessary new technologies should be integrated into curricula respectively lab exercises as fast as possible.
Another option that should be taken into account is, with actual available training set industrial focused hydraulic training is possible, too. This might be of interest in context of new degree programs like “professional training and academic studies”. The system of education seems to be very volatile in this context, actually.

References

[1] Chondros, T.G. “Archimedes life works and machines.” *Mechanism and Machine Theory* 45, no. 11 (2010): 1766-1775.
[2] Fabre, A.-J. "Pneumatic Machines in Antiquity (Air as Source of Energy in the Treatise on Pneumatics of Heron of Alexandria)." *Analecta Historico Medica* (2008): 67-70.
[3] Drumea, P., C. Dumitrescu, I. Bordeasu, L. Vaida, and D. Opruta, “Trends in the Development of Hydraulic Drives.” Paper presented at the 2018 International Conference on Hydraulics and Pneumatics, HERVEX 2018, Baile Govora, Romania, November 7-9, 2018.
[4] Majdic, F. “Possibilities and Challenges on the Field of Water Hydraulics.” Paper presented at the 2019 International Conference on Hydraulics and Pneumatics, HERVEX 2019, Baile Govora, Romania, November 13-15, 2019.
[5] Popovici, I. A., M. Savaniu, O. Tonciu, M Culcea, and A. Teodorescu. ”Various Operation Mode of Construction Machinery Using Energy Obtained from Renewable Sources.” Paper presented at the 2022 International Conference on Hydraulics and Pneumatics, HERVEX 2022, Baile Govora, Romania, November 9-10, 2022.
[6] Rivera, E. F., E. E. Morales, C. C. Florez, and R. M. Toasa. “Development of an Augmented Reality System to Support the Teaching-Learning Process in Automotive Mechatronics.” Paper presented at the 8th International Conference on Augmented Reality, Virtual Reality and Computer Graphics, AVR 2021, Virtual Event, September 7-10, 2021.
[7] Antonya, C., F. Girbacia, C. Postelnicu, D. Voinea, and S. Butnariu. “Saliency Detection in a Virtual Driving Environment for Autonomous Vehicle Behaviour Improvement.” Paper presented at the 8th International Conference on Augmented Reality, Virtual Reality and Computer Graphics, AVR 2021, Virtual Event, September 7-10, 2021.
[8] Montalvo-Lopez, W., P. Catota, C. A. Garcia, and M. V. Garcia. “Development of a Virtual Reality Environment Based on the CoAp Protocol for Teaching Pneumatic Systems.” Paper presented at the 8th International Conference on Augmented Reality, Virtual Reality and Computer Graphics, AVR 2021, Virtual Event, September 7-10, 2021.
[9] Sefu, S. M., and B. A. Tudor. “Intelligent Hydraulics Using Artificial Intelligence.” Paper presented at the 2022 International Conference on Hydraulics and Pneumatics, HERVEX 2022, Baile Govora, Romania, November 9-10, 2022.

[10] Savaniu, M. I., O. Tonciu, R. Panaitescu-Liess, C. Sescu-Gal, M. Culcea, and A. R. Sasu. “Aspects of the Use of AI (Artificial Intelligence) Technology in Construction Equipment Management.” Paper presented at the 2023 International Conference on Hydraulics and Pneumatics, HERVEX 2023, Baile Govora, Romania, November 8-10, 2023.
[11] Lovrec, D. “Education in the Field of Fluid Power Technology – Challenges, Opportunities and Possibilities.” Paper presented at the 2019 International Conference on Hydraulics and Pneumatics, HERVEX 2019, Baile Govora, Romania, November 13-15, 2019.
[12] Banesz, G., A. Haskova, and D. Lukacova. "Pneumatic and hydraulic systems in tertiary education." Paper presented at the 2018 IEEE 12th International Conference on Application of Information and Communication Technologies, AICT 2018, Almaty, Kazakhstan, October 17-19, 2018.
[13] Rojas Suarez, J. P., J. A. Pabon Leon, and M. S. Orjuela Abril. "Development of an electro-pneumatic system for the practical training of pneumatic processes in the university environment." *Journal of Physics: Conference Series* 2073 (2021): 012016.
[14] Azaka, O. A., K. U. Igboka, A. A. Okafor, and C. P. Odeh. "Design and development of a laboratory scale hydraulic arm for engineering education." *Unizik Journal of Technology, Production and Mechanical Systems (UJTPMS)*, Maiden Edition, 2023.
[15] Pate, K., J. Garcia, and F. Breidi. “Enhancing the Learning Experience of Engineering Students Through Digitized Interactive Tools.” Paper presented at the 2021 ASEE Annual Conference, Virtual Meeting, July 26-29, 2021.
[16] Desai, S. R. "Impact of Active Learning Methods on Students’ Learning and Course Results." *Journal of Engineering Education Transformations* 35, no. 3 (January 2022): 133-142.
[17] Chen, W., H. Wang, and L. Zheng. “Research on the Teaching Method Reform of Automobile Related Courses: Take the Vehicle Hydraulic System as an Example.” Paper presented at the 7th Annual International Conference on Network and Information Systems for Computers, ICNISC 2021, Guiyang, China, July 23-25, 2021.
[18] Sheng, X., and X. Hu. “Teaching Method Reform of the Hydraulic and Pneumatic Course Based on Engineering Application Cases.” Paper presented at the IEEE Workshop on Advanced Research and Technology in Industry Applications, WARTIA 2014, Ottawa, Canada, September 29-30, 2014.
[19] Xu, L., L. Cai, and X. Nan. “Research on Teaching Reform of Hydraulic and Pneumatic Transmission Based on OBE.” Paper presented at the 7th International Conference on Education, Management, Computer and Medicine, EMCM 2016, Shenyang, China, December 29-31, 2016.
[20] Sandyk, I., M. Müür, V. Kuts, Y. Bonderenko, S. L. Pizzagalli, and T. Rüütmann. “Pneumatics Laboratory Interactive Educational Experience Development.” Paper presented at the 19th International CDIO Conference, Trondheim, Norway, June 26-29, 2023.
[21] Peng, P., Y. Sun, L. Tang, and H. Yang. “Teaching reform plan for hydraulic and pneumatic transmission courses based on experimental platform.” Paper presented at the 3rd International Conference on Humanities, Wisdom Education and Service Management, HWESM 2024, Atlantis Press, 2024.
[22] Perez-Sanchez, M., and P. A. Lopez-Jiminez. "Continuous Project-Based Learning in Fluid Mechanics and Hydraulic Engineering Subjects for Different Degrees." *Fluids* 95, no. 5 (June 2020): 1-15.
[23] Assaf, H., and A. Vacca. “Hydraulic Trainer for Hands-on and Virtual Labs for Fluid Power Curriculum.” Paper presented at the 17th Scandinavian International Conference on Fluid Power, SICFP’21, Linköping, Sweden, May 31 – June 2, 2021.
[24] Ji, T., B. Ren, and S. Huang. "Hydraulic and Pneumatic Transmission Three-Dimensional Virtual Training System Research." *Journal of Physics: Conference Series* 2219 (2022): 012064.
[25] Ostrowski, I., J. Mozaryn, J. Wang, and D. Cukier. "Lesson Learned from Semester of Online Teaching of Automation Using Simulators." *IOP Conf. Series: Materials Science and Engineering* 1016 (2021): 012005.
[26] Song, J., Z. Chen, Y. Li, and J. Liu. "Teaching System of Hydraulic Transmission Combined with Virtual Reality Technology." *Information* 14, no. 147 (2023): 1-14.
[27] Ismail, A. M. M., N. A. S. Manssor, and H. Abu Kasim. "The Basic of Hydraulic and Pneumatic Teaching Innovation Kit for Application in Fluid Power Technology Course." *Innovative Teaching and Learning Journal* 2, no. 1 (November 2018): 26-36.
[28] Soad, M. M., I. Hanizam, and H. I. Siti. "Design and Development of Portable Pneumatic with Augmented Reality for Teaching and Learning Purposes." *Journal of Advanced Research in Applied Mechanics* 74, no. 1 (2020): 1-9.
[29] Caiza, G., M. Riofrio-Morales, A. Robalino-Lopez, O. R. Toscano, M. V. Garcia, and J. E. Naranjo. “An Immersive Training Approach for Induction Motor Fault Detection and Troubleshooting.” Paper presented at the 8th International Conference on Augmented Reality, Virtual Reality and Computer Graphics, AVR 2021, Virtual Event, September 7-10, 2021.