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

České vysoké učení technické v Praze, FS - doc. Ing. Josef Kolář, CSc.

Participants of the WP 13

ŠKODA Group a.s., Ing. Petr Špalek
FSI VÚT Brno, Ing. Kamil Řehák, Ph.D.
RTI ZČU Plzeň, Ing. Pavel Žlábek, Ph.D.
VZÚ Plzeň, Ing. Jan Chvojan, Ph.D.
CompoTech Plus s.r.o., Ing. Michal Chroust

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 0.25)

TN 02000054/003-V52

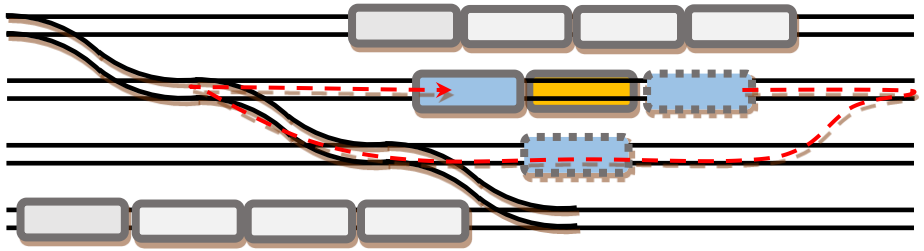
- 3-WP13-002 | **Research on the use of shift two-stage gearbox of a light rail vehicle for regional transport** ,O, (FME CTU 1.0)

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

- research processing in the world of used solutions of the Energy-Tender
- Analysis of the possibility of using Energy - Tender with regard to the of the drive vehicles structure of carriers in the Czech Republic and a study of electrification and the gradual transition to a 25kV/50 Hz traction power supply
- Analysis of the possibility of operational handling of the Energy-Tender wagon
- Assessment of the design concept of the Energy – Tender car ⇒ consultation with Ing. Špalek (ŠTRN) on the basic concept of Energy – Tender ⇒ platform container car with ISO 20 container modules (Aku, H_2, hydrogen cells)



Manipulation of hydrogen energy tender in end terminal rail station

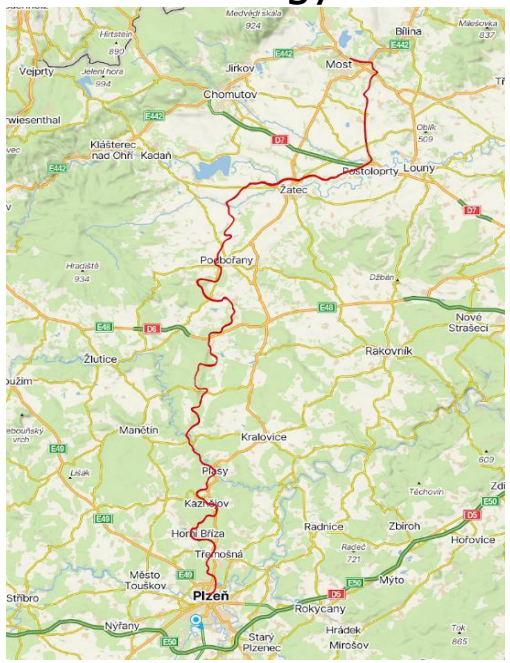
Hydrogen energy tender concept for electric locomotives

Ordinary bogie flat wagon Sgnss 60

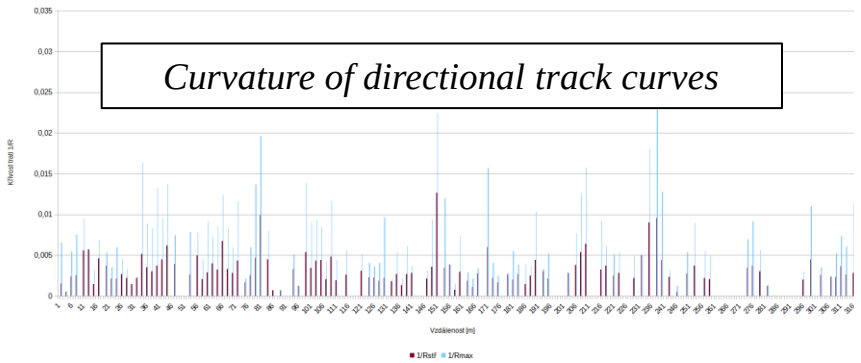
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

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

- Mathematical model of train set driving - the parametric model respects the performance and energy needed to drive the track at the defined track speed.

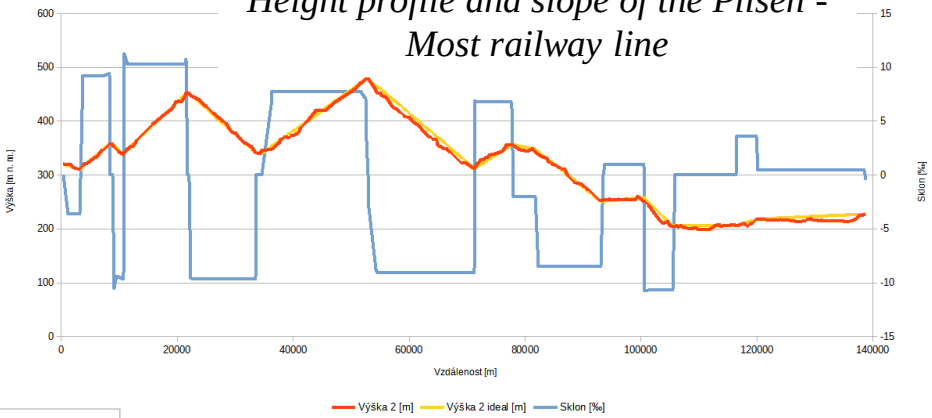


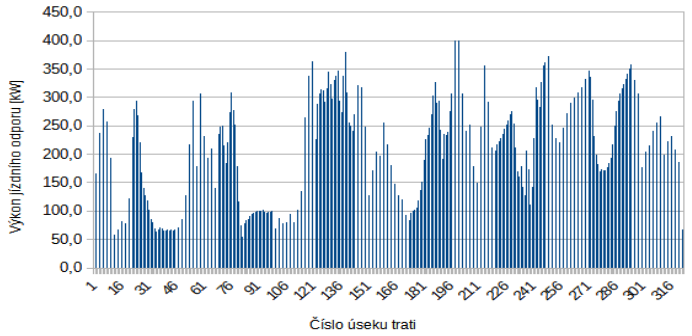
Mathematical model of the non-electrified railway line Pilsen - Most



Curvature of directional track curves

Height profile and slope of the Pilsen - Most railway line

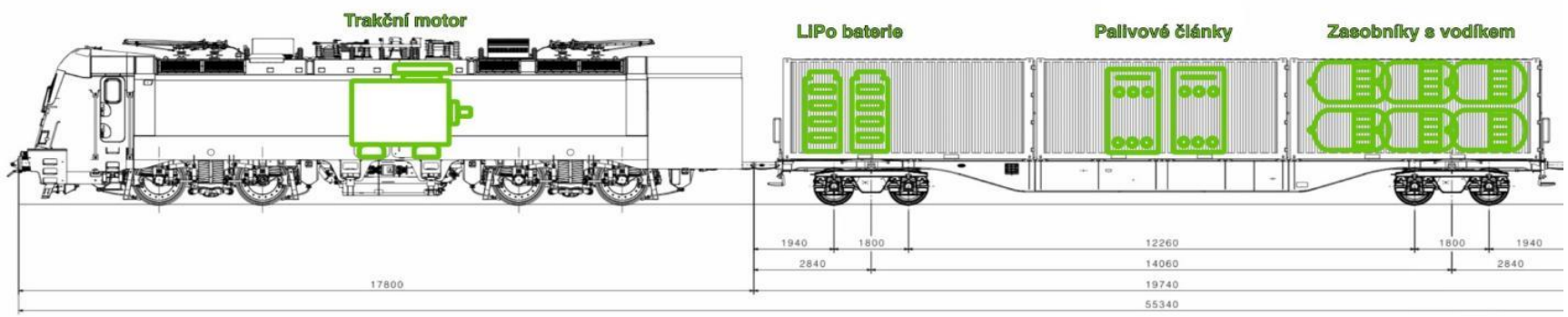


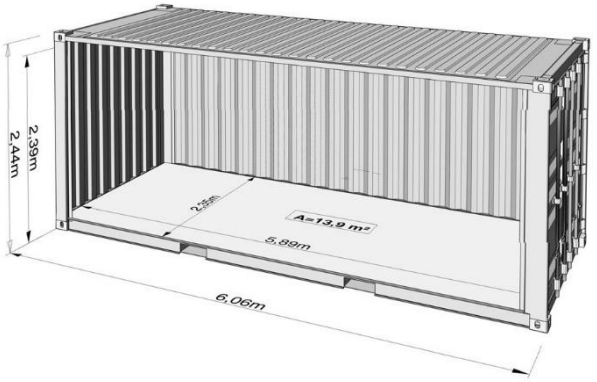


Power to overcome the train's driving resistance in individual sections of the track

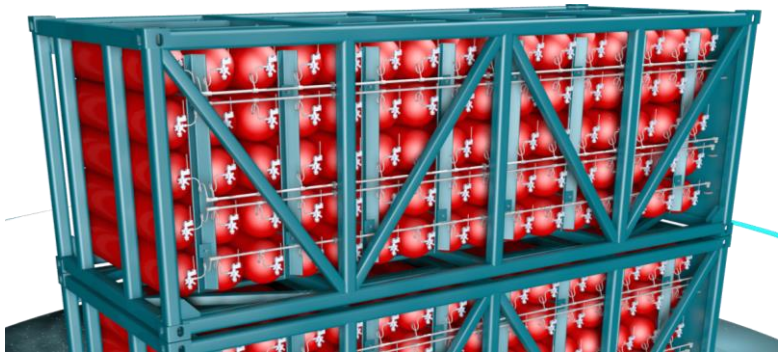
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

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



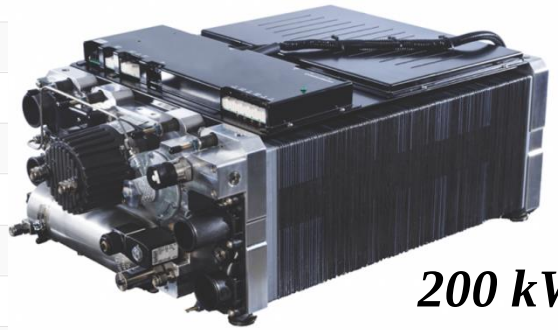


Hydrogen energy tender concept for electric locomotives



Klasifikace kontejnerů acc. ISO 668	1CC
Rozměry (L x W x W)	6.058 x 2438 x 2.591 mm
Hmotnost (GROSS)	28.380 kg
Objem vody	15.272 L
Medium	Stlačený vodík (H2) UN 1049
Max. pracovní tlak	300 Bar
Max. objem plynu	350 kg
Válcové ventily	ruční/elektrické ovládání (volitelné)

Certified ISO Hydrogen container ***MEGC 92 x 166 l***



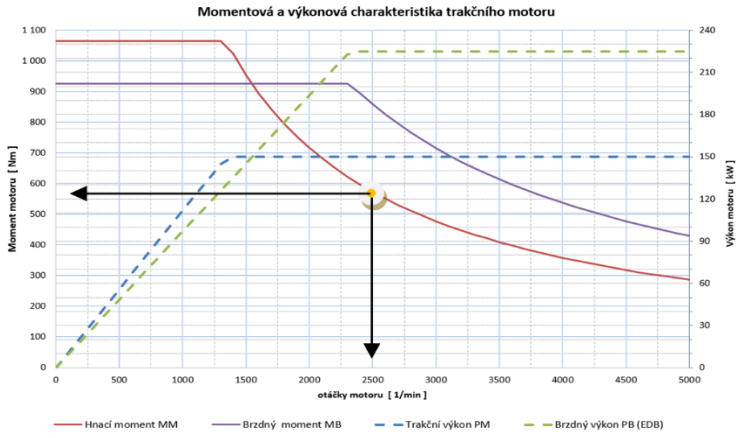
200 kW

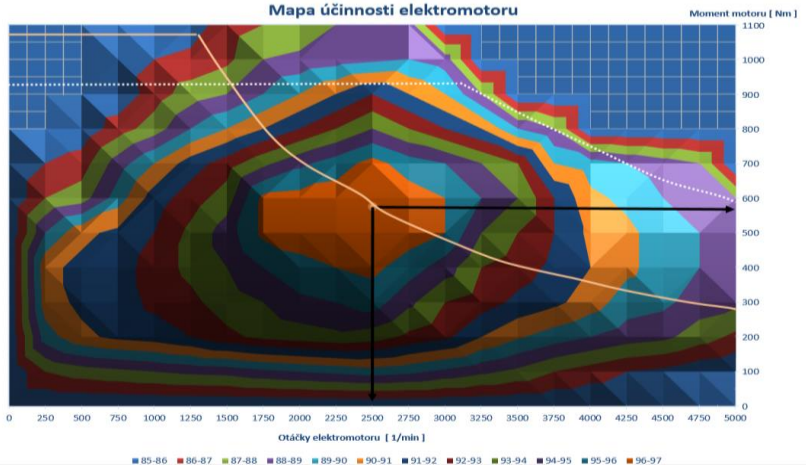
Cummins hydrogen fuel cells used in Coradia iLint trains.
Source: Cummins

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 AC traction motors
- design of the step-up of the adjustable front two-stage gearbox for the regional LKV – BEMU
- creation of a simplified program for calculating the driving cycle of a regional light rail vehicle with a shiftable axle gearboxs
- presentation of simulation results at the international conference ProRail 2023 – Zilina Slowakia



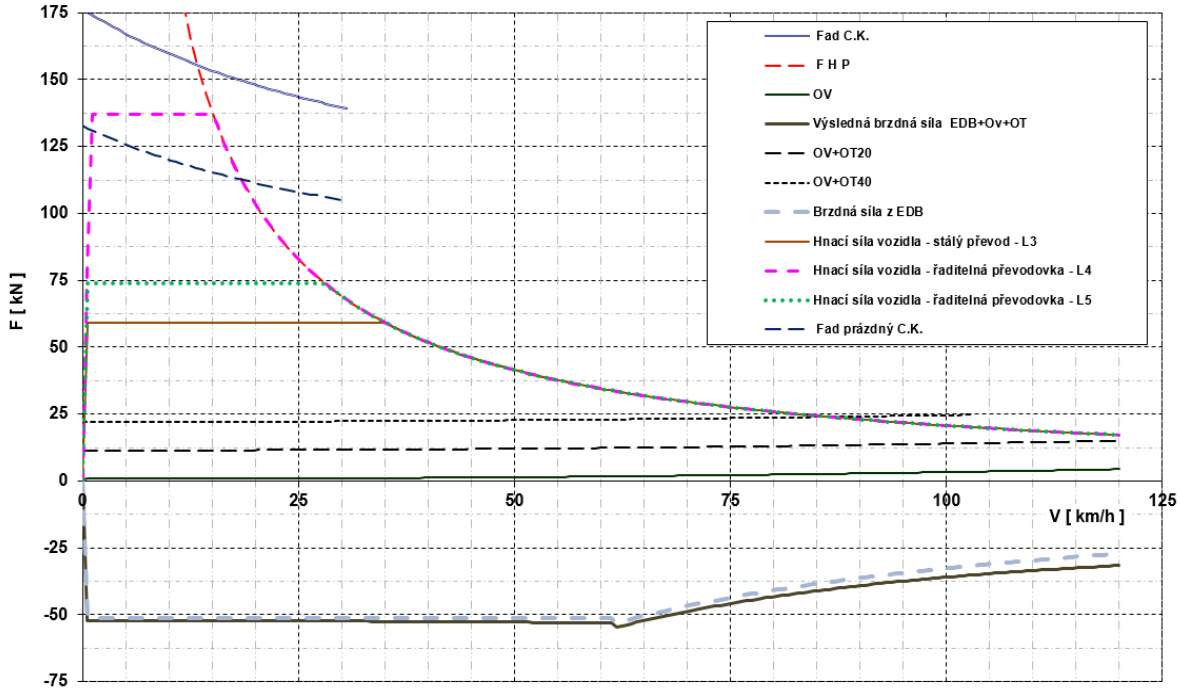


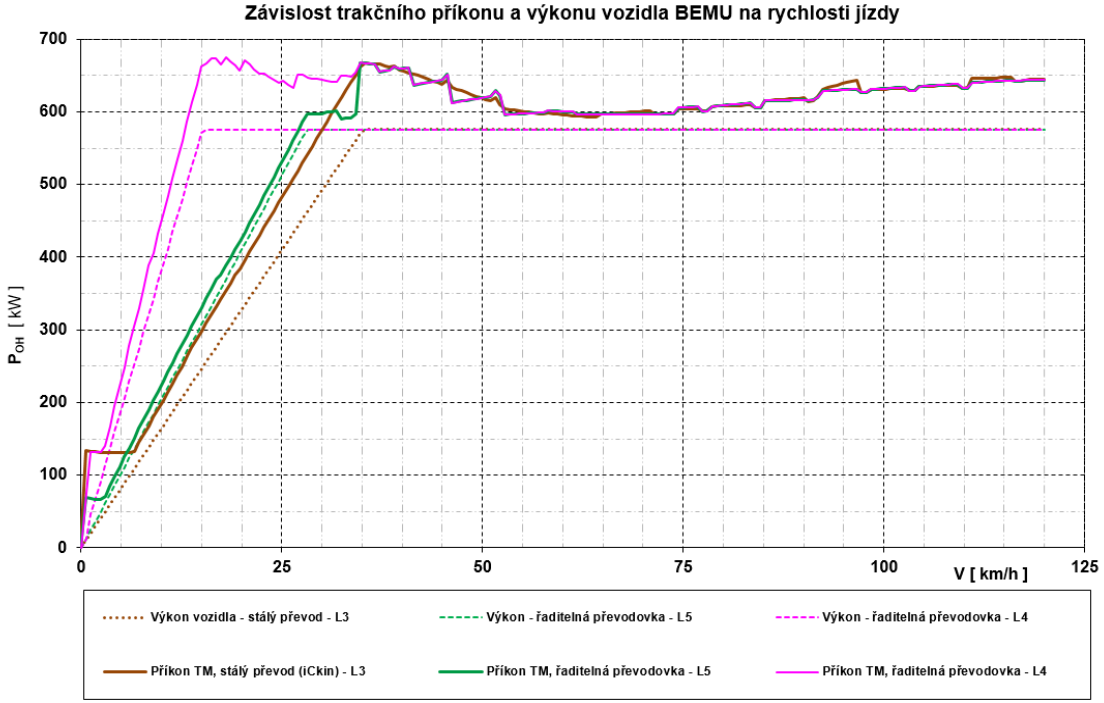
Torque and power characteristics of the traction motor, efficiency map

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

Traction characteristic of the vehicle BEMU 70



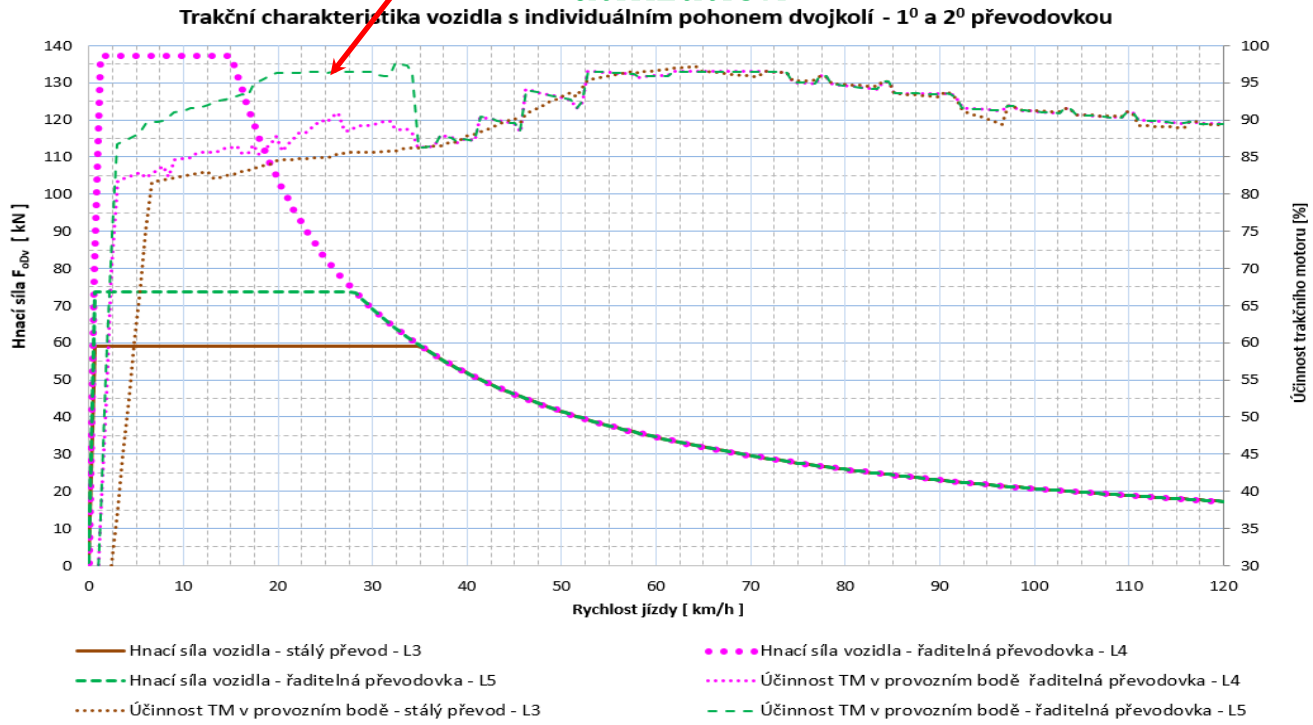


Courses of power and input power of a BEMU vehicle with conventional and non-conventional shift axle gearbox

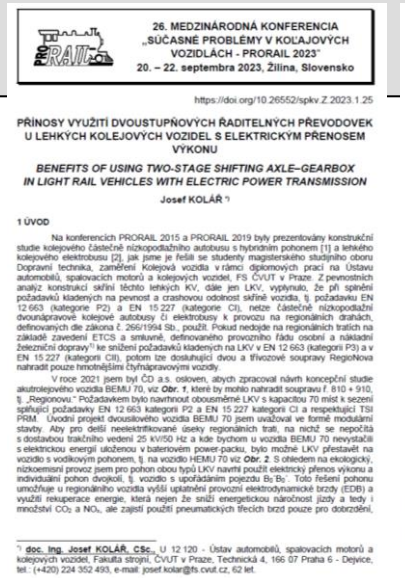
Activities in **3-WP13** Powertrain Components for Future Rail Vehicles

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

Significant improvement in TM efficiency utilization



Courses of efficiency of traction motors in the assessed modes – L3, L4 and L5



26. MEDZINÁRODNÁ KONFERENCIA „SÚČASNÉ PROBLÉMY V KOĽAJOVÝCH VOZIDLÁCH - PRORAIL 2023" 20. – 22. septembra 2023, Žilina, Slovensko

https://doi.org/10.26552/spkv.Z.2023.1.25

PŘÍNOSY VYUŽITÍ DVOUSTUPŇOVÝCH ŘADITELNÝCH PŘEVODOVEK U LEHKÝCH KOLEJOVÝCH VOZIDEL S ELEKTRICKÝM PŘENOSEM VÝKONU

BENEFITS OF USING TWO-STAGE SHIFTING AXLE–GEARBOX IN LIGHT RAIL VEHICLES WITH ELECTRIC POWER TRANSMISSION

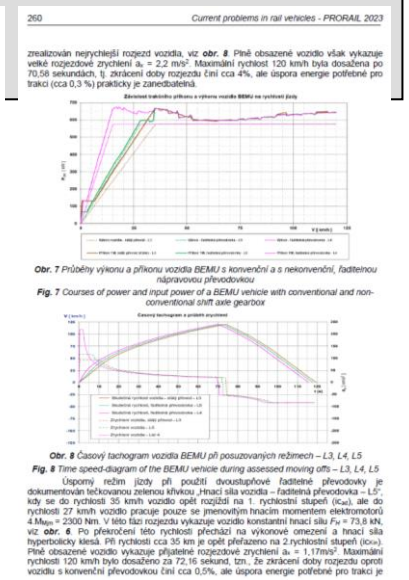
Josef KOLÁŘ [1]

1 ÚVOD

Na konferencích PRORAIL 2015 a PRORAIL 2019 byly prezentovány konstrukční studie kolejového částečně nízkopodlažního autobusu s hybridním pohonem [1] a lehkého kolejového elektrobusu [2], jak jsme je řešili se studenty magisterského studijního oboru Dopravní technika, zaměření Kolejová vozidla v rámci diplomových prací na Ústavu automobilů, spalovacích motorů a kolejových vozidel, FS ČVUT v Praze. Z pevnostních analýz konstrukcí skříní těchto lehkých KV, dále jen LKV, vyplynulo, že při splnění požadavků kladených na pevnost a crashovou odolnost skříně vozidla, tj. požadavku EN 12 663 (kategorie P2) a EN 15 227 (kategorie C3), nelze částečně nízkopodlažní dvounápravové kolejové autobusy či elektrobusy k provozu na regionálních drahách, definovaných dle zákona č. 266/1994 Sb., použít. Pokud nedojde na regionálních tratích na základě zavedení ETCS a smluvně, definovaného provozního řádu osobní a nákladní železniční dopravy [1] ke snížení požadavků kladených na LKV v EN 12 663 (kategorii P3) a v EN 15 227 (kategorii C II), potom lze doslunující dvou a třívozové soupravy RegioNova nahradit pouze hmotnějšími čtyřnápravovými vozidly.

V roce 2021 jsem byl ČD a.s. osloven, abych zpracoval návrh konceptní studie akutrolejového vozidla BEMU 70, viz **Obr. 1**, které by mohlo nahradit soupravu f. 810 + 910, tj. „Regionovu." Požadavkem bylo navrhnout obousměrné LKV s kapacitou 70 míst k sezení splňující požadavky EN 12 663 kategorii P2 a EN 15 227 kategorii CI a respektující TSI PRM. Úvodní projekt dvoustupňového vozidla BEMU 70 jsem uvažoval ve formě modulární stavby. Aby pro delší neelektrifikované úseky regionálních trati, na nichž se nepočítá s dostavbou trakčního vedení 25 kV/50 Hz a kde bychom u vozidla BEMU 70 nevystačili s elektrickou energií uloženou v bateriovém power-packu, bylo možné LKV přestavět na vozidlo s vodíkovým pohonem, tj. na vozidlo HEMU 70 viz **Obr. 2**. S ohledem na ekologický, nízkoemisní provoz jsem pro pohon obou typů LKV navrhl použít elektrický přenos výkonu a individuální pohon dvojkolí, tj. vozidlo s upořádáním pojezdu $B_0'B_0'$. Toto řešení pohonu umožňuje u regionálního vozidla vyšší uplatnění provozní elektrodynamické brzdy (EDB) a využití rekuperace energie, která nejen že sníží energetickou náročnost jízdy a tedy i množství CO_2 a NO_x, ale zajistí použití pneumatických třecích brzd pouze pro dobrzdění,

[1] doc. Ing. Josef KOLÁŘ, CSc., U 12 120 - Ústav automobilů, spalovacích motorů a kolejových vozidel, Fakulta strojní, ČVUT v Praze, Technická 4, 166 07 Praha 6 - Dejvice, tel.: (+420) 224 352 493, e-mail: josef.kolar@fs.cvut.cz, 62 let.



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zrealizován nejrychlejší rozjezd vozidla, viz **obr. 8**. Plně obsazené vozidlo však vykazuje velké rozjezdové zrychlení a_0 = 2,2 m/s². Maximální rychlost 120 km/h byla dosažena po 70,58 sekundách, tj. zkrácení doby rozjezdu činí cca 4%, ale úspora energie potřebné pro trakci (cca 0,3 %) praktický je zanedbatelná.

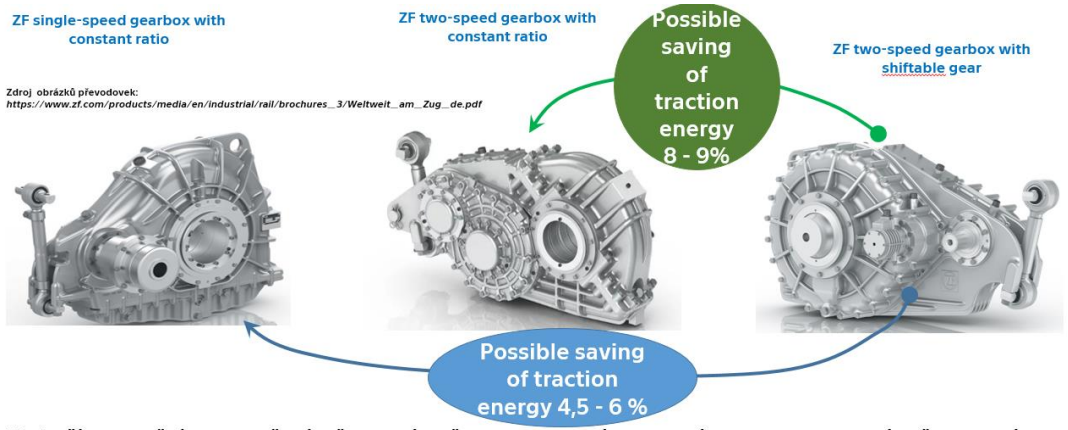
Obr. 7 Průběhy výkonu a příkonu vozidla BEMU s konvenční a s nekonvenční, řaditelnou nápravovou převodovkou

Fig. 7 *Courses of power and input power of a BEMU vehicle with conventional and non-conventional shift axle gearbox*

Obr. 8 Časový tachogram vozidla BEMU při posuzovaných režimech – L3, L4, L5

Fig. 8 *Time speed-diagram of the BEMU vehicle during assessed moving offs – L3, L4, L5*

Úsporný režim jízdy při použití dvoustupňové řaditelné převodovky je dokumentován teckovanou zelenou křivkou „Hnací síla vozidla – řaditelná převodovka – L5", kdy se do rychlosti 35 km/h vozidlo opět rozjíždí na 1. rychlostní stupeň ($i_{C_{II}}$), ale do rychlosti 27 km/h vozidlo pracuje pouze se jmenovitým hnacím momentem elektromotorů 4 M_{MN} = 2300 Nm. V této fázi rozjezdu vykazuje vozidlo konstantní hnací sílu F_H = 73,8 kN, viz **obr. 6**. Po překročení této rychlosti přechází na výkonové omezení a hnací síla hyperbolicky klesá. Při rychlosti cca 35 km je opět přeřazeno na 2.rychlostní stupeň ($i_{C_{III}}$). Plně obsazené vozidlo vykazuje přijatelné rozjezdové zrychlení a_0 = 1,17m/s². Maximální rychlosti 120 km/h bylo dosaženo za 72,16 sekund, tzn., že zkrácení doby rozjezdu oproti vozidlu s konvenční převodovkou činí cca 0,5%, ale úspora energie potřebné pro trakci je



Kolář, J.: **PŘÍNOSY VYUŽITÍ DVOUSTUPŇOVÝCH ŘADITELNÝCH PŘEVODOVEK U LEHKÝCH KOLEJOVÝCH VOZIDEL S ELEKTRICKÝM PŘENOSEM VÝKONU** In: Zborník prednášok II. - XXVI. Medzinárodná konferencia - Súčasné problémy v kolajových vozidlách. Žilina: Vedecko-technická spoločnosť pri Žilinskej univerzitě, 2023, díl 1, s. 255-262. , ISBN 978-80-89276-61-5.

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

- analysis of basic technical properties of new ecological materials for hollow composite shaft
- analysis of sub-models of structural connection steel flange - hollow composite shaft
- created generic CAD models and simplified sub-models for numerical optimizations and optimizations determining the most suitable geometry (composite and insert) as well as the composition of the laminate composite (number of layers, orientation of the main fiber directions, combination of materials)
- in the first phase of the research, models of submodels of the steel flange – hollow composite shaft connection were created for simplified numerical simulations based on the FEM principle

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

- analysis of basic technical properties of new ecological materials for hollow composite shaft

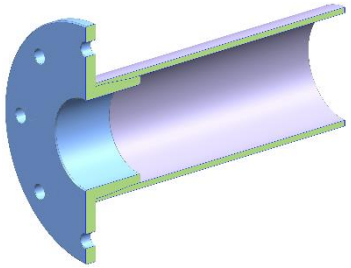
Vlákno	Pevnost v tahu (MPa)	Youngův modul pružnosti (GPa)	Tažnost (%)	Hustota (g/cm^3)
Len	343-1500 (700)	8-100 (70)	1,2-4 (3)	1,4-1,52
Konopí	310-1110 (800)	3-90 (65)	1,3-6 (3)	1,4-1,6
Juta	187-800 (500)	3-64 (30)	0,2-3,1 (1,8)	1,3-1,5
Kenaf	180-1191 (700)	22-128 (55)	1,2-4,6 (3)	1,2-1,4
Kapok	45-93 (60)	1,7-4 (2,9)	1,2-4 (2)	1,47
Kokos	95-270 (200)	2,8-6 (5)	15-51,4 (30)	1,15-1,5
Abaka	12-980 (600)	12-72 (50)	1-12 (4)	1,4-1,5
Ananas	170-1627 (750)	6,2-82 (40)	0,8-3 (2)	0,8-1,6
Curauá	439-495 (460)	10 (10)	1,3-4,5 (3)	0,92
Bambus	140-1000 (500)	11-89 (30)	1,2-4 (3)	0,6-1,5
Sisal	80-855 (600)	9-38 (12)	1,9-4 (3)	1,0-1,5
Olejová palma	248 (248)	3,2-6,7 (4,5)	14-25 (20)	0,7-1,55
E - sklo	**3500**	**73,5**	**4,8**	**2,6**

Primarily elected candidates

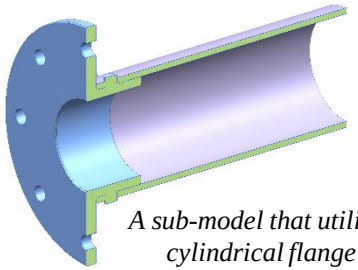
A sample of the comparison of the basic mechanical parameters of natural fibers against the most commonly used conventional fiber (GFRP - type E-glass) incl. their normal ranges

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

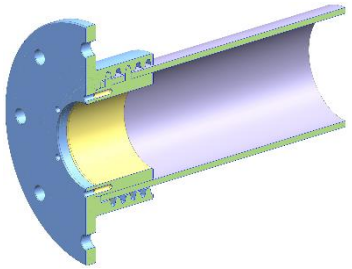
3-WP13-003: Composite shaft modified structure: application of new eco-friendly materials for fibers



A sample of the first sub-model that uses a glued joint at the shaft-to-flange interface

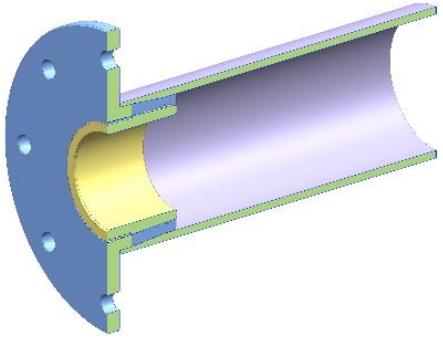


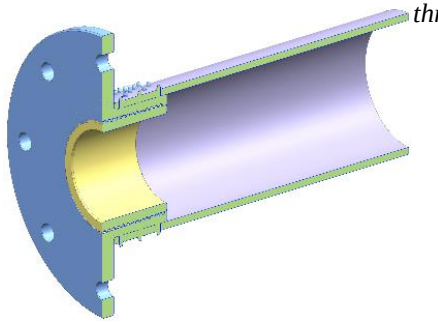
A sub-model that utilizes winding shaft fibers onto cylindrical flange elements using Compotech's manufacturing technology



A sub-model that uses the winding of the shaft fibers on the pin elements of the insert, which, due to their distribution, enable the threaded connection of the insert and the flange, while at the same time ensuring unwanted relative movements through glued and screwed connections

A sub-model that combines a glued joint at the shaft-flange interface and the opening of the flange segments by means of a conical insert using a threaded connection



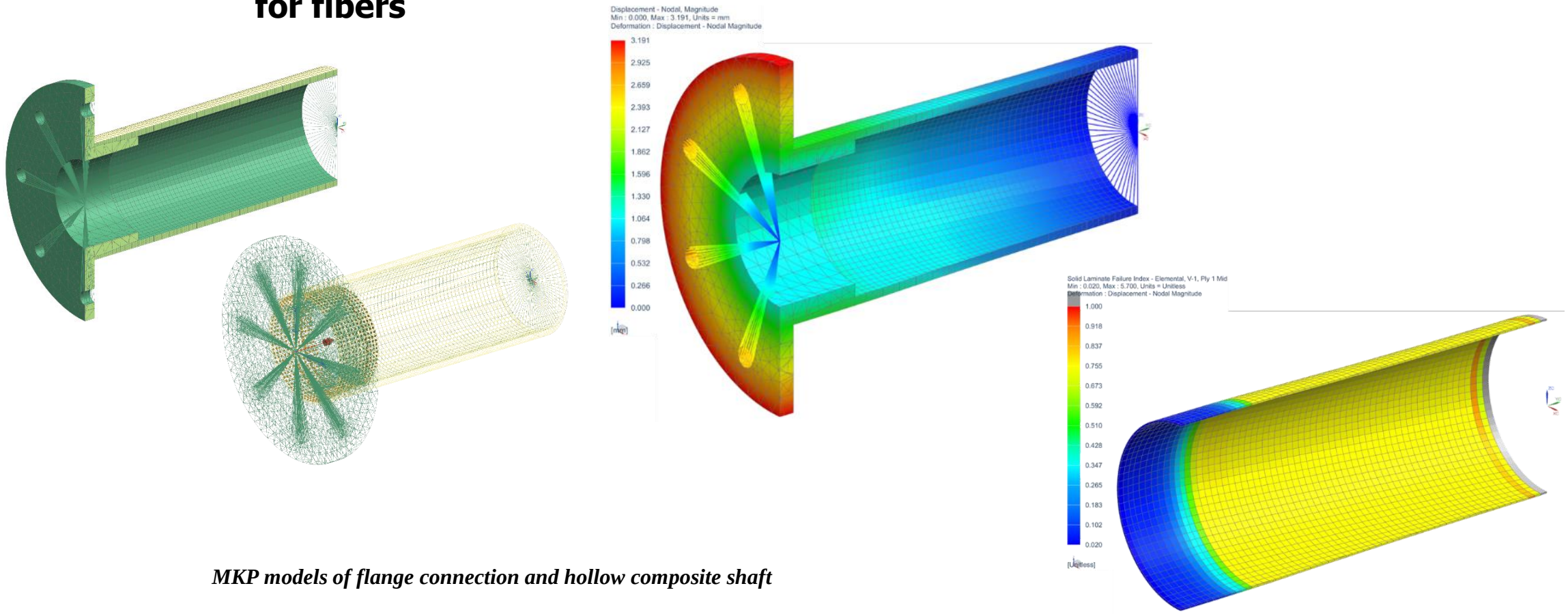


A submodel that combines winding the shaft threads onto the pin flange elements and opening the flange segments with a taper insert using a threaded connection

Examples of flange connection and hollow composite shaft submodels

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



MKP models of flange connection and hollow composite shaft

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
  - the selection and 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

- 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**:

  - the effectiveness of AC traction motors with a power of 150 to 250 kW was investigated
  - the design of the gear ratios of the switchable two-speed gearbox for the regional LKV – BEMU 70 was carried out
  - a calculation program was created for the analysis of the driving cycle of a regional light rail vehicle with a shiftable axle gearbox.

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 selected
    - in cooperation with the company Compotech, an analysis of the appropriate design of the connection of steel flanges and ecological composite hollow shaft is underway
    - strength calculations of the designed submodels of steel flange joints and ecological composite hollow shafts are in progress

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

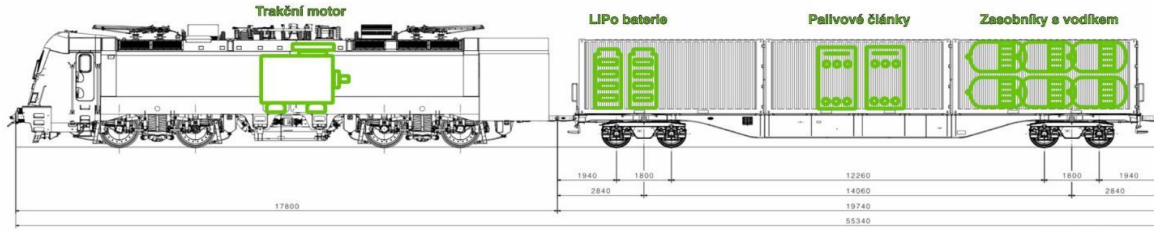
This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres II, project # TN02000054 Bozek Vehicle Engineering National Center of Competence (BOVENAC).

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

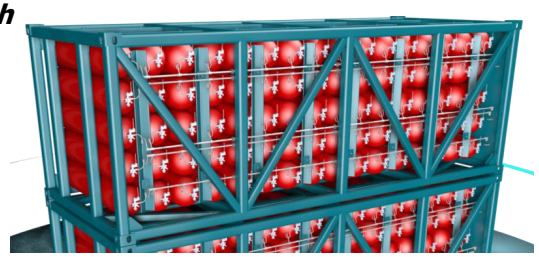
3 – WP13 - 001 *(O) (ČVUT FS 0.3 + ZČU RTI 0.3 + VUT FSI 0.1 + VZUP 0.1 + STRN 0.25)*

Termín: 1.6.2026

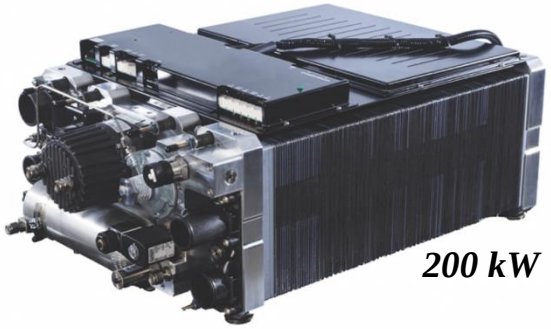
Model energetického tendru pro hnací elektrická vozidla na neelektrifikovaných tratích



Koncept energetického tendru (H_2 + Aku) pro elektrickou lokomotivu



Certifikovaný ISO kontejner pro vodík - ***MEGC 92 x 166 l***



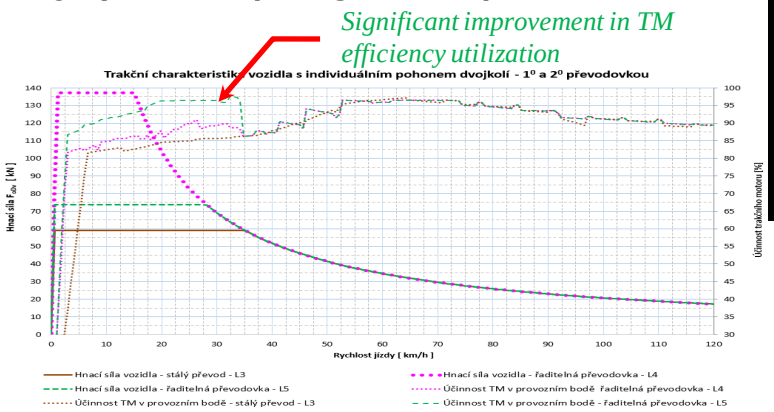
200 kW

Vodíkový palivový článek Cummins hydrogen z jednotky Coradia iLint.

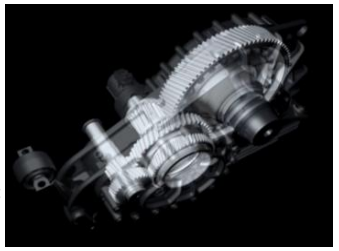
3 – WP13 - 002 *(O) (FS ČVUT 1.0)*

Termín: 1.6.2026

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



Průběh využití účinnosti trakčních motorů při posuzovaných režimech – L3, L4 and L5

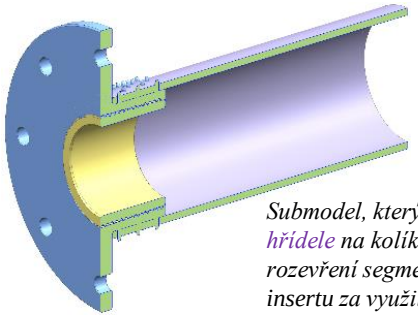


Zdroj obrázku: https://www.zf.com/products/en/rail/products_64372.html

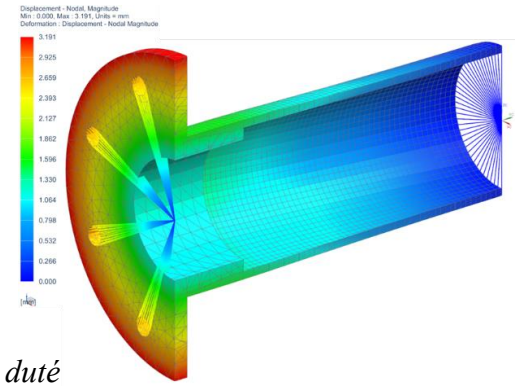
3 – WP13 - 003 *(O) (ZČU RTI 0.25 + BUT FSI 0.25 + VZUP 0.25 + CompoTech 0.25)*

Termín: 1.6.2026

Struktura kompozitní hřídele: použití nových ekologických materiálů pro vlákna



Submodel, který kombinuje navíjení vláken hřídele na kolíkové elementy příruby a rozevření segmentů příruby pomocí kuželového insertu za využití závitového spojení



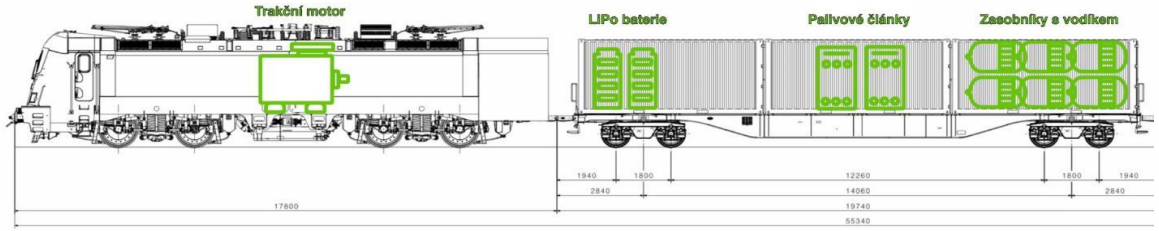
MKP model spojení příruby a duté

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

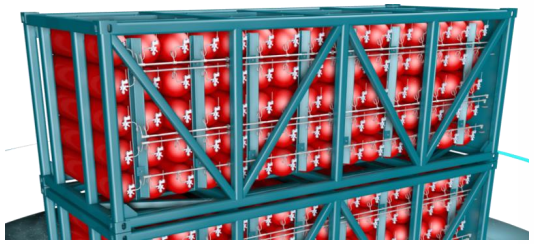
3 – WP13 - 001 *(O) (FME CTU 0.3 + UWB RTI 0.3 + BUT 0.1 + VZUP 0.1 + STRN 0.25)*

Project deadline: 1.6.2026

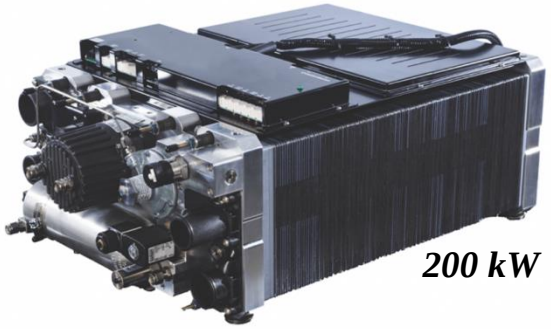
Energy –Tender model for the use of a traction rail vehicle on non-electrified railway lines



Energy tender (Hydrogen + Aku) concept for electric locomotives



Certified ISO Hydrogen container ***MEGC 92 x 166 l***



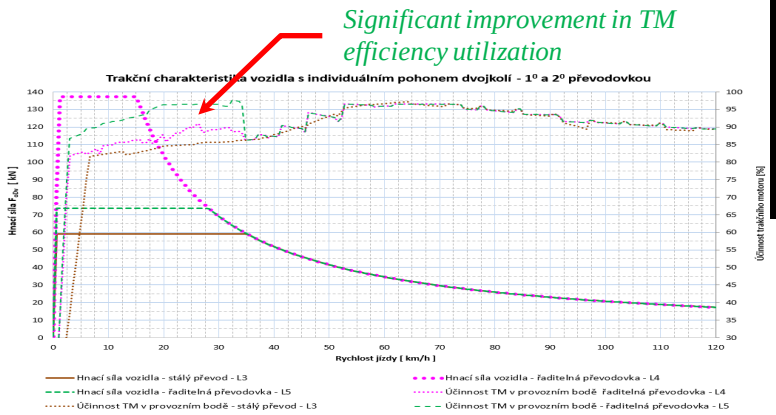
200 kW

Cummins hydrogen fuel cells used in Coradia iLint trains.

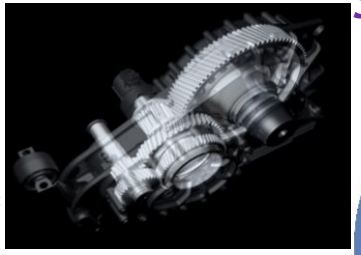
3 – WP13 - 002 *(O) (FME CTU 1.0)*

Project deadline: 1.6.2026

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



Courses of efficiency of traction motors in the assessed modes – L3, L4 and L5

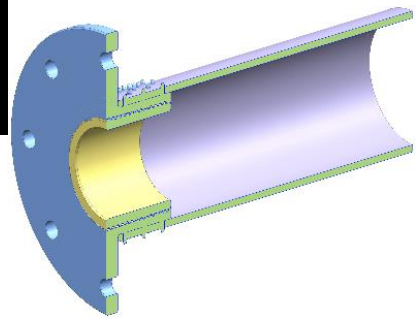


Source of figure: https://www.zf.com/products/en/rail/products_64372.html

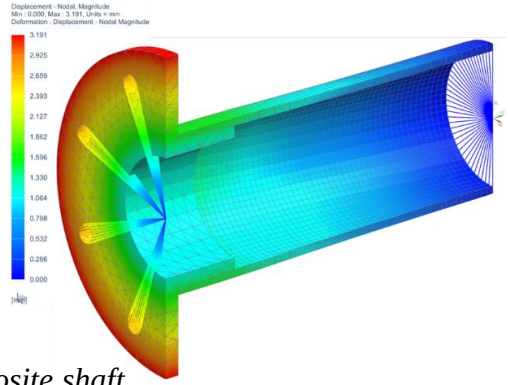
3 – WP13 - 003 *(O)* *(UWB RTI 0.25 + VUT 0.25 + VZUP 0.25 + CompoTech 0.25)*

Project deadline: 1.6.2026

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



A submodel that combines winding the shaft threads onto the pin flange elements and opening the flange segments with a taper insert using a threaded connection



MKP models of flange connection and hollow composite shaft