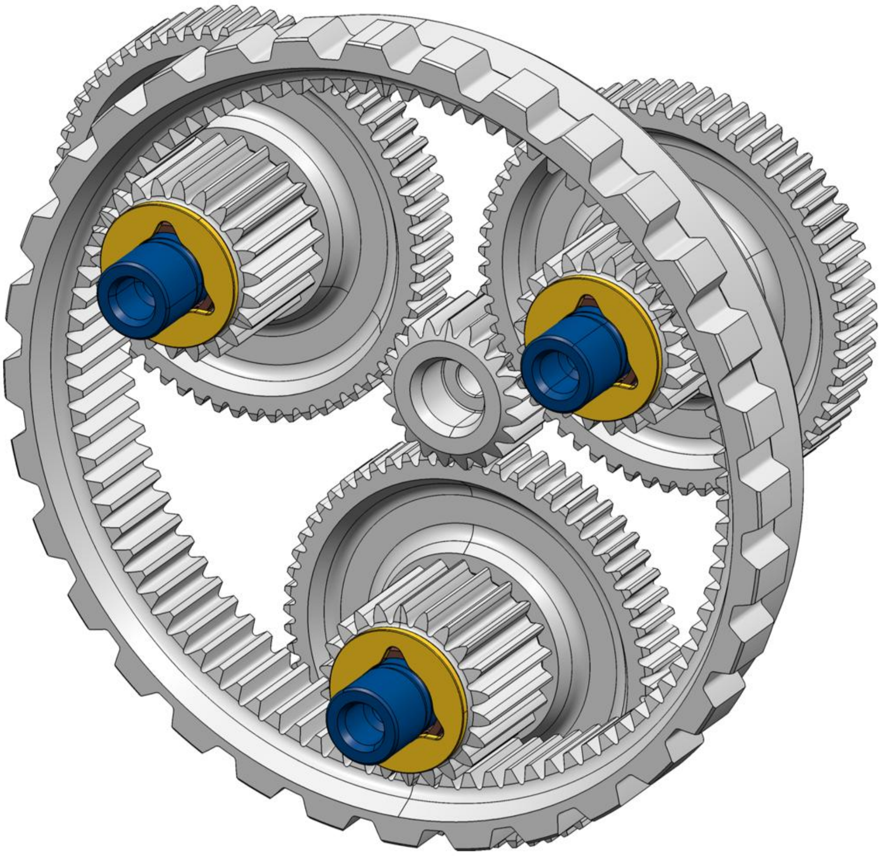
FORMULA STUDENT GEAR SET

Instruction manual



V1 - 2025

Please read the manual thoroughly before installing the gearbox in your race cars. This will reduce the risk of damage.

HUMBEL Gear Technology

Oberfeldstrasse 9

CH-9214 Kradolf

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1. HISTORY AND EXTERNAL DOCUMENTS

1.1 Document history

DATE	REVISION	CHANGE TO DOCUMENT
09 / 2025	**A**	- Document created - Basic specification added

1.2 External documents

For the design, integration, and validation of the shaft-hub connections of the sun gear shaft, several external reference documents must be considered. These documents provide essential information regarding shaft geometry, tolerances, materials and interface requirements, and must be observed to ensure mechanical compatibility, reliability and safety.
The following documents are relevant:

Drivetrain Innovation Kft. – "F-MOT-A_Drawing.pdf"
Contains detailed dimensions and specifications of the spline used in accordance with DIN 5480, as well as a recommendation for the fit of the counterpart.

AMKmotion GmbH & Co. KG – "technical_drawing_motor_a2370dd_dd5.pdf"
Part of the FSE Racing Kit R25, this document specifies the geometry and tolerances of the motor shaft used by AMK.

Fischer Elektromotoren GmbH – "Rotor shaft_TI085-052-070_136178.pdf"
Provides general technical details for the rotor shaft which some teams install as a built-in kit in their race cars. The spline itself is not specified here.

It is the responsibility of the team to obtain and adhere to the specifications defined in these documents. HUMBEL assumes no liability for failures or incompatibilities resulting from deviations or incorrect interpretation of third-party documentation.

Please note: The listed documents were referenced based on their version and availability at the time this manual was created. Future revisions or updates to these third-party documents may affect compatibility and must be reviewed independently by the Formula Student team.

2. LIABILITY AND SAFE OF USE

The HUMBEL Formula Student gear set is a specialized product intended for the development, testing, and integration into non-roadworthy prototype vehicles for research and educational purposes, specifically within the Formula Student competition. It is not approved for public road use, safety-critical applications, or series production vehicles.
Mechanical systems such as gearboxes can pose risks to people, property, and the environment, especially in the case of improper use, integration or maintenance. Appropriate safety measures must therefore be taken to minimize any risk.
Combining mechanical and electrical components in a prototype vehicle is inherently complex. HUMBEL cannot anticipate all possible interactions, influences, or malfunctions that may result from integration into third-party systems. The responsibility for the selection of suitable components and the correct design, installation, and testing of the drivetrain system lies entirely with the FS-Team.

Despite careful engineering and quality control, the following issues may still occur:

- mechanical failure of components
- overheating due to inadequate lubrication or cooling
- bearing damage from improper assembly
- noise or excessive vibration
- gear or shaft breakage under overload
- jamming or binding due to misalignment
- premature wear due to incorrect matching of components

These and other unintended behaviors may occur even when all configurations appear correct.
This gearbox must only be installed, operated and maintained by experienced personnel familiar with the mechanical, safety and thermal characteristics of such systems. All applicable safety standards and technical regulations relevant to the specific use case must be observed.
HUMBEL accepts no liability for any damages or failures resulting from improper use, incorrect system integration, lack of maintenance or unauthorized modifications. This also applies to failed inspections, disqualifications or any consequences during technical inspection by organizers or third parties.
Each gearbox undergoes mechanical inspection as part of the final quality control process. However, HUMBEL provides no warranty or guarantee regarding the safe operation of the product when integrated into a customer-built system. Specifications and the contents of this document are subject to change at any time without prior notice.
All technical drawings, assembly instructions, and recommendations are non-binding and do not constitute guaranteed product characteristics. It is the team's responsibility to verify the suitability of the product for their specific application.

3. OVERVIEW

The HUMBEL Formula Student gear set is a high-performance planetary gearbox specifically developed for use in race cars for the Formula Student / Formula SAE® competition. It is designed as an installation kit, enabling teams to seamlessly integrate the gearbox into their custom in-wheel drive units. The concept was developed in close alignment with the current Formula Student technical regulations[1], and its form, function, and performance characteristics are tailored to meet the unique demands of electric race cars at student competition level.
Leveraging motorsport-grade materials and decades of experience in planetary transmission systems, HUMBEL offers teams a robust and lightweight solution for their cars. The gearbox components are manufactured using advanced processes and undergo stringent quality control to ensure reliable operation even under the extreme conditions of dynamic track use.
From an engineering standpoint, both the macro geometry and the micro geometry have been specifically optimized for the Formula Student environment. In the development process, millions of geometry variants were simulated, evaluated, and compared using state-of-the-art software tools, to arrive at a solution that maximizes efficiency, durability, and performance within the strict packaging constraints of an in-wheel application.
The result is a drop-in ready solution that helps teams focus on integration and performance rather than fundamental drivetrain development – a product developed by professionals for future professionals.

Overview Gear Set			
V1-2025			
Gear ratio	i_{total}	12.48	-
Input torque	T_{in}	32	Nm
Input speed	N_{in}	20.000	1/min
Power	P	36	kW
Output Torque	T_{out}	400	Nm
Weight	M	380	g
Center distance	a	31	mm
Construction space	V	Φ 109 x 28	mm

Figure 1 Overview Gear Set V1-2025

[1] FS-Rules_2025_v1.1.pdf

The current version of the gearbox – **V1-2025** – has been designed for compatibility with the AMK DD5, the Fischer TI085 series, as well as custom-developed motors in combination with 10" Hoosier racing tires.
By standardizing the gearbox design across multiple common motor types instead of offering separate variants for each, we can significantly reduce manufacturing cost – resulting in a more affordable solution for Formula Student teams.

3.1 Technical support

With the purchase of a Formula Student gear set package, each team receives a foundational level of technical support to assist with the integration and use of the product. This includes the opportunity to reach out with questions regarding mechanical interfaces, general installation, racing operation, and product-specific requirements.
We understand that Formula Student teams operate under tight timelines and with highly customized vehicle designs. To support this process, we offer guidance on how to best integrate the gearbox into your drivetrain concept.
For teams requiring extended support services, such as detailed reviews of connecting parts, team's drawings, or advanced design consultation, these services can be arranged separately as an add-on package.

All technical support requests, whether basic or extended, are handled centrally via email at:

fs-gearbox@humbel-gears.com

Please make sure to include your team's name, contact information, and a clear description of your request. If available, attach relevant drawings, screenshots, or other technical documentation to help us support you efficiently.

We're here to help you bring your drivetrain concept to life – with the precision and reliability you can expect from HUMBEL.

3.2 Provided documents and files

In addition to this manual, a set of technical documents and CAD-files is provided to support the mechanical integration and detailed design of the gearbox within the team's vehicle. All files are made available to download via our homepage, together with the latest version of this manual.

The following files are included:

CAD-files

- Complete gearbox assembly as a .STEP file (.stp) – for integration into your vehicle CAD model
  ("HU-FS-Gearset_V1-2025_A_PART.stp")
- 3D-body as a .STEP file (.stp) & 2D-spline contour of the ring gear's hub spline as a .DXF file (.dxf) – for designing and manufacturing of the team-specific wheel hub
  ("HU-FS-Gearset_V1-2025_A_Ring-Gear-Hub.dxf/.stp")

Technical Drawings

- Assembly drawing – AMK version
  ("HU-FS-Gearset_V1-2025_A_Assembly_AMK.pdf")
- Assembly drawing – DTI version
  ("HU-FS-Gearset_V1-2025_A_Assembly_DTI.pdf")
- Sub-assembly drawing – Stepped planet
  ("*HU-FS-Gearset_V1-2025_A_Subassembly_Planet*.pdf")
- Shaft-hub connection drawing – AMK version
  ("HU-FS-Gearset_V1-2025_A_SHC_AMK.pdf")
- Shaft-hub connection drawing – DTI version
  ("HU-FS-Gearset_V1-2025_A_SHC_DTI.pdf")

The files are intended to support precise mechanical adaptation and proper interface definition. Units, tolerances, and relevant standards are specified in the respective drawings. Where necessary, coordination with your manufacturing partner or our engineering team is recommended before release of your parts.

Please make sure to always refer to the current file versions available on the website. In case of version conflicts or technical uncertainties, contact us.

3.3 Parts list

The gearbox is delivered as a complete mechanical kit. Each set includes all required components for one wheel-side drivetrain unit. For a complete electric vehicle, teams will typically require:

- 2 gearboxes for rear-wheel drive configurations
- 4 gearboxes for all-wheel drive configurations
- A 5th set may be considered as a full replacement unit in case of damage or failure during testing or competition

All gearboxes are supplied as fully matched sets, with no single components sold separately.
A key selection must be made during ordering:
There are two versions of the sun gear shaft available, each designed to match a specific motor type:

- AMK DD5 compatible version → w. internal spline connection
- DTI compatible version → w. external spline connection

(both versions can be selected for Fischer motors depending on team's preferences)

Only one of these versions is included per gearbox set – teams must select the appropriate version based on their intended motor system. The sun gear shaft is not interchangeable between motor types due to differing shaft-hub connections.
The desired sun gear version must be explicitly selected in the order form.

Each set therefore contains the following components:

- 1x Sun gear
- 3x Stepped planetary gears
- 1x Ring gear
- 3x Hardened and ground planetary bolts
- 12x Thrust washers for axial support of the planetary gears (with spare washers included to allow replacement in the event of wear during operation or maintenance)

All other components not explicitly listed are not included in the delivery. This includes, for example, needle bearings, lubrication (oil or grease), fasteners (bolts, washers, etc.), or other mounting or auxiliary parts. The selection and sourcing of these components is the responsibility of each team, depending on the individual vehicle design and application.

3.4 Contract manufacturing

Components such as wheel hubs, rotor shafts, or other custom drivetrain parts are of course not included in the gearbox package. These components are typically highly vehicle-specific and must be developed or adapted by the teams themselves.

As an established manufacturer in sectors such as motorsport, aerospace, and precision engineering, HUMBEL possesses the expertise, manufacturing capabilities, and quality standards required to produce such components or to support selected individual manufacturing steps (e.g. hard turning, gear cutting, grinding, heat treatment, or more).

Teams are welcome to request contract manufacturing for custom parts. However, due to the nature of Formula Student projects — with fully individualized, highly complex components and no series production — manufacturing costs are typically very high, especially when compared to standard parts or batch components.

To ensure feasibility and efficient quotation, **teams must include a target price** or budget range with their inquiry. Without a clear pricing framework, HUMBEL cannot process or evaluate team's custom manufacturing requests.

4. PART DESCRIPTION

4.1 Sun gear

The sun gear shaft serves as the input shaft of the gearbox and is connected to the rotor shaft of the team's motors via a splined shaft connection. The gear teeth are identical in design for both versions and have 21 teeth, an optimized reference profile, and microgeometry modifications to improve the contact pattern. The parts are made of motor sport-quality case-hardened steel, and the necessary functional surfaces are ground.

4.1.1 Sun gear – AMK

The AMK version of the sun gear is a simple pinion, 12 mm wide with ground flat surfaces on both sides. Internal splines compatible with AMK and a ground running gear with reduced width on the outside.

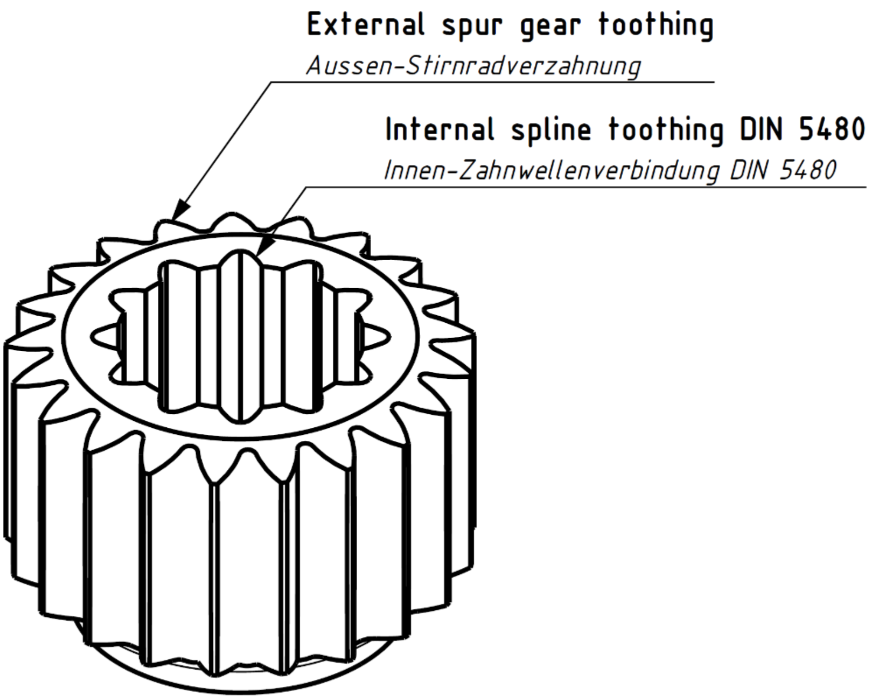


Figure 2 Sun gear shaft AMK

If a team prefers to use external splines for their self-built motor or implementation of the Fischer rotor shaft (due to manufacturing capacities or other internal team reasons), they can also choose this sun gear.

4.1.2 Sun gear – DTI

The variant for DTI, or rather the one for rotor shafts with internal splines (which can typically be manufactured by the teams easily using wire-EDM), is a hollow-drilled shaft approximately 46 mm long. The outer contour is CNC-turned and stress-optimized.

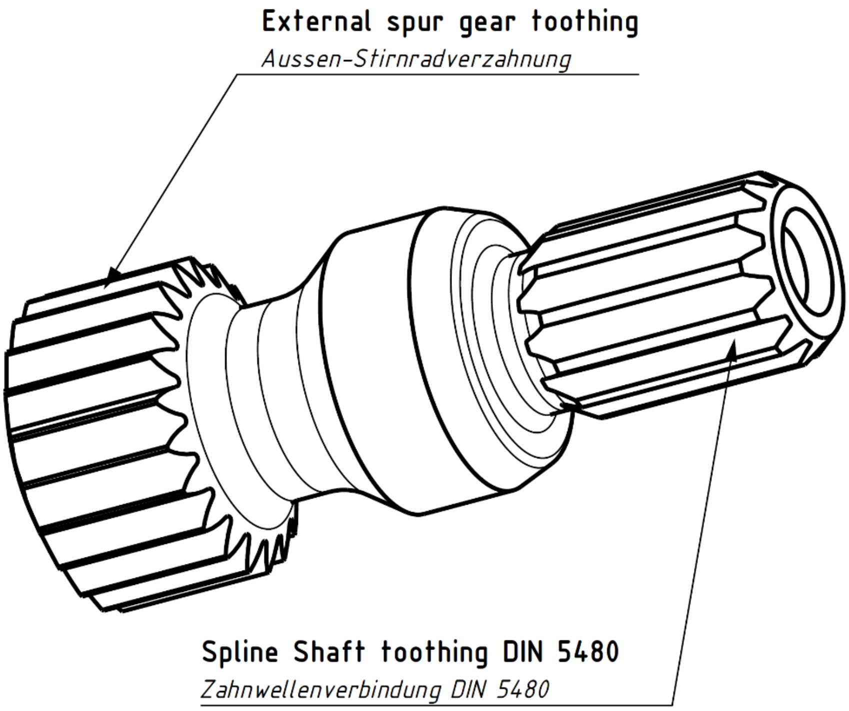


Figure 3 Sun gear shaft DTI

Even though it is not necessary for the DTI motor, we have added an additional ground shaft seat (Ø16 h6) instead of a simple shoulder for teams with their own rotor designs, which serves as a running surface for rotary shaft seals. Since the teams' rotor shafts are often made of titanium (Ti6Al4V), they are unsuitable for seals due to their lack of hardness. Our version of the sun saves the teams from having to use sleeves on their rotor shaft.

4.2 Stepped planet

The planetary gearbox is designed so that it can be operated with 3 identical stepped planets. These are delivered in assembled condition, secured axially with a retaining ring. The planet is designed as a multi-part assembly, as this is the only way to achieve ground tooth flanks on planet 2 (collision between grinding wheel and planet 1) and it results in a more compact design overall (a (hard-) hobbed planet 2 would have to maintain 3-5 mm distance from planet 1).
The ground bore and end faces of planet 2 serve directly as running surfaces for the radial and axial bearings.

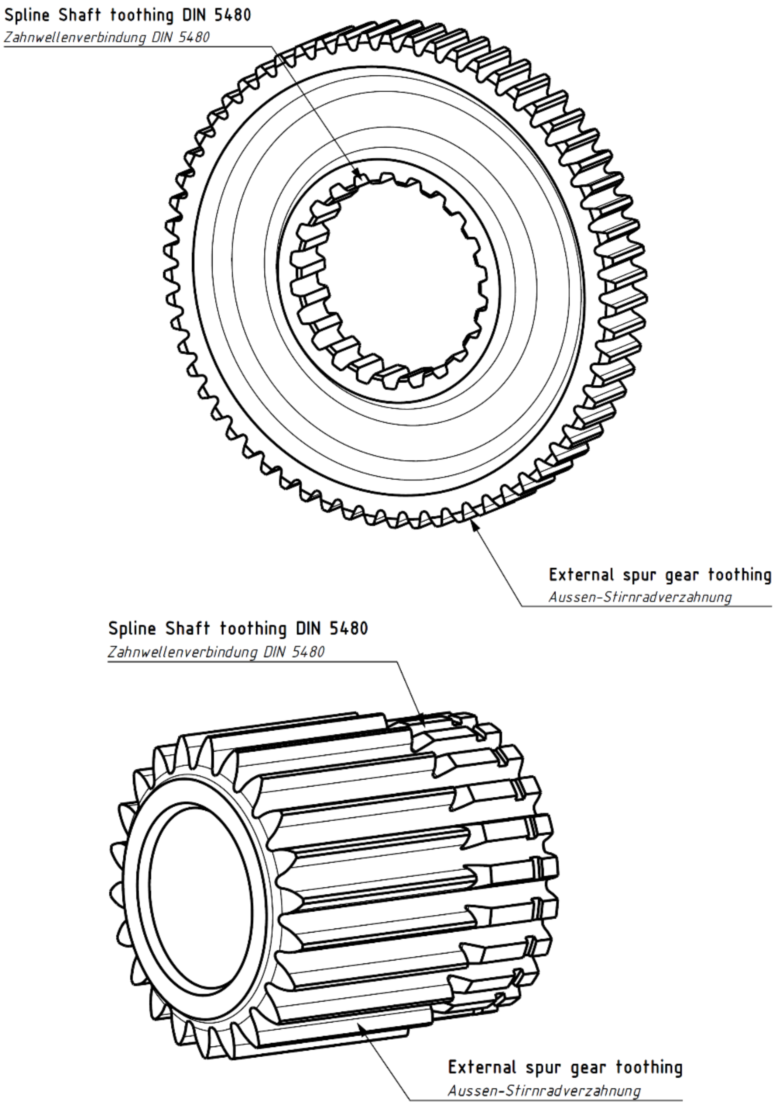


Figure 4 Planet 1 & 2

For maximum precision and alignment, the gear teeth of Planet 2 are also used as splines for the connection to Planet 1.

4.3 Ring gear

The ring gear is made of nitriding steel and is low-temperature hardened to minimize distortion. This eliminates the need for gear grinding, thereby saving costs that are passed on to the purchase price of the teams.

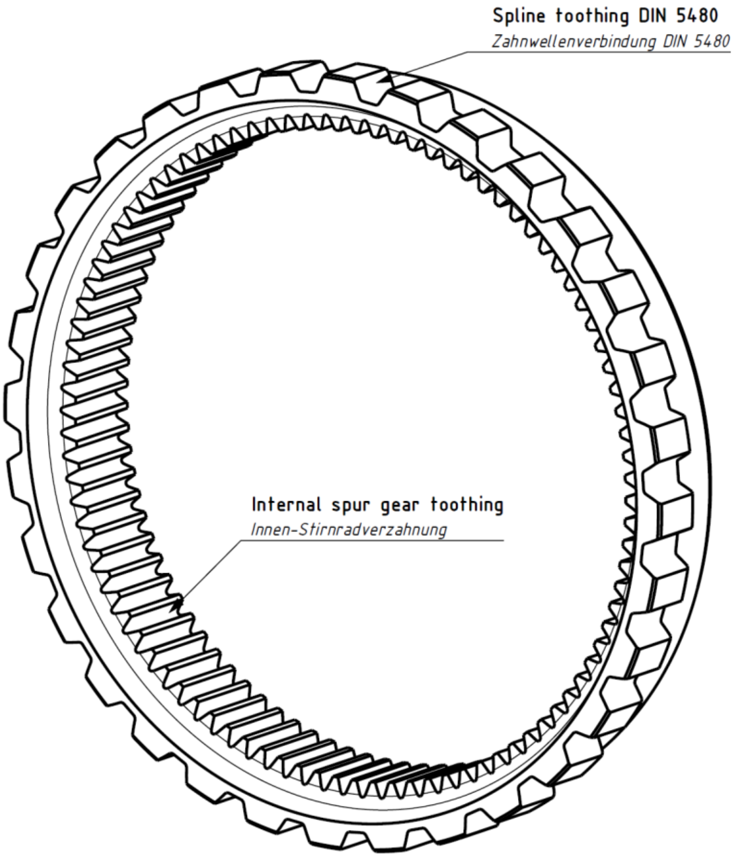


Figure 5 Ring gear

In this transmission, it serves as the output and is therefore directly connected to the team's externally rotating wheel hub. The spline connection is a simple and straightforward option for connecting a shaft to a hub. It is designed with a reduced width to give teams sufficient installation space for axial fixation or other designs in their assembly.

4.4 Planetary bolts

Ground bolt with stepped head shank for easier installation. Ø 9 mm running surface for the needle roller bearings and 8 mm width per bore in the side plates of the planet carrier for adequate surface pressure.

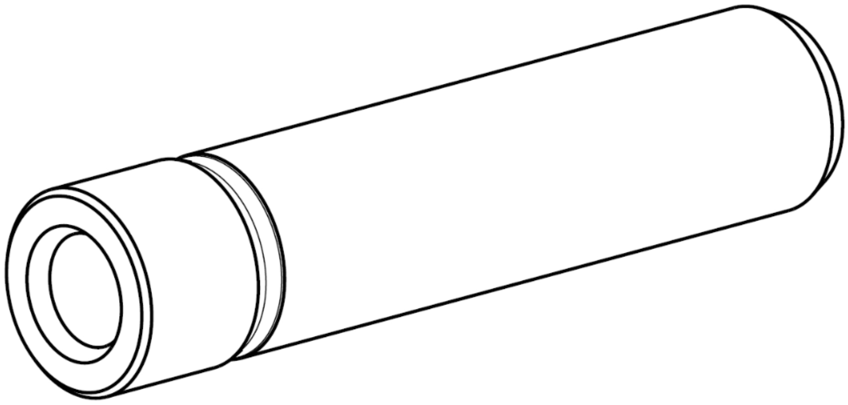


Figure 6 Planetary bolt

For manufacturing and weight reduction purposes, the bolt is drilled on both sides and has an M4 thread on one side for disassembly.

4.5 Thrust washer

Made from 1 mm thick copper-tin blank material, the thrust washer is equipped with three pockets that serve as reservoir for lubrication. The outer diameter is 17 mm.
The material is non-magnetic so that abrasion in the gearbox can be explicitly attributed to wear on the gear teeth and roller bearings.

5. INTEGRATION

5.1 Overall packaging concept

In the Formula Student competition, two different packaging concepts are currently common within team's wheel hub drives:

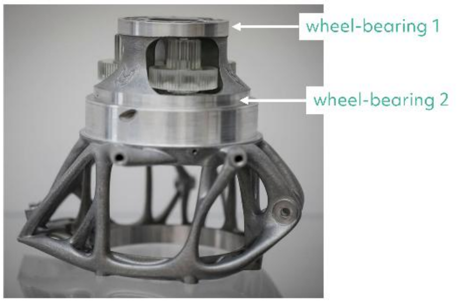
1. Concept: Gearbox between the wheel bearings

Here, the gearbox is placed between the two wheel-bearings, naturally creating the necessary bearing spacing. The inner races of the bearings sit on the side plates of the planet carrier, which must be wider anyway in the commonly used aluminum carriers and have space for bearing races. Although this makes the gearbox as narrow as possible, the high tire forces are transmitted through the planet carrier and deform it accordingly, which increases the load within the gearbox.

2. Concept: Separate bearings, located above the motor

By using thin-ring bearings (such as these from Kaydon), it is possible to use bearings with an inner diameter >100 mm without significantly increasing the weight. These are used to separate the wheel bearings from the gearbox and to relocate them above the electric motors, on the outside of the wheel carriers. The gearbox slides outwards, and the side plates of the planet carriers are no longer fitted with bearings.

The gear set is basically suitable and usable for both concepts.

Concept 1	Concept 2
 *Figure 7 M&H CNC-Technik GmbH (TUG racing)*	 *Figure 8 DHBW Engineering Stuttgart e.V.*
 *Figure 9 Feramic AG (AMZ racing)*	 *Figure 10 DHBW Engineering Stuttgart e.V.*

5.2 Planet carrier and wheel bearings

While in concept 2 the wheel bearings can be selected relatively independently of the gearbox and usually depend on the diameter of the motor, in concept 1 the gearbox must be matched to the wheel bearings, at least in the case of a single-piece planet carrier. This requirement was therefore included in the macro geometry optimization of the gearbox, and the ring gear tip diameter and center distance were optimized discretely for available wheel bearings. With a tip diameter of Ø80.35 mm for the ring gear and a center distance of 31 mm, the current gear set version is therefore perfectly suited for a wheel bearing with an inner diameter of Ø80 mm, leaving enough material in the carrier for the bolt and at the same time allowing the ring gear to be mounted. For example, teams can use a 71816-series angular contact ball bearing from SKF or Schaeffler for the outer bearing. Provided that the load capacity is sufficient, a K08008-series bearing from Kaydon is also a possibility. For the inner bearing, the selection depends heavily on the design of the wheel hub. For a one-piece carrier and one-piece wheel hub (i.e. the wheel hub must fit over the first-stage planetary gears), a bearing must be selected that fits the 109 mm outer diameter of the first stage. With a 71817-series bearing (Ø110 mm OD), you have to mill out the axial shoulder of the outer race in the wheel hub three times to make room for the planets during assembly. One size larger, 71818, works without such an interrupted contact shoulder. At Kaydon, for example, you could opt for a bearing from the K10008 or KB040 series. In any case, you would first mount the inner bearing on the wheel carrier, then slide on the wheel hub and mount the outer bearing at the end. Please ensure that no force is applied to the balls of the bearings during assembly.

Selection of rolling element material, contact angle, and tolerances are the responsibility of the teams. We generally recommend using bearings with high contact angles (not 15°) in all cases, as wheel bearings are subject to high axial forces due to the lateral forces of the vehicle.

We generally recommend using a one-piece planet carrier. If, for assembly or manufacturing reasons, it is not possible for the team to implement such a design, a two-piece carrier can also be used. In this case, however, maximum rigidity must be ensured by properly dimensioned webs and screw connections in order to avoid further increasing the face load factor $K_{h\beta}$ and significantly reducing the service life of the gearbox. Especially when performing topology optimizations, particular attention should be paid to the stiffness of the carrier. This cannot simply be designed according to suspension stiffness goals.

Radially, sufficient clearance should be maintained between the planet carrier and the planets so that they do not collide during operation despite deformation and manufacturing tolerances, and so that lubrication is not affected by high local pressures. A distance of 1-1.5 mm is a reliable value for this.

Teams with 3D-printed planetary carriers that are not completely machined must ensure through meticulous cleaning (sandblasting, vibratory grinding, or similar) that no residues from the printing process contaminate the oil during operation.

An exemplary one-piece planet carrier for AMK motor and concept 1 is shown below. This is a suggestion; not every detail has to be implemented by the teams in their designs. The connections for the wishbones are completely missing.

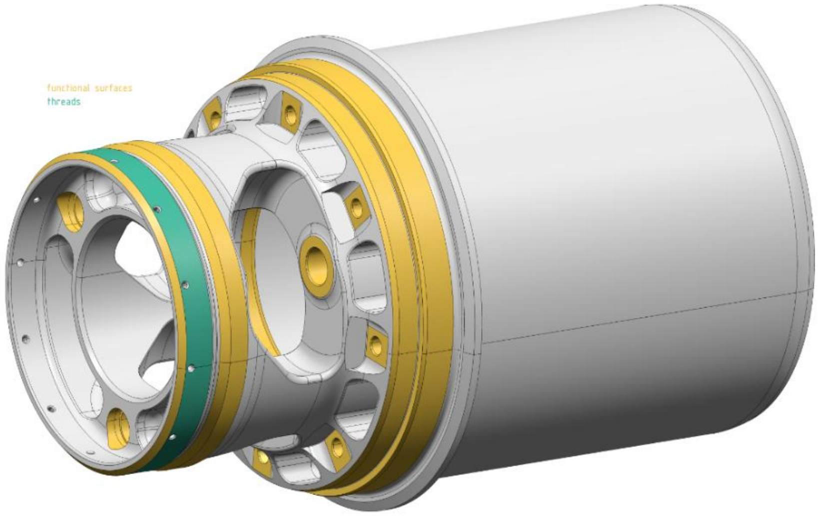


Figure 11 Planet carrier proposal - ISO

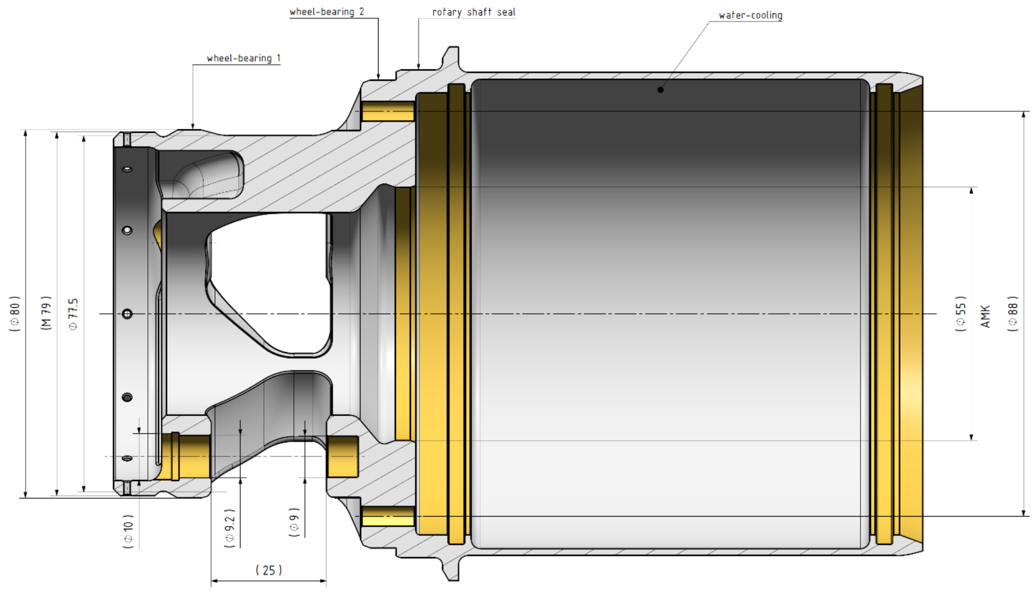


Figure 12 Planet carrier proposal - Section cut

The carrier is equipped with a bearing-seat for an Ø80 mm wheel bearing and a central nut thread for preloading. All relevant functional surfaces are separated for optimum manufacturing. The bolt is secured here with a Ø10 retaining ring as an example. The outer diameter of the webs behind the bearing seat is reduced to 77.5 mm to ensure sufficient clearance for the ring gear during operation.

5.3 Planetary bearing arrangement

The planet gear is mounted on a fixed spindle (planetary bolt) using standard needle roller bearings. Axial positioning is ensured by thrust washers on both sides of the gear. While the thrust washers are included in the supplied assembly, the needle bearings must be selected and procured by the design teams.
The specified bearings are standardized needle roller bearings of type K9×12×10 or K9×12×13, both of which are commercially available from manufacturers such as SKF and Schaeffler.
The planet pin features a larger head for axial support. Two holes must be machined into the carrier to accommodate the pin: a precision (fitting) hole with a diameter of 9.2 mm and an opposing (blind) hole with a diameter of 9.0 mm. To prevent the pin from rotating during operation, it is recommended to secure it with an interference (press) fit. The recommended fit tolerances (H7 / M7) are specified in the technical drawing. If these are too tight for the team, they can deviate from them at their own risk. Geometric form tolerances for the alignment of both holes are also defined and must be adhered to.
Axial retention of the pin can be achieved through various methods, for example by using a retaining ring.
The axial clearance (play) of the planet gear, the thrust washers & carrier must be adjusted to lie within 0.05 mm to 0.15 mm. The planet gears are manufactured with a total width tolerance of 23 mm ±0.04 mm, and each thrust washer is specified with a thickness of 1 mm ±0.03 mm. These tolerances must be considered carefully when selecting the tolerances for the shoulder width in the planet carrier.

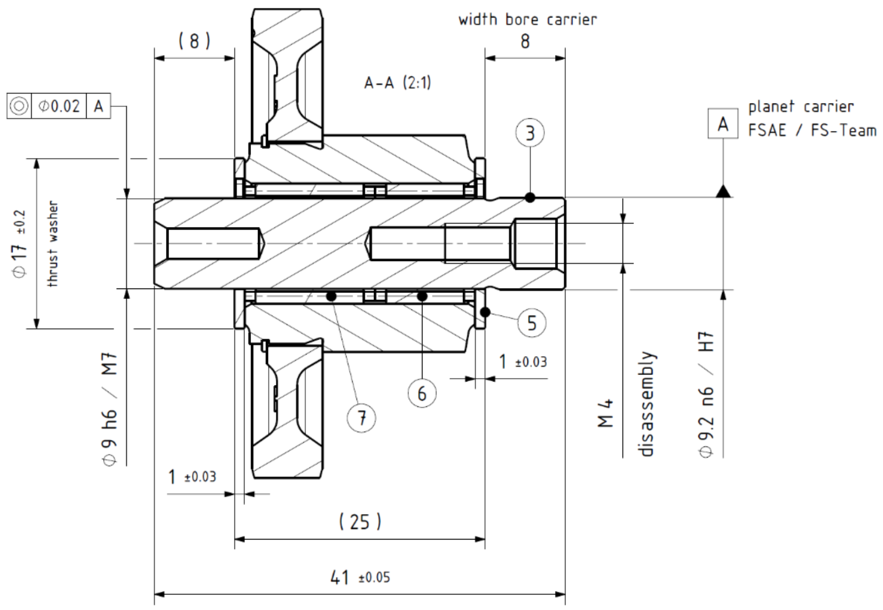


Figure 13 Excerpt from technical drawing "Subassembly Planet"

5.4 Sun gear

The integration of the sun gear naturally depends on the variant: For the AMK variant, either the motor must be positioned accordingly in the assembly so that the retaining ring can be used, as shown in the drawing (“*HU-FS-Gearset_V1-2025_A_Assembly_AMK.pdf*”), or shims and the M4 thread must be used to secure the sun gear. The shims should be designed by the team to be sufficiently thick so that they are not crushed in the interrupted shoulder of the AMK rotor shaft. The maximum permissible distance by which the sun may be shifted relative to the rotor shaft using shims is 3-4 mm. It then overhangs the shaft by approximately 1 mm.
Even though the mech. powertrain is not subject to the “positive locking” rule under the current Formula Student regulations, fasteners should still be secured. HUMBEL accepts no responsibility for loose rings or screws. Therefore, screw locks should be used and/or positive locking or Nord-Locks® should be considered.
The “DTI” sun gear must be installed in accordance with the requirements of the motor manufacturer DTI. These specify the screw and tightening torques. Our CAD proposal also includes a Nord-Lock® washer.
All relevant information on the splines and their tolerances and fits can be found in the technical drawings.

5.5 Ring gear

The integration of the ring gears should be as simple as possible for the teams. Since the wheel hubs are complex turned and milled parts anyway that are usually machined on 5-axis universal milling machines, we suggest an internal spline with an increased root radius to integrate the ring gear in a flank-centered manner. It can be manufactured directly on the same machine with a small end mill, thus also guaranteeing high concentricity.

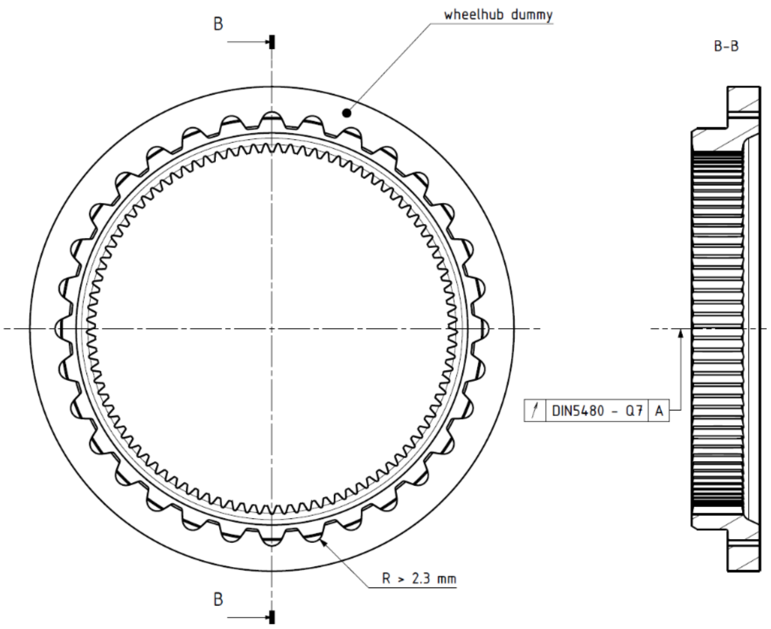


Figure 14 Ring gear & wheel hub dummy

The corresponding gearing table and .dxf-file of the contour are included in the data set, as already mentioned. During production, teams should measure the two-roll / ball dimension of the spline to ensure that the gearing has the desired tooth thickness tolerance. Recommendations, associated dimensions, and required pins are specified.
Of course, teams are also allowed to modify the tooth root according to their preferences, as long as there is no interference with the ring gear. For example, the root radius and root diameter can be reduced if the team plans to erode the gearing anyway and wants to save radial installation space.
It is recommended to secure the ring gear axially with a positive locking and not rely solely on the interference fit of the spline. Here, it is up to the teams to decide on a suitable solution. On one side, it is easy to work with a shoulder in the wheel hub if the splines are profile milled with a normal end mill anyway. In the other direction, the outer race of the wheel bearing, retaining rings, washers and screws, or other ideas from the teams can be used. For wire-eroded splines, a safety device must be provided on both sides accordingly.
An example is shown from the 2022 Formula Student car from RWTH Aachen University with the use of a custom-made retaining ring.

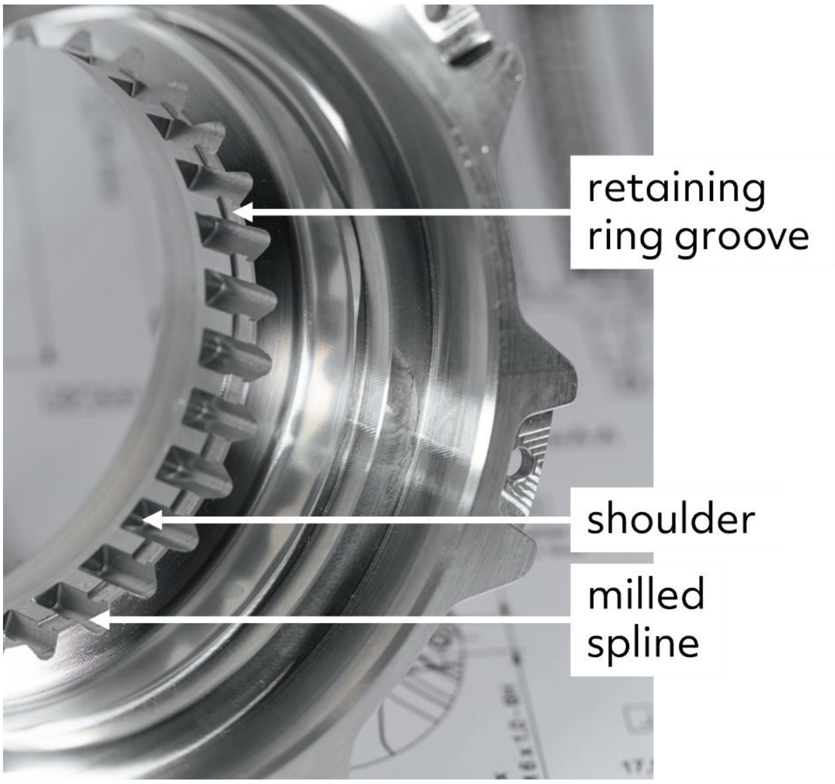


Figure 15 Wheel hub design Aachen 2022

6. INSTALLATION AND ASSEMBLY

Important notes upfront

Cleanliness: Assembly must always be carried out in a clean and dust-free environment, ideally in a separate room. The parts must be cleaned accordingly. If assembly is interrupted, the parts must be protected and covered.

Preparation: Before starting assembly, you should familiarize yourself with the assembly and make sure you understand it. Potential problem areas should be identified. The necessary tools should be laid out ready and not collected when needed.

Visual inspection: All parts should be subjected to a thorough visual inspection, especially the connecting parts such as wheel carriers, wheel hubs, or planet carriers, in order to identify any damage or correct errors before assembly.

Time management: Calmness is essential during assembly. Therefore, sufficient time should be allowed to avoid careless mistakes. Even if unexpected problems arise, remain calm and find a solution. Thermal joining in particular can involve long waiting times, which should be used wisely.

Deviations from recommended procedures or assembly errors can lead to premature wear, functional issues, or mechanical failure. Before commissioning, all interfaces must be checked for proper fit, alignment, and fastening. Final validation under system load should always be performed under safe and controlled conditions.

6.1 Parts cleaning

All gearbox components are delivered with a protective anti-corrosion oil film applied to prevent surface degradation during storage and shipping. Before assembly, all parts must be thoroughly cleaned to remove any oil residues, machining particles, or packaging contaminants.
For best results, the use of an ultrasonic cleaning bath with a suitable industrial degreasing agent is recommended. Alternatively, commercially available cleaners such as LOCTITE® SF 7063 may be used to remove oil and residue from metallic surfaces.
It is essential that all contact and interface surfaces, including custom parts manufactured by the team (e.g., wheel hubs, shafts, adapters), are also free from machining residues, cooling fluids, or protective coatings. Clean surfaces are critical to ensure correct fit, torque transmission, and longevity of the assembly.
After cleaning, all components must be visually inspected for burrs, dents, sharp edges, or any damage or surface defects resulting from manufacturing or handling. Such issues must be corrected before assembly.
Before selecting a cleaning product, compatibility with all materials used in the gearbox - especially gears, plastics, and any coated surfaces -must be verified by the team.

If there is a significant delay between cleaning and final assembly, all cleaned parts must be protected against corrosion. In such cases, a light application of the intended gearbox lubricant oil is recommended to preserve critical surfaces until assembly begins.

6.2 Heating

Since the gears are made of case-hardened steel and are tempered after hardening, their operating temperature is limited, which is also relevant for any thermal assembly processes.
The gears may therefore be heated to a **maximum of 120°C** for assembly purposes, preferably 100°C.
Cooling, on the other hand, is not a problem, so the parts can be cooled down to -70°C or more for assembly, for example.

6.3 Assembly sun gear onto rotor shaft

If the fit is a little tight, heat or cool one of the components to help with assembly. Otherwise, push the parts together as planned and check that they fit correctly (No burrs or gaps).
For teams that use the ground shaft seat for a rotary seal with the DTI sun gear, thereby sealing off the spline from oil lubrication, we recommend installation with a suitable high-pressure assembly paste. The spline of the DTI sun gear is equipped with an end relief for easier installation.
For correct installation of shaft seals, please consult the relevant manufacturer (e.g. Trelleborg or Freudenberg)
Then attach the desired axial locking device. Make sure it is seated correctly and that the tightening torque is correct.
Marking with screw paint is recommended to identify possible rotation during operation.
Installation forces must generally be in accordance with the rotor bearing arrangement or the motor manufacturer. We advise against using hydraulic presses for the assembly of Formula Student transmissions anyway.

6.4 Assembly ring gear into wheel hub

Heat up the wheel hub in accordance with the team's limits and cool down the ring gear, for example with dry ice or liquid nitrogen. Then join quickly but in a controlled manner and ensure a correct fit. Due to the large temperature difference, the parts should simply fall into place. Allow parts under pressure (weights or arbor press) to equalize in temperature.
Then install the desired axial lock, as already described for the sun gear shaft.

6.5 Installation planet assembly

The assembly of the planetary gears depends on whether the team installs a one-piece or multi-piece planetary carrier. In any case, the thrust washers, and especially the needle roller bearings, should be lubricated with the desired lubricant oil before installation.
Especially with one-piece carriers, it is advisable to deep-freeze the bolts before assembly. However, be careful of condensed water here as well.
It makes sense to manufacture undersized bolts from aluminum or similar material as a team, which fit into the holes with some play. This allows you to mount the planets with all the bearings, then heat them in the oven, remove them one by one, and replace them with the correct, frozen bolts without everything shifting when moving back and forth. These are also helpful for checking the axial play of the planets before final assembly and, if necessary, reworking them if the team has not met the carrier tolerances (under no circumstances should the gears be reworked). This must be carried out by the teams in order to ensure the axial play described in the Integration section.
If the team is concerned about trapped air in the blind hole (as in the example of the planetary carrier), a smaller hole, for example 3 mm, can also be used to open the fitting hole towards the motor.
After inserting the bolts, install the correct axial fastening, for example, by attaching the retaining rings.
Here, too, it is advisable to use screw paint to mark the bolts so that you can see if they have turned.

6.6 Alignment gear set and assembly

Even if the planetary gearbox is designed with three identical stepped planets, these must still be aligned during initial assembly. That is very important!
Depending on whether the motor and sun gear are installed before or after the planets in the planet carrier, this is already relevant for the planet assembly step described above.
The planets themselves are delivered already assembled, but thanks to the spline design, they cannot be assembled incorrectly anyway.
To align the sun and planets, the machined markings on the front surface of the large planet (Planet 1) are used. These identify the “zero tooth” of the gearing.
Fortunately, the sun gear has 21 teeth, which means it can be divided by 3. Therefore, when assembling for the first time, the zero teeth simply need to be aligned towards the center axis of the transmission, or rather, they need to engage in every 7th gap of the sun.
The marking may be on the opposite side, which is no longer visible when installed, so it is worth adding further markings with a permanent marker to always identify the zero tooth (for example, paint the tooth tip)

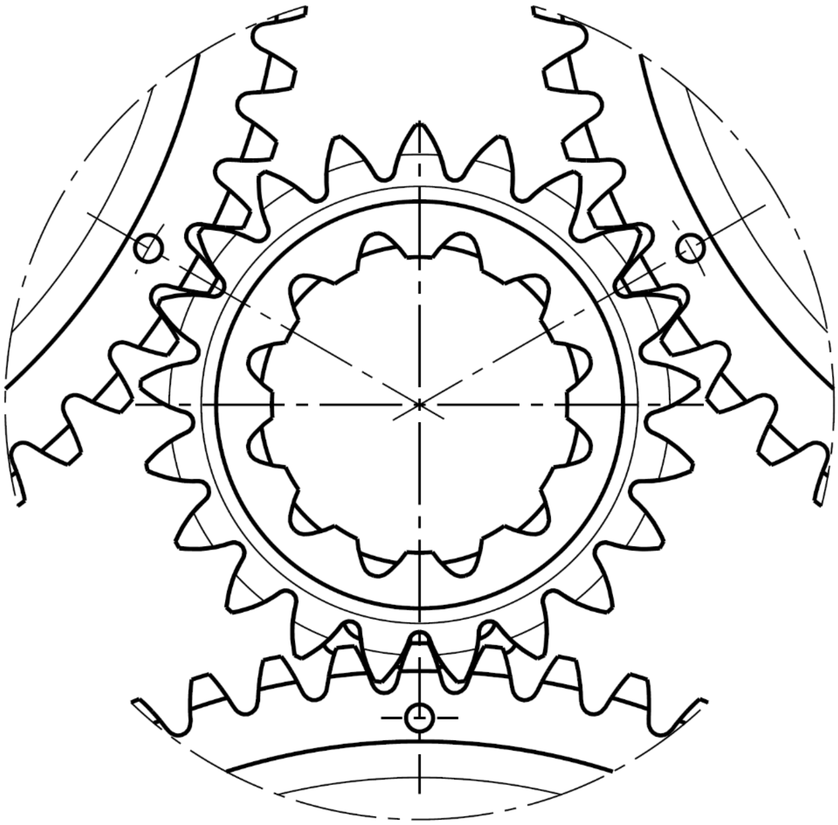


Figure 16 Alignment planetary gears

The image shows the desired alignment and machined markings.
To ensure equal load distribution across the three planets, it is essential that the gearbox is installed correctly. HUMBEL accepts no responsibility for incorrectly installed gearboxes.
Once the sun gear shaft and planets are installed, the ring gear can no longer be inserted incorrectly.
If the team has to install the motor last for their assembly, it is worth 3D-printing a plastic dummy sun and using it to align the planets, removing it after installing the ring gear. This allows the motor with sun to be installed last, and the alignment is still correct and can be checked again.
Teams should also check the overhang of the sun relative to planet 1 when they are assembled. The permissible value can be found in the technical drawings and differs for both versions of the sun. This ensures that the gears mesh correctly.

7. OPERATION AND MAINTENANCE

7.1 Lubrication

The lubrication system is designed as an oil bath lubrication, which is not actively temperature-controlled via a cooling circuit, but is indirectly cooled via the wheel hub and planet carrier by means of convection and the ambient air.
The design is based on an oil temperature of around 80°C, which can be monitored either via a temperature sensor or indirectly via temperature measuring strips on the housings (assuming a few Kelvins delta).
The design was based on Klübersynth GH 6-100 (ISO VG 100) from Klüber Lubrication, a high-performance gear oil based on polyglycol. The high viscosity index of PG oils ensures consistent performance across a wide temperature range. The oil also has a very high scuffing resistance, which was demonstrated with a load stage of 14 in the scuffing tests according to DIN ISO 14635-1. The micro-pitting resistance is GFT ≥ 10 according to FVA 54/7.
The teams can also use high-performance oils from other manufacturers, provided that they demonstrate equivalent performance. To this end, the load stages in the scuffing and micro-pitting tests should be compared. Depending on the viscosity index, it may also be necessary to increase the base viscosity (to ISO VG 150 for example) in order to ensure comparable viscosity and generally the same wear resistance at operating temperature.
The fill level depends greatly on the packaging of the teams, as the dead volume can be correspondingly large. A recommendation for the fill level can be found in the following image. In terms of quantity, however, a minimum value of around 80 ml is recommended in any case; new teams with little experience in particular should use significantly more.

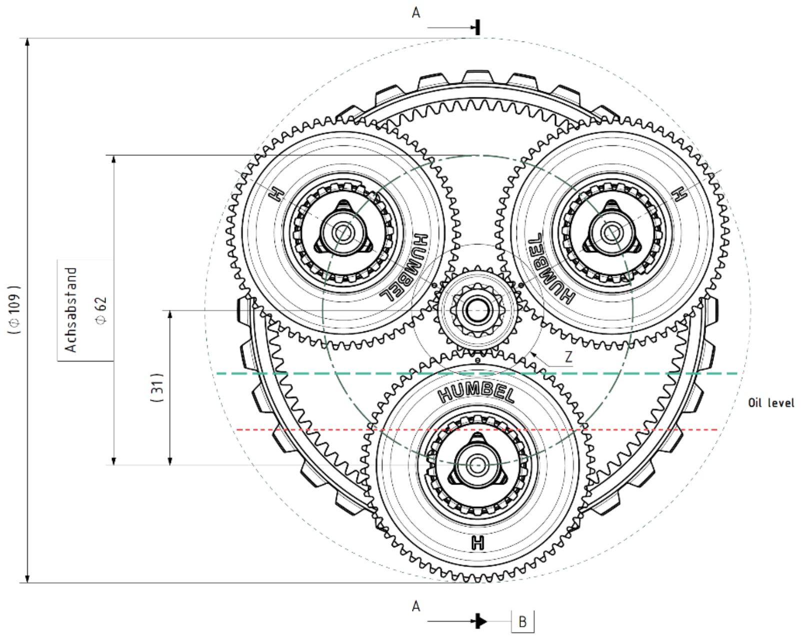


Figure 17 Oil level

7.2 Running-in

Despite the highest manufacturing precision, a running-in process is required for this high-performance gearbox.
Before driving on the track, the transmission should be idled at speed with the vehicle jacked up and stationary in the workshop, paying attention to any noises or vibrations that could indicate problems.
Within the complex on-track commissioning process for Formula Student vehicles, running-in the gears should be easy to accommodate and should not significantly delay performance testing.
The recommended process can be found in the table below.

RUNNING-IN PROCESS				
Stage	Duration	max. Speed N_{in}	max. Torque T_{in}	Subsequent tasks
1	10 km	25 %	25 %	- Check for loose parts - Tighten screws - Check for leaks - Check temperatures
2	10 km	25 %	50 %	- Oil change - Check temperatures - Visible inspection
3	7.5 km	50 %	50 %	- Check temperatures
4	10 km	50 %	75 %	- Check temperatures
5	7.5 km	75 %	75 %	- Oil change - Visible inspection
Race	-	100 %	100 %	-

The teams should ensure that during the various stages, the limits are actually used and that there is no significantly lower load due to track limits or driving style during commissioning. Otherwise, the duration of the stages must be increased to compensate for this.
The teams can add further checks to the schedule after the different stages based on their own knowledge and judgment. This is only a recommendation.

7.3 Monitoring

Teams should closely monitor the gearboxes during operation and watch for changes in noise, vibration, rolling resistance, leaks or temperature development in order to detect damage early on or prevent it from occurring.
Most tests can be performed together with the remaining mechanical checks before each test or race day.
Teams are encouraged to install temperature measurement strips on the wheel hubs and wheel carriers at a minimum in order to indirectly monitor the temperatures of the gearboxes.

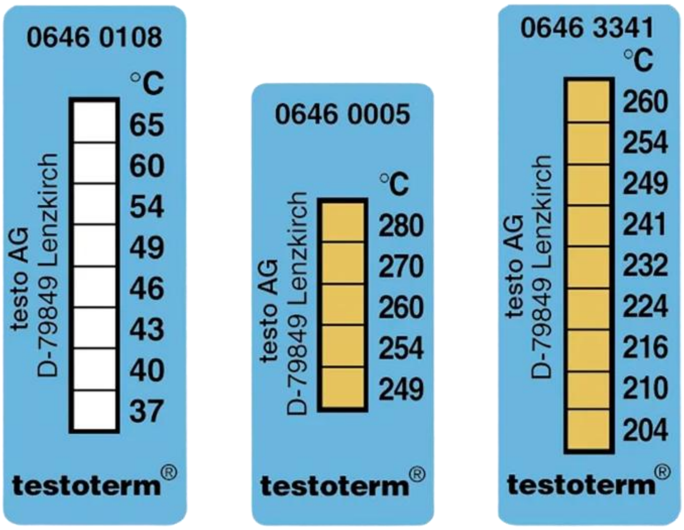


Figure 18 Temperature measurement strips

Contamination of the oil with water due to defective seals must be prevented at all costs and must be checked during oil changes.

7.4 Maintenance

The teams are advised to change the oil every 120-150 km during subsequent operation, to check it for heavy wear using a filter or magnet, and to drive for another 5 km at reduced power after refilling.
Although oil changes can be carried out using small oil drain plugs, it is advisable to flush the assemblies, as otherwise most of the contamination will remain inside. It may therefore be necessary to open the gearbox, or at least the relevant covers and caps, in order to carry out a proper oil change. The teams are required to set their own maintenance intervals for their remaining self-developed components.

List of figures