Workshop Task MD III winter semester 2023/24

For students of mechanical engineering, mechatronics and information technology

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Developing a new generation tractor

figure 1: generations of an agricultural tractor unit (figure based on https://test.fendt.com/de/kundenstimme/4845.html)

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1 Introduction

1.1 Motivation and objectives

During the MD3 workshop you will develop the next generation of the portal axle of a tractor for fruit harvesting tasks. For this development, a solution from a group of students from the last year is available as a reference. In addition, there is **the new development of a post rammer** for stabilizing bushes. The next generation of the drive train will be developed in MD4.

This workshop will provide a **working environment which might be found in an engineering company. The aim is to consolidate your knowledge gained during lectures and exercises and to develop your application skills. The following scenario serves this purpose:**

You work in the development of a renowned manufacturer of agricultural machinery. The management has received a suggestion for improvement from a customer in the sector “harvesting machinery for fruit on shrubs or small trees”. The company has previously developed a tractor unit for difficult terrain. This serves as a reference system. Your development team is given the request to further develop the existing product. Your task is to redesign the portal axle to match the new requirements. You can build on sub-systems of your company’s previous product generations.

1.2 Structure of the task

Please start by reading the **whole** task, in order to fully understand the task and to obtain a complete picture of the interrelationships. **Further information regarding the workshop** can be found in the Appendix. In order to structure the development task, your team leaders have specified a structure, which is explained in more detail in chapter 2.1. This also contains information and specifications on the complete system and the sub-systems to be developed. In chapter 3 you will find the individual tasks that you will work on in the course of the semester. You will submit and present your solutions in a total of 3 project sessions during the semester.

These sessions have the character of an internal milestone in the company! That means, YOU are responsible for presenting your solution to your supervisor. More technical basic conditions and details can be found in chapter 4. These technical basic conditions **have to** be followed. When using purchased or standard components, the basic conditions of the respective supplier have to be considered.

Particularly important comments are marked with  at the side of the page. The corresponding important text passages are additionally marked in **bold**.

1.3 Important notes

During the development of the portal axle, the preparation of the results and during the project meetings, the guidelines, notes and specifications valid for the MD-Workshop must be followed. These can be found in the following documents which are provided to you in ILIAS:

- **Notes regarding the MD-Workshop**
  General rules for the workshop and notes for completing the task
- **Manual Visualization and Technical Drawing in the lecture Mechanical Design**
  Detailed notes regarding the shape and the representation of the technical drawings and schematic diagrams.

You will not be given all the calculation variables you need to find a solution in every task, for example when dimensioning screws. This is due to the following reasons: on the one hand, each solution approach creates individual circumstances and external boundary conditions that would influence a given calculation variable. On the other hand, the independent research should strengthen both the understanding of the topic and the research competence.
If you are missing information, search for relevant data and make reasonable assumptions at appropriate points. Document the assumptions you have made.

Please follow the KIT-Corona-rules.

2 Initial target system for the portal axle of a harvesting machine for fruit

The initial target system contains all functions that are to be completed during the semester. This initial target system can be supplemented by you with further targets and requirements. The solutions will be described in the technical system available at the end of the development stage. The following chapters illustrate the aims to be followed when developing the new product generation. Before this, the previous generation is explained as it is an important reference system. The objectives for the overall system are broken down into the scope of the subsystems. Further details can be found in chapter 3 and chapter 4

Important: If necessary, you can make your own justified assumptions, as long as these don't contradict requirements from the workshop task. You have to document these assumptions accordingly and explain them to your supervisor (tutor) with comprehensible reasons during the workshop.

Please consider that the reference documents provided to you have also been developed by students. Therefore, they may contain errors and improvement potential. The reference documents should not be copied into your own solution without prior analysis.

2.1 Overall System

Reference Previous Generation:

The tractor unit which serves as the initial product, consists of a power split hybrid drive (details see paragraph 4.1) with two electric motors and an internal combustion engine connected by a planetary gear train. The vehicle also has a variable four-wheel drive realized by a central, as well as a front and rear wheel differential. The central differential can variably split the torque between the front and the rear axle. The differentials compensate the speed of the wheels when cornering. All differentials can be locked manually so that driving is possible at all times.

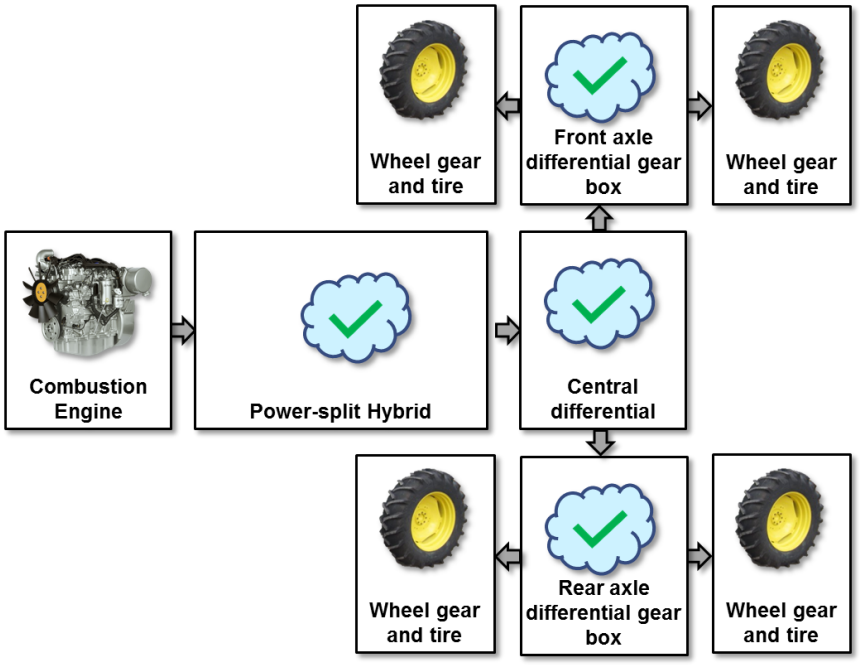


figure 2: diagram power train

The front axle of the vehicle is a portal axle mounted as swinging on the frame of the vehicle. Portal axles are rigid axles with spur gears on the vehicle wheels. They are used to create an offset between the axles and differential, resp. drive shafts. (see figure 3). This design guarantees a higher ground clearance than conventional rigid axles. Areas of application are mainly off-road vehicles. Inverted portal axles, where the drive shaft runs below the center of the wheel, are used for example in city busses. Here, the offset is beneficial to the passengers through a lower middle aisle and thus a lower access/entry height.

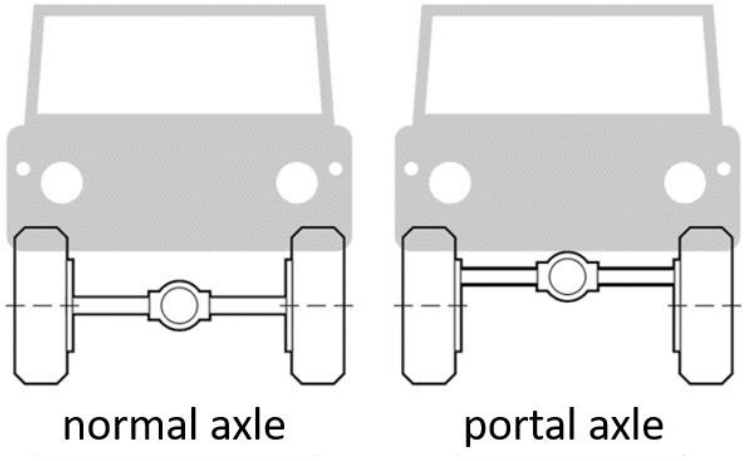


figure 3: comparison normal axle and portal axle

The portal axle consists of the front differential, and is mounted swinging to the differential on the frame.
The differential is connected to the portal gearbox through an axle casing, which supports a cardan shaft. **The offset gear has been designed as a single-stage chain gear**. Also fixed on the axle casing is the vehicle's spring-damper-system, which ensures a constant contact between the tires and the ground, therefore increasing the driving comfort. In order to reduce the load on the drive train, a planetary gear located between the portal gearbox and the wheel hub was used.
The schematic diagram in figure 4 shows the assembly of the portal axle in front view. In this workshop, the red framed area is in the focus.

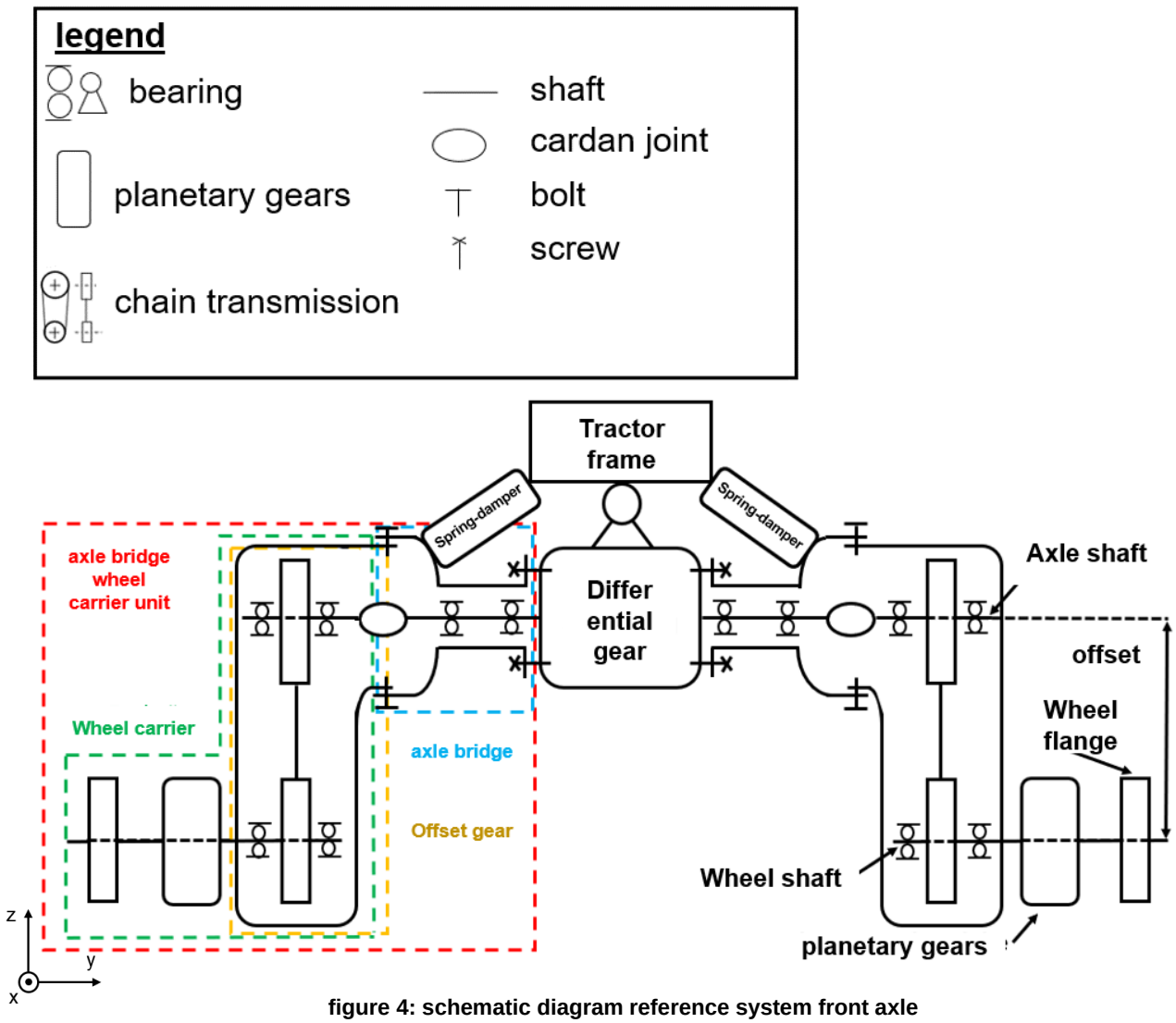


figure 4: schematic diagram reference system front axle

Target system for the next product generation:

For the new product generation, the drive train from the engine to the output of the front differential is initially taken over as “black-box-system”. (figure 2).

After the market launch of the last product generation, you have received a request for improvement from your customers. Most fields can be reached via field roads. Between the road and the field there are often telephone lines suspended. The customers reported that their tractor unfortunately was too high to drive into the field without hitting the telephone lines. Therefore, in the next product generation, a variable height adjustment of the tractor will be developed, which will allow the driver to enjoy a better driving performance on the road, because the smaller axle offset lowers the center of gravity ("road position") and also allows access to fields with telephone lines. In addition, it should also be possible to adjust the height required for harvesting ("working position"). The offset gear connected to the output shafts of the front axle differential has to be adapted for this purpose.

The planetary gear connected to the portal gearbox in the previous model can be taken over. Due to the new restrictions regarding the building space by the added variable offset, the position of powertrain has to be reconsidered. The front differential and the spring-damper-system can be taken over. Only the connection of the spring-damper-system might need changing (see paragraph 2.4)

The axle casing of the portal axle can also be taken over, but it has to be checked whether the current design is suitable for the new model.

The steering and the harvesting tools can be found **outside the power trains**. The steering system, which is a power assisted (servomotor) recirculating ball steering, is taken over from the previous model. In addition, you have to **develop a new pile driver** for stabilizing small trees.

2.2 Subsystem portal gear box

Reference previous generation:

The portal gearbox (figure 4) is a chain gear.

Particular emphasis was put on the rigidity of the shaft of the wheel.

- The **ratio** of the spur gear is **i=1.**
- The **ground clearance** under the tractor is **90 cm**.

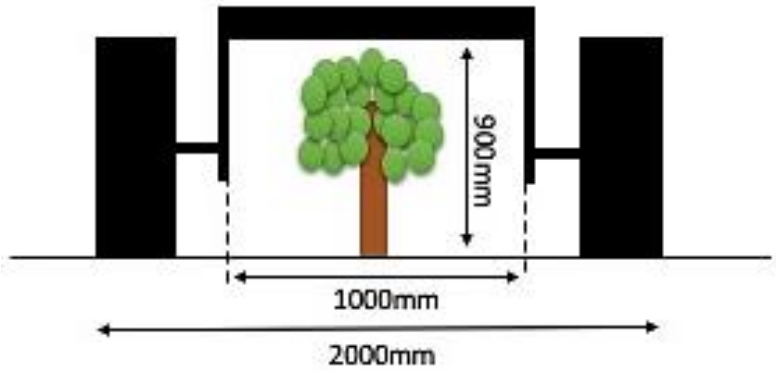


figure 5: dimensions front axle (previous generation!)

Target system for the next product generation:

For the new product generation, the offset between the output shaft of the axle differential and the wheel shaft has to be variably adjustable **from 30 cm to 50 cm**, as this offers optimum driving performance on roads, but also allows harvesting on fields.

Due to the varying offset between the shafts, **the concept of a chain drive has to be reconsidered**.

Please consider the additional requirements that are demanded due to the adjustable offset of the gearbox. In order to guarantee the required vehicle dimensions, at the level of the axle the construction space is limited in width (see chapter 2.10, figure 8). If considered useful, a transmission ratio can be implemented for the portal axle (for the specification of the drive train see chapter 4.1)

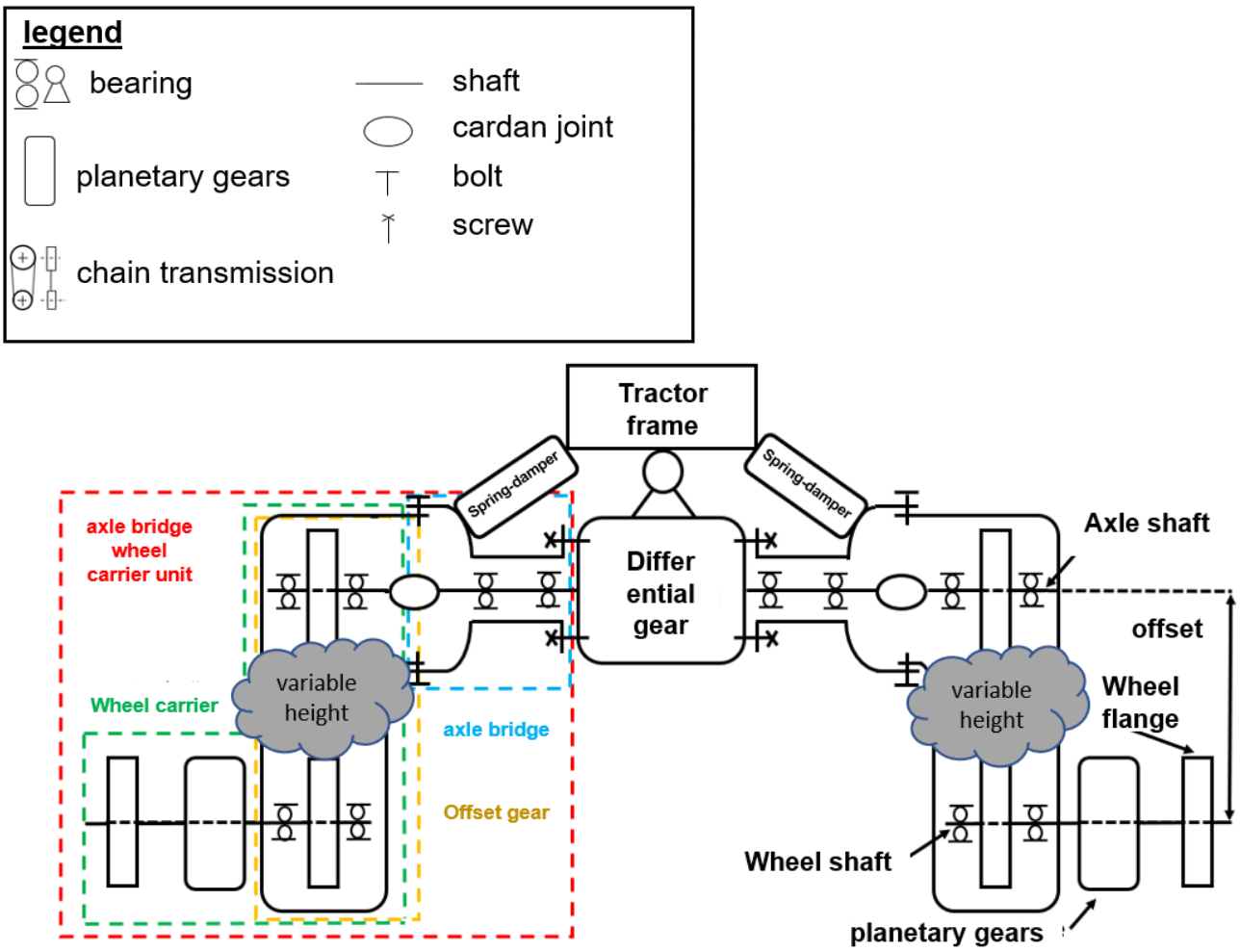


figure 6: schematic diagram front axle

2.3 Subsystem axle casing and drive shafts

Reference previous generation:

The axle casing is the backbone of the axle. Its most important function is to absorb forces and moments and transports these via the suspension between the frame of the tractor unit and the wheels.

- The portal gears are **mounted on the axle casings and rotate around the z-axis (see** figure 4**)**, in order to allow the wheels to turn. The articulated connection is designed with bolts and plain bearings.
- The axle shafts as part of the differentials are supported in the axle casings with **locating/non-locating bearings**.
- The two axle casings are flange-mounted to the differential. the given dimensions can be found in chapter 4.2.

Target system for next product generation:

In principle and if appropriate, the drive shaft from the previous generation can be used. Please note hereby the changing forces. Additional information can be found in **chapter 3.1.3 and chapter 3.2.3**.

2.4 Subsystem Suspension and Spring-Damper System

Reference system previous generation:

The suspension connects the portal axle with the vehicle and allows relative movements between the two systems. The vehicle body can therefore follow the underground in the terrain, the driving comfort is increased. The front axle has been additionally connected to the frame via a spring-damper-system. This was needed to prevent an unwanted dynamic behavior of the chassis and to allow a reset into a neutral position.

Target system for next product generation:

The spring-damper-system can be taken over from the previous generation. Only the connection point to the axle casing must be possibly adjusted. That is due to the changed construction space of your concept. (see chapter 3.2.3).

2.5 Subsystem Differential

Reference previous generation:

The differential in the middle of the axle has two functions: The first one is to divert the torque from the shafts by 90 degrees to the two axles. The second function is to compensate

gear it makes sure that the different speed of the wheels on the outside of the curve and the ones on the inside of the curve does not cause any wheel slip and tensioning in the drivetrain. As opposed to a stiff drive shaft, the differential allows an unconstrained adjustment of the rotational speed and the forces. The drive torque distribution on the two wheels is always 1:1.

Following differential specifications is known from the previous generation:

- The **diameter of the differential's output shaft** is **55mm**.
- The differential is lubricated by an oil bath, the housing and the axle output are sealed. For the **portal gear and bearing in the axle casing an own lubricating concept is planned**.
- The front axle differential has a distance from the ground of 900 mm at its lowest end (see figure 5)

Target system for next product generation:

The differential can be taken over from the previous generation, and is not being changed. The dimensions can be found in chapter 4.2. It should be embedded as Blackbox in your design.

2.6 Subsystem Steering System

Reference previous generation:

For the front axle to be steered, the rotational motion of the steering wheel (direction given by the driver) must be converted into the turning of the wheels. For this purpose, the steering wheel, steering column und linkage must be redeveloped. The connection to the steering knuckle has been purchased. The steering gear is realized by a smooth-running recirculating ball steering.

Target system for next product generation

The steering is taken over from the previous generation. However, please note that the connection of the steering to the portal axle will change due to a changed concept. The system must be accounted for in the construction space and the connection points to other assemblies must be displayed. **(see chapter 3.1.2).**

2.7 Subsystem Planetary Gear

Reference previous generation:

In the previous generation there was a planetary gear between the portal gear and the wheel flange: the **transmission ratio i=6.** This way there is less stress on the transmission: the moments on the axles are low and the torque required is reached just at the wheel. The drive of the planetary gear is carried out by the sun gear, the output by the planetary carrier. The stationary ring gear is integrated in the housing.

Target system for next product generation

In principle, the planetary gearing can be taken over but the position of the drive should be reconsidered due to the new requirements of the construction space. (see chapter 3.2.3).

2.8 Subsystem fruit harvester (OER)

Reference previous generation:

The previous model is a tractor unit equipped with a harvesting tool (OER). Also, in this generation, the fruit harvester will be offered together with the tractor.
The fruit harvester has proven itself in use and can therefore be used unchanged. A new derivation of drawings is not necessary.

2.9 Subsystem pile driver

A pile driver is a tool for driving piles into the ground. When planting young shrubs, a stake is driven near the trunk to protect the small plant from being blown over by strong winds. On orchards, shrubs can buckle due to a storm, among other things, and a pole is needed to stabilize them.
In the past our customers have purchased this tool from other manufacturers. Their superiors now also want to enter the market and offer a pile driver.
The following video can contribute to the understanding of the application of a motor driven pile driver: https://www.youtube.com/watch?v=lpJzFy5y0Ec
You can use the design shown in the video as a reference for your development work.

figure 7: reference product pile driver (www.geo-bil.de)

Target system for next product generation:

Construct a pile driver that allows mobile driving of piles by persons (see fig.7). You have to comply with the following requirements:

- Decide how the pile driver is driven: electrically, mechanically via the power take-off (PTO) or via the air pressure or hydraulic circuit of the tractor
- The motor-driven pile driver was too heavy for the customers. The weight of the pile driver should be low enough to carry the pile driver by hand.
- The diameter of the piles to be driven in is **10 cm**.
- For our own product as you can see for the competitor's product, we want to make sure that the handle on which the tool is held dampens the vibrations initiated by the piles being driven in.

Your concept should be a further development in relation to the competitor's product referenced above (see fig. 7). **You should strive for a solution that is as simple as possible and meets the requirements.** Do not let the shape of your concept deviate too much from the reference, e.g. self-propelled concepts are neither useful nor conform to the boundary conditions in the previous paragraph.

2.10 Requirements for the overall system

- **Very high requirements** regarding the **leakage tightness**: the axle system is directly exposed to influences from the environment and the loss of lubricants can lead to environmental damages.
- the system is used in rough ground, hence a **high stiffness** of the complete system is required
- the operational time of agricultural vehicles can be decades, the maintenance is usually carried out by the user himself. Therefore, **easy disassembly and exchangeability** of the wear and tear parts has to be considered.
- The front axle, which is going to be used in various vehicle models, is manufactured in **high numbers**. The manufacturing processes for all components (except for standard components) need to be chosen accordingly.
- According to §32 of the German Road Traffic Licensing Regulations (StVZO), the **maximum width** of the fruit harvesting tractor is **2550mmm** between the wheels (outer side)
- the area where the **ground clearance** is **900mm**, the width is **1000mm**. (see fig. 8**)**
- the offset of the output shaft of the axle differential and the wheel shaft is 300 mm in "road position" and 500 mm in "working position". The width in this area is 1000 mm (see fig. 8). The diameter of the tires can be found in chapter 4.5. The dimensions of the differential can be determined with the information from Chapter 2.5.

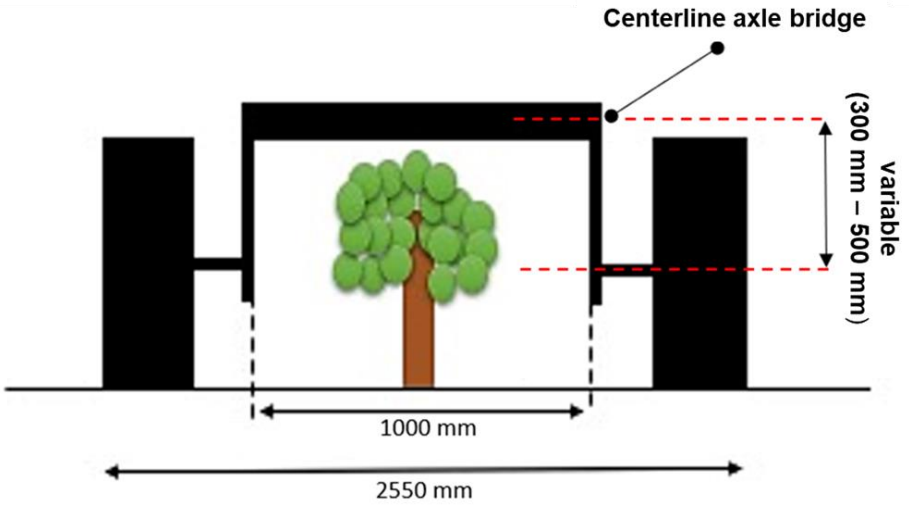


figure 8: dimensions front axle

3 Project Meetings

This chapter explains the steps in the overall MD3 workshop-task. In the style of a real project, you will deal with milestones during your project planning, during which you will present the **development of the project to your superiors**. During the semester, you will have three milestones corresponding the three project meetings. Your design of the portal axle is a compromise between three criteria (e.g. weight, production and maintenance costs). As development team of this portal axle you will **objectively justify your decisions to your superiors** during the project meetings! The development stage of the design will be presented with the help of results partly by **every student (individual work)** and partly as a **group (team work).** The aim of this procedure is an optimal preparation for your MD-exam and for your future working life. **Splitting the work in the group, means you still need to be informed of the other group members work**.

Fig. 9 is an overview of the tasks for the project meetings (PS)

The project meetings will contain topics and exercises covered in MD1 to MD 3.

The results for the project meetings have to be uploaded before the project meeting (as backup) and brought to the project meetings!

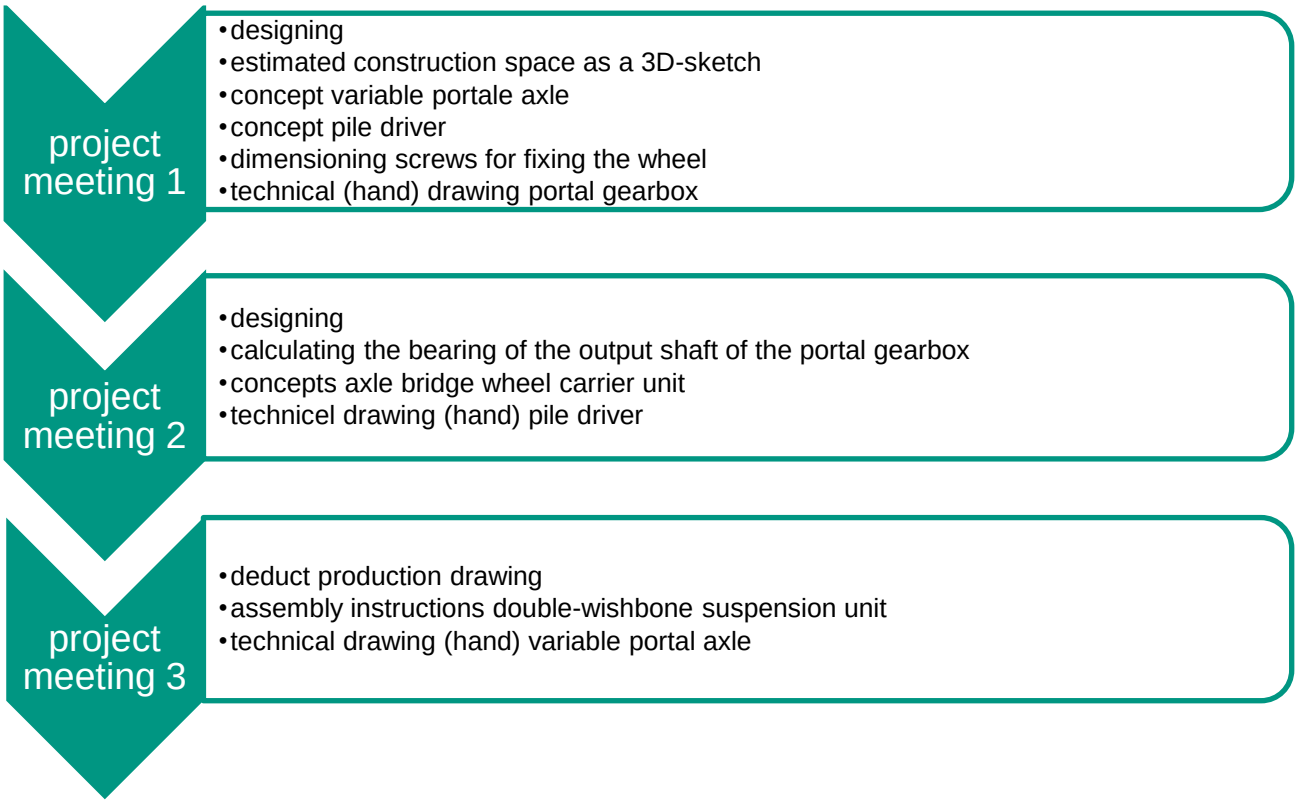


figure 9: overview tasks project meetings

3.1 Project meeting 1 – design variable portal gearbox

For the first project meeting, as a group you design an overall draft of the single sub-systems of the front axle. Please note, that **only mechanical solutions** are allowed in all project meetings (Exception: Pile Driver, see 2.9). **The results for the project meetings have to be uploaded before the project meeting (as backup) and brought to the project meetings!**

The following tasks have to be done:

organisation in the team		
☐	Creating a knowledge management structure for the group (folder structure in SharePoint)	group work
☐	planning the project as a Gantt chart/bar chart	group work
☐	knowledge management for the group	group work
☐	registration to MD III-advanced work	Individual work
design construction space		
☐	3-D-freehand sketch axle (estimate construction space for the individual sub-systems)	individual work
concepts for sub-systems		
☐	C&C²-analysis for the portal axis of the previous generation	group work
☐	Concept of the variable offset gear	group work
☐	At least 2 concepts for the pile driver	group work
dimensioning		
☐	calculating the screws	group work
technical drawing (by hand)		
☐	variable portal gearbox	individual work

3.1.1 Project work

3.1.1.1 Create structure knowledge management for the group.

Every group member will have access to the Microsoft SharePoint group folder. In this folder all the working results will be saved. The structures of the folders should be as shown in the figures 10 and 11.

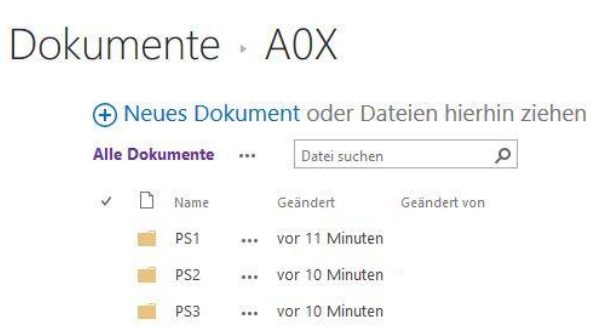


figure 10: folder structure in SharePoint

figure 11: folder structure in PS X

When saving files, please note the following:

- If applicable, consider which **file format** is needed. If required, convert your file into the format needed.
- **Every individual work has to be done and uploaded (separately)** by every team member. For the work to be distinguished, the **initials (first name, name) must be used at the end of the filename**. In the different checklists of saved files an example is used: the student “Paul Eigen”, who is part of group A07.
- **If, for the partial tasks, you have additional files, file these under a self-explanatory name of your choice.**
- In the workshop you present your work results in an orderly fashion. (**Example: a handwritten and scanned-in screw dimensioning does not meet the requirements of a suitable representation, programs such as Maple or Excel are more suitable**). Nevertheless, make sure that the presentation is suitable and that your results are easy to understand. **You yourself are responsible for the timely and complete upload of the results! As a backup, please save a copy of your results on your computer.**
- If your group does not have a laptop please contact mkl3@ipek.kit.edu as soon as possible
- **The completeness of the SharePoint folder is one of the requirements to pass the pre-test.**
- **Create an "Archive" folder at the lowest level. There you can, for example, store several versions of a WORD document, on the basis of which you have created a PDF, as original files.**

3.1.1.2 Project Planning

For the design of the portal axle, create a project plant as a Gantt chart/bar chart using a software of your choice (e.g. MS Project or MS Excel). The project plan fulfils various tasks. It also helps you to better estimate your time frame when the planned and the actual time needed is compared.
This should also include a success control, whether the planned time was sufficient or not (target - actual - comparison). It must always be clear who was responsible for which development step. The aim is to bring the planning closer (from the beginning to the end). This will use this diagram as a guideline/calendar throughout the whole semester. Leads can be found in the document **“Notes to the MD-Workshop”.**

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
project plan	depending on the program being used	GXX_Projektplan.xxx	*A07_Projektplan.xlsx*	…/PS1/ 00_Organisation/

3.1.1.3 Registration to MD III pre-test

Prove to the **Campusmanagement** (https://campus.studium.kit.edu/) that you have registered for the **pre-tes**t. Please download the registration confirmation and save it so that you can quickly prove your registration in the workshop. (e.g. by embedding it in the presentation or uploading it to SharePoint).

3.1.2 Construction space

Think about how to assemble the construction. Plan the following sub-systems as black-box resp. as placeholder

- differential
- portal gearbox
- spring-damper-system
- wheels
- axle casing

- steering
- planetary gear
- additional restrictions for parts to be rebuild

Each group member generates a 3D freehand sketch of the front axle. Use simple geometry in dimetric or isometric projection for the sketch. The components listed above may be represented as “black box”, i.e. very simple housing. Hereby keep in mind to write the rough dimension and the orientation in space. Details are not necessary. The difficulty is to clearly show the connections of the individual assemblies to the overall system. If components are "broken off", it must be clear where they come from and what function they have in the overall system (no "broken off" shafts running into nothing without labeling).

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
Estimation construction space/3D-sketch	PDF (from scan/ picture)	GXX_Bauraum_Initialen.pdf	*A07_Bauraum_PE.pdf for student “Paul Eigen“*	…/PS1/ 01_Aufgabenergebnisse

3.1.3 Concepts for variable gear box

Develop a concept for the variable portal axle. Pay attention to all requirements in chapter 2.1 and chapter 2.2. When doing this, you need to consider which components from the previous generation need changing in order to meet the new requirements for the construction space. Also, think about what result the variable offset has on the forces which act on the portal axle during steering. Check, if a redesign is needed and how it could be realized. **Analyze the previous system with the help of the reference drawing and depict your concepts as a schematic diagram. For this purpose, carry out a C&C²-analysis for the portal axle of the previous generation.** Use your analysis to identify potential problems in the previous model, fix them and support the success of your further development with a C&C2 analysis. Consider that **different driving maneuvers lead to different forces**. Based on the results, you can develop your new concept. **The most important points are:**

- Which systems will conflict with the new requirements?
- How can the new requirements, constraints and goals be implemented economically in the next generation? The previous generation is an internal reference, but external references from competitor products or other industries can also be helpful. Describe the following in your concepts:
    - which subsystems can be taken over from the previous generation or external references, with slight adjustments (takeover variation)
    - for which subsystems, starting from the previous generation, the functional principle is retained, but adaptations to the design are necessary (design variation).
    - for which subsystems, starting from the previous generation, a new solution principle has to be implemented and a new design solution has to be found (principle variation).

Attention: In this workshop **only mechanical solutions** are allowed, purchased parts are an exception. To raise the tractor and thus adjust the "field position", you may use hydraulic cylinders (bought-in part) which are extended in longitudinal direction. You do not have to represent these hydraulic cylinders, only the connection to the wheel carrier unit must be visible, which can be variably adjusted upwards according to your concept. You can choose a suitable position and connection for your concept and the direction of action of the hydraulic cylinder yourself. For the new application of the machine, the offset between the output shaft of the axle differential and the wheel shaft should be **variably adjustable from 30 cm to 50 cm**.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
analysis previous system	PDF (from scan/ picture)	GXX_analyse_portalachse.pdf	*A07_analyse_portalachse.pdf*	…/PS1/ 01_Aufgabenergebnisse
1 File with all mentioned information for each concept	PDF (from scan/ picture)	GXX_konzept_Nr_portalachse.pdf	*A07_konzept_01_portalachse.pdf*	…/PS1/ 01_Aufgabenergebnisse

3.1.4 Concepts for the pile driver

By means of schematic diagrams, create **at least two different concepts**. A diversity of solutions is needed in order to discuss the **advantages and disadvantages of the various solutions.**

It is expected, that the component connections are labelled with the characteristics in your concepts: form ft, frictional locking and metallic continuity. In addition, the chosen component connections should also be rated by using, amongst others, the following criteria: transmit torque, support axial load, centering, disassembly. Find more useful, reasonable criteria! **Clearly label and justify in your schematic diagrams the chosen component connections! The concepts refer to the entire pile driving process (subsystems 1 and 2, see fig. 12)**

- **Every team member has to be able to explain the functionality of all concepts in the project meetings!**
- **Carry out an evaluation of all concepts based on the criteria** and choose the concept which you will design.
- If you use parts of the reference system for your design, document the sources and why you have chosen these products as reference. Also, justify which part you will use in your product and what you change. Remember that you always have to give your manager objective reasons for your results (e.g. through a benefit analysis).

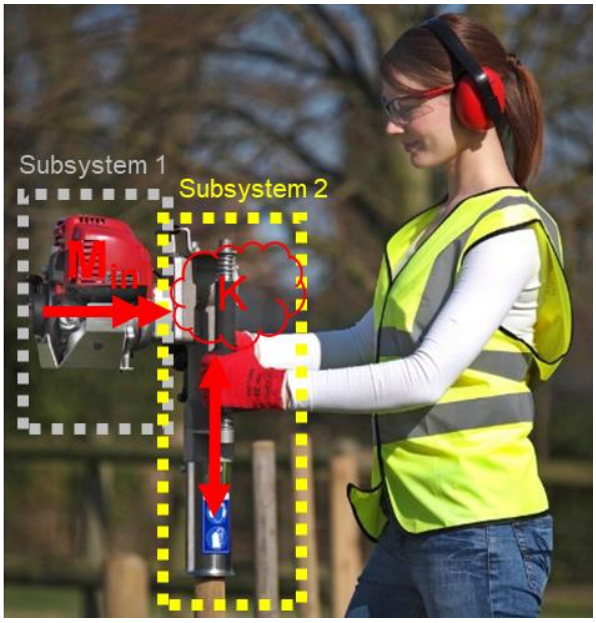


figure 12: reference product pile driver (www.geo-bil.de)

1) Selection of the drive concept:

The pile driver should be driven by a power source, which has to be selected. The pile driver should be lighter than the competing models on the market. Therefore, the pile driver shall be connected to the tractor and the

necessary energy has to be transmitted to the pile driver via a mechanism (example for understanding: a hydraulic motor could be mounted on your pile driver (prime mover) and it's operated by a hydraulic circuit of the tractor by connecting this motor to the tractor via hydraulic hoses). You have several possibilities to create a drive for the pile driver on the tractor:

- hydraulic and air circuit of the tractor
- Electric motor with tractor as power source
- mechanical energy of the power take-off (PTO)
- you can develop further possibilities yourself, if they are sensibly justified

Make a well-founded decision as to **which type of drive you choose**. The power engine you choose will be a purchased part and is not shown in your technical drawing. It is sufficient to show the connection of the motor shaft and break it off after the motor flange. You have the choice in the arrangement of the individual components of the system. For the first milestone, this part of the task has to be worked out only as a concept and does not have to be integrated into the technical drawing, which you will have to prepare later in the workshop (see chapter 3.2.5).

2) Mechanical principle of pile driving:

In the **creative part (K)** you will consider how you can turn a **horizontal rotary movement into a hammering mechanism**. It is required that you can place your tool on a pile of any length and thus directly hit the pile. It is not required to initiate the impact process by means of a coupling, the pile driver hits the pile immediately after "plugging in" (for understanding, the linked video from chapter 2.9 can be used).

Since you are developing this tool for customers who drive in a large number of piles, the pile driver has to be driven by a power machine.

Always keep the requirements from chapter 2.9 in mind for both steps:

The motor-driven pile driver was too heavy for the customer. The weight of the pile driver has to be low enough to carried it by hand.

The diameter of the piles to be driven in is **10 cm**.

Vibrations, which are initiated by the hammering in of the piles, should be damped for the user.

Retain the setup from subsystem 2 (fig.12) and consider how you can mechanically implement the required impact function.

In order to limit the scope of the task, you can make the following assumptions:

- It is difficult to make a statement about whether the impact force is sufficient to drive the pile into the ground, since this depends on the nature of the soil (it is heavier in clayey soil than in sandy soil). You can assume that your concept provides a sufficiently large impact force.
- A heavy pile driver has the advantage of greater inertia, which both makes it easier to drive the pile and reduces the rebound after the blow. Nevertheless, concentrate on the requirement to develop a concept that is as light as possible. This requires more general estimates of "impact performance per weight" for different concepts.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
PER CONCEPT 1 file containing all mentioned information	PDF	GXX_Pfahlramme_KonzNr.pdf	*A07_Pfahlramme_Konzept_02.pdf*	…/PS1/ 01_Aufgabenergebnisse
documentation choice of concept	PDF	GXX_Pfahlramme_Auswahl.pdf	*A07*_Pfahlramme_*Auswahl.pdf*	…/PS1/ 01_Aufgabenergebnisse

3.1.5 Calculating the screws following VDI 2230

The tires need new screws for connecting the rim with the wheel flange. Therefore, a **mathematical proof of the screw joint** is required. Planned are up to now M12 screws, strength class 10.9. **The dimensioning has to be verified**. Choose a suitable program for your calculations. Additional information can be found in chapter 4.5.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
workflow procedure dimensioning	PDF	GXX_Schraube_Ablauf.pdf	*A07_Schraube_Ablauf.pdf*	…/PS1/ 01_Aufgabenergebnisse
files used for calculation	depending on program used, e.g. Excel or Maple	GXX_Schraube_Berechnung.xxx	*A07_Schraube_Berechnung.xlsx*	…/PS1/ 01_Aufgabenergebnisse
documentation of assumptions, values used and final result	PDF	GXX_Schraube_final.pdf	*A07_Schraube_final.pdf*	…/PS1/ 01_Aufgabenergebnisse

3.1.6 Generational development portal transmission

The function of the portal gearbox is to enable an “offset between the wheel hub and the axle”, which distinguishes the portal axles from the normal driven, rigid axles. In order to further develop the transmission for the next product generation, you should start by analyzing the portal gear of the previous generation. Show which parts you can take over and which need changing. Justify where you want to take over/use the principle but do not want to carry out any changes, e.g. for a simpler assembly or manufacturing. **Always state why parts are being changed or taken over** and document your analysis accordingly (e.g. as an annotated drawing of the previous generation transmission). Keep in mind that there may be potential for optimization in the previous generation. If you adopt something without further thought, you will be held liable for the unlikely event of design errors, so always make sure that you do not transfer any errors to the new product generation. Based on the concept developed in 3.1.3, you have to draw a technical drawing (by hand) of the portal transmission with the corresponding changes. **Please consider the fundamental requirements for technical hand drawings in the MD workshop.**

In various recognized written publications, there are often simplified representations of standard components. In the context of this course, only those representations are allowed which were provided to you in the course of the lecture and exercise (see referenced documents section) or which are prepared according to the guidelines mentioned above. If you can't find a representation you are allowed to use other sources.

The drawing contains:

- The axle and wheel hub as well as the planetary gear. (you do not need to show the cardan joint)
- Your drawing (**same sheet!**) should also **contain** a **3D-sketch**, from which the overall design/shape of the **transmission housing**, the **partition** of the housing and **the connection of the transmission** to the surrounding sub-systems emerges.
- **Roughly calculate the minimum diameter of the solid shafts** when using 42CrMo4, and considering the maximum torsional stress and a (justified) safety factor. References can be found e.g. in *Konstruktionselemente des Maschinenbaus 1* (Steinhilper, W., Sauer, B.).
- Particular attention to be paid to a stiff support of the axles and of the shaft-hub joints involved in the transmissions of the torque.
- If both transmissions are symmetrical to each other, it is sufficient to depict one portal transmission.

If sectional views are required to understand the function of the variable offset gear as an outsider, make them on one sheet just like everything else that belongs to the drawing (generally applicable). (For the display of sectional views: see chapter 1.3)

Each workshop participant creates a technical hand drawing with 3-D sketch. The technical hand drawings do not have to represent different solutions in order to learn technical drawing, but the technical hand drawing has to be made by each workshop participant.

file to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
analysis previous generation	PDF (scan/picture)	GXX_Analyse_VersGetr	*A07_Analyse_VersGetr.pdf*	…/PS1/ 01_Aufgabenergebnisse
technical drawing (by hand)	PDF (scan/ picture)	GXX_VersGetr_Konstruktion_Initialen.pdf	*A07_VersGetr_Konstruktion_PE.pdf for student Paul Eigen*	…/PS1/ 02_Technische_Handzeichnung

3.2 Project meeting 2 – design of the pile driver

At the second project meeting, the pile driver chosen in the first project meeting to be designed is explicitly displayed. In addition, concepts have to be drawn for the axle bridge-wheel carrier unit and the dimensioning of the bearing for the variable portal transmission has to be done. **The results for the project meetings have to be uploaded before the project meeting (as backup) and brought to the project meetings!**

The following tasks have to be done:

organisation in the team		
☐	Update of the project plan	group work
corrections from the 1st project meeting		
☐	work on adjustments/corrections from PS1	group work / individual work
concepts – Axle bridge-wheel carrier unit		
☐	minimum 2 concepts for the axle bridge wheel carrier unit	group work
calculation – support		
☐	calculating support at output portal transmission	group work
technical drawings (by hand)		
☐	Technical drawing (hand) pile driver	individual work

3.2.1 Continuous design

update your project planning based on the results of the first project meeting (possible required adjustments to be considered) and improve the results of the work which will be presented in the second project meeting. Carry on maintaining your knowledge-management structure.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
project plan	depending on used program	GXX_Projektplan.xxx	*A07_Projektplan.xxx*	…/PS2/ 00_Organisation

3.2.2 Adjustments / corrections from PS1

If in the first project meeting, you were told by the project leader to rework single tasks, redesign them **completely new**! **File the redesign in the same folder as the original file. Label the redesign with the suffix UB.** At the next project meeting, present without being asked, the corrections including the drawing to be reworked.

3.2.3 Concepts - Axle bridge-wheel carrier unit

With axle-bridge-wheel-support unit (see Figure 4), the subsystem, which extends **from the output of the front differential** (differential does not need to be shown, it is sufficient to show how it is flanged to the axle-bridge), through the axle-bridge (including the cardan joint), through the joint (which allows the wheel-support unit to rotate about the horizontal axis, leaving the axle-bridge relatively unmoved), through the wheel-support unit **to the wheel flange**.

Based on your results from the PS1, consider how to implement axle bridge and wheel carrier into the new product generation. Develop 2 concepts. Especially, consider the construction space of the respective components.

Specifically, you should question the positions that your predecessors considered for the individual assemblies and change them if necessary.

To name a few suggestions that you could refer to:

Ask yourself whether the planetary gearhead is well positioned in front of the wheel flange, or would be more suitable elsewhere. A cardan shaft with cardan joint was installed, would you have made the same choice? If yes: also in the same place? An oil bath lubrication was used, is this also compatible with the new requirements? Etc.

Part of the concept is amongst others:

- rough dimensions of the system,
- a detailed schematic diagram
- checking the functionality, especially whether the interfaces are elaborate,
- the support concept
- lubrication and sealing concept
- the assembly through partition the housing and the lid needs to be assured.
- the load behavior: Are stiffeners or similar necessary due to further development in order to withstand the forces acting on the system?

In addition, choose suitable criteria for selecting the concept. Suggest suitable criteria for choosing a concept, evaluate the concepts using these criteria and suggest a selection for the next project meeting, during which the concept will be implemented.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
PER CONCEPT 1 file with all mentioned information	PDF	GXX_Radträger_KonzNr.pdf	*A07_Radträger. K2.pdf*	…/PS2/ 01_Radträger
documentation selection concept	PDF	GXX_Radträger_Auswahl.pdf	*A07_Radträgerr._Auswahl.pdf*	…/PS2/ 01_Radträger

3.2.4 Calculating bearing reaction forces and calculating the bearings

The support of the output shaft of the portal gearbox has been considered to be particularly critical by the project leader. Appropriate bearings need to be chosen.

Carry out a calculation of the life span, based on the basic conditions from **chapter 4.3** and your design drawing from the PS1. Then, choose a suitable bearing from the catalogue, and use it in the next generation of development in PS3.

Files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
workflow procedure choosing the bearing	PDF	GXX_Lagerauswahl_Ablauf.pdf	*A07_Lagerauswahl_Ablauf.pdf*	…/PS2/ 01_Aufgabenergebnisse
files used for calculation	depending on program, e.g. Excel / Maple	GXX_Lagerauswahl_Berechnung.xxx	*A07_Lagerauswahl_Berechnung.xxx*	…/PS2/ 01_Aufgabenergebnisse
documentation assumption, values used and final selection	PDF	GXX_Lagerauswahl_final.pdf	*A07_Lagerauswahl_final.pdf*	…/PS2/ 01_Aufgabenergebnisse

3.2.5 Technical drawing (hand) of pile driver

Produce a technical (hand) drawing for pile driver, based on the concept chosen in PS1.

Keep to all specifications from the task in chapter 3.1.4, which you should already have integrated into your concept. You **only have to draw the "Subsystem Impact Device"**, which is shown in figure 12. Regardless of the concept you have chosen, your drawing and the concept should have a shaft at the transition from subsystem 1) to subsystem 2) according to the specifications (see chapter 3.1.4). Describe how the shaft and the input torque can generate an impact motion by your concept and also consider how the pile driver is held and where exactly the pile is inserted.

Note: In chapter 3.1.4 it was specified that your drawing does not have to show how to switch the pile driver on and off (keyword: e.g. no couplings). Therefore, you only have to show the part of your concept, the subsystem 2), including the complete housing and the handles where you hold the pile driver in a technical drawing.

Each team member draws a technical (hand) drawing with 3D-sketch.

Files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
technical drawing (hand)	PDF (scan/ picture)	GXX_Pfahlramme_Konstruktion_Initialen.pdf	*A07_Pfahlramme_Konstruktion_PE.pdf (for student Paul Eigen*	…/PS2/ 02_Technische_Handzeichnung

3.3 Project meeting 3 – overall concept

In the third project meeting the planetary gear is designed and the overall concept is compiled. In addition, an assembly instruction for the variable offset gear unit is to be prepared and a production-ready drawing of the wheel shaft is to be created. **The results for the project meetings have to be uploaded before the project meeting (as backup) and brought to the project meetings!**

The following tasks have to be done:

Organization in the team		
☐	Updating the project	group work
Corrections from the PS2		
☐	Work on the corrections from the PS2	individual / group work
instructions for assembly		
☐	assembly instructions for the variable offset gear	group work
design for manufacturing		
☐	produce drawing for manufacturing input shaft portal transmission	group work
technical drawing (hand)		
☐	N**ew** technical drawing (hand) portal axle	individual work

3.3.1 Continuous project work

Update your project plan based on the results of project meeting two (possible needed corrections have to be considered) and refine the planning for the work results which are to be presented in the project meeting.
Carry on working on your knowledge-management structure.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
project plan	depending on the program used	GXX_Projektplan.xxx	*A07_Projektplan.xxx*	…/PS3/ 00_Organisation

3.3.2 Corrections from PS 2

If in the second project meeting, you were told by the project leader to rework single tasks drawings or calculations), redesign them **completely new**! **File the redesign in the same folder as the original file. Label the files with the suffix UB.** At the next project meeting, present without being asked, the corrections including the drawing to be reworked.

3.3.3 Assembly instructions variable offset gear

Produce the assembly instruction for the variable offset gear unit (cardan joint and planetary gear unit do not have to, but can be included in the wheel carrier unit assembly instructions). Also describe the time sequence of the necessary activities for the assembly. A "step-by-step instruction" is required from you, and you are allowed to be creative in its design. If necessary, combine several individual components into assemblies for a better overview. Reference components and sub-assemblies in your technical drawings, for example by using numbers. The aim is to make you aware and emphasize the aspect of mounting/ the assembly of constructions.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
assembly instructions	PDF	GXX_Montage.pdf	*A07_Montage.pdf*	…/PS3/ 04_Radträger

3.3.4 Drawings for manufacturing the input shaft of the offset gear

Produce a manufacturing drawing of the input shaft of the portal transmission. This can be done as a CAD drawing. Pay special attention to the **dimensioning suitable for manufacturing**, as well as a suitable choice of the **dimensional, geometrical, surface and positional tolerances**. For the workshop, take all the sources you have used for choosing the necessary tolerances with you.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
drawing suitable for manufacturing	PDF (scan/picture)	GXX_ZeichAbl.pdf	*A07_ZeichAbl.pdf*	…/PS3/ 01_Aufgabenergebnisse

3.3.5 Technical (hand)drawing portal axle

Produce a technical (hand)drawing for the portal axle. The drawing should show the **output shaft of the differential** (differential black-box does not have to be displayed) **to the wheel flange**. Since the portal axle is symmetrical, it is sufficient to display one side.

Each team member produces a new technical (hand) drawing with 3D-sketch.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
technical (hand) drawing	PDF (scan/ picture)	GXX_Gesamt_Konstruktion_Initialen.pdf	*A07_Gesamt_Konstruktion_PE.pdf für Student Paul Eigen*	…/PS3/ 02_Technische_Handzeichnung

4 Notes design

4.1 Specification powertrain

relevant characteristics (output Power-Split):

- Power-Split hybrid arrangement
  - 4 cylinder 4-stroke turbodiesel
  - 2 E-motors
- maximum power of the system: 80kW (at 4000 U/min)
- maximum torque: 400 Nm (at 1700 U/min)

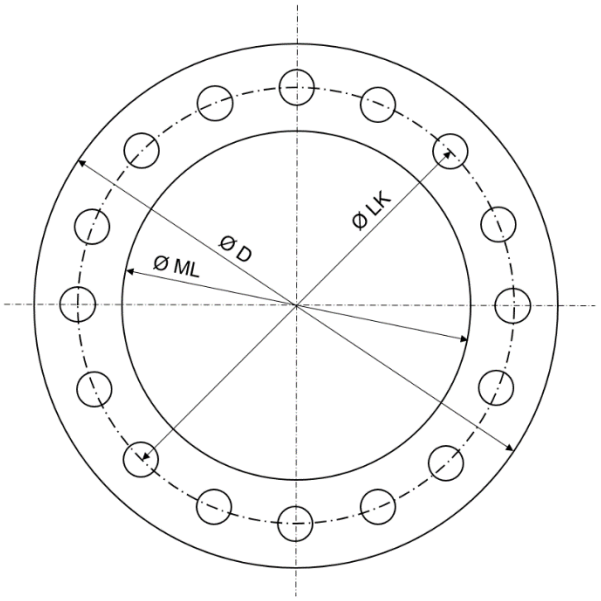


figure 13: dimensions flange

Relevant transmission ratio:

- ratio engine to including differential: i=4
- ratio overall drive: i=24

4.2 mounting dimensions differential

dimensions connecting flange for axle casing

- number of bolted joints: 20 (M15)
- bolt circle diameter LK: 250mm
- centre hole diameter ML: 230mm
- outer diameter D: 270mm

see abbreviations: figure13

The housing can be assumed cylindrical, but can be modified for possible connecting options for the suspension or the spring-damper system. The housing is 250mm wide, the outside diameter of the housing corresponds to the outside diameter of the connecting flange.

4.3 Dimensioning the bearing

Basic conditions for dimensioning of the bearing of the output shaft of the offset gear are given in the following table. Impacts during driving can be neglected. Gear forces cannot be neclegted.

overall life span	15 years
operating time tractor	200 days/year and 8h/day
average speed	8 km/h
weight on front axle	2000 kg
height uneven ground	30 cm
height of uneven ground reached in	0,2 s

Formulas for calculating gear forces for straight spur gears:

- tangential force: $F_t = \frac{2 \cdot M_t}{d_w}$
- normal force: $F_n = \frac{F_t}{cos(\alpha)}$

- radial force: $F_r = F_t \cdot tan(\alpha)$
  - α: pressure angle, M_t torque d_w: pitch circle diameter

4.4 Dimensions Planetary Gear

The dimensions of the planetary gear depend on whether the output is from the ring gear or from the planetary carrier. The input is always from the sun gear.

dimensions	output from ring gear	output from planetary carrier
ratio i	6	6
module m	2	2
number teeth sun gear	32	32
pitch circle diameter sun gear [mm]	64	64
root diameter sun gear [mm]	59,6	59,6
outside diameter sun gear [mm]	68	68
Number of teeth of the ring gear	192	160
pitch circle diameter ring gear [mm]	384	320
root diameter ring gear [mm]	388,4	324,4
outside diameter ring gear [mm]	380	316
number of teeth of the planet gear	80	64
pitch circle diameter planet gear [mm]	160	128
root diameter planet gear [mm]	155,6	123.6
outside diameter planet gear [mm]	164	132

4.5 Dimensioning wheel flange

Information is based on information from Michelin: http://landwirtschaft.michelin.de/
The dimension of the tires is given: 12.4 R24. Therefore, the following rim size is required: W11x24

rim centre diameter [mm]	221
diameter of the tires [mm]	1149
outer circumference [mm]	3420
pitch circle diameter [mm]	275
number of bolts per rim [-]	8
Coefficient of friction between tire and rim μ_T [-]	0,2
Coefficient of friction between head of bolt μ_K and thread μ_G [-]	0,12
total clamping length (flange - rim) l_k [mm]	60
Surface quality in bolt taper R_{zK} [µm]	40
Surface quality of contact surface and thread R_z [µm]	25
contact force p_g [N/mm²]	600
weight on front axle [kg]	2000
Current wheel bolts	M12, strength class 10.9
material flange	42CrMo4
safety factor of bolt	1,25

The following basic conditions are assumed:

- the braking only by the rear wheels.

- in extreme case the entire driving torque can be equally distributed over the four wheels onto the ground.
- Torques around the rim axle (e.g. due to drive torque) and transverse forces are **force-fit** supported.
- It can be assumed that the distance between the screws is big enough: there is no reciprocal influence
- The E-modulus for flange and rim is $E = 2{,}05 \cdot 10^5\ N/mm^2$.

The tightening is torque-controlled.

Ø Zoll	Dimension	CAI Reifen	Neureifenmaße Breite mm	Durchm. mm	stat.Hbm. mm	Abr.umfg. mm	Felgen empfohlen zugelassen Zoll	CAI Schlauch(1)	Reifen-inhalt 75 % Liter	Profil-tiefe mm
24	**9.5 R 24** 107 A8/104 B TL AGRIBIB	123932	247	1040	472	3097	**W8** W7	170035	64	32
	11.2 R 24 114 A8/111 B TL AGRIBIB	123864	294	1092	498	3292	**W10** W9	170037	92	37
	12.4 R 24 119 A8/116 B TL AGRIBIB	123788	324	1149	520	3420	**W11** W10	170037	115	41
	13.6 R 24 121 A8/118 B TL AGRIBIB	123868	366	1197	539	3559	**W12** W11	170039	151	43
	14.9 R 24 126 A8/123 B TL AGRIBIB	123848	408	1259	561	3733	**W13** W12 W11	171114	187	48
	16.9 R 24 134 A8/131 B TL AGRIBIB	123854	460	1330	586	3935	**DW15L** W14L DW14L W15L	170042	243	55
28	**12.4 R 28** 121 A8/118 B TL AGRIBIB	123832	322	1262	577	3764	**W11** W10	170051	134	40
	13.6 R 28 123 A8/120 B TL AGRIBIB	123782	372	1308	592	3893	**W12** W11	170053	172	46
	14.9 R 28 128 A8/125 B TL AGRIBIB	123850	403	1358	612	4050	**W13** W12	170148	210	47

figure 13: dimensions for tires Michelin AgriBib (excerpt)

Rim Terms

The complete rim (wheel) is the connection between the tyre and the vehicle.
The "wheel" consists of the rim and the nave. The rim profile is standardised to ensure interchangeability with the tyre.

Example of a tractor front wheel rim W 14 L x 20

W **= Rim shape (single low bed) (code)**
14 **= Rim width in inches** (between rim flanges)
L **= Rim flange design (code)**
20 **= Rim diameter in inches**

Example of a tractor rear wheel rim DW 12 L x 38

DW **= Rim shape (double low bed) (code)**
12 **= Rim width in inches** (between the rim flanges)
38 **= Rim diameter in inches**

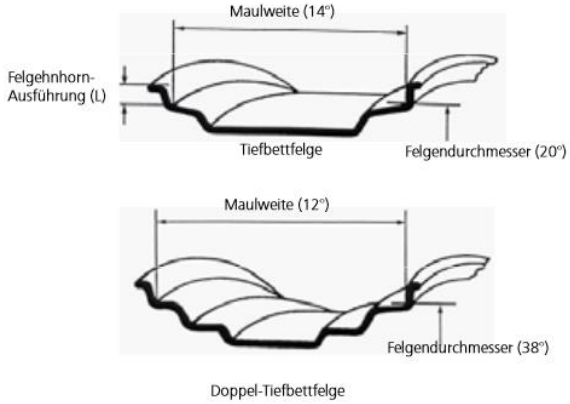
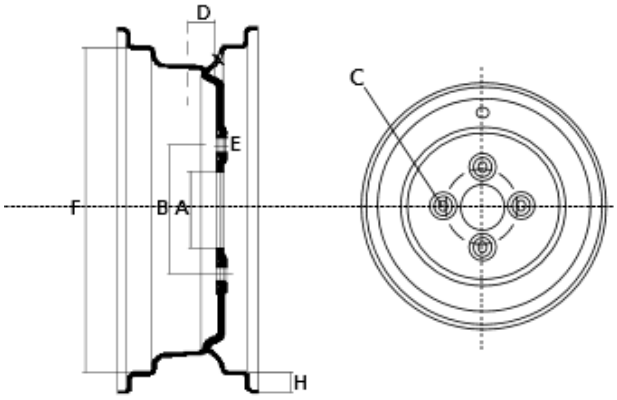


figure 14: naming of rims (excerpt rim catalog: bohnenkamp.de)



The most common connection Types

Number of Bolts	Centre Hole ⌀	Bolt hole circle
4	60	100
5	67	112
5	94	140
5	110	160
6	110	150
6	161	205
8	221	275
10	281	335
12	371	425

A = Centre hole diameter mm
B = Bolt hole circle mm
C = number of bolt holes
D = Offset mm
E = Bolt hole diameter mm
F = Rim diameter inch
G = Rim width inch
H = Rim flange

figure 15: dimensions rims (excerpt of rim catalog: bohnenkamp.de)

4.6 Further Literature

- Steinhilper, W., Sauer, B. (Hrsg.) (2016). Konstruktionselemente des Maschinenbaus 1. Berlin Heidelberg: Springer Verlag.
- Steinhilper, W., Sauer, B. (Hrsg.) (2016). Konstruktionselemente des Maschinenbaus 2. Berlin Heidelberg: Springer Verlag.
- Hoischen, H., Fritz, A. (Hrsg.) (2016). Technisches Zeichnen: Grundlagen, Normen, Beispiele, darstellende Geometrie. Berlin: Cornelsen.
- Gomeringer, R. et al. (2017). Tabellenbuch Metall. Haan-Gruiten: Verlag Europa Lehrmittel - Nourney, Vollmer GmbH & Co. KG.
- **DIN-standards and VDI guidelines can be found in the Perinorm database.** (You have to be in the KIT-network to access the Perinorm database.)