Contents of Work Package **3-WP13** Tools of Design and Components for Advanced Vehicles - Powertrain Components for Future Rail Vehicles

FACME_3-WP13: Powertrain Components for Future Rail Vehicles

Coordinator of the WP 13

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Contents of Work Package **3-WP13** Powertrain Components for Future Rail Vehicles

Main Goal of the WP

- Find the optimal amount, production technology and processing for using ecological fibers of replacing glass and carbon fibers in the composite hollow shaft used in the driving bogie of railway vehicles with final lower environmental impact.

- We see the use of Energy-Tender for traction rail vehicles as a possibility of using electric traction vehicles for operation on non-electrified lines, which, for example, make up about 2/3 of railway lines in the Czech Republic. Assessing the possibility of using an Energy-Tender for modernized traction electric vehicles of the 2nd generation (equipped as part of ETCS modernization) on regional non-electrified lines, determining the energy need, driving range and train mobility on non-electrified lines.

- The use of a shift two-stage gearbox in the design of the electric drive of wheelset will allow better use of the efficiency of the traction electric motor. It will reduce traction energy consumption, CO_2 emissions and noise. Another benefit is the reduction of dynamic effects in the wheelset drive and thus the extension of the service life and LCC cycle of the gearbox. To assess the suitability of use for light rail vehicles for regional transport and for metro units.

- Shortening the time between concept research and application of an innovative product on the market (time-to-market, TTM) by about 20% by using the accumulated experience from previous solutions and early elimination of development dead ends in its initial phase.

Contents of Work Package **3-WP13** Powertrain Components for Future Rail Vehicles

Partial Goals for the Current Period

- Design several construction variants of connections (inserts for axisymmetric parts used in two-wheel drive) for which generic CAD models and simplified submodels were created for numerical optimization of lifetime calculations. Reduce the price of composite parts and increase the possibilities of their recycling. In the first phase, simplified numerical simulations based on the FEM principle in combination with parametric optimization were created for the individual submodels, with the aim of determining the most suitable geometry (composite and insert) as well as the composite composition of the laminate (number of layers, orientation of the main fiber directions, combination of materials).

- In the first phase of the research of the Energy - Tender, a partial goal was to conduct a search in the world of used solutions, to establish its basic vehicle concept, driving arrangement and to define the basic technical parameters of the vehicle. Implement of a basic driving cycle simulation on a suitable regional non-electrified railway line.

- In the first phase of the research on two-stage shiftable axle gearboxes, assess possible energy savings during the start-up of BEMU light rail vehicles with a shiftable gearbox by means of a simulation calculation and analyze the design solution of a two-stage shiftable axle gearbox.

Contents of Work Package **3-WP 13** Powertrain Components for Future Rail Vehicles

3-WP13: Powertrain Components for Future Rail Vehicles

Official 3-WP13 Deliverables:

Main Goal

- 3-WP13-003 | **Composite shaft modified structure: application of new eco-friendly materials for fibers** ‚G_{funk}‚ (UWB RTI 0.25 + VUT 0.25 + VZUP 0.25 + CompoTech 0.25)

TN 02000054/003-V54

Other goal

- 3-WP13-001 | **Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines** ‚O‚ (FME CTU 0.3 + UWB RTI 0.3 + BUT 0.1 + VZUP 0.1 + STRN 0.2)

TN 02000054/003-V52

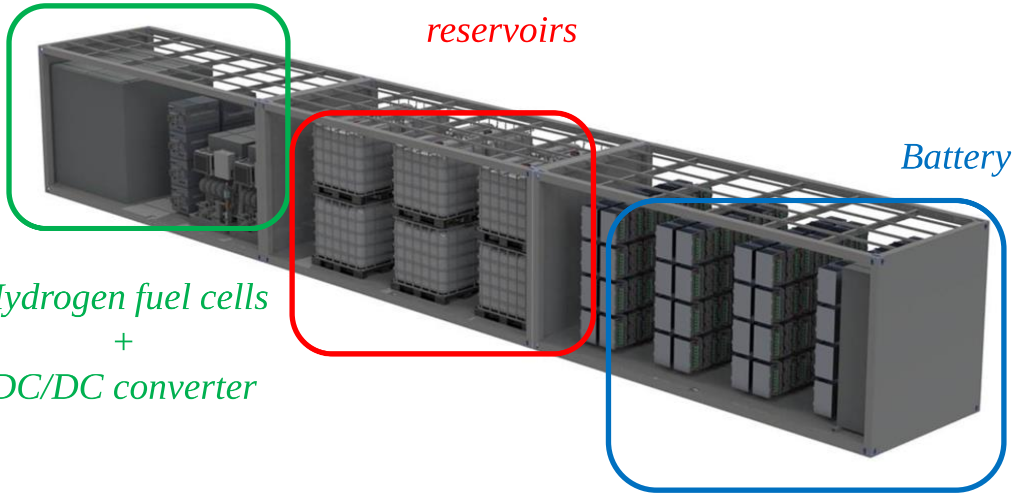
- 3-WP13-002 | **Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport** ‚O‚ (FME CTU 1.0)

TN 02000054/003-V53

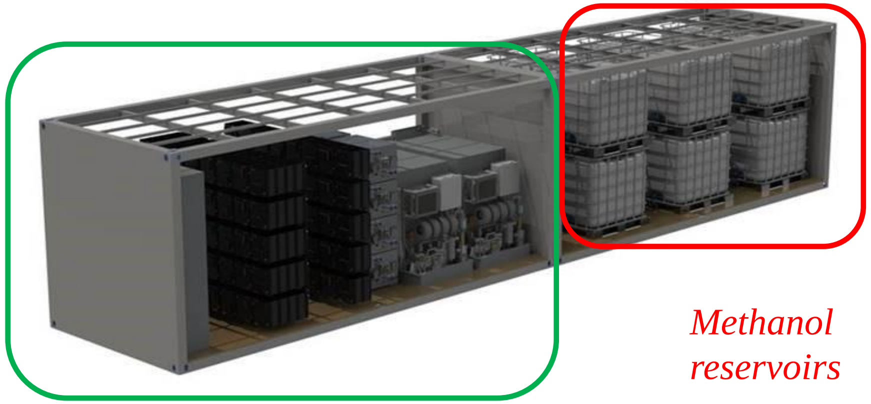
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-001: Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines

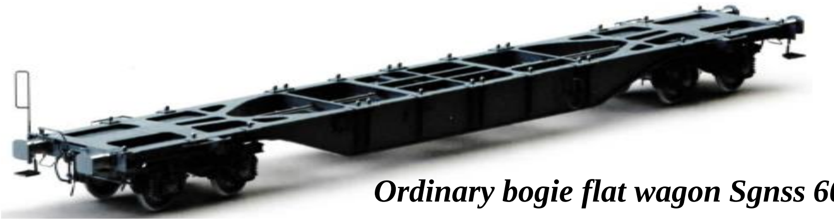
- defining the maximum weight of wagon Energy-Tender, design of the Energy-Tender containers concept
- consultation on the design arrangement of Energy–Tender containers with the companies: Tremondi Inc. and Devinn Inc.



Three containers of hydrogen – battery energy tender



More suitable solution it 3 containers - better distribution of weight on the two-axle bogies.



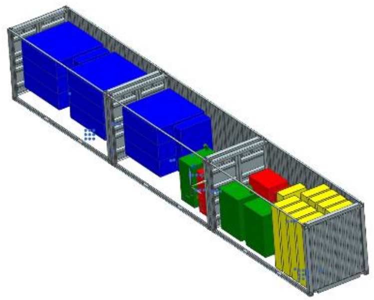
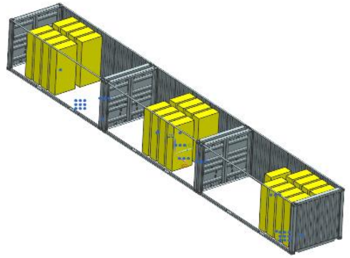
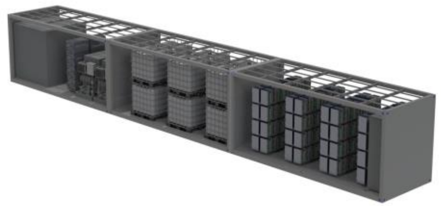
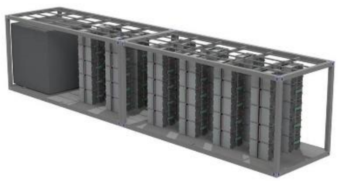
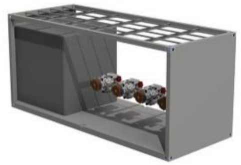
Ordinary bogie flat wagon Sgnss 60

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-001: Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines

Comparison

	Var. 1 – Hydrogen-battery		Var. 2 – Battery		Var. 3 - Methanol-battery -T		Var. 4 – Battery - T		Var. 5 - Diesel-battery - T	
	Value	Note	Value	Note	Value	Note	Value	Note	Value	Note
Weight [kg]	29 500	Without weight of containers (6 500 kg battery, 3x fuel cells + 3x output modules = approx. containers up to 3.5 t = approx. 10 000 kg)	19 500	without weight of containers (weight of containers cca 4 500 kg)	31 500	Without weight of containers (12 000 kg battery, 13 000 kg methnal storage, 6 500 kg - 8x fuel cells and 2x steam reformers)	11 700	Estimate without structure, cooling and switchgear, without weight of containers	16 700	Weight of diesel power unit not specified - estimate up to 5 000 kg, 11 700 kg weight of battery compartment
Power[kW]	2 000	300 kW hydrogen + battery	2000	Battery only	2 000	240 kW Hydrogen + battery	2 000	Battery only	2 000	520 kW motor + battery
Capacity [kWh]	7 100	6400 kWh hydrogen + 700 kWh battery	2 000	Possibility to increase the capacity up to a weight limit of 45 t, approx. 6400 kWh (for 2 560 000 EUR) - weight approx. 30 t	16 200	14 000 kWh of hydrogen in the form of methanol (12 000 l) + 2 200 kWh of battery	2 200	Ability to increase capacity by expanding battery storage to a third container up to the weight limit	2 200	Option to expand capacity by expanding battery storage in the remaining 2 containers up to the weight limit - same battery storage as in Option 4 considered
Price [EUR]	1 440 000	development costs 630 000 (according to the offer)	800 000	Development costs 350 000 (according to the offer)	2 447 650	EUR 1 012 000 batteries, EUR 118 800 methanol storage, EUR 1 316 850 reformers + fuel cells	1 012 000	(according to the offer - DC part without container construction, electrical switchboard, heat exchanger and cooling distribution)	1 378 350	366 350 EUR engine (according to the offer - DC part without container construction, electrical switchboard, flue pipe, radiator and distribution)

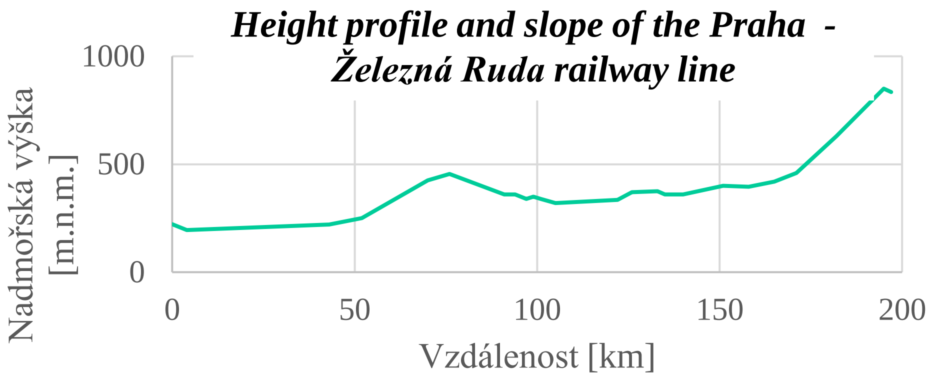






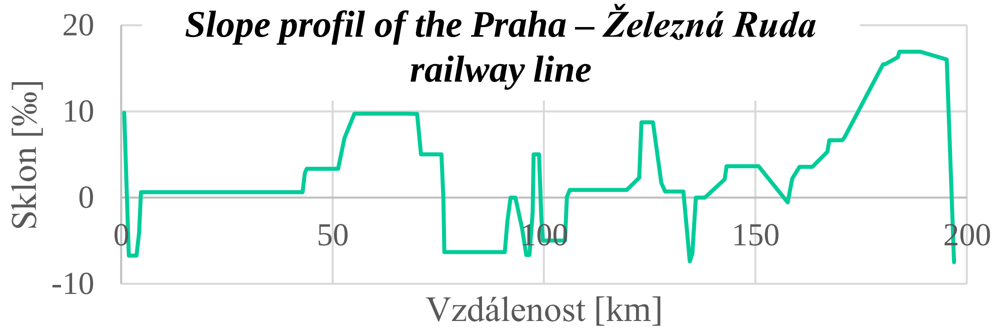
Tremondi Inc. and Devinn Inc. – summary results

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-001: Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines

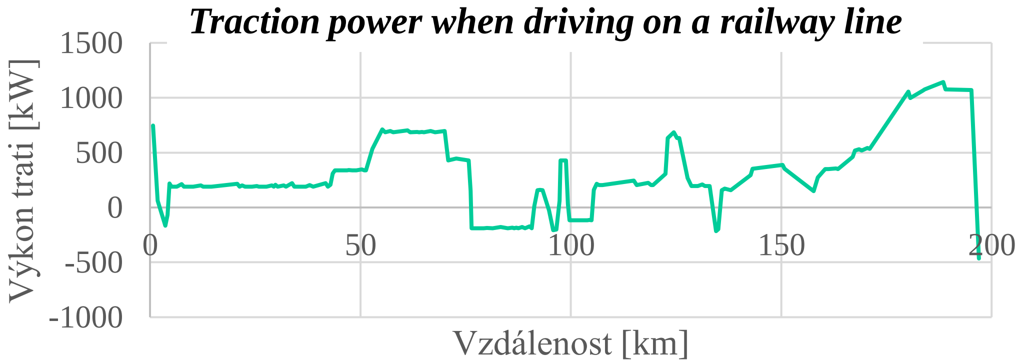
- energy capacity calculation of wagon Energy–Tender for the line: Praha - Plzeň - Klatovy - Železná Ruda





Traction requirements

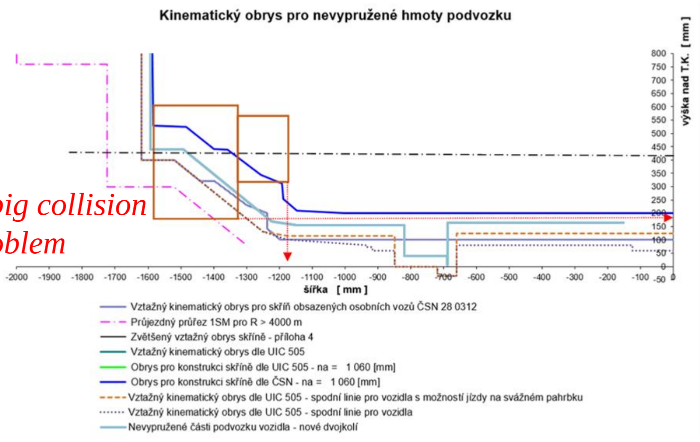
Maximum power	**2000 kW**
Nominal power	**1500 kW**
Time of nominal power	**1 hour**
Battery capacity	**2000 kWh**



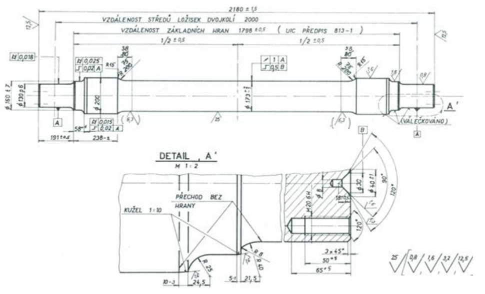
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-001: Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines

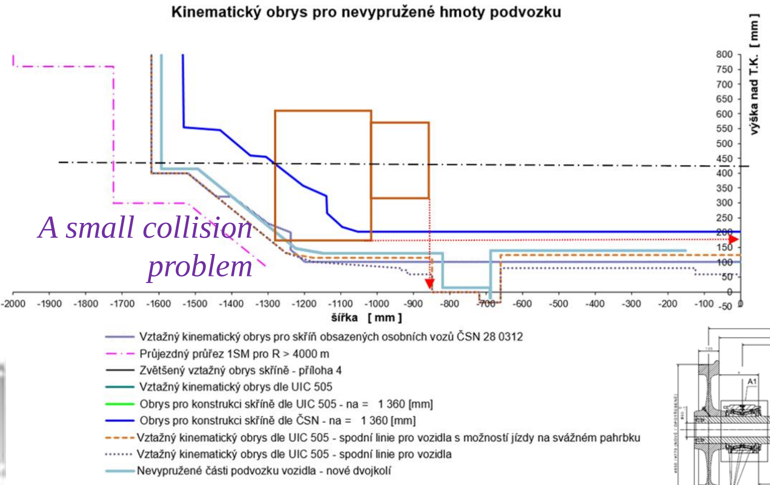
- calculation of the driving resistance of the wagon Energy – Tendru, assessment of the concept of a separate drive for the platform wagon
- assessment of the possibility of installing a direct wheelset drive in selected two-axle bogies

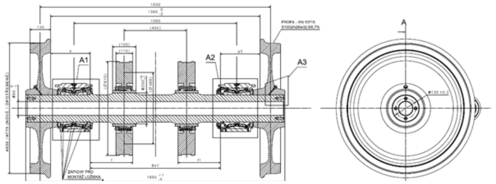


Analysis of the position of the gearbox in the lower part of the contour for the rail vehicles – cargo bogies



Drive unit 30 kW: ASM + gearbox



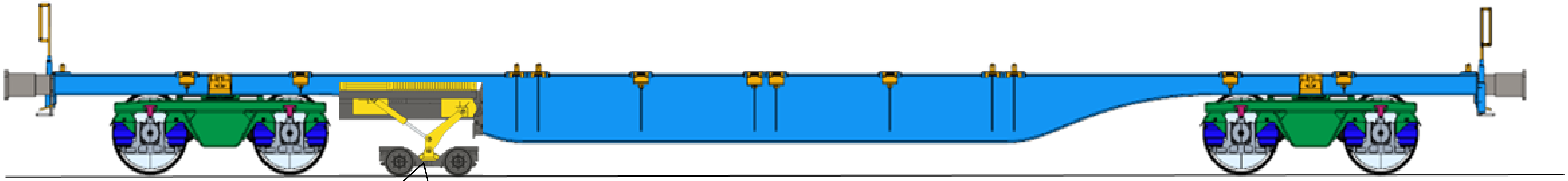


Analysis of the position of the gearbox in the lower part of the contour for the rail vehicles – bogies 11EV1 with air secondary suspension

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-001: Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines

- assessment of the possibility of installing a direct wheelset drive in selected two-axle bogies



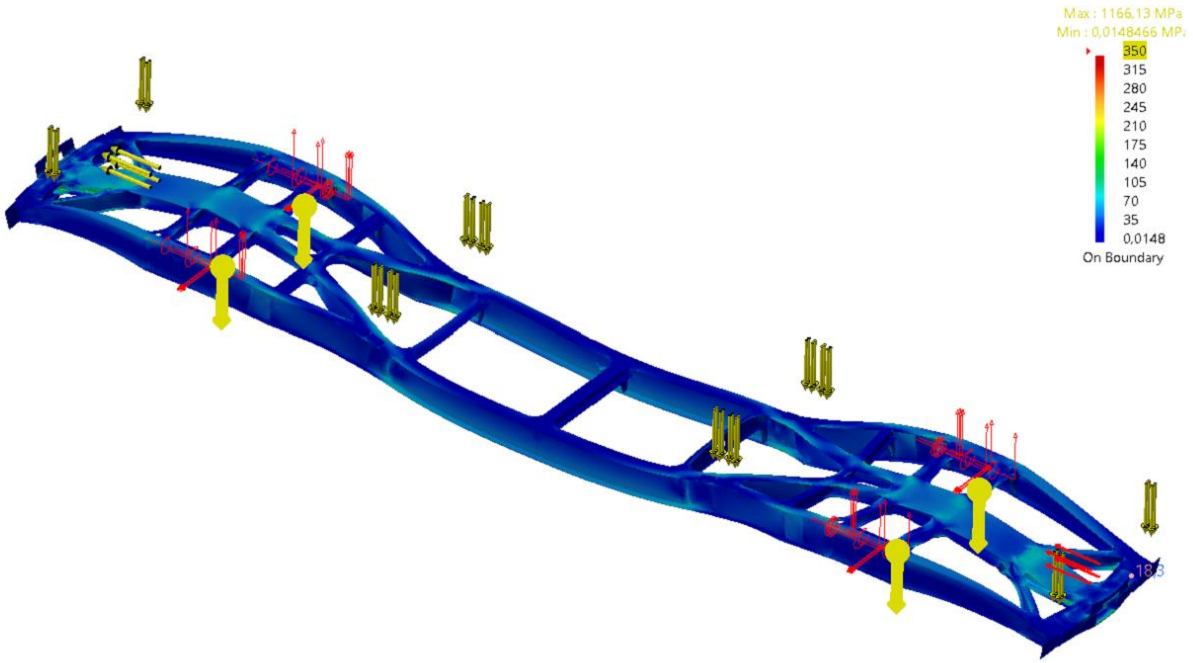
autonomous running gear with a single drive axle with tires or with a two-axle bogie with wheelsets with small wheels .

Ordinary bogie flat wagon Sgnss 60 whit drive unit

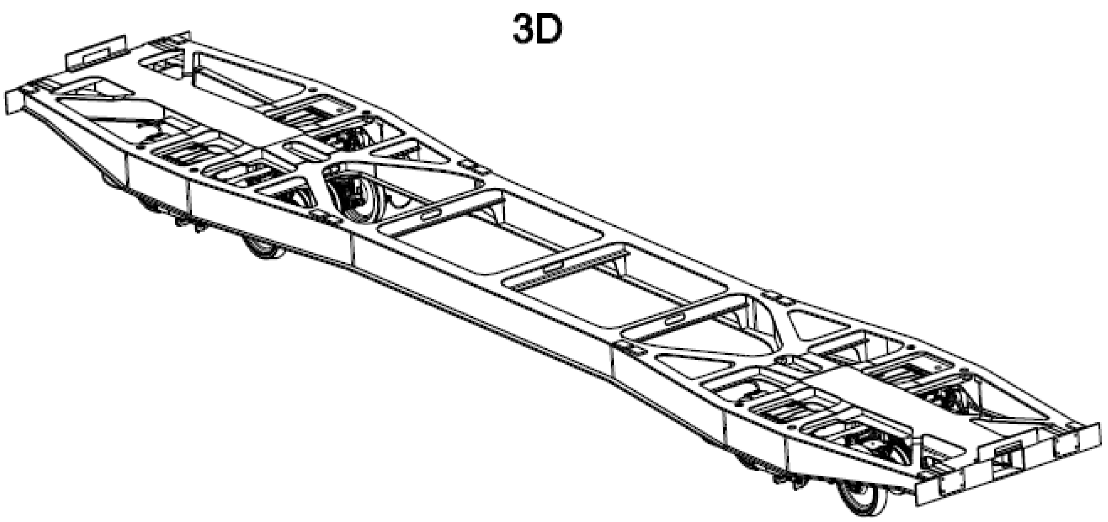
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-001: Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines

- concept design of main frame the platform wagon Energy – Tendru with two-axle bogies with air secondary suspension



FEM calculation of the main frame for the wagon Energy-Tender

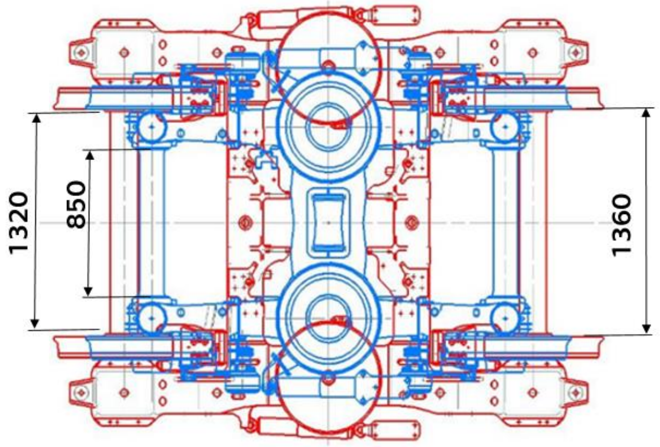


3D model wagon for the wagon Energy – Tender with bogies with air secondary suspension

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-002: Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport

- analysis of the dimensional possibilities of installing shift two-stage axle gearboxes into traction bogie the regional train
- design of the a concept of the shift two-stage gearbox for the regional LKV
- research into the efficiency map of ACM and PMSM traction motors



Plan view comparison of bogies with outer and inner frame

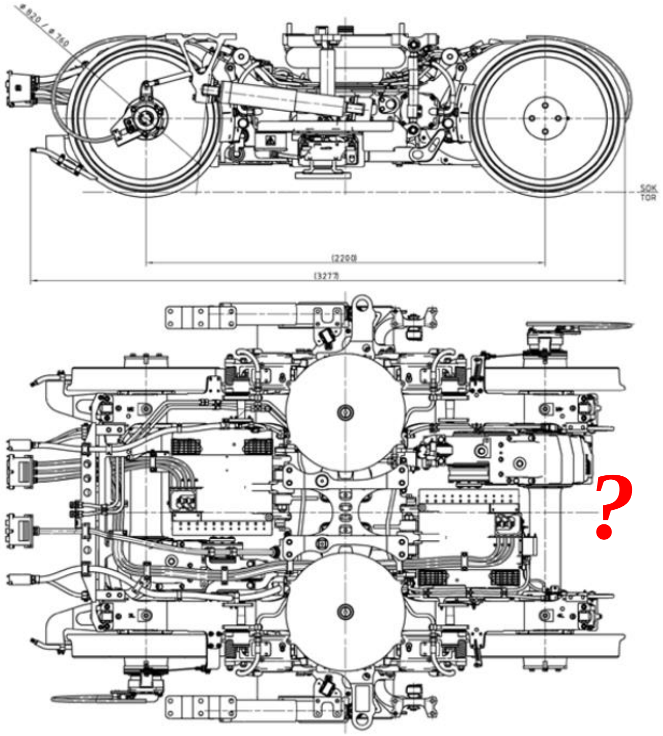
Conclusions from the analysis

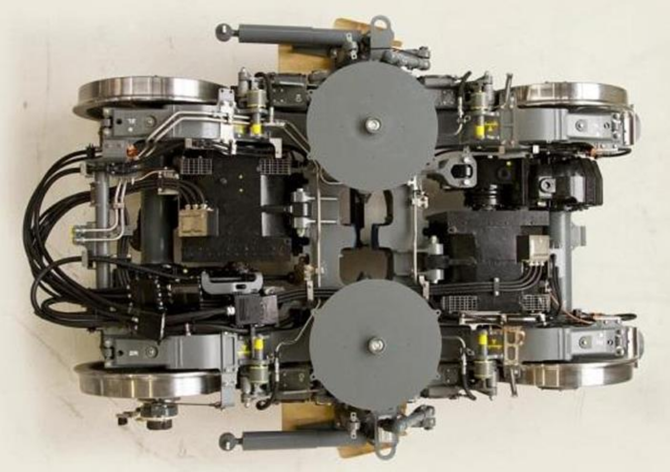
- *in rail vehicles for regional and suburban transport, the use of two-axle traction bogies with an internal frame is increasingly being used with regard to weight savings and reduction of inertial effects*
- *with a wheelbase of 1360 mm, this significantly limits the transverse base for the installation of an wheelset drive, i.e. a traction motor + axle gearbox*
- *the design of the traction drive must fit into the transverse base of approx. 850 mm*
- *for more powers up to 400 kW, it will be necessary to use a PMSM with a hollow shaft for the inner frame, and the axle gearbox will be connected to the cardan shaft, equipped with a gear coupling in the PMSM cavity and on the other side of the gearbox a disk flexible coupling.*

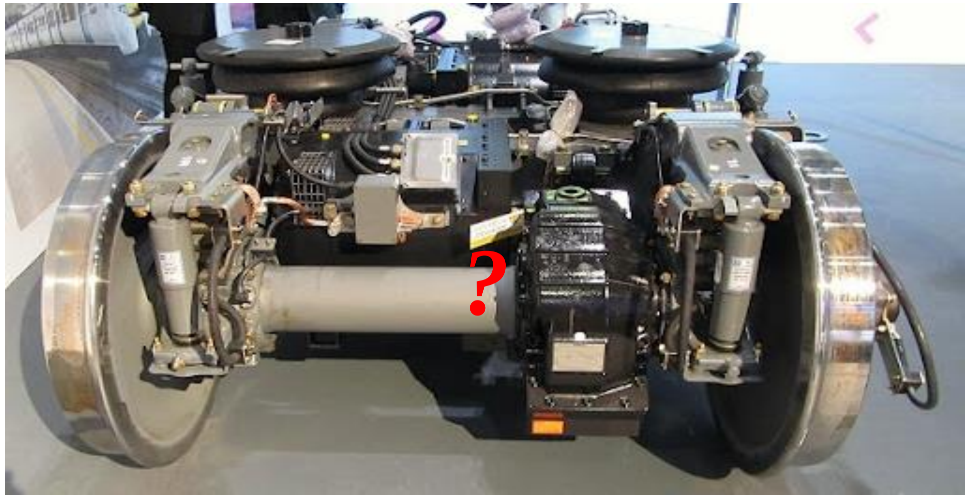
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-002: Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport

- analysis of the dimensional possibilities of installing shift two-stage axle gearboxes into the traction bogie regional train - LRV







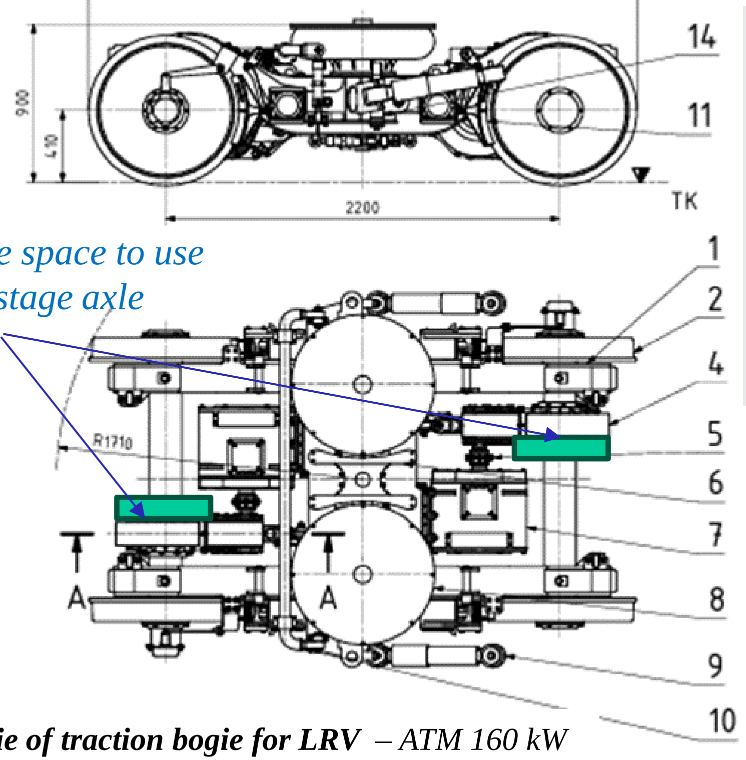
Bogie SF 7000

– asynchronous motor ATM 425 kW + axle gearbox with composed constant gear ratio

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

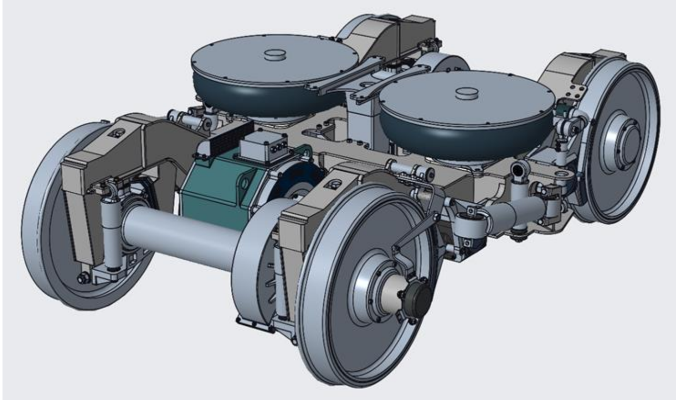
3-WP13-002: Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport

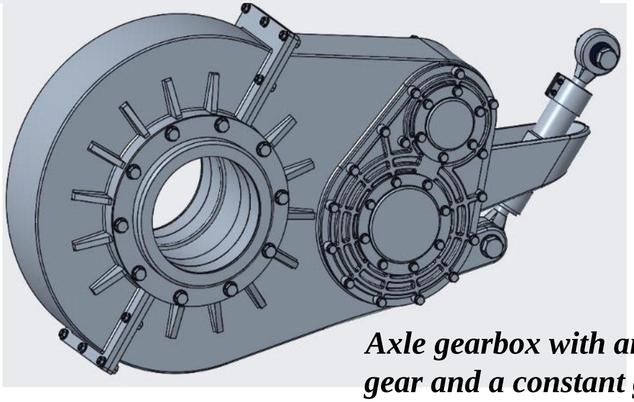
- design of the a concept of the shift two-stage gearbox for the regional LRV



There is free space to use a shift two-stage axle gearbox.

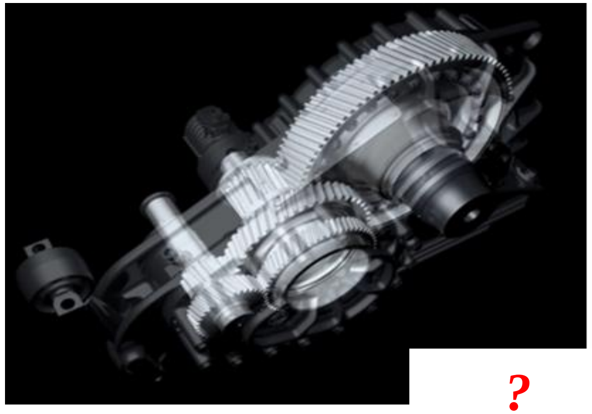
***Design studie of traction bogie for LRV** – ATM 160 kW + gearbox with constant gear ratio*



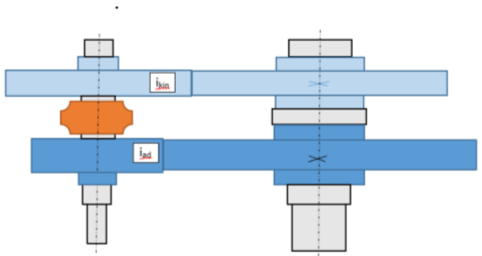


Axle gearbox with an inserted gear and a constant gear ratio

Axle gearbox ZF Get2



Shift two-stage axle gearbox



?
Three-shaft or two-shaft design

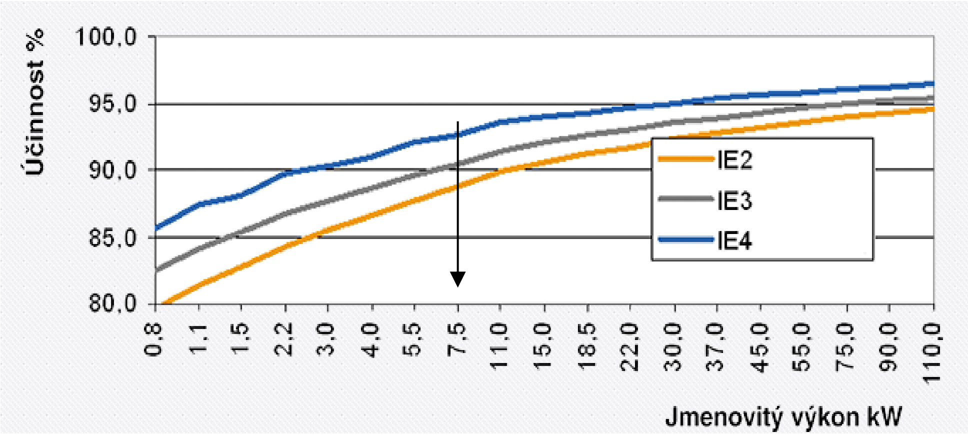
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-002: Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport

- research into the efficiency map of ACM and PMSM traction motors

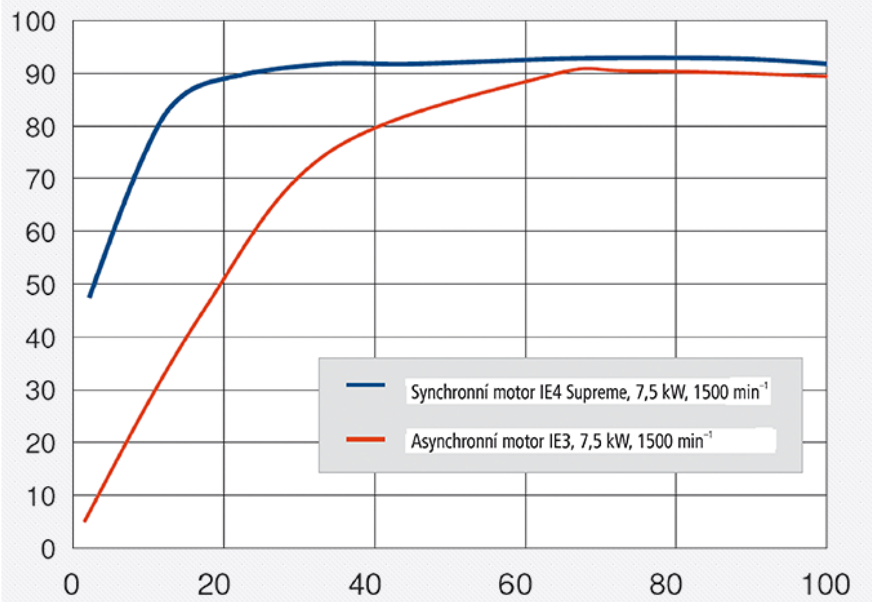
Efficiency of electric motors according to standard international classification:

IE 1 Standard
IE 2 High
IE 3 Premium
IE 4 Super Premium (for synchronous motors)



Efficiency values of 4 pole electric motors depending on their nominal power

Course of efficiency of asynchronous electric motor and synchronous electric motor at partial and full load



Problem: Efficiency maps for electric motors with power P_{jm}= 120 to 250 kW are not available.

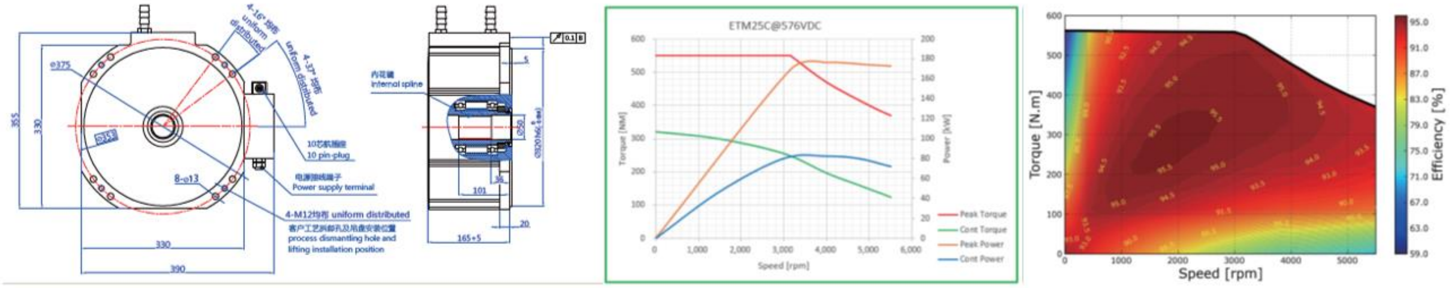
A synchronous electric motor shows significant savings in electrical energy at partial load.

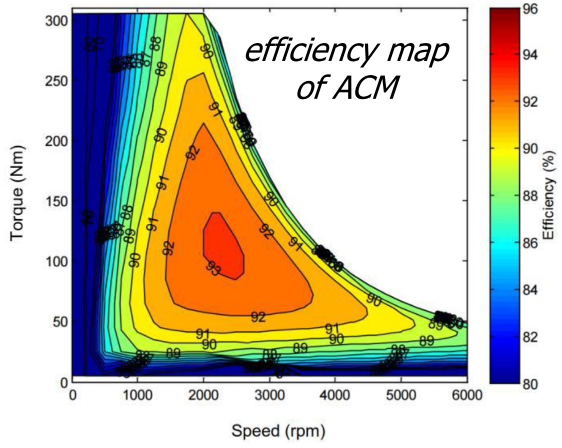
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-002: Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport

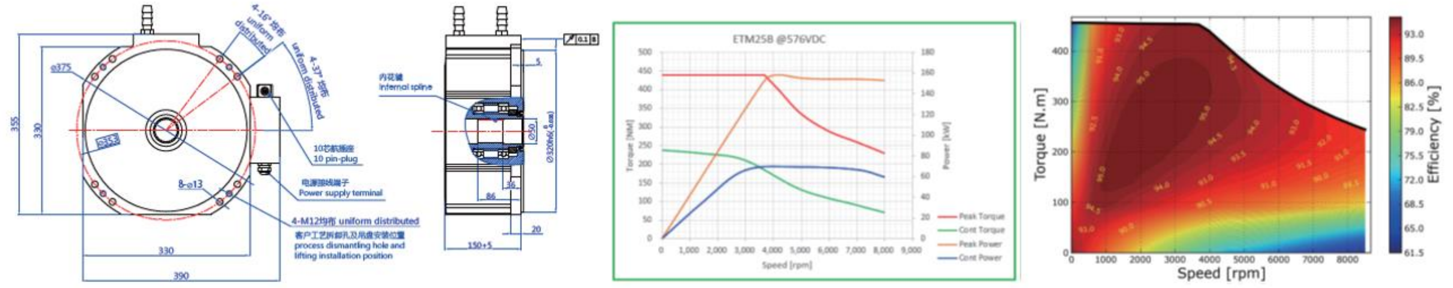
- research into the efficiency map of ACM and PMSM traction motors

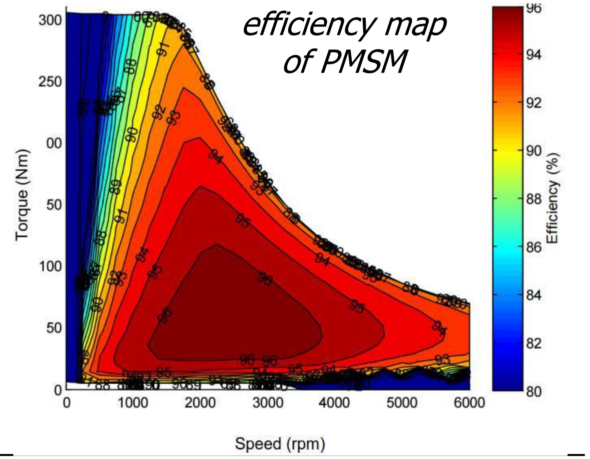
Synchronní trakční motor ETM 25C385: P_{jm}/P_{max} = 80/165 kW, M_{jm}/M_{max} = 255/550 Nm, n_{jm}/n_{max} = 3000/5500 min^{-1}, 14 pólů, max. účinnost = 96%, Hmotnost 57,7 kg





Synchronní trakční motor ETM 25B385: P_{jm}/P_{max} = 66/150 kW, M_{jm}/M_{max} = 210/440 Nm, n_{jm}/n_{max} = 3000/8000 min^{-1}, 14 pólů, max. účinnost = 95,7%, Hmotnost 46,7 kg





Problems: Efficiency maps for electric motors with power P_{jm}= 120 to 250 kW are not available.

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-003: Composite shaft modified structure: application of new eco-friendly materials for fibers

- Selection of representatives (from specified candidates) from eco-friendly composite materials and representatives from conventional composite materials to enable their direct comparison
- Production of boards of selected candidates to enable the production of test samples
- Production of test samples according to ASTM/ISO standards
- Experimental testing of samples to determine mechanical parameters
- Creation of refined numerical models (FEM) of functional samples of selected case studies (composite shaft)

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-003: Composite shaft modified structure: application of new eco-friendly materials for fibers

- Selection of representatives (from specified candidates) from eco-friendly composite materials and representatives from conventional composite materials to enable their direct comparison

Flax fibers in the form of roving - FR1000 - FLAX LinCore 1000

Glass fibers in the form of roving - R-310 – S-2 Glass

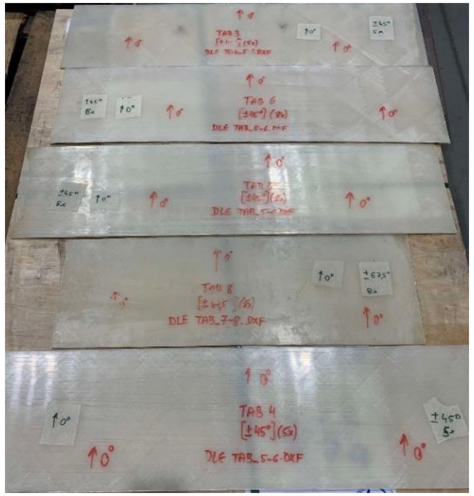
- *Taking into account the research carried out and the current availability, flax fibers more precisely FR1000 - FLAX roving LinCore 1000 were chosen as the main representative of eco-friendly fibers.*
- *To enable a direct comparison with existing solutions that are primarily made of glass or carbon fibers, representatives in the form of R-310 – S-2 Glass ®Roving (glass roving) and UD CFRP T700 12k (carbon roving) were added.*

Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-003: Composite shaft modified structure: application of new eco-friendly materials for fibers

- *Following the choice of specific types of fibers (linen, S2-Glass, T700 12k), Compotech produced laminate prisms, which were then cut into plates.*
- *Specifically, the production of plates was carried out for all basic directions that are needed to obtain the necessary mechanical parameters of the laminate (0°, ± 45°, ± 67.5°).*

Rolled sheets of linen fibers



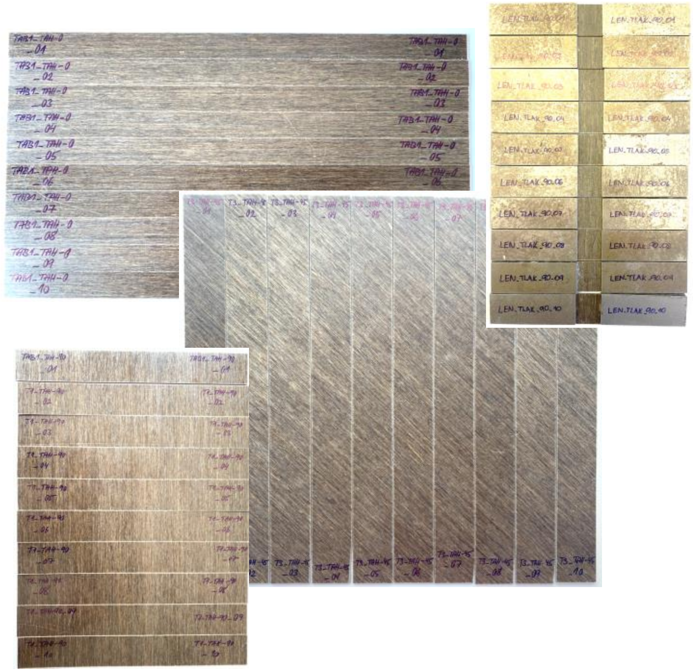
Winded fiberglass sheets

Winded carbon fiber sheets

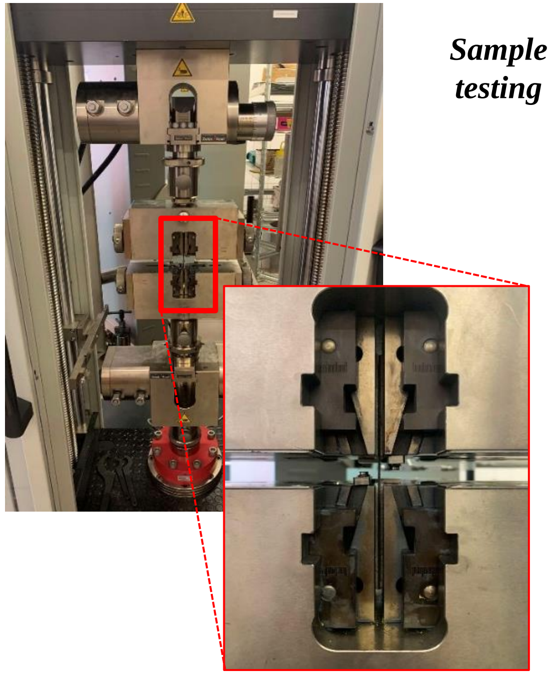
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-003: Composite shaft modified structure: application of new eco-friendly materials for fibers

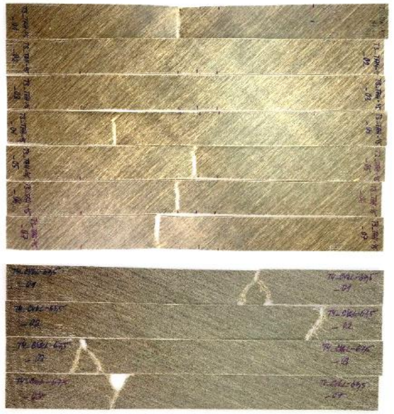
- *experimental measurement of test samples using electromechanical testing device Zwick-Roell Z250.*



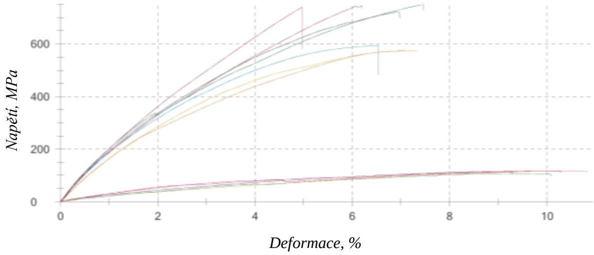
Sample of final test samples for exp. measurement (UD FLAX)



Sample testing



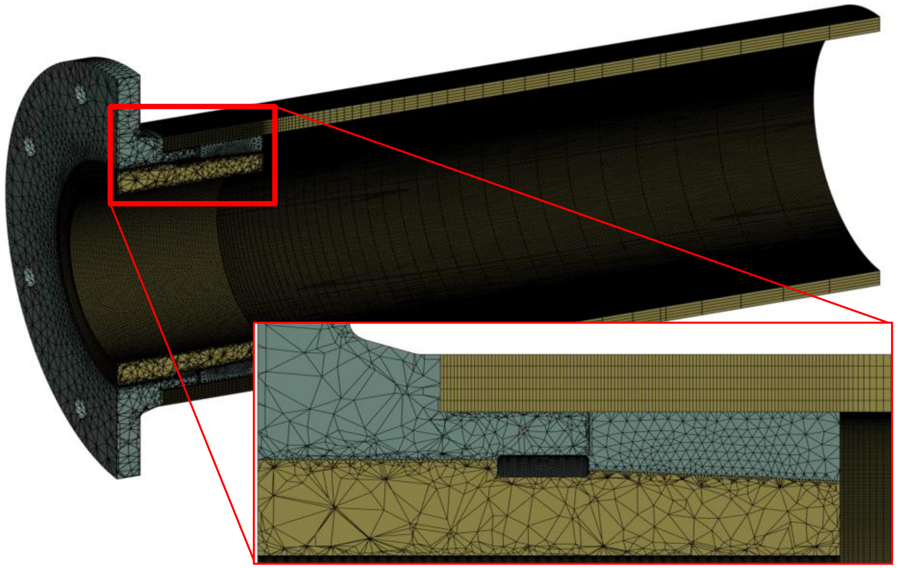
Sample of broken samples



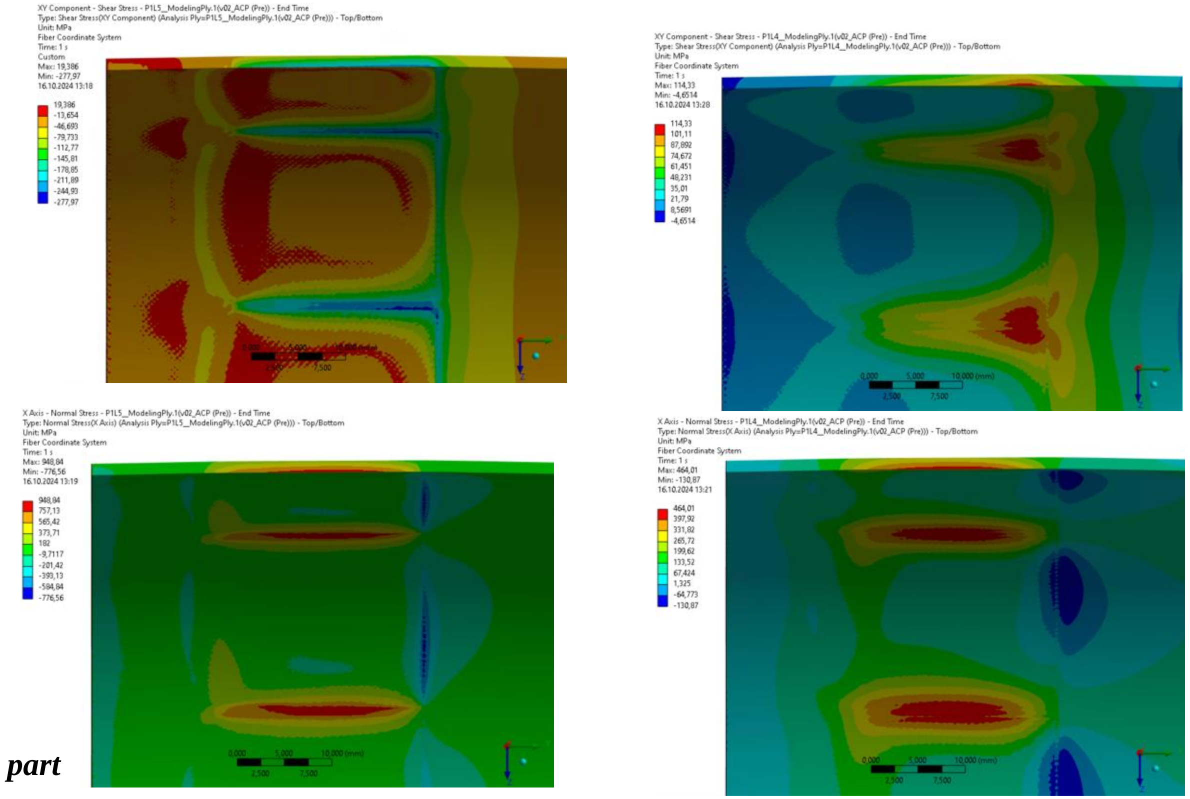
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

3-WP13-003: Composite shaft modified structure: application of new eco-friendly materials for fibers

- *the problem of numerical modeling is solved (for this purpose, a case study in the form of a wound shaft with glued inserts was used).*



MKP models of flange connection and hollow composite shaft



Demonstration of the distribution of the main stress components in a composite part

Fulfillment of goals and deliverables of **3-WP13** Powertrain Components for Future Rail Vehicles

Current State of Deliverables and Fulfillment of Goals

- 3-WP13-001 | **Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines** , O, VI./2026, FME CTU 0.3 + UWB RTI 0.3 + BUT 0.1 + VZUP 0.1 + STRN 0.25

  – **in progress & no major delays:**
  - a basic analysis of the conceptual solution of the wagon Energy-Tender was carried out
  - a basic analysis of the technical parameters of suitable components for the Energy-Tender is underway
  - simulation calculations of train run are underway to determine the traction power and energy capacity of the Energy-Tender
  - concepts of design solutions for independent vehicle drive during manipulative driving were assessed

- 3-WP13-002 | **Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport** , O, VI./2026, CTU FME 1.0

  – **in progress & no major delays**:
  - analysis of the dimensional possibilities of installing shiftable axle gearboxes in the drive of regional trains
  - design concept design of a two-stage shiftable gearbox for regional LKV
  - obtaining efficiency maps of ACM and PMSM traction motors

Fulfillment of goals and deliverables of **3-WP13** Powertrain Components for Future Rail Vehicles

Current State of Deliverables and Fulfillment of Goals

- 3-WP13-003 | **Composite shaft modified structure: application of new eco-friendly materials for fibers**, G_{funk} , VI./2026, (UWB RTI 0.25 + VUT 0.25 + VZUP 0.25 + CompoTech 0.25)

  – **in progress & no major delays:**
  - suitable ecological materials were purchased and functional test samples were produced
  - in cooperation with the Compotech company, testing of functional samples of materials and the appropriate technical connection of steel flanges and ecological composite hollow shafts is underway
  - the strength FEM calculations of the ecological composite hollow shaft are being refined table ecological materials were selected

Fulfillment of goals and deliverables of **3-WP13** Powertrain Components for Future Rail Vehicles

List of Due Deliverables and Their Added Value

- **3-WP13-001** – the use of Energy-Tender for currently operated electric locomotives (2nd and 3rd generation) and electric units would enable the gradual withdrawal of old diesel locomotives from operation on non-electrified lines and thereby reduce emissions (CO2, noise, smoke,...) and reduce the number drive rail vehicles.
- **3-WP13-002** – the use of two-speed shiftable axle gearbox in new four-axle light rail vehicles with individual wheelset drive with a power of 150 to 250 kW/wheelset can, with the right mode of electric drive, enable savings in operating costs and traction energy.
- **3-WP13-003** - research into new eco-materials for composite elements used in wheelset drives and in bogies of rail vehicles can lead to a reduction in their weight and a reduction in the cost of recycling these composite products.

The solution of project tasks enabled the employment of young students and PhD students and strengthened the scientific cooperation between RO (U12 120 ČVUT FSI, VTI WBU, VUT) and industrial partners (Škoda Group, Compotech) and to carry out contract research. The partial knowledge gained contributes to increasing competitiveness and the possibility of further development and cooperation of the RO and industry. In this way, VUKV, Škoda Group and Compotech will contribute to the sustainability of investments and the application of new products on the world market.

Current contribution of **3-WP13** Powertrain Components for Future Rail Vehicles

Assessment of the Contribution of Deliverables

- The research activities carried out should contribute to improving the efficiency and expanding the utility properties of the dependent traction railway vehicles.
- They contribute to the expansion of knowledge about new ways of drive rail vehicles, their and experimental testing of dynamic behavior and vehicle reliability/lifetime.
- New findings and outputs can be applied in the design of new bogies and alternative drives for new rail vehicles, e.g. at Škoda Group, Compotech and others.
- The knowledge gained is regularly presented at professional conferences.

Current contribution of **3-WP13** Powertrain Components for Future Rail Vehicles

Assessment of the Formal/Administrative Goals of the Work Package

We assume that the use of allocated funds, the commercialization of research, and the fulfillment of contractual research will be fulfilled by all partners participating in the implementation of 3-WP13 during the years 2023-2026.

Acknowledgment

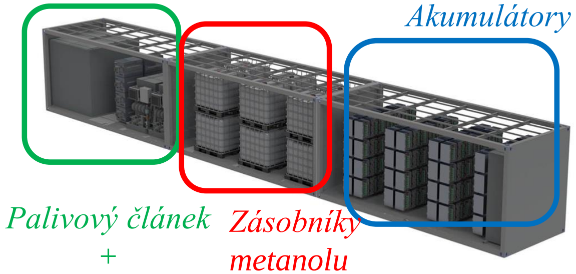
This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres II, project # TN02000054 Bozek Vehicle Engineering National Center of Competence (BOVENAC).

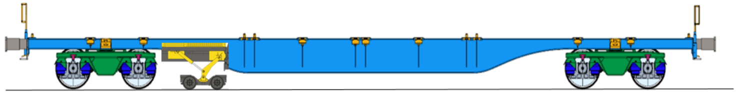
Výtah z prací 2023-2025 na **3-WP13** Komponenty hnacího ústrojí pro budoucí kolejová vozidla – dosaženo v roce 2023

3 – WP13 - 001 (O) (ČVUT FS 0.3 + ZČU RTI 0.3 + VUT FSI 0.1 + VZUP 0.1 + STRN 0.25)

Termín: 1.6.2026

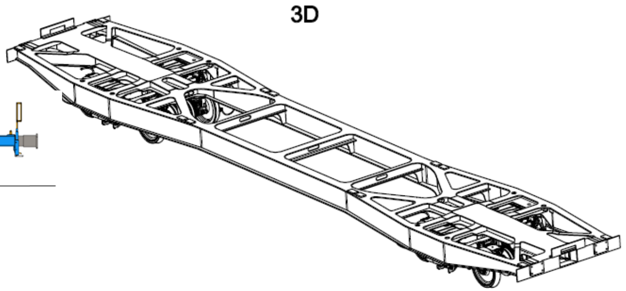
Model energetického tendru pro hnací elektrická vozidla na neelektrifikovaných tratích

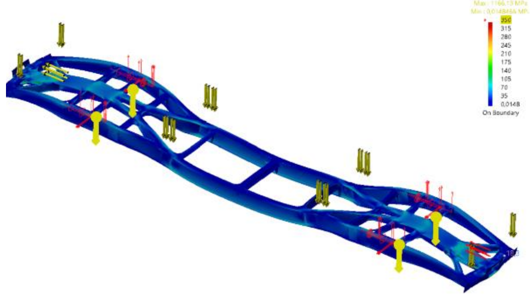




Model kontejnerového vozu Sgnss 60 s přídavnou hnací jednotkou pro manipulační jízdu

Koncept uspořádání kontejnerů energetického tendru (H_2 + Aku) pro elektrickou lokomotivu



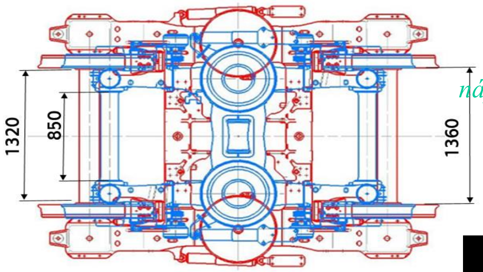


3D model plošinového vozu pro podvozky se vzduchovým vypružením a MKP pevnostní výpočet jeho rámu.

3 – WP13 - 002 (O) (FS ČVUT 1.0)

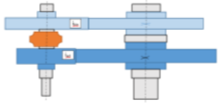
Termín: 1.6.2026

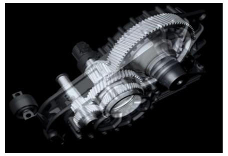
Výzkum využití dvoustupňových řaditelných převodovek u lehkých kolejových vozidel pro regionální dopravu

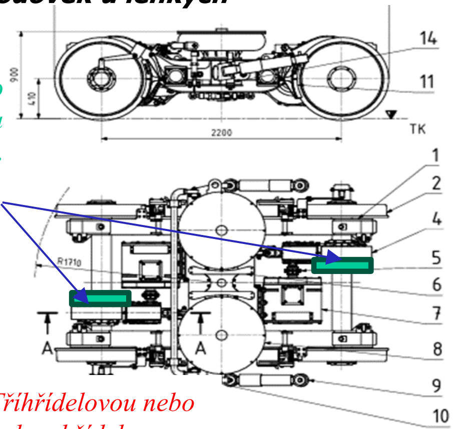


Porovnání podvozků s vnitřním nebo vnějším rámem

Zde je prostor pro dvoustupňovou nápravovou převodovku.





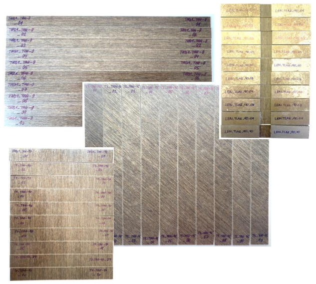


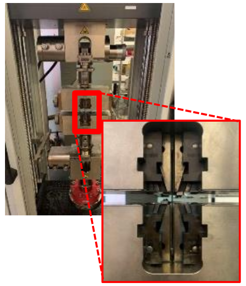
Tříhřídelovou nebo dvouhřídelovou

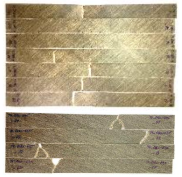
3 – WP13 - 003 (O) (ZČU RTI 0.25 + BUT FSI 0.25 + VZUP 0.25 + CompoTech 0.25)

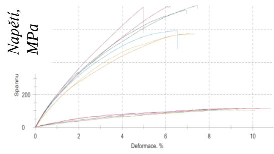
Struktura kompozitní hřídele: použití nových ekologických materiálů pro vlákna

Termín: 1.6.2026

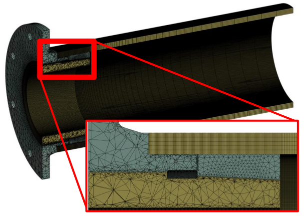








Experimentální zkoušení testovacích vzorků



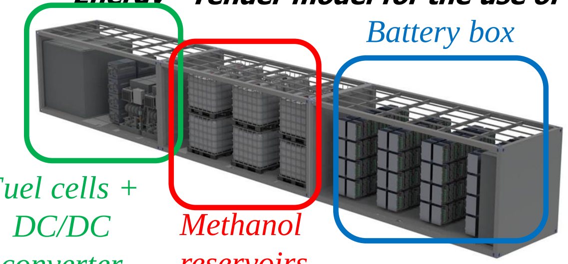
MKP model spojení příruby a duté kompozitní hřídele

Results of **3-WP13** Powertrain Components for Future Rail Vehicles – Achieved 2023-2025

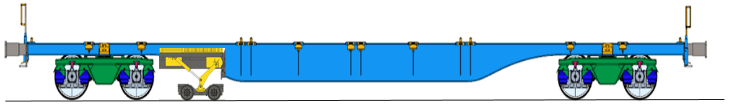
3 – WP13 - 001 (O) (FME CTU 0.3 + UWB RTI 0.3 + BUT 0.1 + VZUP 0.1 + STRN 0.25)

Project deadline: 1.6.2026

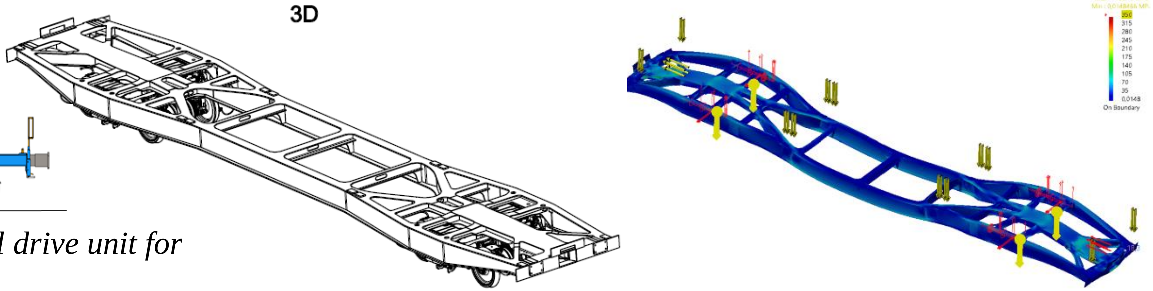
Energy –Tender model for the use of a traction rail vehicle on non-electrified railway li



Concept of arrangement of energy tender containers (Hydrogen + Battery) for electric locomotives



Model of container wagon Sgnss 60 with additional drive unit for wagon handling

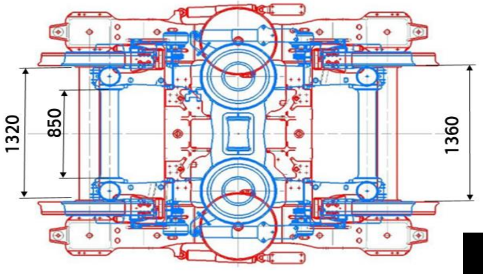


3D model of container wagon Energy - Tender with bogies with air suspension and FEM strength calculation of its frame.

3 – WP13 - 002 (O) (FME CTU 1.0)

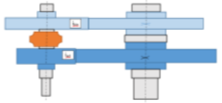
Project deadline: 1.6.2026

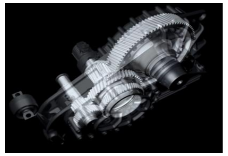
Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport

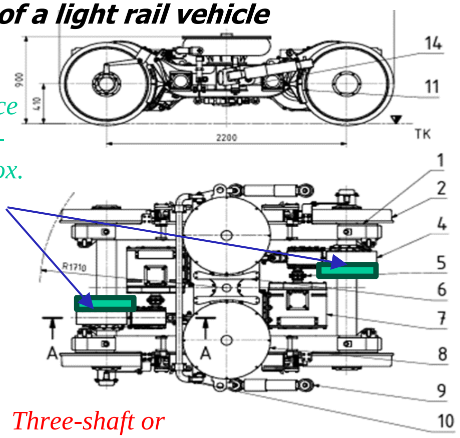


Plan view comparison of bogies with outer and inner frame

There is free space to use a shift two-stage axle gearbox.





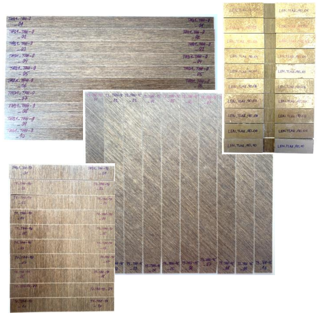


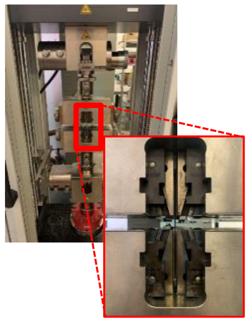
Three-shaft or two-shaft design

3 – WP13 - 003 (O) (UWB RTI 0.25 + VUT 0.25 + VZUP 0.25 + CompoTech 0.25)

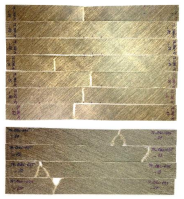
Project deadline: 1.6.2026

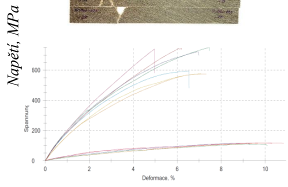
Composite shaft modified structure: application of new eco-friendly materials for fibers

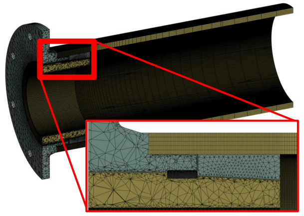




experimental measurement of test samples







MKP models of flange connection and hollow composite shaft