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Term paper on the design and construction of a gear shaft

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Abstract

In the subject of Machine Elements, the teaching content covered in lectures, exercises, and calculation tutorials are supplemented by a term paper to be completed over the course of the semester, in which the knowledge gained on the design and construction of machine elements is to be applied independently to the design of an assembly. Support for the term paper was supplemented by the option of weekly submission and correction of interim results, which cannot be done manually due to the large number of calculations and interim results required and the number of students participating. The implementation of the term paper assessment, the associated challenges, and the experience gained are summarized below.

Im Fach Maschinenelemente wird die Vermittlung des Lehrinhalts in den Vorlesungen, den Übungen und dem Vorrechnen durch die semesterübergreifende Erstellung einer Belegarbeit ergänzt, in dem die gewonnenen Erkenntnisse zur Auslegung und Gestaltung von Maschinenelementen selbständig zur Gestaltung einer Baugruppe eingesetzt werden sollen. Die Betreuung der Belegarbeit wurde um die Möglichkeit einer wöchentlichen Abgabe und Korrektur von Zwischenergebnissen ergänzt, die aufgrund der Vielzahl an erforderlichen Berechnungen und Zwischenergebnissen sowie der Anzahl der teilnehmenden Studierenden nicht händisch erfolgen kann. Die Umsetzung der Belegbewertung, die damit verbundenen Herausforderungen und gesammelten Erfahrungen sind nachfolgend zusammengefasst.

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1. Machine Elements

At the Technische Universität Dresden third- and fourth-semester students learn the basic knowledge of machine elements that is important for mechanical engineering in three semester hours of lectures, two semester hours of exercises, and one semester hour of calculation tutorials in the summer semester. At the beginning of the winter semester, the lecture deals with the determination of load assumptions and strength calculations, which form the basis for further mathematical proofs for the various machine elements. Building on this, students learn the design procedure and basic rules for the construction of shafts, the design options for connections between shafts and hubs, and the calculation and design rules for bolted connections, springs, and couplings. The course then covers the design and dimensioning of roller bearings, plain bearings, and gear drives. The exercises serve to independently apply the knowledge learned through tasks on various topics. A detailed explanation at the beginning of the weekly classes enables students to quickly familiarize themselves with the topics, help them to understand the formulas and diagrams, and prepares them to work on the exercises independently. The calculation tutorials in the summer semester provide in-depth insight into how to find solutions using various calculation tasks.

In addition to the courses for the mechanical engineering program, the fundamentals of machine elements are offered as Design Theory for the mechatronics, renewable energy systems, economics, and textile and clothing technology programs. Due to the halving of the weekly semester hours compared to the module scope for the mechanical engineering program, only selected topics are covered in a reduced scope. It becomes particularly clear during the exercises that the prior knowledge that students can contribute varies greatly and must be taken into account when introducing the individual courses.

2. Term paper

For all the aforementioned degree programs, students must complete a term paper during the module, in which they apply and deepen their acquired knowledge to design and engineer an assembly consisting of a shaft with bearings, a gear, and a pulley (Fig. 1).

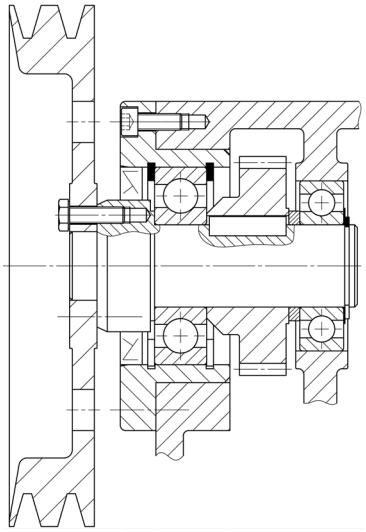

Fig.1: Excerpt from the drawing for the assembly

The assembly is already familiar to students of mechanical engineering from courses in the second semester. Depending on the first letter of their first and last names, students are given different specifications for the shaft material to be used, the bearing distance, the position of the gear wheel and the belt pulley, the power and the gear parameters. Based on this data, the first step in completing the term paper is to determine the forces acting on the gear wheel and the belt pulley and to calculate the resulting support reactions (Fig. 2). With the knowledge of the bearing forces, the bending moments, and the torque, a rough determination of the required shaft diameter in the area of highest stress can be made. For the minimum shaft diameter in this case, the feather key or shrink fit connection must be designed, a shoulder for the fixed bearing must be created by increasing the shaft diameter, and the bolted connection between the pulley and the shaft must be designed. Shaft shoulders and the feather key nut are critical areas for a fatigue-resistant shaft design, so that the fatigue strength must be verified at these two points on the shaft. Finally, the bearing service life for the fixed and loose bearings must be determined and, based on the geometric parameters developed, a production-oriented single part drawing and an assembly drawing of the assembly with a housing must be created.

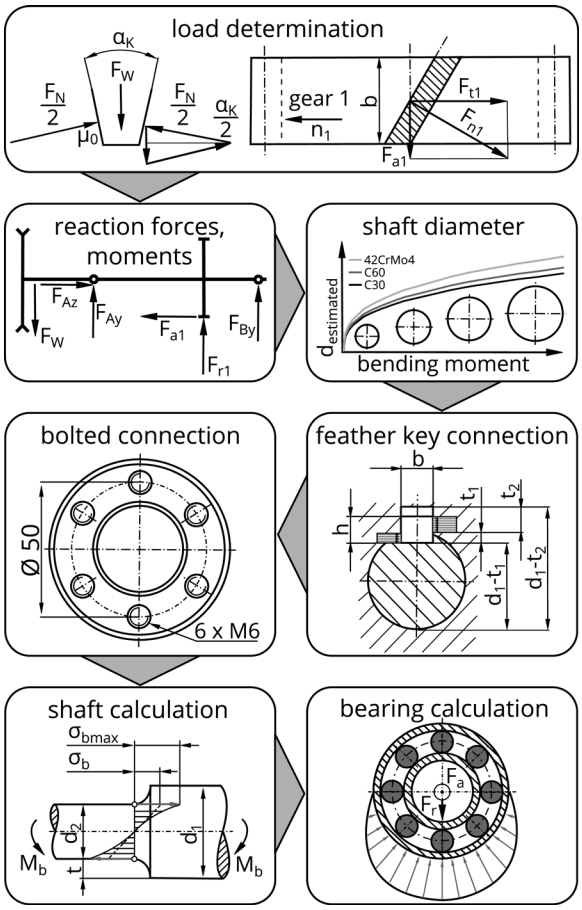

Fig. 2: Schematic sequence of processing

The term paper must be submitted with a complete documentation of the calculations, drawings, a parts list, and an assembly instruction. Support for the term paper is provided in the exercises, in a forum on the OPAL learning platform, and, in some cases, individually after classes, in personal discussions, and via email. Due to the long processing time over the entire module period, students have tended to start working on the term paper very late in the past, which made it difficult to carry out exercises, especially in the last few weeks before the deadline, due to the large number of questions that arose, and meant that the supervision of the term paper required an enormous amount of time concentrated in a short period. Several additional tutors were required to answer questions, especially in the Design Theory exercises.

3. Continuous course supervision

Driven by the high teaching and supervision workload at the end of each winter semester in the subject of Design Theory, the goal was to create a tool that would prompt students to use the content taught in the exercises as soon as possible to work on the subtasks of their term paper. This should enable students to deepen and consolidate the knowledge they have acquired in a timely manner, clarify open questions on the individual subtasks directly in the forum or during the class, ideally ensure comparable progress among all students, and help students avoid starting their work right before the deadline. As an incentive for students, a weekly interim check of the results is offered, but due to the more than 60 students enrolled, this cannot be done manually.

In order to implement the desired interim checks, the entire calculation process for the term paper is mapped in MATLAB, taking into account the variety of variants described above. In addition to entering formulas, it is necessary to implement tables for feather keys, bolted connections, tolerances, and bearings, as well as to programmatically map diagrams that cannot be described with formulas. Students are provided with a result overview in the form of an EXCEL spreadsheet in which the calculation results can be entered (Fig. 3). This file can be uploaded to the learning platform OPAL in a submission folder by a specified deadline.

The files must then be downloaded manually. The result overviews are stored in a complex folder structure in a compressed archive. MATLAB is used to automatically unzip these archives, create a list of students who have uploaded a file, load the result overviews individually, read out personal details and the essential input data, calculate the results for the respective term paper variant using this data, compare them with the entered values, and mark the correctness with red or green in the overview. At the same time, an evaluation table is created in which the results of the correction are saved for each student. After the overviews have been successfully corrected, the documents can be sent automatically by email using another script. If the correction process runs without errors, the handling of the EXCEL files is particularly computationally intensive, so that, depending on the available computing technology, the correction time is between 15 and 30 seconds per document. The scripts have not yet been optimized in terms of computing time.

Overview of results of the term paper

First name:	*fill in!*	Last name:	*fill in!*	Student-ID	*fill in!*

First name (1. l.)	
Last name (1. l.)	

a=	*0* mm
b=	*0* mm
c=	*0* mm

M_{tan}=	*0,00*	Nm, nominal
F_W=	*0,00*	N for M_{tan}
F_t=	*0,00*	N for M_{tan}
F_r=	*0,00*	N for M_{tan}
F_a=	*0,00*	N for M_{tan}

Bearing forces calculated based on input power:

Width of the bearing A:	*0,0* mm	Gear center - position 2	*0,0* mm

nominal load [N]				with operation factor				with impact factor [N]			
F_{Ax}=	*0,00*	F_{Bx}=	*0,00*	F_{Ax}=	*0,00*	F_{Bx}=	*0,00*	F_{Ax}=	*0,00*	F_{Bx}=	*0,00*
F_{Ay}=	*0,00*	F_{By}=	*0,00*	F_{Ay}=	*0,00*	F_{By}=	*0,00*	F_{Ay}=	*0,00*	F_{By}=	*0,00*
F_A =	*0,00*	F_B =	*0,00*	F_A =	*0,00*	F_B =	*0,00*	F_A =	*0,00*	F_B =	*0,00*

Fig. 3: Excerpt from the result overview

4. Practical application

In the winter semester of 2022/23, the checking of interim results was offered to students in the Design Theory course for the first time. To avoid problems when filling out and exchanging the data sheets, the template for entering the interim results is made available unprotected at the beginning. The first challenges arise in specifying the appropriate variant for checking name-dependent parameters. The variant number should be entered, but often the initial letters or a range of letters are entered, so that free entry is quickly replaced by a selection list. A similar procedure is required for entering the shaft and bore tolerances (e.g., H7) for recalculating the shrink fit. Further challenges arise from the use of a period instead of a comma as the decimal separator in the result overviews, as this is not checked in the script from the outset and text is transferred instead of numerical values. A check of the input values and, if necessary, a conversion is added to the script retrospectively. In addition, the cells for entering values in the result overviews will be formatted and the worksheets protected. Frequent queries regarding the pending return of corrected documents arise due to the uploading of PDF files instead of EXCEL overviews, missing names, mixed-up first and last names, and missing or incorrect student ID numbers, which are required to determine the email addresses for the return of documents.

During the development of the script, an EXCEL file is used to calculate interim results for the term paper, and various exercises are used to test the programmed modules. Despite intensive preparation and checking of the script, corrections to the calculations have to be made during the interim checks. In discussions with individual students and when discussing the calculation method, errors were found and corrected in the scripts. However, some of the corrections made meant that the correct results from the previous week were incorrect in the subsequent correction. The students' dissatisfaction had to be appeased by overing additional possibilities for interim submissions.

5. Evaluation

The time required to correct the result overviews was very high in the 2022/23 winter semester. In addition to making the corrections, the script had to be adjusted at least once a week to catch incorrect entries or formatting errors. In addition, there were extensive questions in the forum, by email, and in personal conversations. The script and template developed are also being used in the Machine Elements course since the 2023 summer semester. The time required for this has been significantly reduced.

In the 2023/24 academic year, interim submissions of the result overviews were offered for the first time over the two-semester module period between the beginning of November and the end of May, a total of 19 times. The evaluation of the information provided on the individual submissions and the progress made

by each student was initially carried out manually. Due to the extensive data and the objective of continuous evaluation in each semester, the collection of statistical parameters was also implemented using scripts.

The number of students who submitted their result overview is shown above the submission deadlines in Fig. 4. It is clear that only about one-fifth of the students took advantage of the first eleven opportunities to submit their results in the 2023/24 winter semester. From the beginning of the summer semester (bar 12), the number of participants rose significantly until three weeks before the submission deadline and remained at a high level even during the last two submission opportunities.

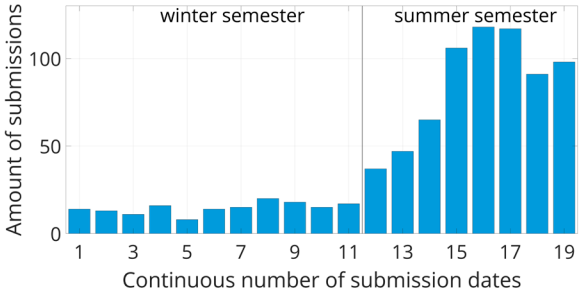

Fig. 2: Number of result overviews submitted on the 19 dates; multiple submissions were possible

A total of 165 students submitted their documents, and more than 91% of students took advantage of the opportunity to submit interim submissions at least once. On average, students used the interim submission option 5.1 times. Fig. 5 shows the distribution of students across the number of possible submissions and illustrates the resulting average.

The distribution clearly shows that the majority of students did not begin working on their coursework until the summer semester, meaning that a maximum of eight submissions were possible. Only about 8% of students took advantage of the opportunity to submit more than nine times. In contrast, 20% of students took advantage of the offer less than three times. Interestingly, the distribution of the number of students plotted against the frequency of submissions is comparable to the distribution of exam grades. In the middle grade range, there is a slight normal distribution. The number of students who fail, on the other hand, is disproportionately high.

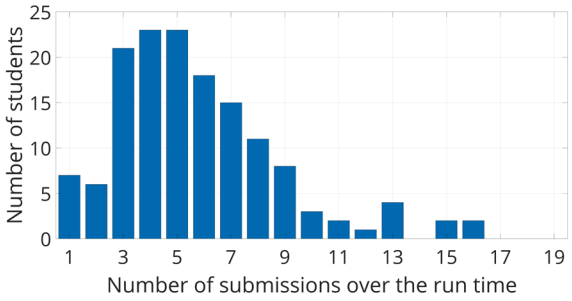

Fig. 3: Number of students plotted against the frequency of use of interim submissions

An exemplary evaluation of the performance achieved in relation to the number of interim submissions used for the period mentioned shows (Fig. 6) that an average of at least two submissions were required to achieve at least 50% of the points, and that the average percentage of points rose almost continuously to 100% after ten interim submissions.

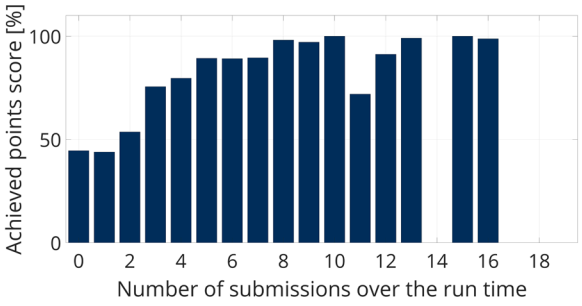

Fig. 4: Results of the course assessment in relation to the number of interim submissions

Almost 80% of students who started in the winter semester achieved 90% of the points in the calculation. Only 40% of students achieved this rating when they started in the summer semester. The grade is based equally on the corrected calculation results and the drawings. Due to the small number of students who submitted their interim results more than nine times, the values given for the average score are not representative. A statistical evaluation in a longitudinal study will be possible in the future.

6. Summary and outlook

The offered interim check of the calculation results is intensively used by a large number of students and, at the same time, provides an opportunity for a better overview of their progress, status, and challenges while working on

the term paper. When students receive feedback on incorrect results, they question the approach to solving the subtasks more closely. This offers a good basis for ensuring that the knowledge to be learned can be taught in a more targeted manner. After completing the term paper, interest in the corrected calculation is often low and the causes of errors are not questioned. The introduction of interim corrections has made it possible to shift the learning process into the working time. By taking advantage of the opportunity to submit interim assignments, students can demonstrably improve their achievable score in the calculation section. The findings and results will be incorporated into communication with students and used in the exercises as an incentive to start working on term paper early.