Workshop Task MD IV
Summer Semester 2024

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Version: **1.1**

Development of a New Powertrain Generation for an Agricultural Tractor

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

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Introduction

1.1 Motivation & Objectives

As in the previous semester, this workshop will offer a working environment, which can be found in an engineering office. The aim of this workshop is to consolidate the knowledge gained during lectures and exercise and to further improve your skills in applying what you have learned.

During this workshop task, your team will work in the development department of a known manufacturer of agricultural machinery and is responsible for developing the powertrain for the new product generation. For this, in a first step the objectives (aimed benefit) have been identified, which are to be achieved with the next product generation. For a better overview, the objectives are classified in the categories provider, customer and user. These should provide a starting point for the new product generation, and a basis for reasoning and evaluation for important decisions. **This is an initial status, which must be completed and adapted during the further development work**.

provider	customer	user
• **customer acquisition** by offering a broader drive portfolio • saving development effort due to the modular design • possible sales of attachments • **Possible partnerships** with manufacturers of attachments	• **low one-time investment costs** for the working machine as an all-round-machine • **low secondary costs** due to the economical operation of the agricultural machine • **great variability due to attachements**	• **greater comfort when starting** due to the reduction of vibrations in the powertrain • **simple maintenance**

table 1: objectives for supplier, customer and user benefits

It has already been decided that a partial objective for the new product generation is that it should have a **modular hybrid powertrain**.

1.2 Structure of the Task

Before you start, you have to read through the **complete** task in order to know all the interrelationships. Chapter 2 *Initial System of Objectives for the Powertrain of the Tractor* includes explanations to the complete system and to the subsystems which you will develop. First, the functions of the existing system from the previous generation are described. Then, in terms of a first basic product specification, objectives and requirements, and guidelines deriving from them for the complete powertrain and the individual subsystems of the new product generation are described in more detail.

In chapter 3, you will find the result of the project design of the development process carried out by the head of the department. In this chapter the project is split into work packages, which you will present in three project meetings. Also, the system of objectives for the individual subsystems of the powertrain will be further specified in this chapter. The task ends with the appendix in chapter 4, which contains further important specifications to be met, as well as references for further reading.

Important statements are in **bold**, statements of particular importance are additionally marked with a ⚠.

1.3 Important Notes

During the development of the drivetrain, the preparation of the work results and the execution of the project meetings, you have to observe and comply with **basic guidelines**, notes and specifications that are generally applicable to the MD Workshop, in addition to the **present assignment**. These are contained in the following documents, which are provided to you via ILIAS:

- „*Basic instructions on the Workshop Mechanical Design IV* “:
  Basic rules for the workshop and notes regarding working on the task.
- „*Handbook visualisation and technical drawing*“:
  Detailed notes to the format of technical drawings and principal sketches.

The task is a **balance** between creative **freedom** and clearly defined **boundary conditions** and **specifications**. Therefore, you will notice that not all calculation variables needed are given to you in every task. This is due to two reasons: on one hand, each approach (for a solution) leads to individual circumstances and external marginal conditions, which would influence a given parameter. On the other hand, independent research should consolidate both understanding the topic and research skills. In the case of missing information, search for relevant data and make **reasonable assumptions** in the appropriate situation. Please document these.

2 Initial System of Objectives for the Powertrain of the Tractor

The following paragraphs describe the previous generation as a central reference product. Based on this, the objectives to be followed in the development of the new product generation, are explained. The objectives for the complete system are broken down into the targeted functional range for the individual subsystems (TS) of the new product generation. Further, more precise details to be found in chapters 3 and 4.

IMPORTANT: If necessary, you can make your own well-founded assumptions, as long as these do not contradict those given in the task. These assumptions must be documented accordingly and you must be able to reasonably justify these to your supervisor (tutor) within the limits of the workshop.

Please bear in mind that the reference data/documents provided were also developed by students, i.e. they may be faulty and have a potential for improvements. Hence, this reference data/documents should not be integrated into your own solution without analysing it beforehand.

Figure 2: competitor Fendt Vario 200

2.1 Overview of the Complete Powertrain

2.1.1 Reference product previous generation

The current product generation is a **power-split hybrid** (Figure 3) **permanent four-wheel drive**. A combustion engine works in combination with two electric motors. The power of the engine and two electric motors flows into a planetary gearbox, so that the power can be bundled (see Figure 6).
The main function of the powertrain is to drive the wheels. For this, the power is first distributed by the central differential on the front and rear axle in order to achieve an all-wheel drive. Additional differentials on the individual axles provide a further power split to the individual wheels. The transmissions integrated in the hub of the wheels have already been developed by you. This last speed and torque conversion directly on the wheels reduces the strain on the powertrain components between the engine and the wheels. An auxiliary function of the powertrain is to drive a power take-off shaft. This is used to drive machine (e.g. hay balers, pile drivers) which can be connected to agricultural machines. The conversion of the torque and the speed required for this is realised by the power take-off (PTO).

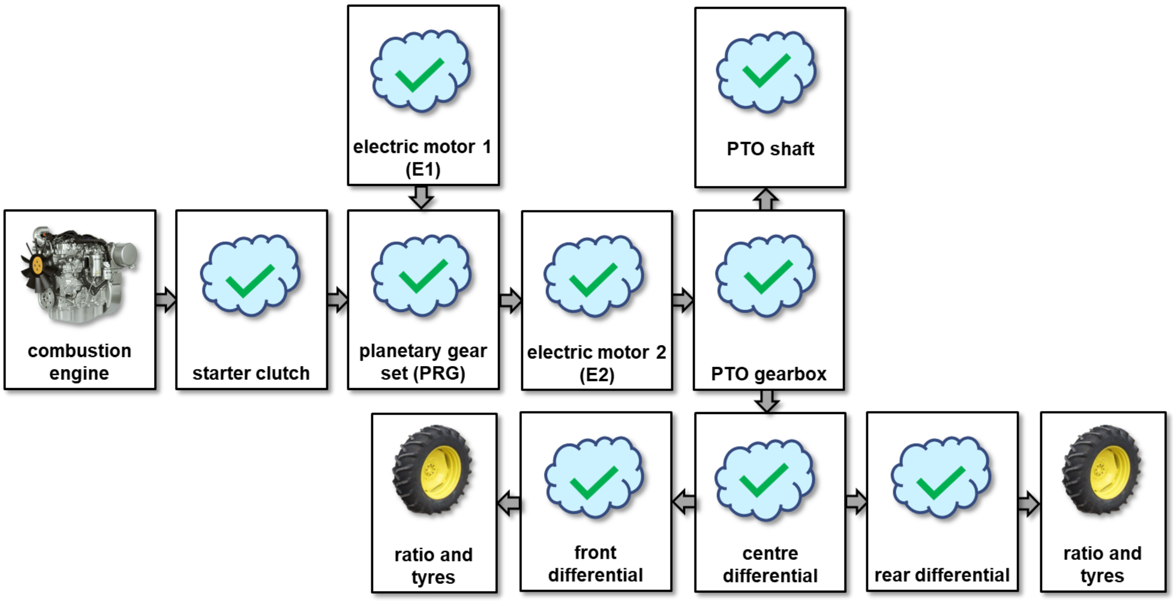


Figure 3: diagram complete powertrain of the previous generation

Intra-corporate **product documentation**, which is needed as basis for the development of the new product generation, can be found on **SharePoint** (**Link**). This documentation from which necessary information can be found, includes the drawings of the planetary gear set (PRG) as well as the technical drawing of the complete system of the previous generation.

2.1.2 System of objectives for the next product generation

It has been found that the complex and expensive powertrain of the previous generation could only attract a small clientele, which was reflected in the low sales figures. Therefore, the management decided to offer the powertrain in the **following 2 variants** in the future.

2.1.2.1 Variant 1: combustion engine

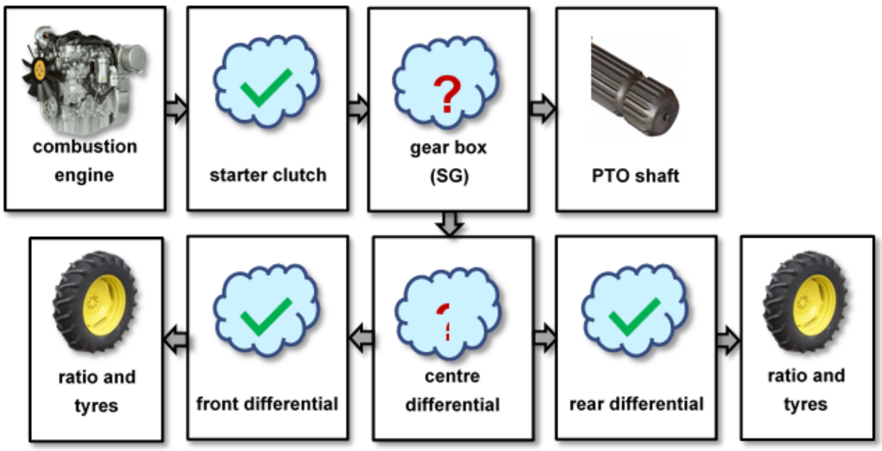


Figure 4: scheme for variant 1: combustion engine of the new product generation

The first variant corresponds to a classic internal combustion engine powertrain structure with a starting clutch and automated manual transmission.

2.1.2.2 Variant 2: Parallel Hybrid

In this variant, the **parallel hybrid**, a **hybrid module** is arranged between the combustion engine and the transmission. This consists of an electric motor and a planetary gearbox. The hybrid modules provides hybrid functions such as recuperation, start-stop, boosting, load point shifting, sailing and limited pure electric driving. In addition, the electric motor can take over the supply of further unit (e.g. cooling units). Optionally, it is possible to charge batteries using mains (plug-in hybrid, PHEV). The main advantages of this hybrid concept include fuel saving combined with the possibility of transporting people and goods in a pure electric mode (last-mile delivery).

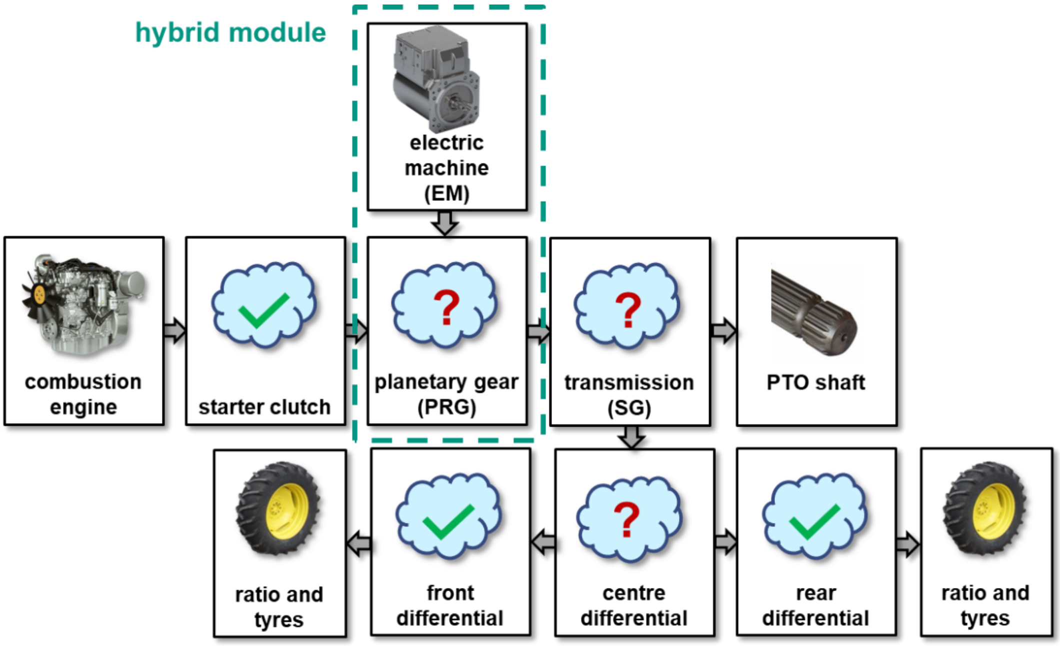


Figure 5: scheme for variant 2: parallel hybrid for the new product generation

In order to keep the development and manufacturing **costs** for the two new variants **low**, the powertrain is to be designed as a **modular** system. The new modular hybrid transmission consists of the **starter clutch**, the **hybrid module** and an **automated shift gearbox**. For variant 2 parallel hybrid: here, only the **hybrid module** between starter clutch and shift gearbox is to be added as an "**add-on**". The **other sub-systems** are to be identical in both variants.

IMPORTANT: the **spatial arrangement of the sub-systems is your responsibility.** The different sub-systems of the powertrain are mounted on a vehicle frame. Further notes regarding the overall system are given in section 4.1.

2.2 TS shift gearbox

2.2.1 Reference system element from the previous generation

The previous generation did not have a shift gearbox.

2.2.2 System of objectives for the next product generation

For a revolutions/torque conversion in the powertrain, a **shift gearbox** is needed, which adapts the torque and the number of revolutions of the engines (combustion engines and electrical machine) to the traction power requirement of the tractor. A purely **mechanical transmission** is to be used for the tractor. Mechanical transmissions are either form-fit or force-fit based. In order to achieve the highest possible efficiency, a **form-fit power transmission** is to be used. The **changing gears process has to be synchronised**. To reduce wear as well as to dissipate heat from the transmission, a lubrication system is necessary. The mechanical transmission should cover two speed ranges. The "working gear" range is for the slow movement at nominal revolutions, e.g. for baling round bales, whereas the "driving gear" is for the fast driving/movement on the road. There should be a reverse gear for both ranges. The **shift gearbox** is not **actuated** by the driver using a shift lever, but **automatically**.

2.3 TS hybrid module

2.3.1 Reference system element from the previous generation

The power split hybrid drive (Figure 6) of the previous generation consists of a **combustion engine** (**VKM**) as well as two **electric motors** (**E1&2**). The power flow of the combustion engine and the electric motor/machine E1 are couple via a **planetary gear (PRG).** An **engageable starter clutch (AK)** is located between the planetary gear (PRG) and the combustion engine (VKM). This makes it possible to separate the VKM from the rest of the power train, which allows **pure electric driving**. Furthermore, the starter clutch is needed in order to start the combustion engine. The electric motor/machine E1 can be used either as a motor to drive the tractor or as a generator to charge the battery. A **brake (B),** which is mounted on the planetary gear (PRG), fixes the sun gear of the gearbox if for example the electric motor is disconnected from the powertrain, and the vehicle is to be driven by the combustion engine only. Furthermore, a **clutch with integrated brake (K&B)** is mounted after the planetary gear (PRG) in order to enable a pure electric drive via the electric motor/machine E2. A **second gearbox (ZWG)** is connected to the electric motor E2, which permits the variable drive of the power take-off shaft PTO.

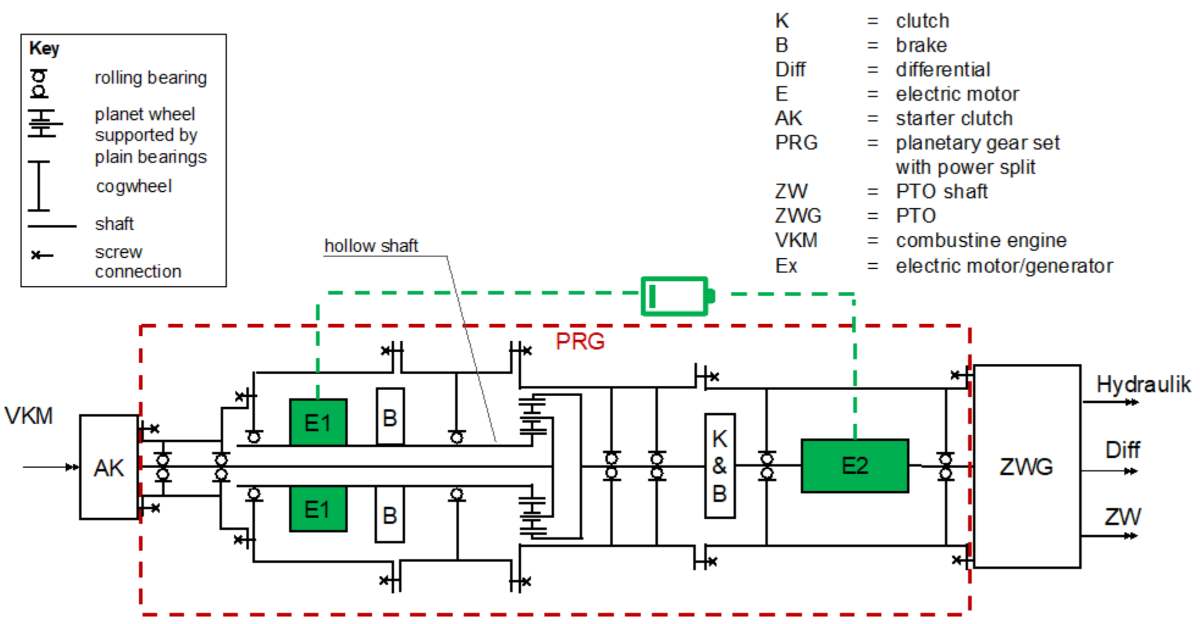


Figure 6: principal sketch previous generation

The planetary gear of the previous generation is used as reference for developing the new product generation. To save costs, as many components as possible should be **kept/carried over** or **replaced by less expensive ones**. C**arryover, Embodiement and Principle variations** must be **justified** in the project meeting.

2.3.2 System of objectives

For implementing variant 2: **parallel hybrid** of the powertrain, the **power flows** of the **combustion engine** and the **electric motor** must be coupled in the **hybrid module**. As in the previous generation, the power flow is merged in the **planetary gear**. An important goal for the design of the hybrid module is the simple installation between the **shift gearbox** and the **starter clutch**. From the modular concept results the **boundary condition** that the **starter clutch** and **shift gearbox** must also be **assembled** without the hybrid module for variant 1: combustion engine. Both variants are to be assembled on the same production line, so the design of the **interfaces** and the **lubrication concept** of the hybrid module and the surrounding sub-systems should support a **fast** and **flawless assembly**.

2.4 PTO drive

The PTO shaft is used to drive work equipment that are connected to the tractor, and **should be possible to be engaged when the machine is stationary and the engine is running**. The PTO shaft is placed in **the middle between the rear wheels**. At nominal revolutions of the combustion engine, the PTO drive should be possible in two different levels (540 rpm and 1000 rpm). You will plan the gears and gear changing devices.

2.4.1 Reference system element from the previous generation

In the previous generation, the power split in the powertrain takes place in the **PTO (ZWG**).

2.4.2 System of objectives

Due to cost reasons and design space, no additional housing for the PTO is to be planned for the new product generation. The **power split** for the PTO shaft is to take place in the **shift gearbox**. Technical data for the PTO shaft can be found in chapter 4.7.

2.5 TS starter clutch

A **starter clutch (AK)** is placed in the mechanical power flow between the hybrid module and the combustion engine (variant 1) resp. between the combustion engine and the shift gearbox (variant 2). This is needed due to the minimum revolution of the combustion engine, which cannot start from idle under load. For this purpose, at start, it matches the input revolutions of the transmission to the revolutions of the engine. Furthermore, it serves to interrupt the power flow during gear changing and fully electric driving, and also protects the complete system from overload by preventing the transmission of excessive torques. The starter clutch is an engageable clutch which, according to VDI guideline 2240 in principle can be realised as externally, speed, torque or direction actuated.

2.5.1 Reference system element from the previous generation

For the tractor there is an **externally actuated clutch system**. In addition to the previously mentioned starter clutch, further couplings and clutches (see Figure 6, B, K&B), are mounted in the powertrain. These are necessary for the function of the power-split hybrid on one hand, and for the PTO shaft to function as required on the other.

2.5.2 System of Objectives

A starter clutch must also be used in the new product generation. You must check whether the starter clutch of the previous generation meets the requirements of the new work machine, and redesign if necessary. The **torque transmission of the starter clutch** is **friction based**.

2.6 Combustion engine

2.6.1 Reference system element from the previous generation

The new product generation will use the same combustion engine as the previous generation.

2.6.2 System of objectives

The combustion engine is to be integrated without any modifications in the hybrid power train, you do **not need to further develop** this engine. The technical data can be found in paragraph 4.2.

2.7 TS electric motor

The electric motor/machine for the hybrid function is a purchased part, you do not design it. Specifications can be found in chapter 4.4.

2.8 TS traction battery and tank

A traction battery is required in order to provide the electrical energy for the electric machine, and a fuel tank for the combustion engine. Their dimensions are to be taken into account for the overall concept. For the dimensions of the battery, see section 4.5. The geometry of the fuel tank is up to you.

2.9 Axle differentials

When cornering, the wheels on the axle have a different speed, since the outside wheel travels a longer distance than the inside wheel. In the case of a stiff, one piece drive shaft, this would result in tyre slip, high wear and stress on the powertrain due to tension. In order to avoid this, a transmission is needed, which in contrast to a rigid through drive with a one piece shaft, allows a unconstrained compensation of the speed and the forces. For this differential the **ratio of the driving torque** of the left and right wheel must be **50/50**.

Vehicles, which also drive in rough terrain need a locking differential: when traction is lost for one wheel the torque is still transmitted to the other wheel.

2.9.1 Reference system element from the previous generation

The previous product generation has two identical differentials: front and rear axle, which can be locked under load while driving.

2.9.2 System of objectives

The new product generation should have a front and rear axle differential lock. The differential locks from the previous generation have proven to be reliable. Therefore, they should be used **without modifications**.

2.10 All Wheel Drive / Central differential

For **AWD** vehicles with permanent all-wheel drive, in addition to the differentials a **central differential** between the front and rear axle is needed. This will compensate the tyre radius and the distances between the axles.

2.10.1 Reference system element from the previous generation

The central differential of the previous generation splits the power in the ration 50/50 between the front and rear axle.

2.10.2 System of objectives

The central differential of the new product generation must take over the functionality of the previous generation, and extend it by a **differential lock that can be engaged by the driver while driving**. When designing the housing of the differential, attention must be paid to the fact that in the sense of the modular design, the housing **can be flanged to the housing of the shift gearbox**.

2.11 Wheels and wheel hub transmissions

The axles respectively wheels of the tractor are connected to the chassis on the front axle by a spring-damper system. This is not necessary on the rear axle, since shocks and road bumps are absorbed by the tyres. For calculations it is assumed that the wheels are perfectly round.
Integrating one gear in the wheel hubs ensures that lower torques act in the preceding part of the powertrain. That means, the dimensioning of the subsystems can be accordingly smaller. Figure 7 shows as an example the wheel hub transmission of one of the previous reference products.

Figure 7: wheel hub transmission of a tractor

For the new product generation, the wheel hub transmissions **from the previous product generation are going to be used without any modifications**. **You do not need to redesign them**. The technical data for the transmissions can be found in paragraph 4.9. Please consider that decisions already made for your **MD III workshop are still valid** and should be taken over for the further development.

2.12 Chassis

The chassis is a welded construction made of closed steel profile, which forms a **full frame**. This means that the components of the powertrain do not take over any load bearing functions of the frame, i.e. their design is neither partially nor fully self-supporting (see Figure 5). This design results in a hight bending and torsional stiffness.

The joining of parts of the powertrain to the chassis is not rigid, damping elements have been used instead. The chassis for the new product generation is **also to be designed as a full frame**. As in the previous generation, the connection of the parts to the chassis is to be realised with damping elements.

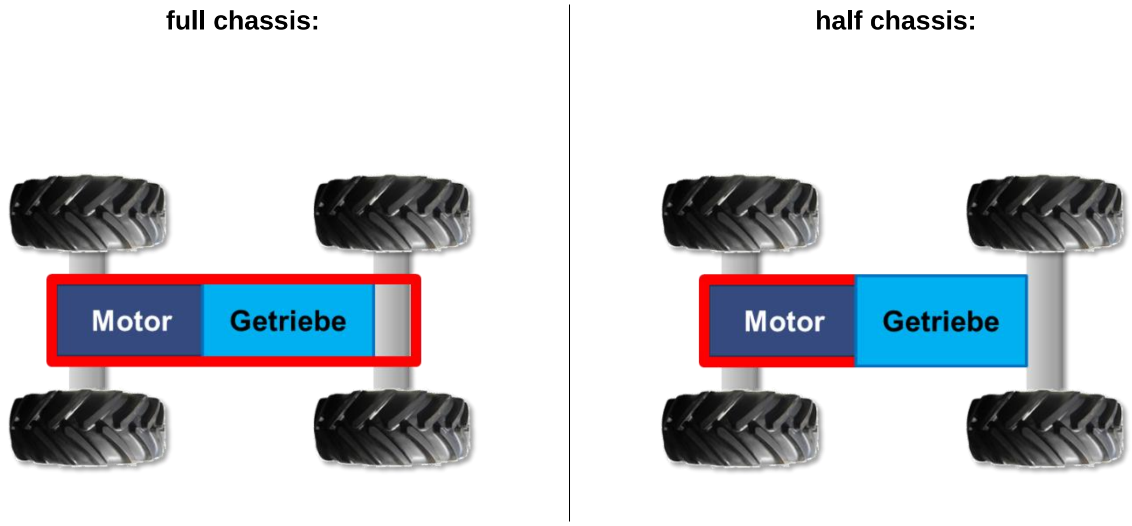


Figure 8 schematic diagram of different types of chassis (red)

2.13 Auxiliary Systems

Any auxiliary systems (e.g. pumps, cables, actuating elements) may be bought in. For a successful integration in your system, it is required that you **sufficiently understand the function** of these systems (and explain accordingly). **Known technologies** are to be applied (hydraulic, pneumatic, mechanical or electrical).

3 Development generations and development process

In the development, your product passes different defined development stages, resp. maturity levels. These levels are known as **development generations**. $E_m G_n$ means the *m*th development generation for developing the *n*th product generation. The current product generation under development is the fifth in your company (G_5). Usually there are connections between the development generations and the defined time in a development process, which divides it into different phases. The development of your tractor consists of three project meetings resp. milestones, during which you will present the next development generation in a clear and structured presentation. The **main results** of the tasks will be presented, further partial results will be shown on request. As a development team, you will **justify** your **decisions objectively** to your supervisor (tutor)!

Figure 9 gives you an overview of the components of the development generations and thus the content of the three milestones. More detailed explanations to follow in the next paragraphs.

E_1G_5	E_2G_5	E_3G_5
complete powertrain, development hybrid module	Design shift gearbox	System integration and choice of couplings/clutches
• **Project planning** • **Complete powertrain**: concept and rough design construction space estimation • **Hybrid module**: C&C²-analysis G_4 concept design	• **Project planning** • **Shift gearbox:** concept choice of bearings, dimensioning input shaft, cost calculation, design • **Central differential** concept	• **Project planning** • **Clutches in the powertrain:** specification, selection, dimensioning starter clutch • **Shift gearbox:** drawing derivation input shaft • **Complete system:** design variant 2 including central differential • **Final presentation**

Figure 9: overview content for the individual project meetings

3.1 $E_1 G_5$– Overall design and development of the hybrid module

The first development generation contains an overall design for the powertrain. Also, the planetary gear set of the predecessor G_4 is to be analysed and finally the hybrid module of the new product generation to be developed. Two first concepts for the shift gearbox must be created. You must work on the following parts of your task:

organisation		
☐	create a knowledge management structure for the group (folder structure in SharePoint)	team work
☐	project planning	team work
☐	register for the project pre-test MD IV	individual work
complete system powertrain		
☐	concept and rough design	team work
☐	estimation construction space & 3D-sketch	team work
Hybrid module		
☐	analysis of previous generation	team work
☐	Detailed concept	team work
☐	technical drawing (hand) of the hybrid module	Individual/ team[1] work

[1] **each team member** hast to hand in a **technical drawing (hand) for each project session**. It is recommended to develop a detailed concept in **Teamwork**, which is then **finished (design and drawing) in individual work**.

3.1.1 **Organisation**

3.1.1.1 Create a knowledge management structure for the group

Each member of your group will receive an email containing the access details for the group folder on Microsoft SharePoint. In this folder, all your work results will be saved. Create a structure of the folder as shown in Figure 10.

Figure 10: structure of the folder SharePoint

When saving files, consider the following guidelines:

- Pay attention to which **files and where appropriate file types** are needed and create them **before** the next workshop in the corresponding folder. If necessary, convert your files in the format requested.
- Make sure that the picture, especially the technical drawing, are of good quality and high resolution.
- **Each individual work must be uploaded separately by every group member**. In order to distinguish the files within the group, the **initials** should be added **to the end of the filename**. In the following checklists for the various subtasks, this is shown by using "Paul Eigen" as an example. He is in group A0X.
- If **additional files** are needed for individual subtasks, these files must be filed in the **appropriate folder**. The files must have a **self-explanatory, short description of your choice.**
- **For the workshop the digital version of all documentation is to be shown (except for the technical drawing),** by opening them directly from SharePoint folder. For the access to SharePoint use the KIT-WLAN/ VPN. Nevertheless, make sure you have an offline copy of the folder.
- The completeness of the SharePoint folder is one of the requirements to pass the pre-test.
- **Create an "Archive" folder on the lowest level**.

3.1.1.2 Project Planning

Create a project plan for the individual workshops according to the subtasks. This project plan should be done for the **overall project**. Modifications, which arise during the project must continuously be implemented. You should make sure that you already assign responsibilities for the individual tasks, and if possible estimate the workload for the single subtasks. These can be found in the document „**Basic instructions on the Workshop Mechanical Design IV** ". Update your project planning continuously.

Files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
project plan	depending on the program being used	GXX_project plan.xxx	*A0X_project plan.xlsx*	…/E1G5/organisation

3.1.1.3 Registration to the MD IV tutorial 76-T-MACH-105285

Provide evidence (with a screenshot) that you **registered** with the campus management (https://campus.studium.kit.edu/) for the **tutorial** 76-T-MACH-105285 (depending on the course respectively the valid examination regulations).

3.1.2 **Complete System Powertrain**

Find out more about hybrid systems for commercial vehicles such as tractors. For this purpose, use in particular information regarding competitor products, the KIT library catalogue and the recommended literature. **Document the result** of your research accordingly**.**

Develop a concept according to which you will realise the two variants of the power train. Individual subsystems of your concept can be represented as a black box. Your supervisor is interested in the answers to the following questions **among others**:

- What is the power flow from the engine to the wheels?
- Which operating modes are available?
- Which subsystems are necessary respectively active for which operating mode?
- Which reference products and reference system elements are used for the subsystems?
- What types of variations are used to develop the subsystems? (carryover variation, embodiement variation, principle variation)?

The concept should include at least:

- A **system diagram** for each variant showing subsystems, ratios and power flow through the subsystems, and delivering answers to the questions above. Tools suitable for creating these diagrams is e.g. PowerPoint.
- Calculations for the transmission ratios (including ratios in the shift gearbox)

Note:

- When calculating/choosing the gear ratios pay attention to the requirements from the initial system of objectives and the specifications from the appendix.
- For specific subsystems (hybrid module gearbox, clutches): the detailed schematic diagrams containing details to bearings, lubrication etc. are to be created for later project meetings, according to the task. In the focus for the drive concept is the **function of the complete system** and the specification of the effort for developing the subsystems.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
results of research	PDF	GXX_resultsresearch.xxx	*A0X*_resultsresearch.*pdf*	…/E1G5/completesystem
drive concept for realising both variants	PDF	GXX_driveconcept.xxx	*A0X*_ driveconcept.*pdf*	…/E1G5/ completesystem
calculating the gear ratios	depending on the program	GXX_calculations.xxx	*A0X*_ calculations.*xls*	…/E1G5/ completesystem

3.1.2.1 Estimation construction space & 3D-sketch

Estimate the design space for the powertrain of the tractor. The exact layout of the subsystems is your responsibility. The construction space estimation is to be made for the **more critical** of the two powertrain variants. It should include **all subsystems of the powertrain (**see Figure 4 and Figure 5), **up to and including the wheels.** Also take into account design space for the **traction battery** and the **tank**. Use rather **simple, but nevertheless feasible geometry**. **That means, e.g. that the dimensions match the concepts for planetary gear set and PTO and the approximate diameters of the cog wheels determined**. Also, choose an **appropriate scale** for the presentation, which must be roughly met. Thus, it is evident at first glance that the planned design space is feasible and free of conflicts.
At this point, a perspective view according to standard or details, e.g. individual screws of gearbox covers, are not required. Make sure that your representation is **easy to understand, without any further explanation** and that it includes all **relevant information**, **especially the dimensions** of the planned **design spaces** and of the geometry of the chassis. Furthermore, the **shape** of the **chassis components and their joints** (**welded construction**) should be clearly recognisable.

NOTE: Both **hand sketches** and **views from CAD models** are possible as solutions.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
estimation design space	PDF (from scan/ picture/ CAD-Model)	GXX_constructionspace.pdf	*A0X_* constructionspace.*pdf*	…/E1G5/completesystem

3.1.3 **Hybrid Module**

3.1.3.1 Analysis and optimisation potential of the previous generation

The planetary gear set developed by the students from the previous years is to be modified in accordance with your new hybrid concept (parallel hybrid instead of power split hybrid). For this, perform a **C&C² analysis** for the various **operating modes** of the PRG of the **previous generation** (see Figure 11) and documentation on SharePoint). Document this accordingly, so that the identified working surface pairs and channel and support structures are easily apparent. Think about, which parts can be **adopted** for the new product generation, what can be **optimised** or what **changes** in the **power flow** for the new hybrid concept are to be made.

For the above mentioned and possibly other partial aspects create documentation if necessary and point out where you see **potential for optimization**.

files to be saved **(optionally, the information can be summarised in one document, e.g. in the form of a draft with additional information)**				
content	**file type**	**naming scheme**	*example*	**folder**
C&C² analysis PRG previous generation	PDF / ppt	GXX_analysis_PRG.pdf	*A0X_* analysis*_PRG.pdf*	…/E1G5/hybrid module
documentation to optimization potentials and necessary changes of the PRG	PDF / ppt	GXX_document_PRG.pdf	*A0X_documenation_PRG.pdf*	…/E1G5/hybrid module

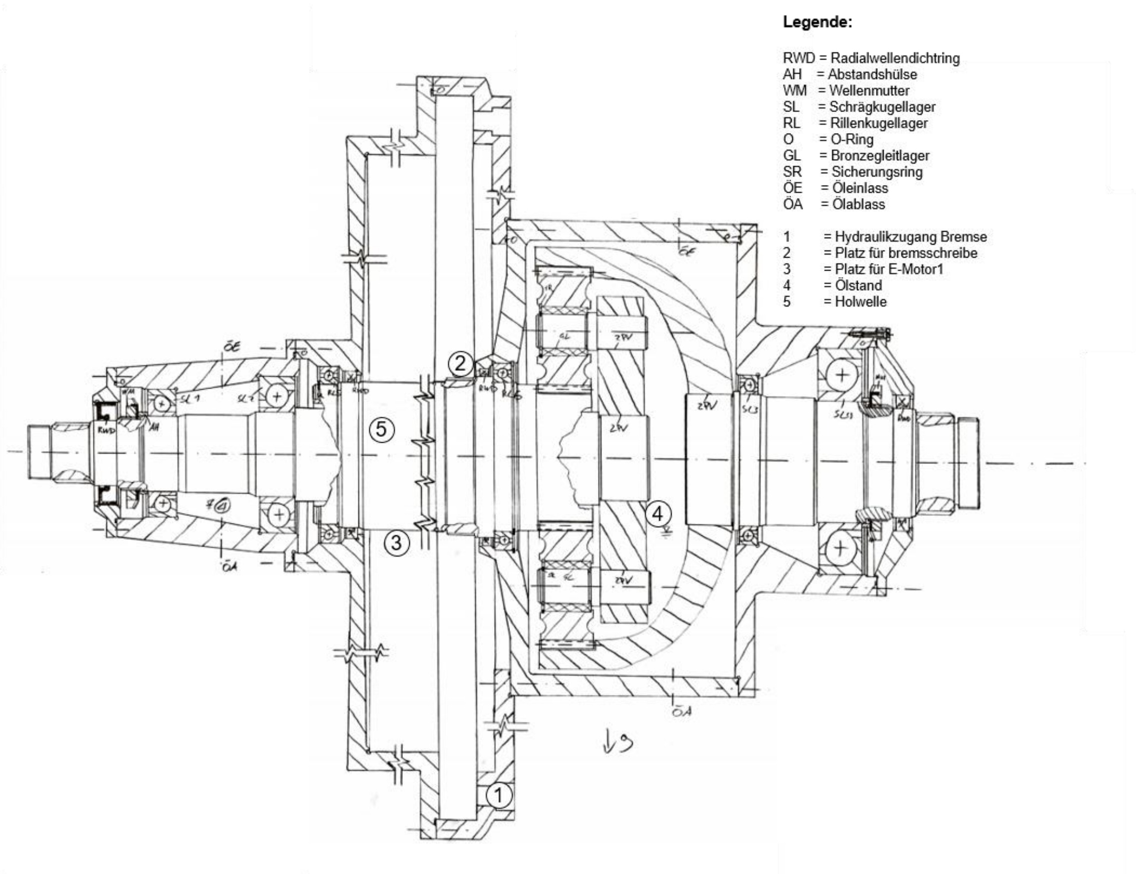


Figure 11: drawing planetary gear set reference system element

3.1.3.2 Detailed concept

For the new product generation, develop a detailed concept for the hybrid module, from the **input shaft of the hybrid module** to the **output shaft to the gearbox** (see Figure 6), including the interface to the clutch, the electric motor (paragraph 4.4) and the gearbox, in which the optimisation potentials and the needed modifications can be implemented. The concept includes at least:

- **Kutzbachplan** for the different operating modes
- Specification of the individual **gear ratios and number of teeth**
- **Estimating** the **diameters** and widths **of the cog wheels** based on the gear ratios for a chosen module.
- **Approximate** calculation of the **minimum diameters** of the shafts, based on the maximum torsional torque.
- **Schematic diagram** of the arrangement of the shafts, supporting the shafts, arrangement of the cog wheels and other components which are functionally relevant, as well as splitting housing including the covers and interfaces. Perspective views are possible and often helpful, e.g. to illustrate the spatial layout of several shafts.
- **Lubrication concept** (if oil pumps or similar are necessary: to be plotted as a Blackbox)
- **Bearing arrangement** and choice of bearings (extended life calculation is not requested)

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
one file with all required information	PDF (scan/picture)	GXX_hybrid module_concNr.pdf	*A0X_hybrid module_concept.pdf*	…/E1G5/hybrid module

3.1.3.3 Technical drawing (hand) of the hybrid module

Based on your detailed concept, design the hybrid module **from the input shaft** to the **output shaft for the shift gearbox**, and create a technical (hand) drawing. The drawing should include at least a **3D-design** showing the **components of the gearbox housing**, the **overall shape of the housing** as well as its **fixing to the chassis**.
Make sure that your technical drawing of the hybrid module **corresponds** with the previously developed concept and with the basic conditions resulting from the estimation of the design space and the interfaces to the surrounding subsystems. **Please pay attention to the basic guidelines** for technical (hand) drawings in the MD workshop**.** The electric motor/machine may be stopped after the flange, mating and sealing surfaces should be visible. The shaft end of the electric motor/machine cannot be reworked.

NOTE: If a brake is intended, it is sufficient to plan the brake disc and the mounting device for the calliper.

files to be saved				
content	file type	naming scheme	*example*	folder
technical drawing (hand) PRG	PDF from scan/photo	GXX_hybrid module_ *drawing_Initials* .pdf	*A0X_hybrid module_ drawing_PE .pdf for student Paul Elgen*	…/E1G5/hybrid module

3.2 E_2G_5 – Design of the shift gearbox

For the second development generation: the couplings in the powertrain are being reworked, and the transmission for the drive of the PTO shaft and the hydraulic pump must be planned in detail. In addition, the subsystems of the first development generation are to be adapted where necessary.

organisation		
☐	continuous project planning	team work
rework E_1G_5		
☐	If necessary rework according to feedback from last milestone.	individual/ team work
shift gearbox		
☐	2 concepts and selection proposal	team work
☐	selection of bearings	team work
☐	technical (hand) drawing of the shift gearbox	individual / team work[1]
☐	checking the dimensions of the input shaft	team work
☐	listing the costs for chosen standard components	team work
central differential		
☐	Concepts for the central differential	team work

3.2.1 **Organisation – continuous project planning**

Update your project planning based on the results of the first project meeting (take into account possible additional development work which may be needed to rework existing subsystems) and refine the planning for the results to be presented at the second milestone.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
project plan	depending on the program	GXX_project plan.xxx	*A0X_* project plan.*xlsx*	…/E2G5/organisation/

3.2.2 **Rework E_1G_5**

Carry out necessary rework from E_1G_5.take into account the feedback from the last milestone, and use the current iteration to include possible improvements. **Save the rework in the same folder as the original file. Please use the suffix UB when saving the file**.

example:

New technical drawing starter clutch by Paul Eigen:

A0X_AK_construction__PE_UB.pdf

3.2.3 **Shift gearbox**

3.2.3.1 2 concepts and selection proposal

Design at least **two concepts** for your shift gearbox. Then choose the variant you want to develop further based on suitable evaluation criteria (utility analysis). Discuss your choice in the project meeting.

- **Principal sketches(s)** with arrangements of the shafts, bearing arrengement of the shafts, arrangement of cog wheels and other functionally relevant components as well as dividing the housing including covers. Perspective views are possible and often helpful, e.g. to illustrate the arrangement of several shafts
- A gearbox diagram with **power flow** (cf. exemplary Figure 12)
- Determine the different **ratios** (see calculations from your overall concept)
- **Estimation** of the **minimum cog wheel diameter** and **– widths** based on the calculated ratios and a chosen module.
- **Approximate** calculation of the **minimum diameter** of the shafts, based on the transmitted torsional moment
- Concept for **actuating elements** located in the **gearbox housing**, its **guiding through the housing** and the interface outside the housing, i.e. how the actuators are controlled here (automated!). In principle, mechanical, hydraulic and electronical solutions are allowed.
- **Lubrication concept**: if necessary, shift gearbox and central differential can use a common oil supply. For circular lubrication, the oil pump and other subsystems do not need to be designed.
  Further details of the gearbox specification can be found in the appendix, paragraph 4.3

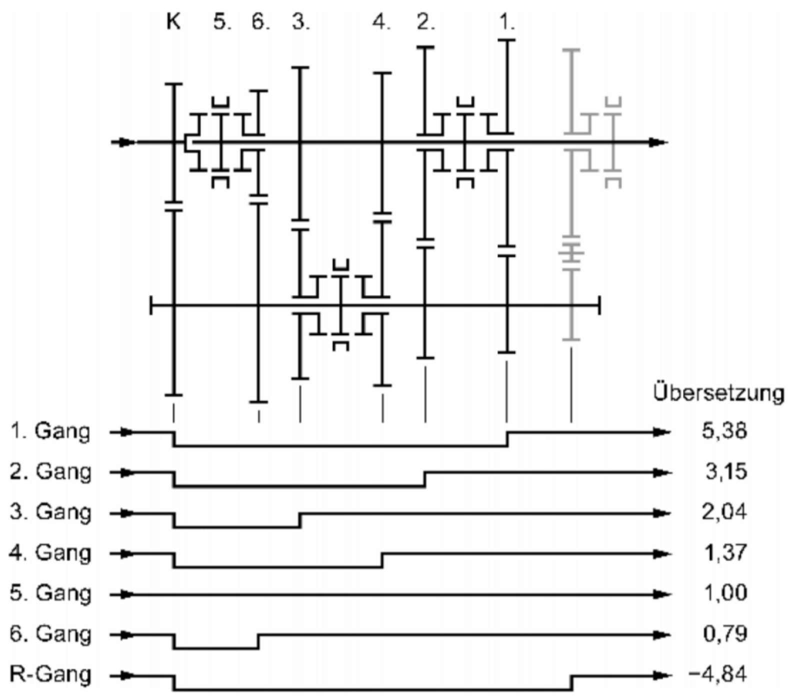


Figure 12: gearbox diagram, power flows and ratios of an automated 6-gear-transmission (Naunheimer et al. 2007, p. 211)

NOTE:

If you consider it necessary: in addition to the engaged ratios you can plan additional gear stages in the gearbox.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
PER CONCEPT 1 file with all named information	PDF	GXX_concept_SG_1.pdf	*A0X_concept_SG.pdf*	…/E1G5/SG
documentation of concept selection	PDF	GXX_SG_Selection.pdf	A0X_SG_Selection.pdf	…/E1G5/SG

3.2.3.2 Selection of bearings

The project leader has identified the bearings of the shift gearbox as being very critical, and would like you to choose appropriate bearings for **all bearing arrangements in the shift gearbox**. Based on the requirements from the initial system of objectives and the dimensions of your design, perform an **extended life calculation**. Make assumptions regarding the overall operating time (e.g. based on the number of working hours per day, number of operating days per year, targeted rating life in years) and the **load collective** (i.e. proportion of the individual operating modes of the overall operating time). Then, choose appropriate bearings from the product catalogue and use them (latest) in your next development generation in **E_3G_5**

Specify **tolerances** for the bearing seat **according to the manufacturer’s recommendation**. Make sure the **function of the non-locating bearings is correctly implemented**.

NOTE:

- This process is not required for needle bearings, needle rings, or similar and intermediate shafts for reverse gears
- In SharePoint you will find the dimensioning of bearings of the previous generation. These can be used as a template, or you access calculation tools already used in MD III. This way, you can save some effort/time.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
process flow for choosing the bearings	PDF	GXX_choiceofbearings_SG_flow.pdf	*A0X*_selectionOfBearings _*SG_flow.pdf*	…/E2G5/SG/calculations
used calculation files	depending on the program, e.g. Excel or Maple	GXX_choiceofbearings _SG_calculation.xxx	*A0X*_selectionOfBearings _*SG_calculation.xlsx*	…/E2G5/SG/ calculations
documentation of assumptions, values used and final bearing choice	PDF	GXX_choiceofbearings _SG_final.pdf	*A0X*_selectionOfBearings _*SG_final.pdf*	…/E2G5/SG/ calculations

3.2.3.3 Technical (hand) drawing shift gearbox

Design the chosen concept for the shift gearbox **from the input shaft** of the shift gearbox including the **interface** to the **hybrid module**, as well as the **interface** to the **central differential** and the **output shaft** to the **PTO shaft**.

Create a technical (hand) drawing of your design. The drawing should include at least a **3D-design** showing the **components of the gearbox housing**, the **overall shape of the housing** as well as its **fixing to the chassis**. Also, draw the **switching actuators** based on your concept. It can be interrupted outside the housing. However, the actuation here must be clear (e.g. linear or rotational movement).

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
technical drawing (hand) shift gearbox	PDF from scan/photo	GXX_SG_ *drawing_Initials* .pdf	*A0X_SG_ drawing_PE .pdf for student Paul Elgen*	…/E2G5/SG

3.2.3.4 Dimensioning the input shaft of the shift gearbox

For the input shaft of the shift gearbox (without hardened outer surface) carry out a **stress analysis based on the elliptical procedure as shown in the tutorial.** For the input shaft of the differential use **42CrMo4**. Depending on the result of the analysis, specify whether and to what extent (i.e. specify any measures to be taken, which you do not need to carry out) modifications are required in course of a further development iteration. As a working base use the procedure shown in the tutorial.

NOTE: the complete dimensioning of shafts and their design are generally iterative, interdependent processes: a first design is based on an approximate estimation of the minimum diameter of the shaft. Then, for example the analysis is carried out following the elliptical procedure. If the required safety cannot be achieved, the design must be adapted. This is followed by another analysis, etc. For it not be to be too time-consuming, only carry out the first iteration in the workshop based on your design. Any changes/adjustment can be carried out in the overall design in the third project meeting.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
flow chart for dimensioning calculation	PDF	GXX_dimensioning_EW_flow.pdf	*A0X*_dimensioning *_EW_Ablauf.pdf*	…/E2G5/SG /calculations
files used for calculation	depending on the program used, e.g. Excel or Maple + PDF	GXX_dimensioning _EW_ calculation.xxx	*A0X*_dimensioning *_EW_* calculation*.xlsx*	…/E2G5/SG / calculations
documentation of assumptions, values used and final result	PDF	GXX_dimensioning _EW_final.pdf	*A0X*_dimensioning *_EW_final.pdf*	…/E2G5/SG/ calculations

3.2.3.5 Cost Calculation for Standard Parts

Generate a cost calculation, showing the **total cost per gearbox** of the following standard components needed in your shift gearbox:

- rolling bearings
- radial shaft seals
- O-rings (selection of rings with standard material properties e.g. hardness 70 Shore-A)
- lock nuts
- circlips
- screws

Unless elsewhere required (e.g. rolling bearings) a rough choice of the standard components is sufficient, especially based on the required geometric dimensions. For **quantity based prices**, consider the production for one year. Keep in mind, that **using standard components** makes your product cheaper and therefore leads to a **competitive advantage**. **Using non-standard components** where this is not absolutely necessary **must** be **sufficiently justified** to your supervisor, if the design is to be approved.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
overview calculation	PDF	GXX_cost_calculation_SG.pdf	*A0X*_cost_calculation *_DG.pdf*	…/E2G5/SG/cost_calculation
reference, price lists, data sheets for individual parts, etc.	PDF	-	-	…/E2G5/SG/cost_calculation

3.2.4 **Central Differential**

As a team, develop at least two different concepts for the locking central differential of your drivetrain. Based on suitable criteria, choose one of the concepts for implementation. Consider the following notes and guidelines.

3.2.4.1 Concept Central Differential

- Draw **principal scetches** that clearly show the functionality – especially the differential and its actuators- and the power flow. The diagrams also include the housing and housing splitting, and the connection to the shift gearbox.
- Gearbox **shafts** are to be **roughly dimensioned** for both concepts
- Specify module and number of teeth for cog wheels
- Work out a lubrication concept. If necessary, the shift gearbox and the central differential could be lubricated by a common oil supply.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
PER CONCEPT 1 file with all named information	PDF	GXX_concept_cDiff_1.pdf	*A0X_concept_SG.pdf*	…/E1G5/SG
documentation choice of concept	PDF	GXX_cDiff_choice.pdf	*A0X_SG_choice.pdf*	…/E1G5/SG

3.3 E_3G_5 –System Integration and Choice of Couplings/ Clutches

In the third project meeting, you will present the design and layout of the missing subsystems. Connect the subsystems you have developed using clutches/couplings and present the final result.

organisation		
☐	continuous project planning	team work
rework E_2G_5		
☐	If needed, rework according to the feedback from the last milestone	individual/ team work
shift gearbox		
☐	production drawing derivation of the input shaft	team work
Clutches/Couplings in the Powertrain		
☐	Choice of the clutches/couplings in the powertrain	team work
☐	Dimensioning the friction pads for the starter clutch	team work
final presentation		
☐	10 minutes presentation of the results	team work
complete system		
☐	technical drawing (hand) with all the subsystems and final dimensioned sketch of the chassis	individual / team work[1]

3.3.1 **Organisation – continuous project planning**

Update your project planning based in the results of the previous project meeting (take into account any additional development that may be necessary to rework the existing subsystems), and improve/refine the planning for your results.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
project plan	depending on the program being used	GXX_ *project plan*.xxx	*A0X_project plan.xlsx*	…/E3G5/ 00_organisation/

3.3.2 **Rework E_3G_5**

Perform the necessary rework from E_2G_5. Proceed as already explained in paragraph 3.2.2.

3.3.3 **Shift gearbox**

3.3.3.1 Production drawing

Create a production drawing derivation of the input shaft of the shift gearbox. This can be done in a CAD system or by hand. Pay particular attention to the dimensions suitable for manufacturing and the appropriate choice of geometric dimensioning and tolerancing. In a separate document, indicate the sources used (for example, technical manuals or bearing catalogs).

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
production drawing	PDF	GXX_production_drawing_ EW.pdf	*A0X*_production_drawin g *_EW.pdf*	…/E3G5/ production_drawin g
list of references	Word/PDF	GXX_production_drawing_ resources.pdf	*A0X*_production_drawin g *_resources.pdf*	…/E3G5/ production_drawin g

3.3.4 **Clutches/Couplings in the Powertrain**

3.3.4.1 Choice of the clutches/couplings in the powertrain

Based on the procedure presented in the lecture and your powertrain concept from the first project meeting, create a documentation showing which **requirements** apply for which **clutches** in the powertrain. Also consider, which of these clutches/couplings can be purchased parts and which must be produced internally. This is needed for the creation of a cost calculation. Auxiliary shafts, which may be necessary due to the distance between different subsystems, do not have to be designed or drawn. However, in order to choose the clutch/coupling the **diameter of the shafts** must be **roughly** calculated. At the project meetings you should have digital documents, e.g. the manufacturer's technical data sheets of the chosen clutches.

files to be saved				
content	**file type**	**naming scheme**	*eExample*	**folder**
documentation of assumptions , values used and final choice	PDF	GXX_choiceclutch_powe rtrain.pdf	*A0X*_ choiceclutch _ powertrain.*pdf*	…/E3G5/clutches_i n_the_ powertrain

3.3.4.2 Dimensioning of the friction pads for the starter clutch

Dimension the friction pads for your starter clutch. The frictionally locking starter clutch must be designed, so that the maximum torque delivered by the combustion engine can be transmitted friction based and non-slip, without exceeding the nominal surface load on the clutch disc. Document your calculations and file them as shown below.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
files used for calculation	depending on the program, e.g. excel or Maple+PDF	GXX_dimensioning_frictionpads_starterclutch.xlsx	*A0X_ dimensioning_frictionpads_starterclutch.xlsx*	…/E3G5/clutches_in_the_powertrain/dimensioning
results of the dimensioning	PDF	GXX_dimensioning_frictionpads_starterclutch.pdf	*A0X_ dimensioning_frictionpads_starterclutch.pdf*	…/E3G5/clutches_in_the_powertrain/dimensioning

3.3.5 **Overall System**

3.3.5.1 Technical (hand) Drawing with all subsystems of variant 2: parallel hybrid

Create a **coherent** assembly drawing for your powertrain **from and including the input of the starter clutch and the flange of the electric motor up to the output shafts to the central differential (including central differential).** Pay attention to the following:

- for subsystems that are already part of the previous development generations: take into account the **reference notes** received during the milestones regarding the **further development**.
- choose an appropriate scale, the entire drawing must fit on **one** DINA1 or DIN A0 **drawing**.
- the depiction must clearly show how your system works. Under certain circumstances a layered cut might make sense.
- on your drawing, include a **3D sketch of the powertrain including the connections to the chassis**. Among others, this must show the position of the chosen section.

NOTE:

- if using **identical clutches** or other **gear changing mechanisms**, only one of them must be shown as a section, the other ones do not have to be drawn as a section (not as blackbox, but external housing features).
- The **hybrid module** does **not** have to be shown **as a section** (but can be done in preparation for the exam), only the coupling to the starter clutch and the central differential should be visible.

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
technical (hand) drawing	PDF (scan/ picture)	GXX_design_overall_initials.pdf	*A0X_design_overall_PE.pdf* *for student Paul Eigen*	…/E3G5/design_overall

3.3.6 Final Presentation

Finally, you present your product to **potential buyers**. Prepare a **10-minutes presentation** in which you present the **highlights** of your powertrain. Pay particular attention to the advantages your product has over competitors. In particular, address selected beneficial aspects for providers, users and customers (table 1), which you consider as a particular strength of your product. You are free to choose the type, respectively the presentation media used (e.g. MS PowerPoint). A presentation can (but does not have to!) e.g. the following rough structure:

- highlight(s) and benefits, distinction from the competition
- technical solutions in different subsystems on which the highlights are based
- conclusion / summary

Make sure that you **stick** to the **time schedule**. If needed **practise** your **presentation**. If there are any issues with the time schedule, **concentrate** on the **important parts**, and consider what can be omitted.

As **complete presentation** of your project work is **not going to be possible, focus** on one or a few **highlights.**

files to be saved				
content	**file type**	**naming scheme**	*example*	**folder**
final presentation	depending on the program	GXX_final_presentation.pdf	*A0X_final_presentation.pdf*	…/E3G5/final_presentation

4 Appendix: Further Specifications

4.1 Overall System

- The two powertrain variants are to be **mass-produced at 10,000 units per year**, 5000 of which are hybrids.
- As the tractor is directly exposed to environmental stress, and losses of lubricant can lead to environmental damage, the **demands on the sealing system are very high.**
- As the system is used in difficult terrain, a **high stiffness** of the entire system is required.
- As, quite often, agricultural machines have a lifetime of several decades, and they are serviced by the user themselves, make sure that the wear and tear components are **easy to disassemble and replace**
- the powertrain is to be used in several models and is **mass produced**. Appropriate manufacturing processes must be planned for all components, except the standard ones.
- the transmissions must be designed as **mechanical transmissions**.
- in addition, pay attention to the following **dimensions** for the tractor excluding the front-lifting unit:

maximum length:	3300 mm
maximum width:	2550
minimum ground clearance:	900 mm

- the offset of the output shaft of the (axle) differential and the shaft of the wheel shaft is **300 mm in „road position“ and 500 mm in „working position“**. The width in this area is **1000mm**

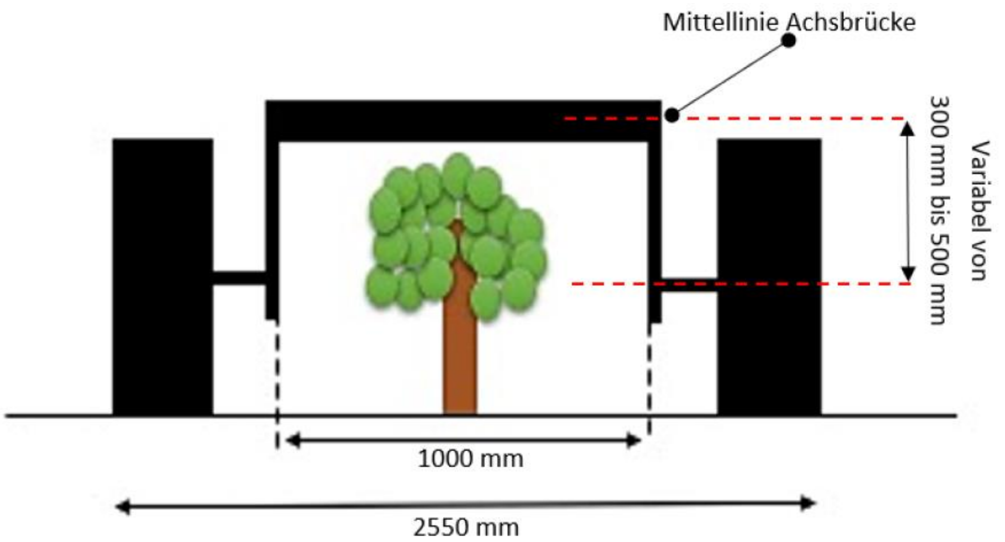


Figure 13: dimensions

4.2 Combustion Engine for the Fourth Product Generation

Technical Specification:

engine type:	4-cylinder engine, 4-stroke Turbodiesel
cylinder type :	cast iron bushing
engine displacement:	4525 cm³
compression ratio:	17,6 : 1
power/ torque:	53 kW at 2.200 rev/min maximum torque 350 Nm at 1.250 rpm
rotational speed:	starting rotational speed 800 rev/min maximum rotational speed 2200 rev/min (electronically limited)

4.3 Specification shift gearbox

Gear changing:	automated
Synchronising:	needed
Gear stepping:	2 speed ranges: working and driving range with following gears

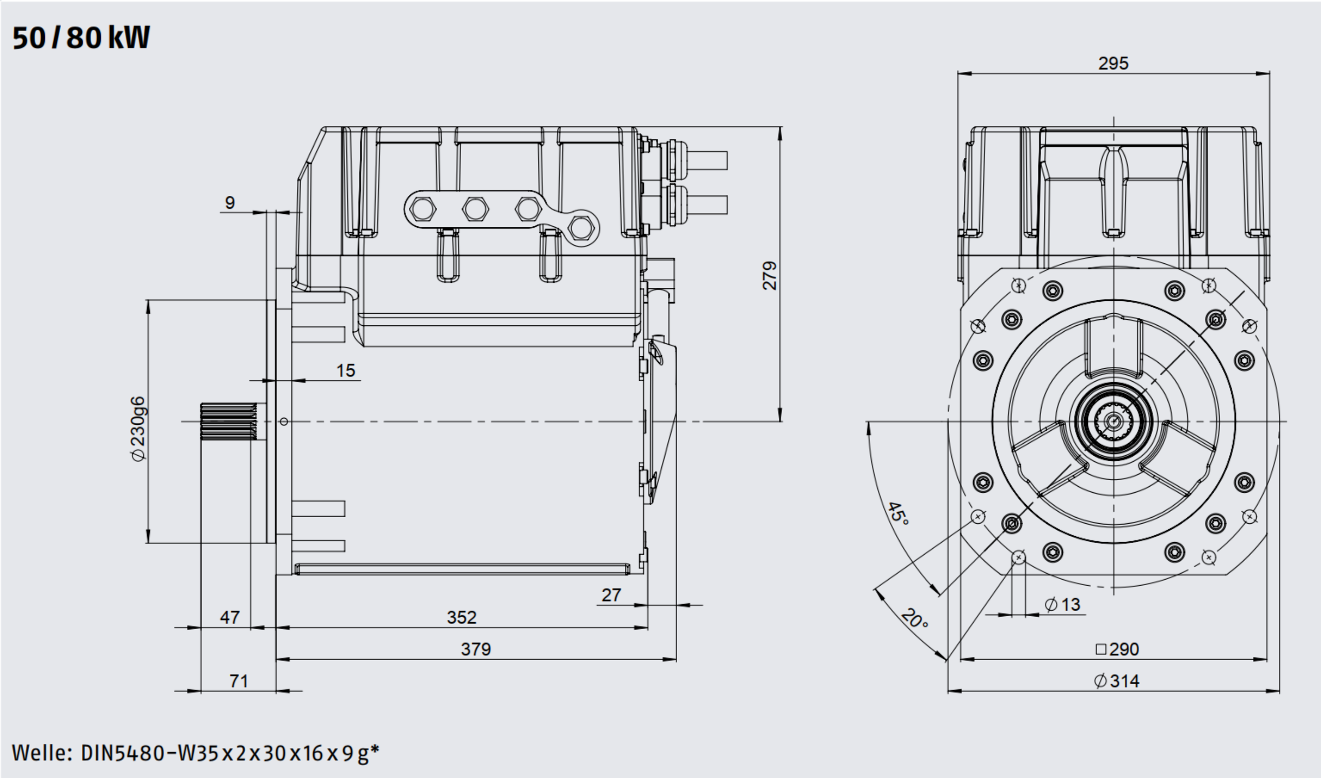
- working gear
    - gear 5,0 km/h ± 2%
    - R-gear 2,0 km/h ± 2%
- driving range
    - gear 8,0 km/h ± 2%
    - gear 15,0 km/h ± 2%
    - gear 30,0 km/h ± 2%
    - gear 40,0 km/h ± 2%
    - R- gear 5,0 km/h ± 2%
- additionally 1 neutral gear

to consider: the gear ratios of the differentials and wheel hub gears are included in the target speed!

4.4 Electric Motor for Parallel Hybrid

Buschmüller powerMELA 50kW

type of motor:	permanent magnet synchronous motor	
motor power from revolutions	KW / min^{-1}	50 / 3000
nominal torque	Nm	160
maximum revolution	1/min	6000
peak moment	Nm	245



4.5 Traction Battery

capacity: 19,2 kWh height: 442mm, length: 390mm, width: 832mm

4.6 Starter Clutch and Flywheel

For the dimensioning of the friction pad assume a material combination grey cast iron/organic pad. Therefore, use a **constant friction coefficient as per VDI 2241 sheet 1 and an allowable contact pressure as per VDI 2241 sheet 2**. Assume a constant contact force in the working surface pairs of the clutch. The clutch disc should be replaced with as little effort as possible.

4.7 Differential

ratio central differential: i=1

ratio differential (axle): i=4

Gear ratio of wheel hub gears according to your design in MKL3

4.8 PTO according to ISO 500

Speed at rating speed of the combustion engine and switched off e- machine:	step 1: 540 rpm step 2: 1000 rpm

Dimensions as per Figure 14. The groove fixes the cardan shaft of the connected devices, e.g. hay baler.

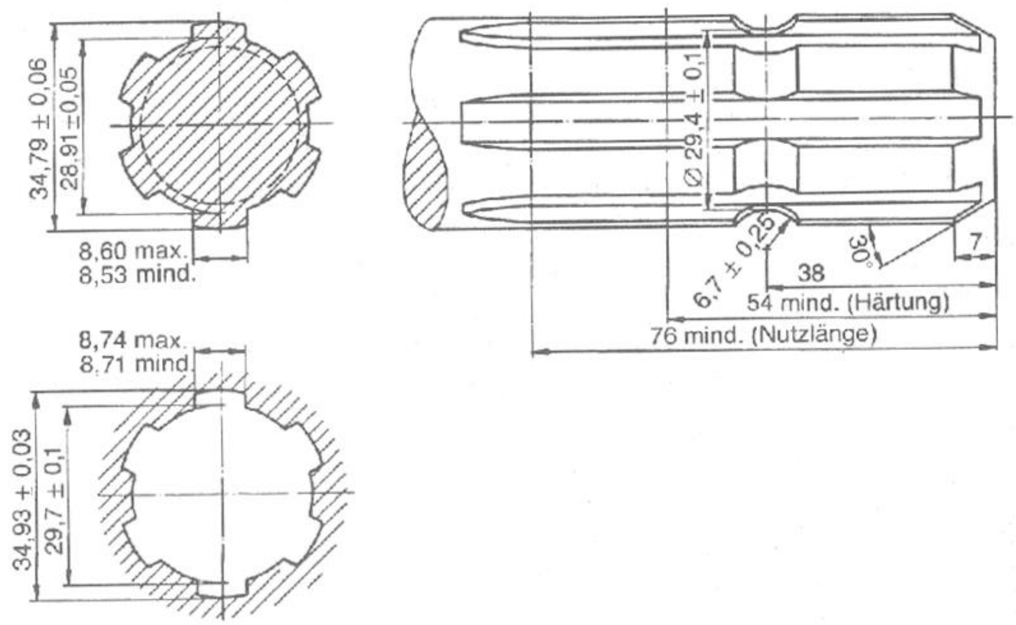


Figure 14: PTO according to ISO 500

4.9 Wheels and Wheel Hub Transmission

size of the rims:	W12.4 * 24 (in) (the same front and rear)
size of tyres:	width 324 mm, outside diameter 1149 mm, rolling circumference 3420mm
wheel hub transmission:	dimensions and ratio (i=6) in accordance to your drawings from MD III

5 Further Readings

Gomeringer, R. et al. (2017). Tabellenbuch Metall. Haan-Gruiten: Verlag Europa Lehrmittel - Nourney, Vollmer GmbH & Co. KG.

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DIN standards and VDI guidelines can be viewed in the Perinorm database (KIT network)