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Establishing student projects - About our approach in offering contacts outside of lectures and exercises

T. Schulze*, J. Weber, B. Beck, J. Weber

Chair of Fluid-Mechatronic Systems (Fluidtronics), Institute of Mechatronic Engineering, Faculty of Mechanical Science and Engineering, TU Dresden

Abstract

The decline in student numbers in mechanical engineering contradicts the existing shortage of skilled workers and the urgent need of the industry for qualified graduates. Particularly noticeable is the decreasing attendance in the courses of the Chair of Fluid-Mechatronic Systems at TU Dresden from 2015 to 2022. To counteract this trend and attract more students, three long-term application examples were developed as part of student projects: a hydraulic cargo bike, a low-pressure hydraulics demonstrator, and fluid technology components manufactured using 3D printing.
These projects have helped increase the attractiveness of the department by offering practical experiences that benefit both students and the industry. The students were able to deepen and apply their technical skills, develop project management and problem-solving abilities, and enhance their social skills such as teamwork, independent work, creativity, and innovation. Within these practical offerings, several student projects have already been completed, more students have been attracted to the field, and the public visibility of the department has been improved.

Der Rückgang der Studierendenzahlen im Maschinenwesen steht im Widerspruch zum bestehenden Fachkräftemangel und dem dringenden Bedarf der Industrie an qualifizierten Absolventinnen und Absolventen. Auffällig ist ebenso die geringe Präsenzteilnahme an den Lehrveranstaltungen. Um diesem Trend entgegenzuwirken und mehr Studierende zu gewinnen, wurden an der Professur für Fluid-Mechatronische Systemtechnik der TU Dresden im Rahmen von Studienarbeiten drei langfristig nutzbare Anwendungsbeispiele entwickelt: ein hydraulisches Lastenfahrrad, ein Niederdruck-Hydraulik-Demonstrator und mittels 3D-Druck hergestellte Fluidtechnik-Komponenten.
Diese Projekte haben dazu beigetragen, mehr Studierende mit interessanten Studienarbeiten für die Fluidtechnik zu begeistern und durch erlebbare Anschauungsmaterialien die öffentliche Sichtbarkeit des Fachgebietes zu erhöhen. Die Studierenden konnten praxisnahe Erfahrungen sammeln, ihre fachlichen Kompetenzen vertiefen und anwenden, Projektmanagement- und Problemlösefähigkeiten entwickeln sowie ihre sozialen Kompetenzen wie Teamarbeit, eigenverantwortliches Arbeiten und Kreativität sowie Innovationsfähigkeit ausbauen.

*Corresponding author: Tobias.Schulze2@tu-dresden.de

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1. Decline in student numbers

In the years up to 2021, a significant decline in student numbers can be observed in Germany and at *TU Dresden* in particular. Fig. 1 shows the trend for all subject groups up to the academic year 2023/2024. Across Germany, the number of students enrolled in the first semester of higher education has fallen slightly by 6% since 2015, from 506,580 to 481,469. In comparison, the decline at *TU Dresden* is almost twice as large at 11%: the number of students in their first semester of higher education fell from 5,514 in 2015/16 to 4,484 in 2021/22 and reached 4,881 in 2023/2024.

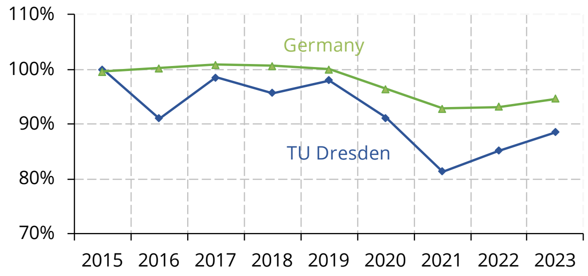

Fig. 1: Students in their first semester of higher education in Germany [1] and at TU Dresden [2] since 2015[1].

About one third of all students are enrolled in Engineering sciences (according to [3, 4], defined since 2015). In Germany in 2024, 27% of the first year students started in engineering sciences. The same year at *TU Dresden*, 35% of all students started within an engineering subject (electrical engineering and information technology, computer science, mechanical engineering, architecture, civil engineering, hydrosciences, transport engineering and business informatics) [2].

From 2015 to 2023, the number of first-year students in this subject group fell by 13% across Germany, while it fell by 30% at *TU Dresden*. This shows that interest in engineering at *TU Dresden* is declining more sharply than the national average.

A detailed analysis of the individual faculties at *TU Dresden* in Fig. 2 shows different developments. At 63%, the *Faculty of Mechanical Engineering* recorded the sharpest decline in new students. At the *Faculty of Electrical Engineering and Information Technology*, there were 27% fewer new students, while the *Faculty of Computer Science* even recorded an increase of 29%.

These developments illustrate the need to take targeted measures to increase the attractiveness of *TU Dresden* and the *Faculty of Mechanical Engineering* in particular to attract more students.

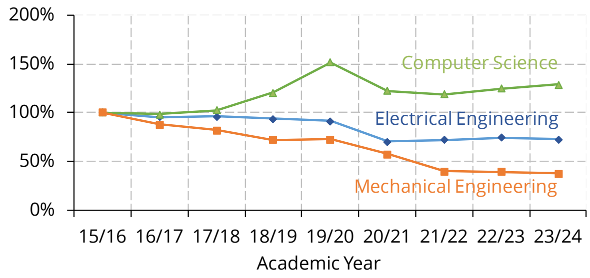

Fig. 2: First-year students at the Faculty of Engineering at TU Dresden since 2015/16 [2].

2. Developments and challenges at the chair

The *Chair of Fluid-Mechatronic Systems* offers courses in the main study program (semesters 5-9 of the diploma degree programs *Mechanical Engineering, Mechatronics* and *Teaching at Vocational Schools*) with different thematic focuses, which include both theoretical and practical phases. The largest course offered by the professorship is *"Fluid power components and system control"*. It comprises of 2 semester hours per week (SWS) of lectures and 1 SWS of tutorials. It is a compulsory module in the 5th

[1] *Notes on the evaluation of the statistics:*

- *The federal statistics refer to the statistical year. Thus, for 2013, first-year students from summer 2013 and winter 2013/14 are counted. In contrast, the number of first-year students at TU Dresden is shown by academic year. In the academic year 2013/14 (shown here as 2013), first-year students from the winter semester 2013/14 and summer semester 2014 are counted including students on leave of absence. This difference evens out over time.*
- *The term "first-year students" refers to students who are starting from scratch. Students in their first semester are recorded as a further key figure. This also includes those who had already studied another subject before starting their new degree course. In engineering at the TU Dresden, this figure is approx. 50% higher than the number of "first-year students" starting their studies from scratch.*

semester of the Diploma and Bachelor's degree courses in *Mechanical Engineering* (*General and Constructive Mechanical Engineering* (*AKM*), *Automotive and Rail Vehicle Engineering* (*KST*)) and in the *teaching* degree course *at vocational schools (Production Engineering))*. As a result, students with different prior knowledge and interests take part, while at the same time a wide variety of academic topics are covered.

Despite its importance and breadth, there has been a clear decline in student numbers. Fig. 3 shows the trend of students enrolled in the course compared to the total number of newly enrolled students in mechanical engineering at *TU Dresden*. A relative decrease of 54% from 2015 to 2023 in the course correlates with the general trend at the *Faculty of Mechanical Engineering* of 61% from 2013 to 2021. This means that students who opted for the field of mechanical engineering at the start of their studies also took part in the course to the same extent. Possible reasons for this are:

- The *Fluid Engineering* specialization is only offered at two universities in Germany (*TU Dresden*, *RWTH Aachen*).
- The course is compulsory for *AKM* and *KST* students.
- Fluid technology is widely used in various industrial sectors such as aircraft and mobile hydraulics, sealing technology or control engineering.

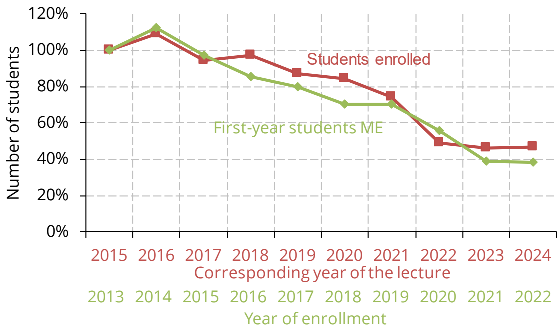

Fig. 3: Number of students enrolled at the TU Dresden. Faculty of Mechanical Engineering (ME) and at the course "Fundamentals of Fluid Power Drives and Controls" in comparison (October of each year).

Fig. 4 shows the number of enrolled students compared to actual exam participation from the winter semester 2015/16 to the winter semester 2023/24. In addition to the decline in student numbers already mentioned, the graph shows the comparison between total number of students enrolled on the course and number of students who participate in the final exam. What is striking is the increased decline in exam participation up to the winter semester 2021/22, where there is the greatest discrepancy between students registered for the course and those actually taking the exam.

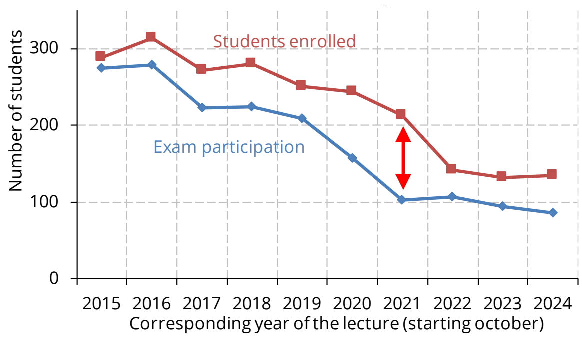

Fig. 4: Participation in the subject "Fundamentals of Fluid Power Drives and Control Systems" - enrolment vs. exam participation.

This dip could be due to various factors, which will be examined in more detail below. In order to halt the decline in student numbers and especially exam participation, various measures were developed and implemented at the professorship from spring 2022, e.g. the establishment of student working groups (WGs), which are described in chapter 3.

The initial results show that the proportion of exam participation from the winter semester 2022/2023 is back at the original level of 2016/2017 and 2018/2019. This suggests that the measures taken appear to have been successful, although numerous other influencing factors could not be considered. For example, according to analyses by Hillebrecht [5], in addition to teaching quality, the quality of the study organization, (supra-)institutional aspects, socio-demographic characteristics or professional activity alongside studies can also influence the course of study and examination participation. According to Hillebrecht, however, further comprehensive observations and standardized measurement instruments are currently required to better understand their influence on academic success and to design future measures in a more targeted manner.

It is clear that – in addition to the number of students – the current situation and the background of the students currently in the main study program must also be taken into account. This also includes, for example, the effects of the coronavirus pandemic. The low attendance rate during the corona pandemic may have caused deficits in teaching and learning behavior as well as in contact between students and lecturers. The quantification of this influence based on the hybrid course "Fundamentals of fluid power drives and control systems" offered in winter semester 2021/22 shows that, according to Fig.4 , the greatest discrepancy between students enrolled in the course and those actually taking part in the exam has so far existed here. Fig. 5 shows the attendance at lectures and exams over the course of the semester, which was recorded manually for each lecture approx. 20 minutes after the start: Although 213 direct students were enrolled, only 131 attended the lecture at the beginning of the semester. In addition, there was a steady decrease over the course of the semester to around 50 students at the end of the semester. Interestingly, there were 154 registrations for the written exam (25.1.2022), but in the end only 103 (68%) actually took part (28.02.2022).

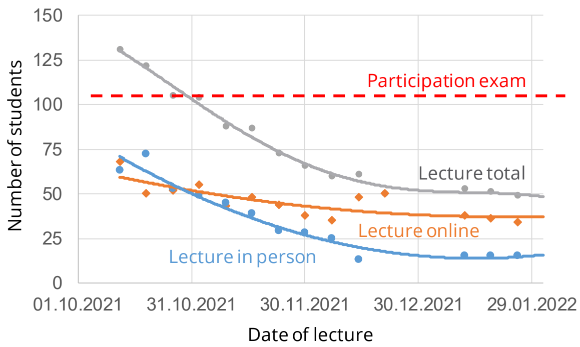

Fig. 5 : Participants in the subject "Fundamentals of Fluid Power Drives and Control Systems" (course and written exam) in winter semester 2021/22.

In the final internal teaching evaluation, possible reasons for the high withdrawal rate were discussed. As many students only decided not to take part a few days before the exam, they may not have felt sufficiently prepared. In addition, the intrinsic and extrinsic motivation of the students for the specific subject area of fluid mechatronics could have decreased. In both cases, a causal influencing factor may be the loss of contact between teachers and students, which was particularly evident during the coronavirus pandemic.

In addition, these developments also have concrete consequences for the professorship: the falling student numbers are reflected, for example, in fewer applications for student research projects and SHK activities.

3. Countermeasures at the professorship - idea of the student working group

The Chair's experience to date shows that

- direct contact with students throughout the entire study period,
- opportunities for networking and mutual exchange as well as
- additional offerings beyond the traditional curriculum (e.g. excursions, guest lectures, conference participation)

are essential for arousing interest in the subject area, highlighting career prospects and, in particular, increasing motivation for active participation in courses.

In addition, scientific findings show that self-regulated learning (SRL) can significantly increase student motivation. Theoretical models emphasize the role of self-regulation in motivation and learning success. Empirical studies show that SRL improves performance and motivation by promoting autonomy and self-efficacy, and strengthens students' ability to set and achieve their goals. [6,7,8,9]

In order to transfer and apply these findings to teaching at the professorship, the following methods and associated sub-goals were identified:

- To create a collaborative learning environment for students by offering working groups (WGs) where they can support each other and work together on projects.
- To illustrate the relevance of what has been learned through practical, realistic application examples and to arouse/increase students' curiosity and general interest in the subject area.

- Using self-regulated learning through experimentation to provide students with more opportunities to test theoretical concepts practically/actively and explore them independently, which promotes their motivation and understanding.

In summary, the combination of self-regulated learning, practical application examples and networking in student working groups can significantly increase student motivation and understanding. These approaches not only promote autonomy and self-efficacy, but also prepare students better for applying the lecture content and taking the exams during the semester. Examples such as the existing university groups *Akaflieg*, *TURAG* and *Elbflorace* at *TU Dresden* show that such concepts can be successfully implemented and promote the link between studies, research and industry.

Thanks to funding from the *Faculty of Mechanical Engineering* as part of teaching/learning projects, the professorship was able to launch a project in June 2022 that addresses the challenges outlined above with regard to the declining number and participation of students at the *Chair of Fluid-Mechatronic Systems Engineering*.

The primary aim of the project was to improve teaching and to increase general interest and curiosity in the subject area through practical application examples. The aim was to reduce the withdrawal rate from examinations and motivate a higher proportion of enrolled students to actively participate in courses offered by the professorship. In addition, student exchange ("help for self-help") and contact with lecturers should be promoted to receive direct feedback on the quality of teaching.

In the long term, the project should halt or counteract the decline in student numbers. This will be achieved by continuously improving our didactic teaching methods ("making teaching more attractive") and by establishing cross-semester-spanning student research projects and assignments. Demonstrators will be developed together with students that can be used as 'tangible fluid technology' to increase the visibility of mechanical engineering, particularly fluid mechatronics. They can be used during lectures and tutorials in all of the professorship's courses as well as in a general social and school context, for example in school projects or presentations on campus and at public events such as the *Dresden Science Night*.

A central component of the project was the preparation of a student working group consisting of a core team of 4-12 students who are responsible for the conception, development and implementation of various projects within the group. They are supported by one or two research assistants. The aim was to develop application-oriented, comprehensible demonstrators that make fluid technology topics "tangible" in practice.

So far, three application examples have been tested as part of the project, which are explained in detail in the following chapters:

1. A **cargo bike** with a hydrostatic drive instead of a chain drive,
2. a demonstrator for **low-pressure hydraulics** in the 0 to 50 bar range and
3. the evaluation of **3D printing** as a manufacturing method for fluid technology components in the low-pressure range.

4. Application example "cargo bike"

The concept of the *cargo bike working group* is based on the "National Fluid Power Vehicle Challenge" in the USA [10], in which student working groups equip bicycles with hydrostatic drives within a semester and test them in various disciplines. Fig. 6 shows two winners from the 2017/18 season.

In contrast to the USA, where the teams change after each semester and development begins anew, the professorship's *cargo bike* working group pursues the goal of building a functional demonstrator within one semester and continuously developing and optimizing it across semesters.

The concept of the working group provides for a multi-stage structure: A core team of students from various fields of study and specializations from the entire range of courses offered by the professorship (see *chapter 2, p.2*) is largely responsible for the conception, development and implementation of the project. Within the working group, it is possible to complete activities either individually or in groups.

In addition, well-defined detailed questions can be worked on separately - e.g. as part of student research projects or final theses.

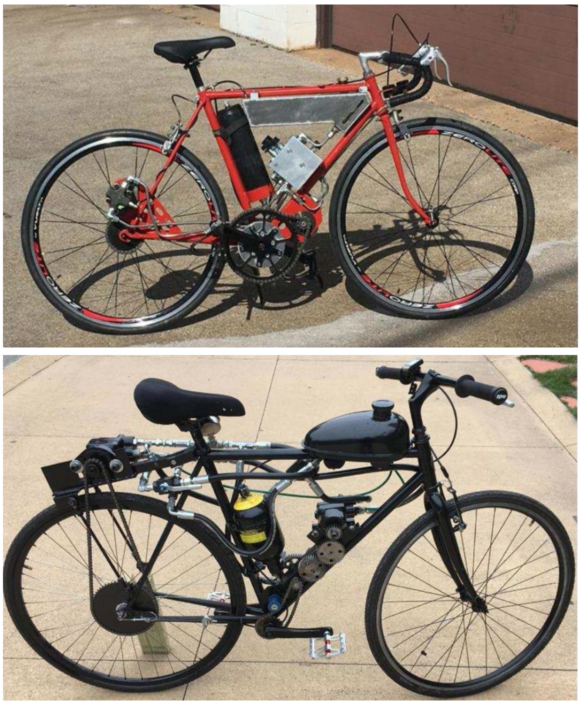

Fig. 6: Hydraulic bicycle at Cleveland State University (top) and the Milwaukee School of Engineering (bottom) [10].

In terms of technical aspects and development priorities, hydraulic transmissions enable traction-free, stepless gear ratios as well as flexible power transmission and energy storage.

The knowledge about the properties of hydraulic transmissions, their design and dimensioning, imparted in the lectures and exercises, can be put into practice with this application example. In addition, further development focuses on both mechanical engineering and fluid technology in particular, such as

- concept development,
- modeling and simulation,
- system design and
- experimental tests and optimization.

In addition to the technical aspects, the working group also promotes non-technical (social and interdisciplinary) skills such as teamwork, project management, communication and presentation skills as well as sales activities. Among other things, the concept of the AG provides for

- experiences and results are presented to other members of the working group as well as the professorship at fixed intervals and
- the demonstrator is supervised and presented by students at public events such as laboratory tours or the *Dresden Science Night*.

In addition, a versatile use is conceivable, e.g.

- as a rental bike for transportation and errands in the campus catchment area,
- as a basis for discussing new technologies and business areas with sponsors and industrial partners or
- as an example of use in lectures, exercises and teaching practicals for the practical explanation of lecture content.

For the integration of hydraulic transmission, the use of a cargo bike was identified as a technologically more promising basis in comparison to the use of weight-optimized everyday bikes with mature mechanical power transmission.

The aim of the working group's previous work was to design and dimension drive concepts and to investigate them on the basis of simulations. As a result of the design development process according to VDI 2221, a hydraulic 7-speed gearbox consisting of a toothed ring pump and three independently engageable orbital motors as well as a basic concept for a hybrid drive with hydraulic accumulator were developed. Both systems were set up and investigated as a 1D system simulation model.

As a result of the work, a system variant is now available as a rough design. For further development, suitable motors and pumps must be developed that function at very low speeds and high torques and can also be integrated into the cargo bike.

The project idea was well received in the industry. The company CUBE [11] provided a frame for the cargo bike, which forms the basis for the work that has been carried out and will be carried out in the future with regard to the installation of the hydraulic drive (Fig.7)

Despite intensive advertising measures, however, not enough students were found to set up a working group. Only two student research projects focusing on *hydraulic cargo bikes* have been completed so far to achieve the development results described above. Several factors could explain the low level of participation: The complete conversion was perceived as too difficult, which deterred potential interested parties.

Fig. 7: The chair's cargo bike as the basis for installing the hydraulic drive.

In addition, a hydraulic bike does not initially offer any significant advantages over e-bikes due to its principle, i.e. without specific optimization of the drive technology. Our hope that the enthusiasm for hydraulics would compensate for this disadvantage was not fulfilled. In addition, due to the low number of students overall, there were only a few interested parties, as other projects such as 3D printing or low-pressure hydraulics were more attractive.

5. "Low-pressure hydraulics" application example

Similar to the concept of the hydraulic cargo bike, the design and control of large industrial hydraulic systems can be reproduced on a small scale and further developed independently in the *low-pressure hydraulics* application example. The aim of the example project was to develop a demonstrator that can be operated independently in the low-pressure range using simple hydraulic circuits and controls based on single-board computers (e.g. Raspberry PI) or microcontrollers (e.g. Arduino or ESP32).

The advantage of self-sufficient systems designed in this way is that they can be easily scaled in terms of their complexity and difficulty and can therefore be adapted to different levels of knowledge.

For example, simple circuits can be used for student research projects and internships or more complex systems for dissertations. At the same time, the interaction between different domains such as mechanical structure, hydraulic system and electrical control can be clearly illustrated. In the specific example, this means that the mass can be moved using gesture control. This makes it possible to visually and acoustically experience how the motor rotates with the pump and how the cylinder moves.

The basic technology required for the construction could be procured from funds for teaching/learning projects of the *Faculty of Mechanical Engineering*, which underlines the importance of financial support for such projects. To date, five student projects have already worked on a closed hydraulic compact drive (Fig. 8). The group was able to work on a common topic, while each student was given an individual sub-task. For example, the drive system for the low-pressure hydraulic system was developed jointly, with one student developing the hydraulic structure and another the control system.

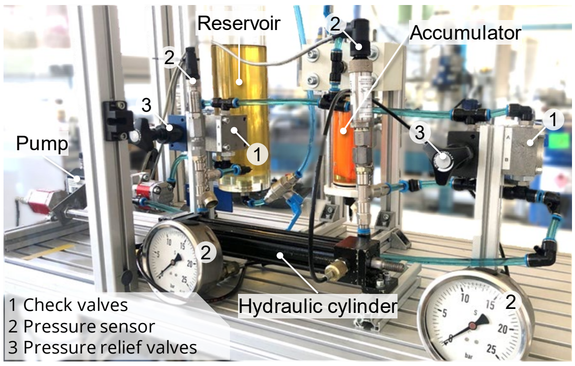

Fig. 8: Demonstrator of a closed hydraulic compact drive.

The developed hydraulic compact drive was presented by students of the working group at the *Dresden Science Night* and could also be tried out by the guests themselves. The feedback was very positive. This increased interest in and understanding of fluid power drives among both target groups.

6. Application example "3D printing"

Current industrial applications already use components manufactured using 3D printing, as these are lighter, more compact and more energy-efficient than traditionally manufactured components [12]. As a modern manufacturing technology, 3D printing offers students another interesting field of technology within fluid power: through cost-efficient prototyping, for example of complex valve or channel geometries, and rapid iteration, they can gain practical experience and deepen their knowledge of the fundamentals of fluid technology and the functioning of hydraulic components.

In a total of three student research projects to date, the students have used the 3D printer procured with funds from the *Faculty of Mechanical Engineering* for teaching/learning projects to produce various hydraulic components from industrial applications. They then examined these regarding the suitability, possible applications and limits of the new production technology under special fluid technology aspects such as tightness or pressure resistance (Fig. 9). After a technical briefing, the students were able to work independently and implement their own ideas.

The application of a modern and innovative manufacturing technology in conjunction with the independent execution of experiments and testing of various (own) designs was rated as very positive and motivating by the students. In addition, the developed components can be used as demonstrators in teaching or at public events to illustrate fluid technology.

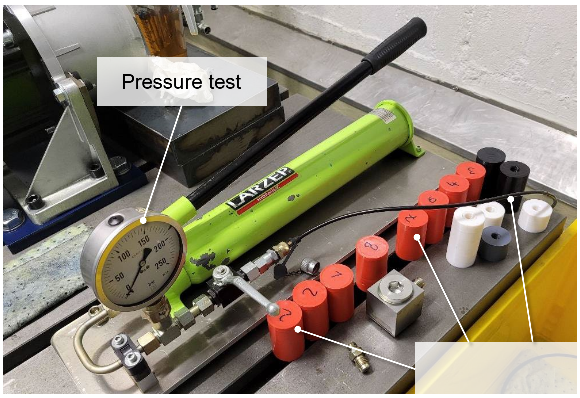

Fig. 9: Pressure test for additively manufactured test specimens with different pressure settings and materials.

7. Conclusion

The *TU Dresden*, in particular the *Faculty of Mechanical Engineering*, has been confronted with a significant decline in student numbers in recent years. In addition, there are high withdrawal rates for examinations, as observed at the *Chair of Fluid-Mechatronic Systems Engineering*. These developments have negative consequences, such as a lack of support in research and teaching.

Consequently, there is an urgent need for action to counteract this trend and increase the attractiveness of *Fluid Power Technology*. This includes the introduction of practice-oriented teaching methods, the promotion of self-regulated learning through student working groups and increasing the visibility of the subject area. The transfer of industrial application examples into a comprehensible and manageable size is a useful building block on this path. Ideally, this should be done by the students themselves, but – as the experiences from the projects presented shows – it requires a considerable amount of support from academic staff. The example of the *cargo bike* working group, which was not accepted by the students as expected, illustrates the need for further analysis and adjustments in order to achieve positive effects in the long term.

Nevertheless, initial successes are visible, particularly in the application examples of *3D printing* and *low-pressure hydraulics*. These projects show how innovative approaches can be implemented in teaching to increase student interest and motivation. For example, the presentation of the low-pressure hydraulics demonstrator at the *Dresden Science Night* aroused widespread interest, and the positive feedback speaks for its success. A total of ten student research projects were completed in 2023 and 2024 as part of the example projects presented. With a total of around 25 student research projects at the professorship each year, this is a good result. In addition, further company contacts have been established to support the projects.

The next steps include further topics for student research projects, the derivation of specific exercise and lecture content and the further development of the demonstrators.

Acknowledgements

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