Contents of Work Package **3-WP09:** New Solutions for Automotive Transmissions

3-WP09: New Solutions for Automotive Transmissions

Coordinator of the WP

České vysoké učení technické v Praze, doc. Dr. Ing. Gabriela Achtenová

Participants of the WP

VŠB – Technická univerzita Ostrava

BUT – Brno University of Technology

ŠKODA AUTO a. s.

CompoTech Plus

Main Goal of the WP

Research into new materials, production or technological procedures, structural elements, as well as completely new concepts of transmission mechanisms with the primary goal of reducing vibrations and noise. Support for structural design and experimental measurement using simulation and calculation methods.

Partial Goals for the Current Period

Composite shaft design for use in vehicles. Design of microgeometry of automotive transmission gearing to reduce transmission error and for final grinding of asymmetric powder metal gearing. Development of a simulation tool for gear stiffness measurement

Contents of Work Package **3-WP09:** New Solutions for Automotive Transmissions

3-WP09: New Solutions for Automotive Transmissions

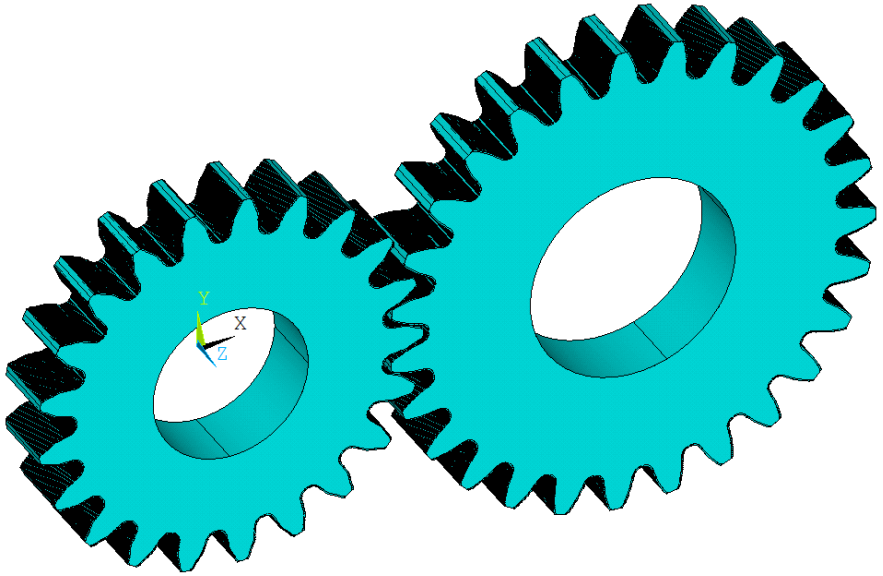
Official 3-WP09 Deliverables

- 3-WP09-001 | **Gear with low transmission error**, G-funk, VI./2026, BUT 0.3; TUO 0.3; SA 0.4
- 3-WP09-002 | **Digital twin of the test bench for monitoring gear mesh** , O, VI./2026, BUT 0.3; TUO 0.3; SA 0.4
- 3-WP09-003 | **Composite Joint Shaft** , G-funk, XII./2025, CTU FME 0.4; SA 0.1, Compotech 0.5
- 3-WP09-004 | **Composite Joint Shaft dedicated and optimised for usage in passenger car's powertrains**, O, VI./2026, CTU FME 0.4; SA 0.1, Compotech 0.5
- 3-WP09-005 | **Powder Metal assymetric gearwheels**, G-funk, XII/2025, CTU FME 0.6; SA 0.4
- 3-WP09-006 | **Gearboxes for electric vehicles**, O, VI/2026, CTU FME 0.9; SA 0.1

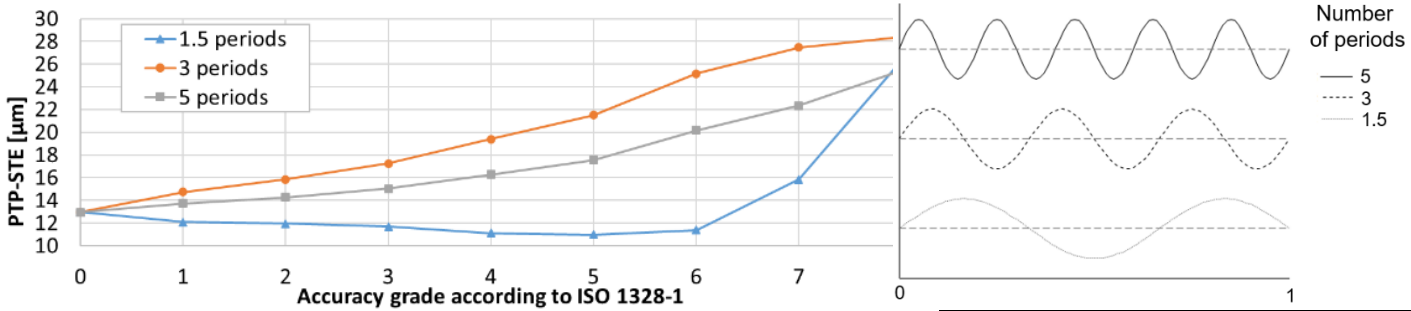
Activities in **3-WP09:** New Solutions for Automotive Transmissions

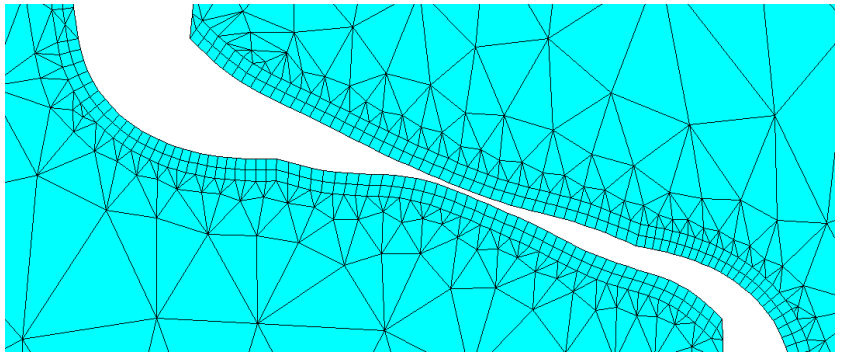
3-WP09-001: Gear with low transmission error

- Creation of APDL code in Ansys Mechanical
  - Sine waves of different amplitudes and periods
- Peak-to-peak values according to ISO 1328-1
- Design and manufacturing gears
- Performing measurement with serial and new gears



Grade	1st	2nd	3rd	4th	5th	6th	7th	8th
Total profile tolerance F_α [µm]	2	2.9	4.1	6	8	12	16	23

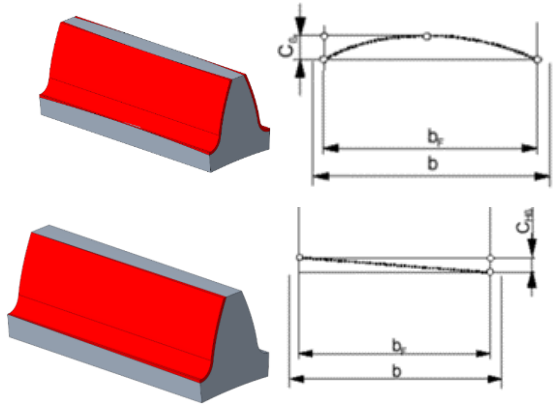


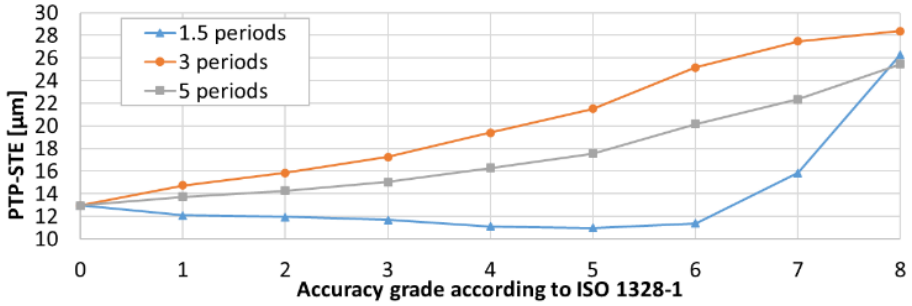


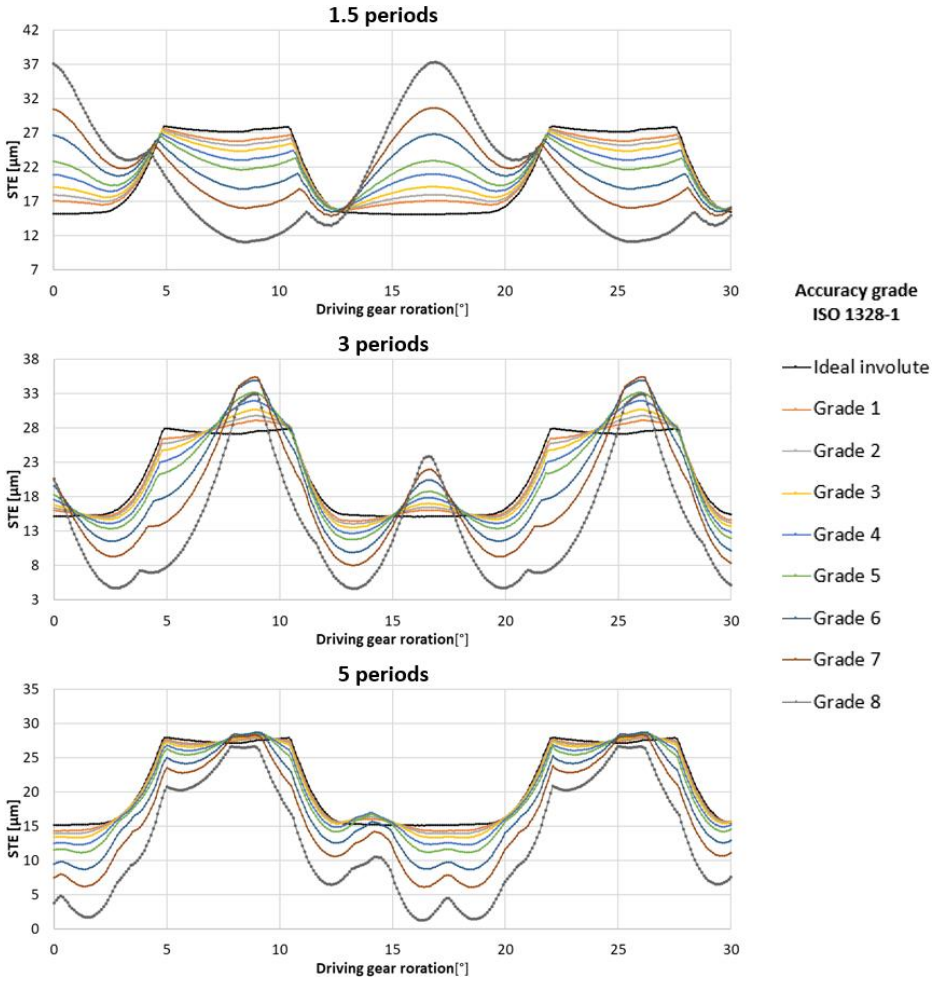
Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-001: Gear with low transmission error

- Creation of APDL code in Ansys Mechanical
  - Macro-geometry
  - Parameters of the sine function added to the involute
  - Spur / Helical gears
  - 2D / 3D
  - Number of teeth on each gear
  - Modification of Tip Relief
  - Manufacturing inaccuracy





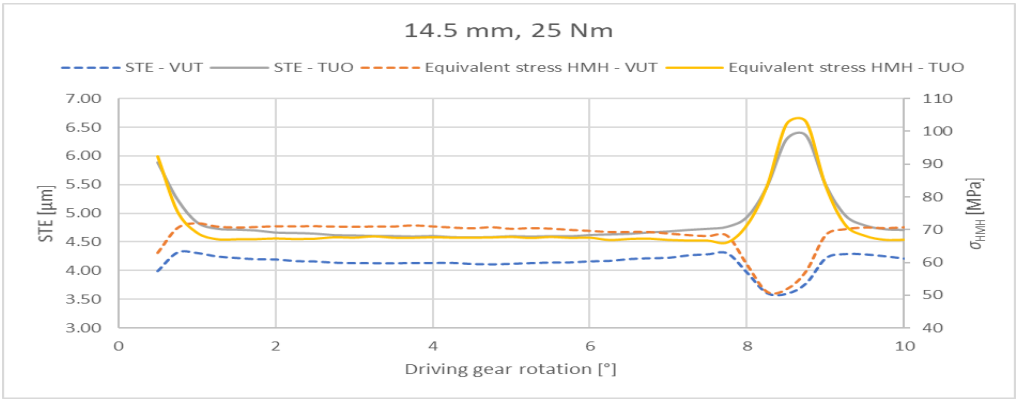


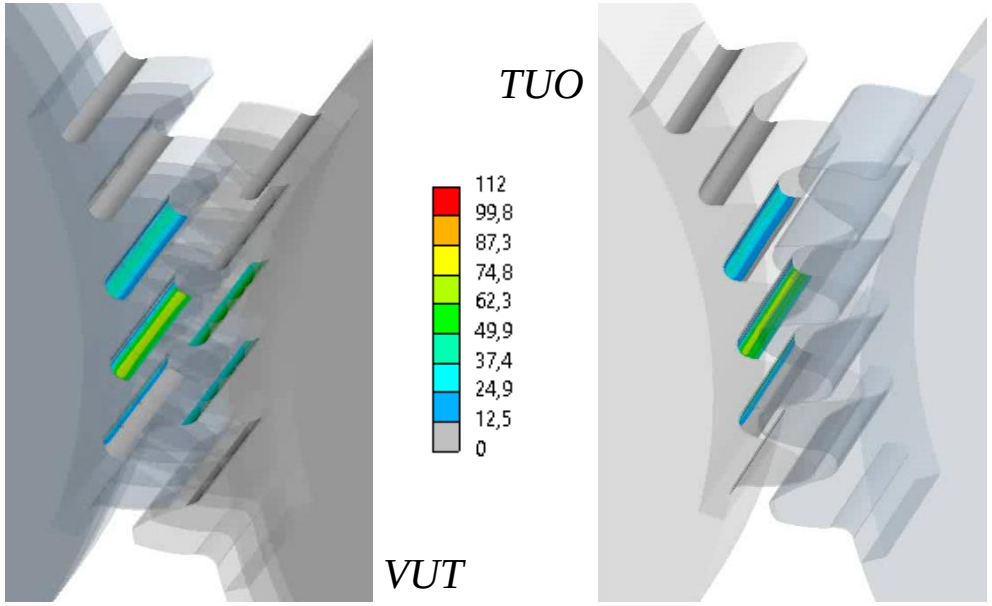
Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-001: Gear with low transmission error

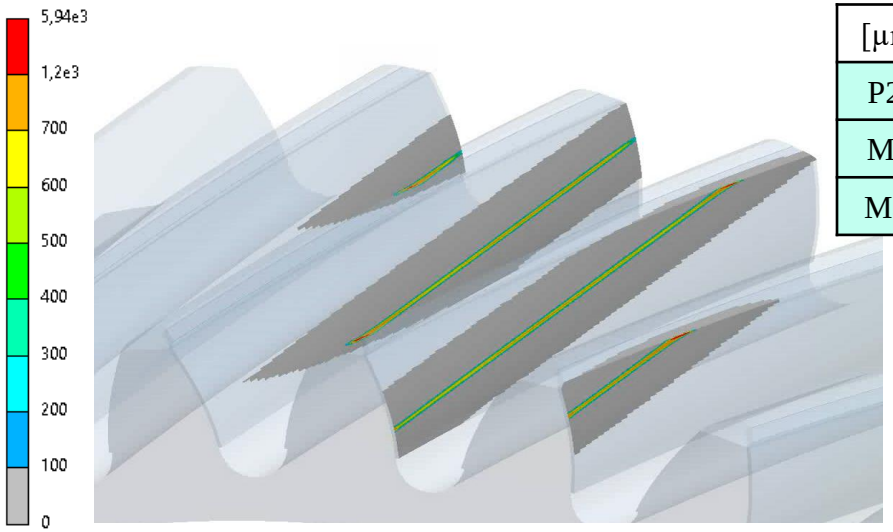
Perform numerical study for different

- Gears
- Loading
- Equivalent stress at load 25 Nm
- Designed and manufactured gears

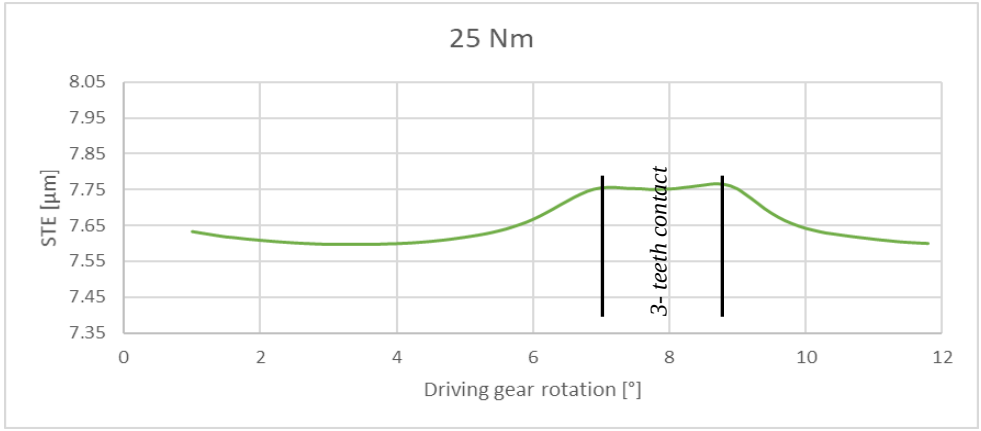


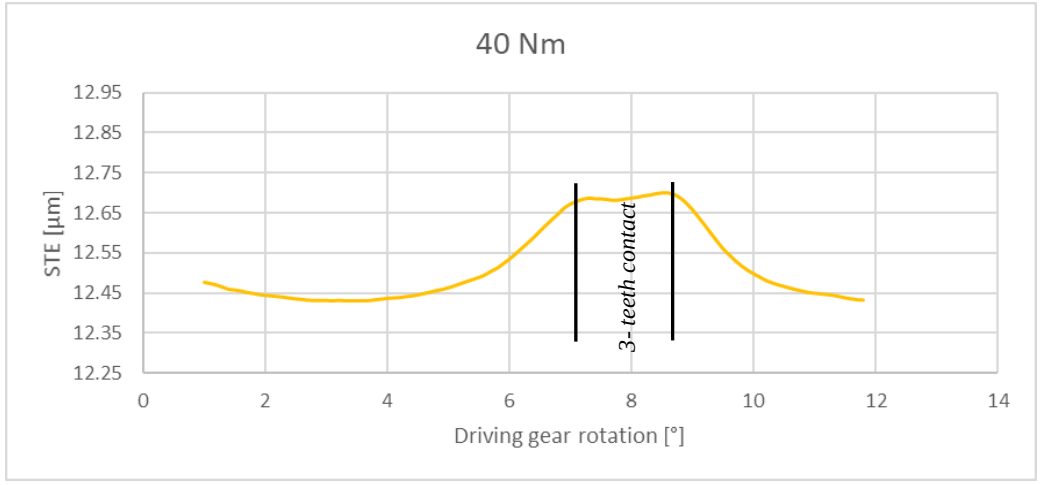


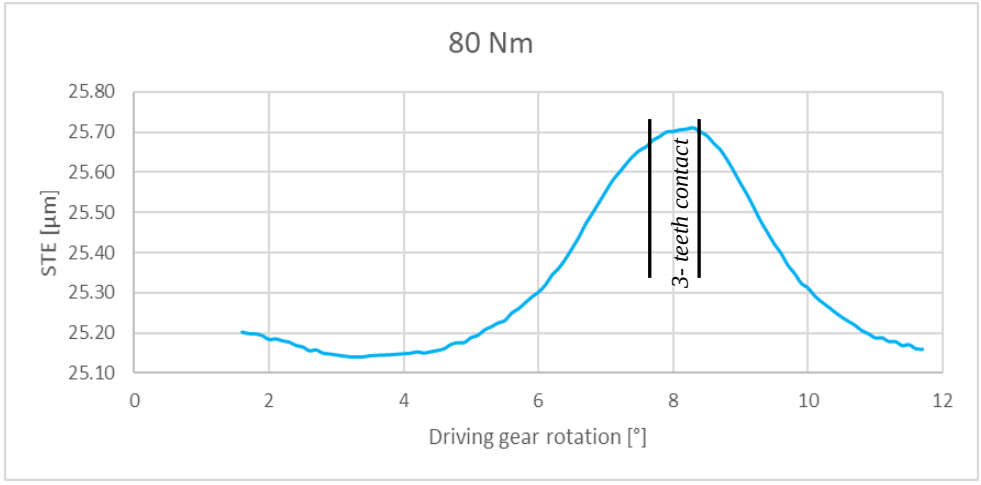
Activities in **3-WP09:** New Solutions for Automotive Transmissions



[µm]	80 Nm	40 Nm	25 Nm
P2P	**0.57**	**0.27**	**0.17**
Min	25.14	12.43	7.60
Max	25.71	12.70	7.77



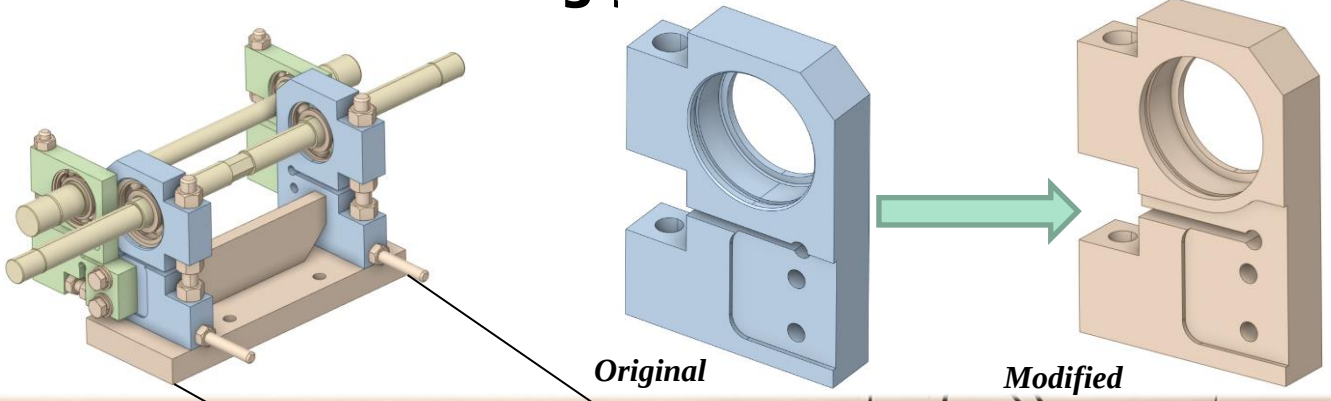


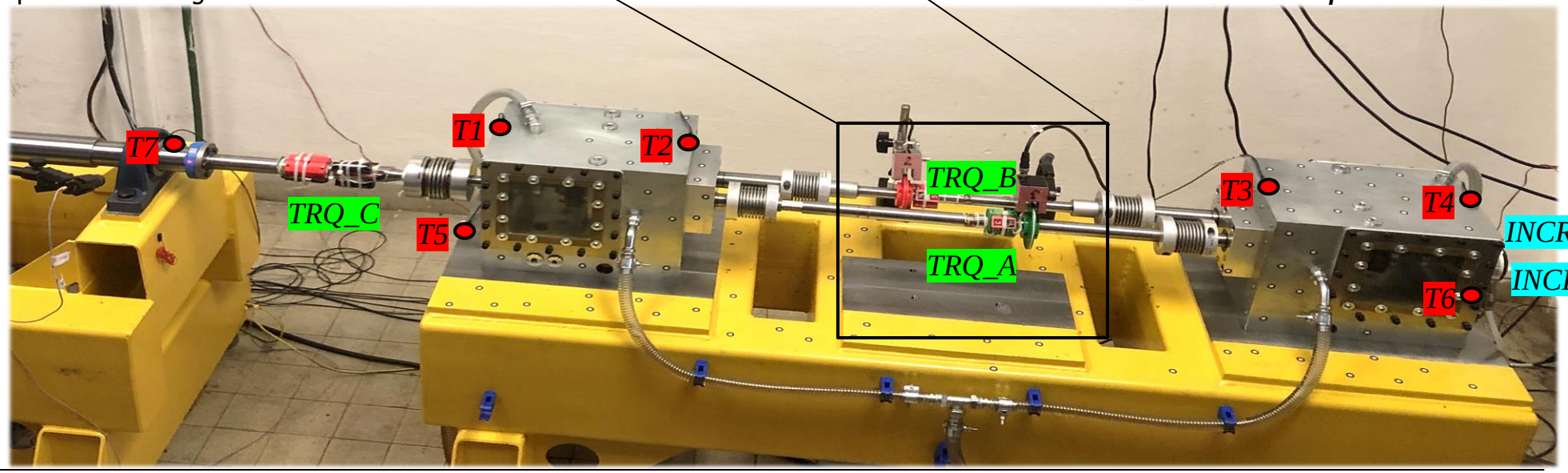


Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-002: Digital twin of the test bench for monitoring gear mesh

- Perform measurement with different gear pairs
- Data analysis
- Perform numerical simulation
  - Creation of whole loop
  - Combination of spur and helical gears

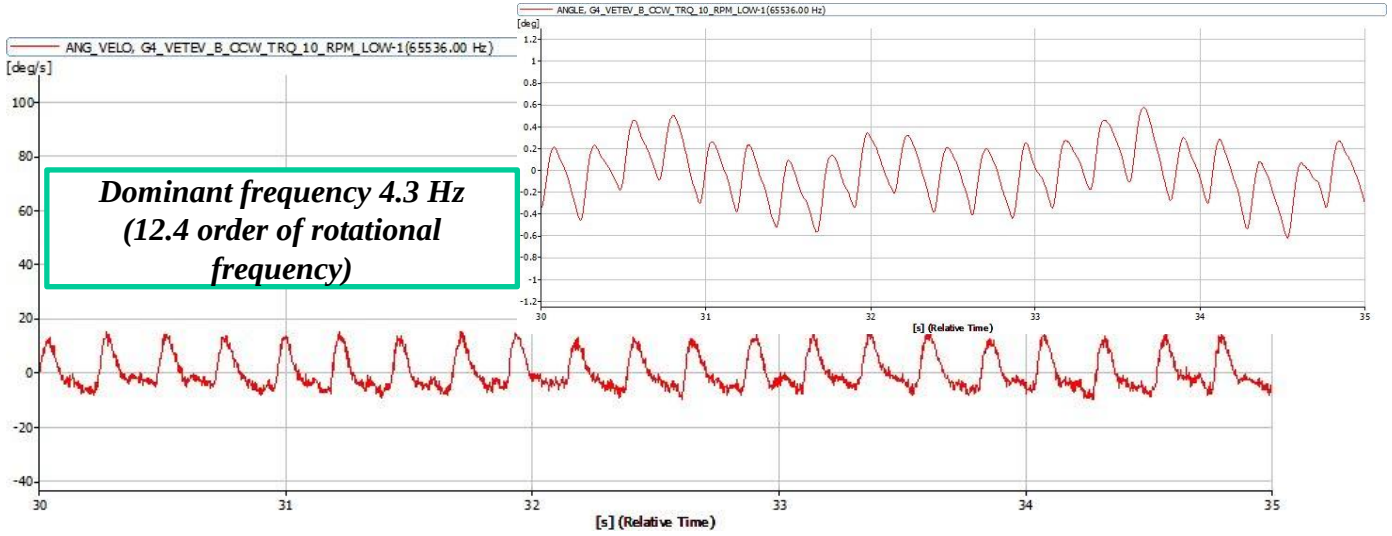


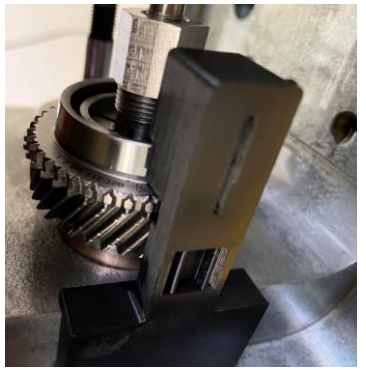


Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-002: Digital twin of the test bench for monitoring gear mesh

- Perform measurement with different gear pairs
  - Ensuring the same starting position
  - 39/40 and 38/41
  - CW, CCW
  - 0; 10; - 10; 25; -25 Nm
  - Adequate number of revolution
- Measuring of TE at both gears (technical and tested)

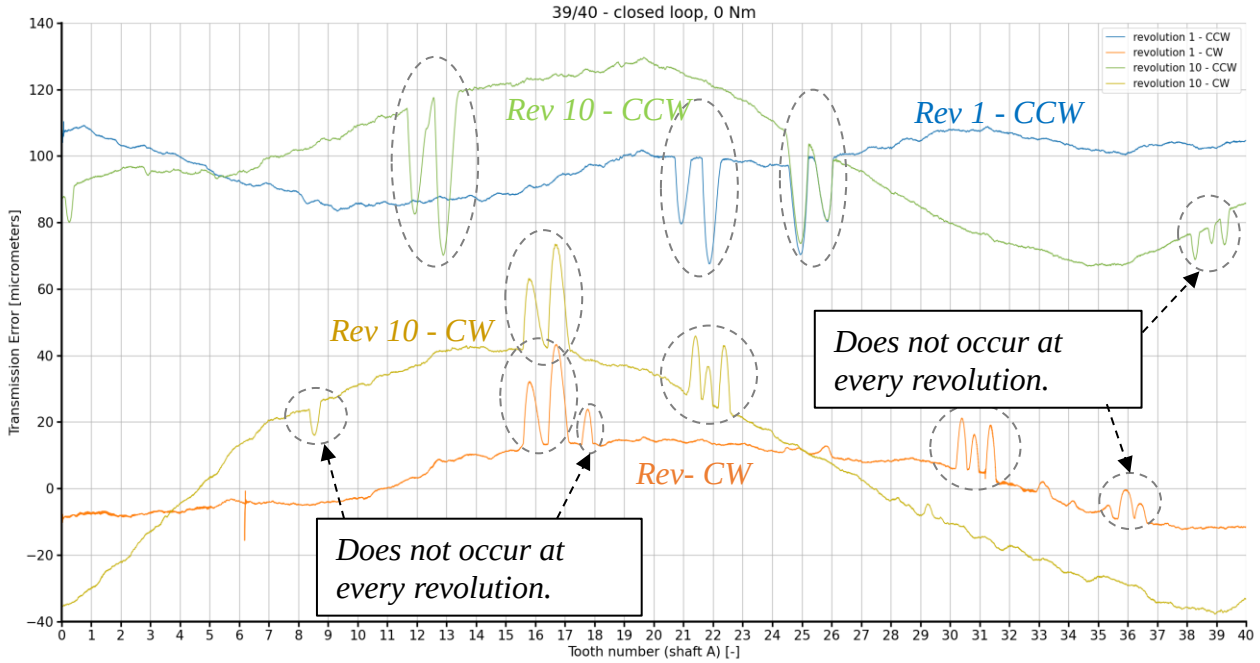


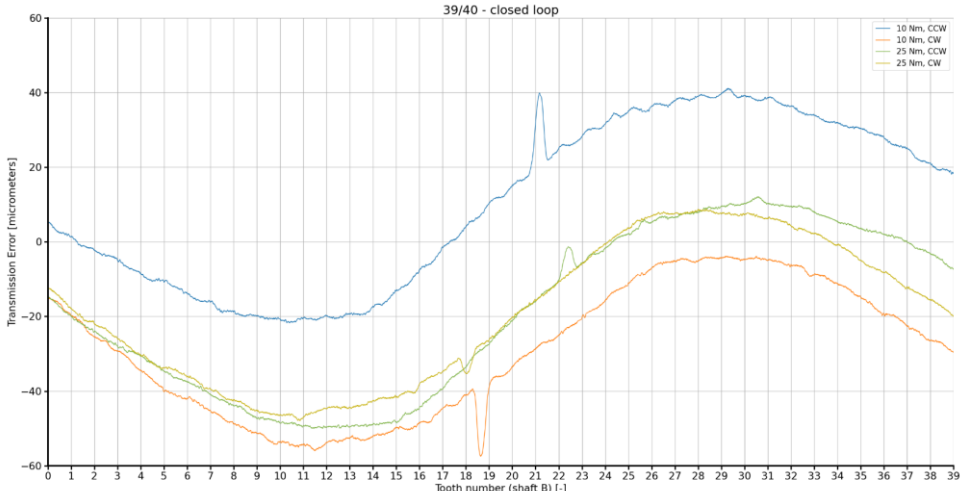


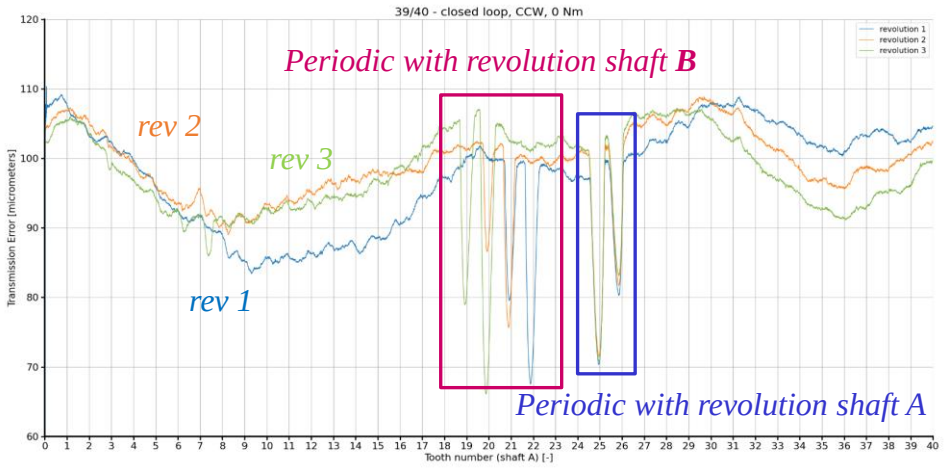
Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-002: Digital twin of the test bench for monitoring gear mesh

- Data processing





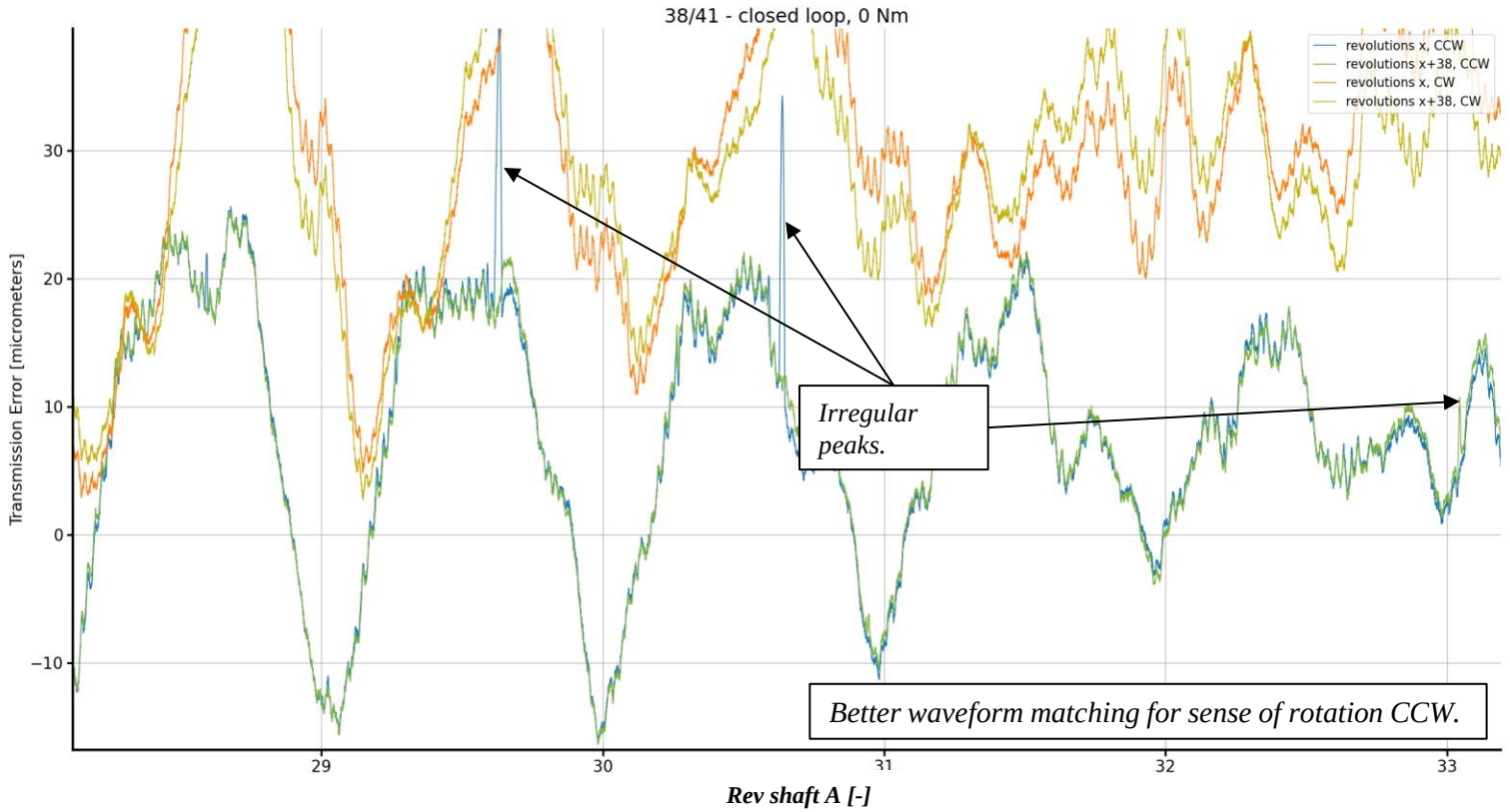


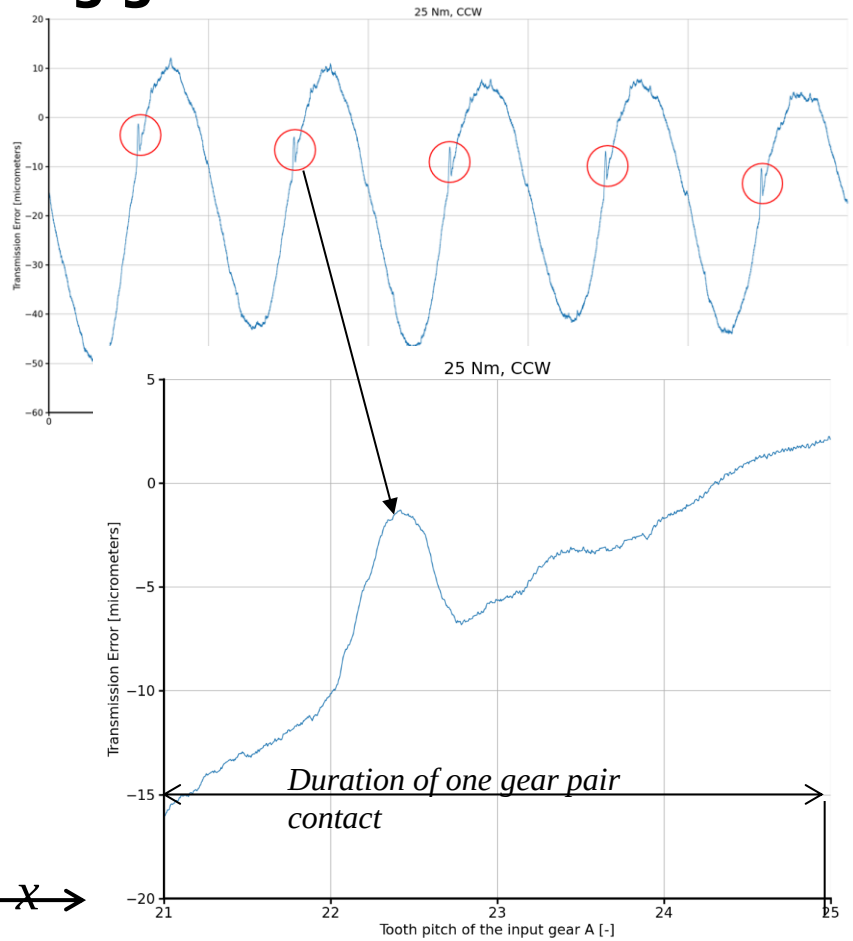
Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-002: Digital twin of the test bench for monitoring gear mesh

- Data analysis

– **0 Nm**, rev *x* a *x+38* shaft **A**

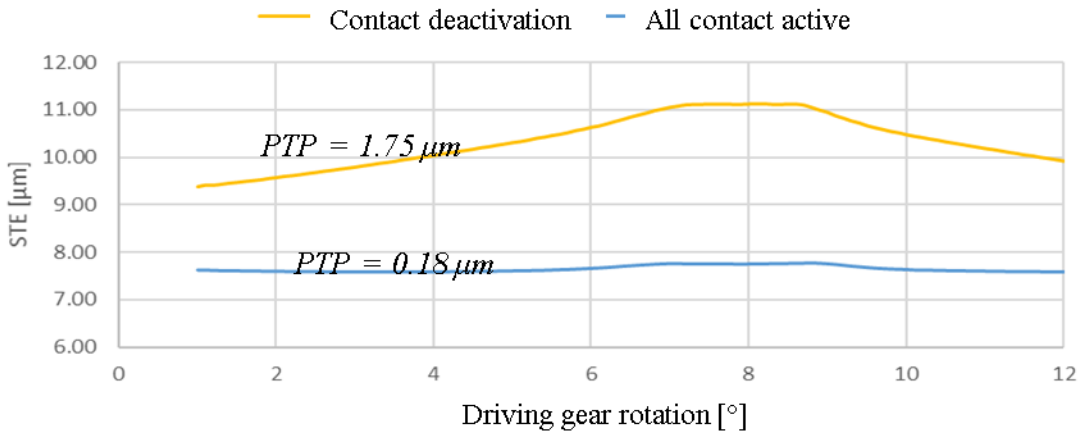


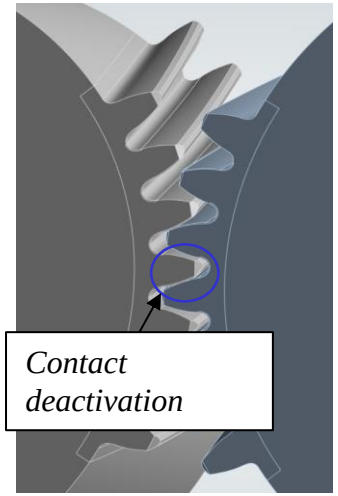


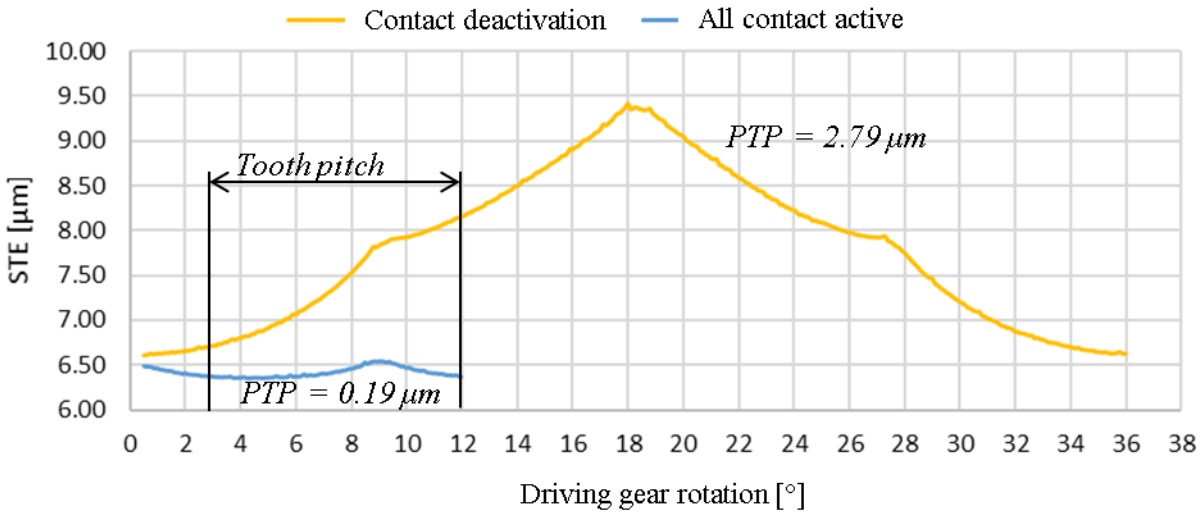
Activities in **3-WP09:** New Solutions for Automotive Transmissions

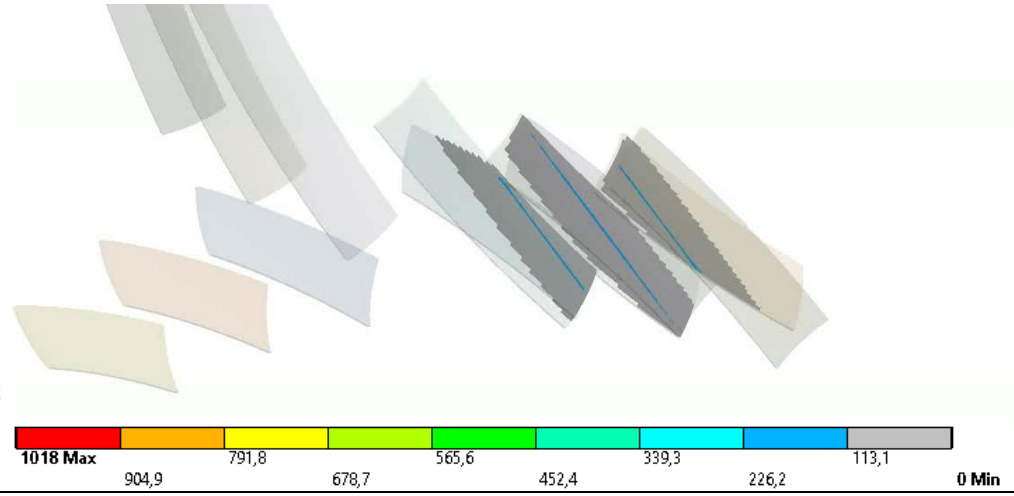
3-WP09-002: Digital twin of the test bench for monitoring gear mesh

- Identification of the problem
- 39/40 teeth
- Geometry without modification
  - Effect of bevel







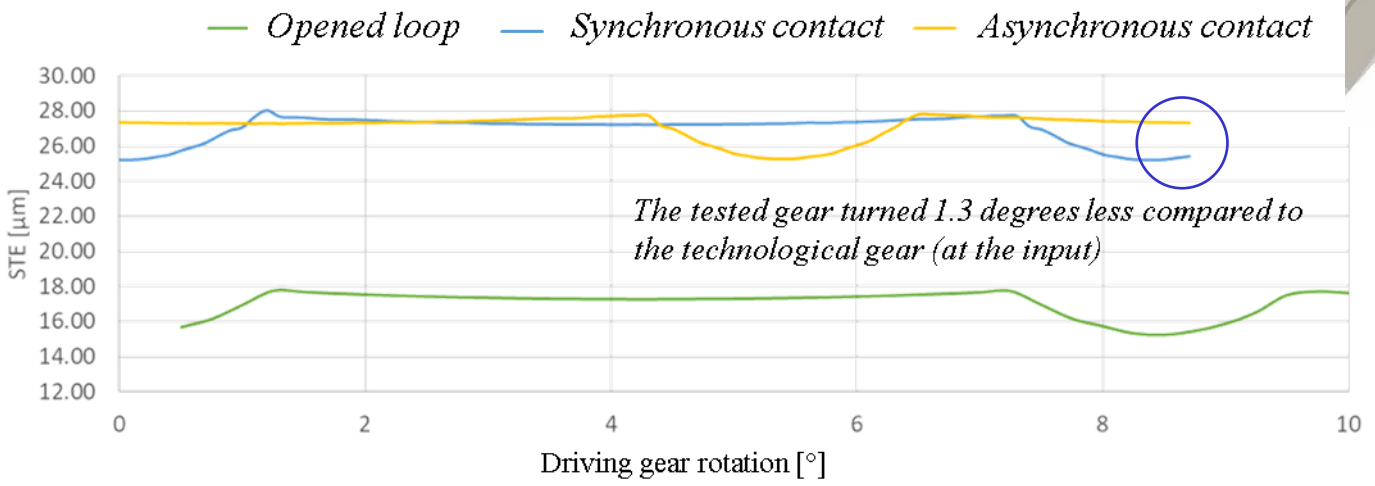


Activities in **3-WP09:** New Solutions for Automotive Transmissions

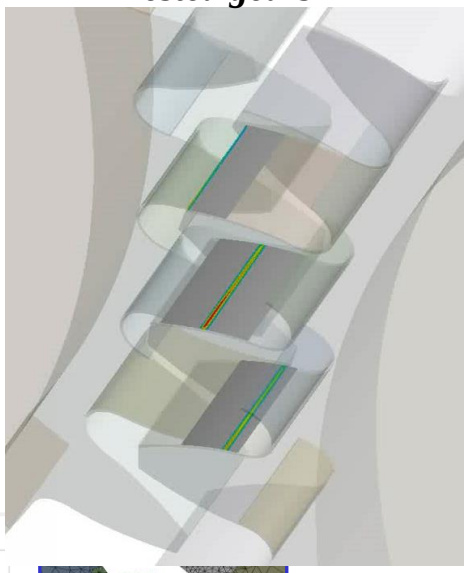
3-WP09-002: Digital twin of the test bench for monitoring gear mesh

- PTP on the flexible vs. rigid shafts vs. opened loop

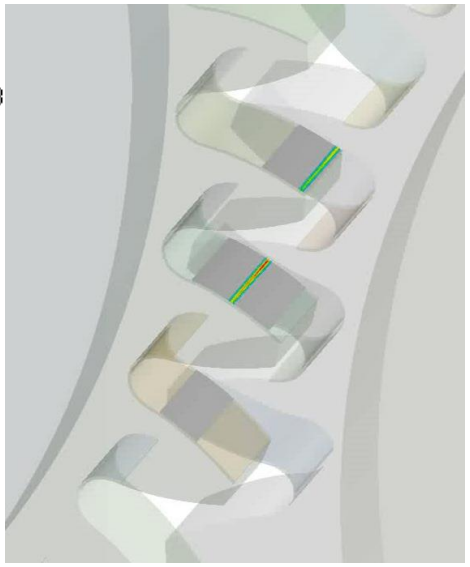
25 N·m	PTP STE [µm]
Opened loop	2,51
Rigid shafts – synchronous contact	0,72
Rigid shafts – asynchronous contact	2,11
Flexible shafts – synchronous contact	2,52
Flexible shafts – asynchronous contact	2,53

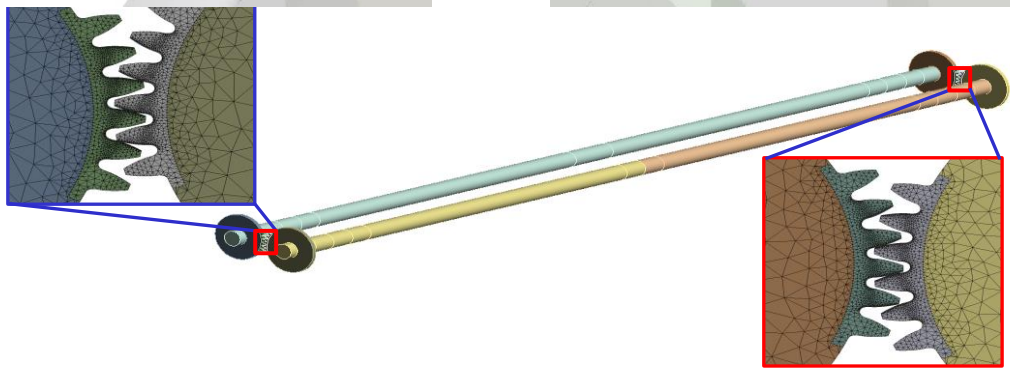


Tested gears



Technical gears

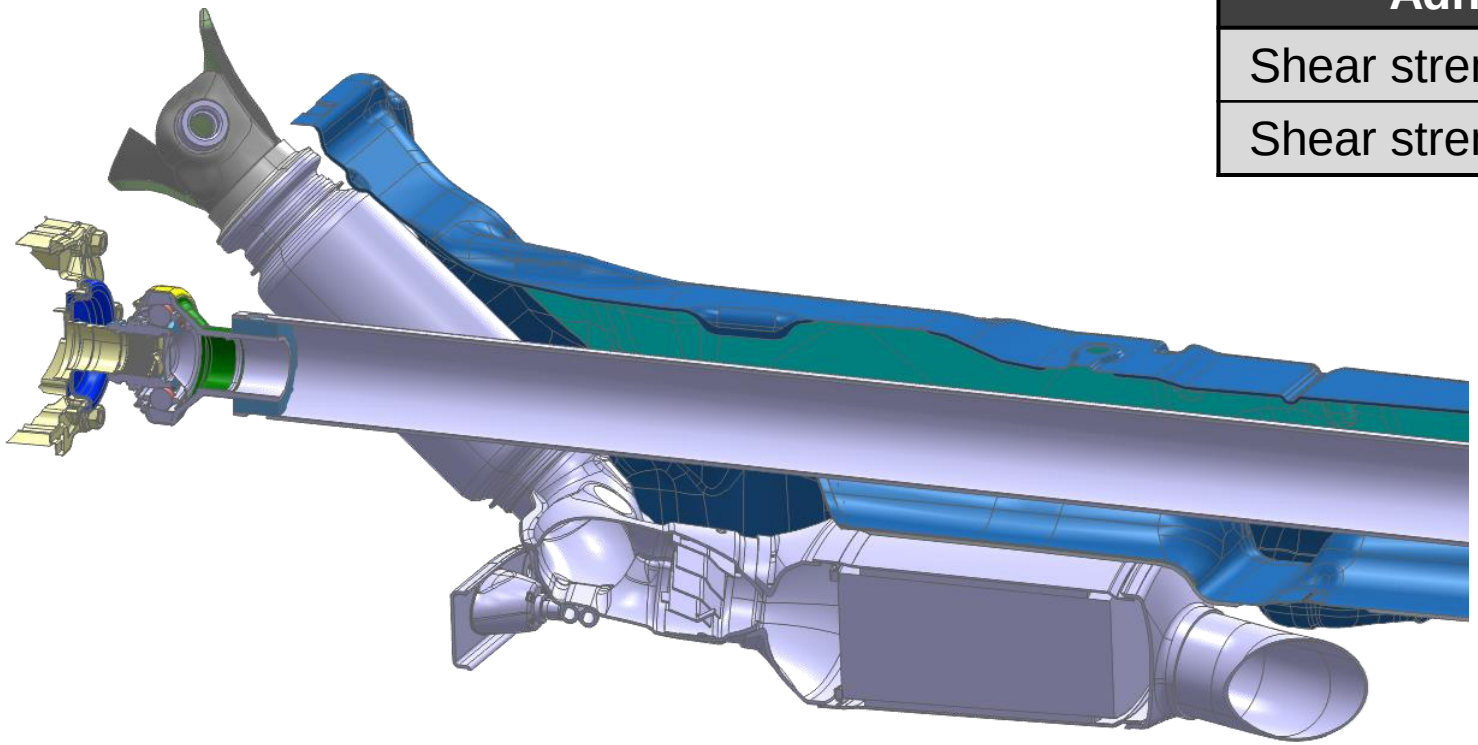




Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-004: Composite Joint Shaft dedicated and optimised for usage in passenger car's powertrains,

Possible adhesive joint close to exhaust pipe

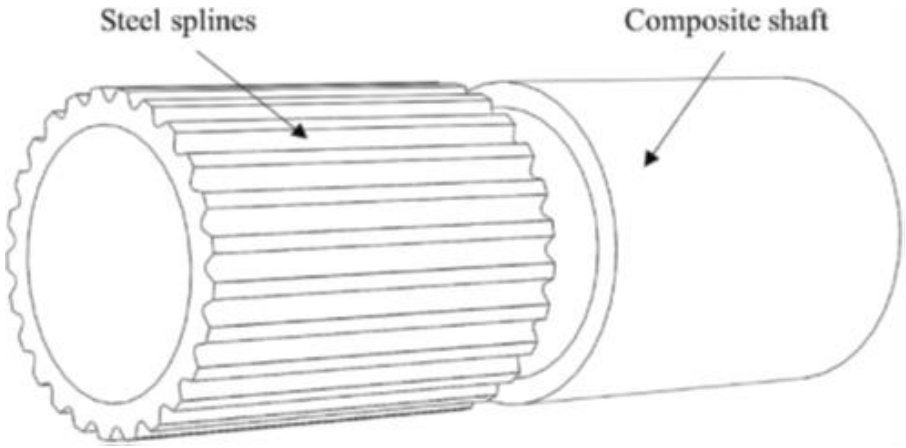


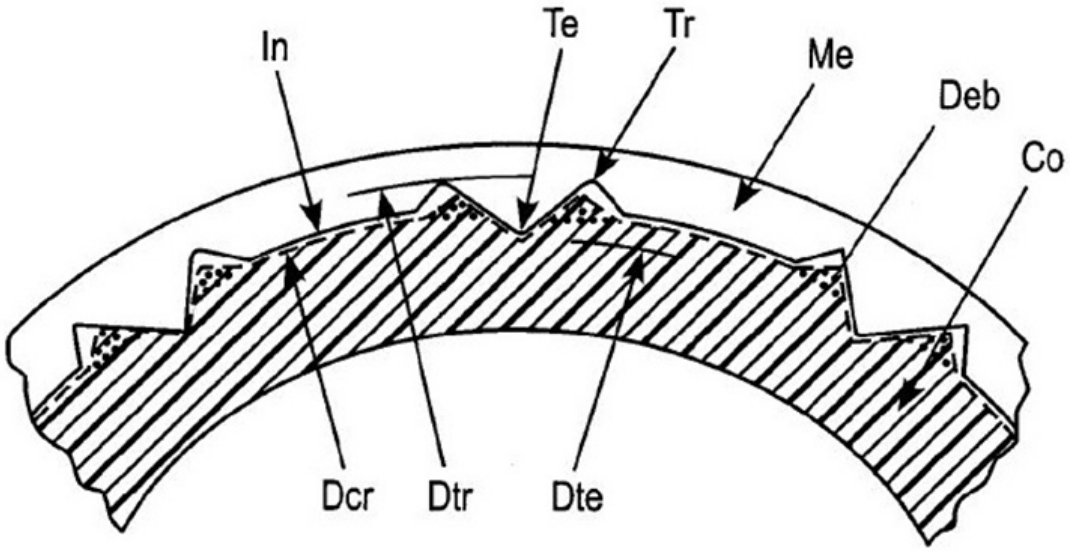
Adhesive variant	A	B
Shear strength at 20 °C [MPa]	42	35
Shear strength at 80 °C [MPa]	9	26

Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Alternative – „microsplined joint" (patent 2006)
- Missing details (load bearing capacity, geometry, dimensions)

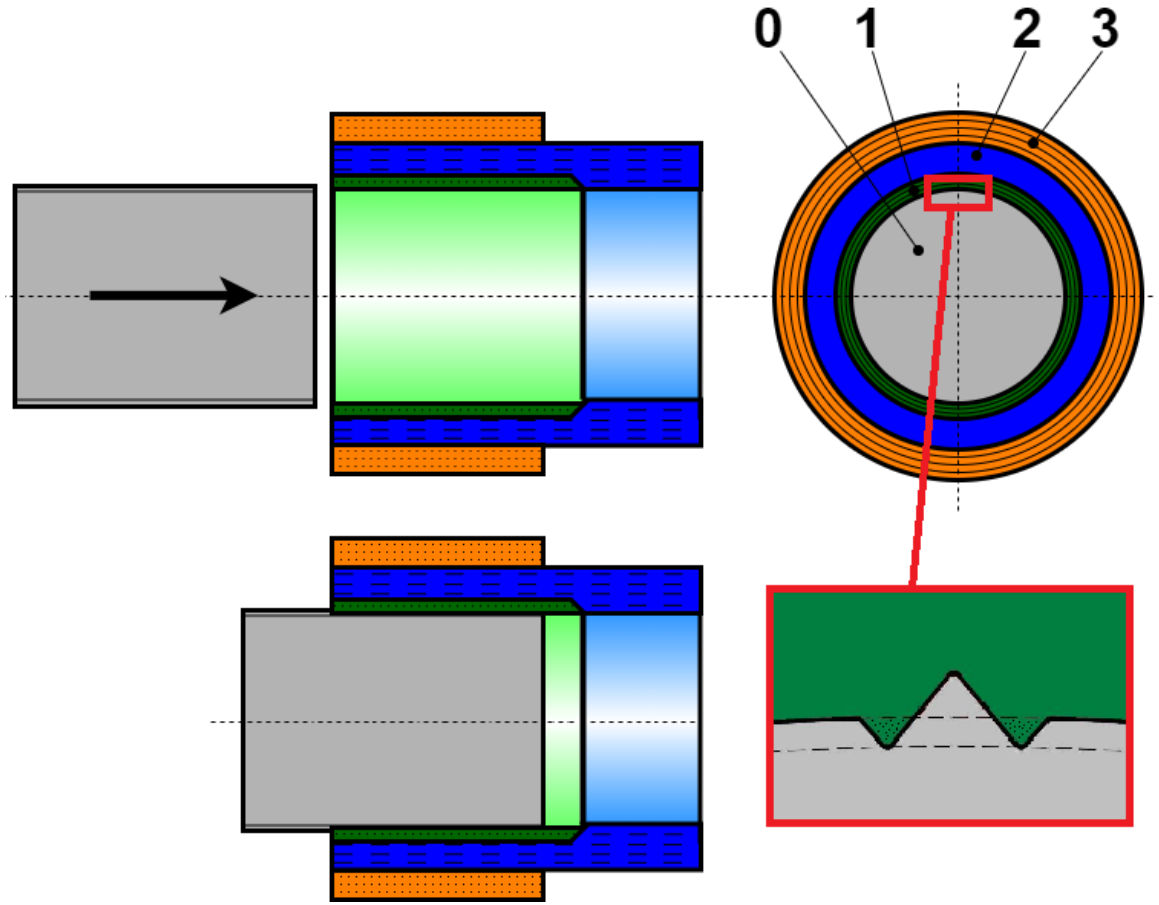




Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Our proposal



0 – Steel shaft

1 – Glass fiber layer (90°)

2 – Main layer

3 – Reinforcing layer (90°)

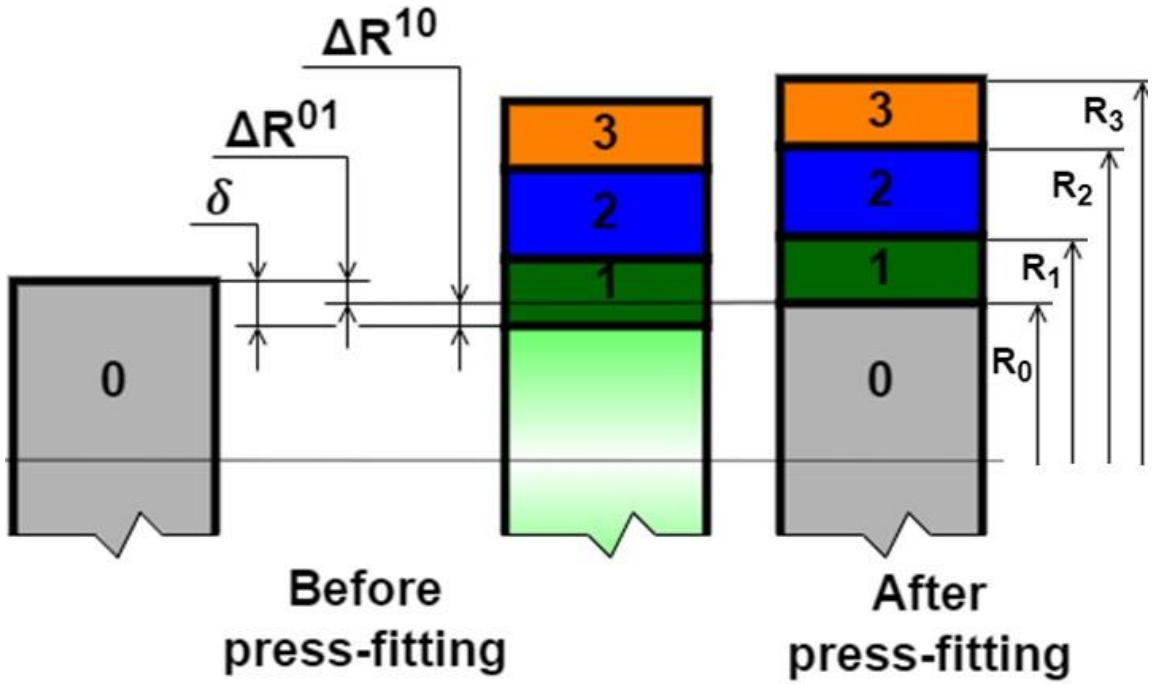
Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Simplified model

$$M_{max} = 2\pi \cdot p_{01} \cdot R_0^2 \cdot L \cdot f$$

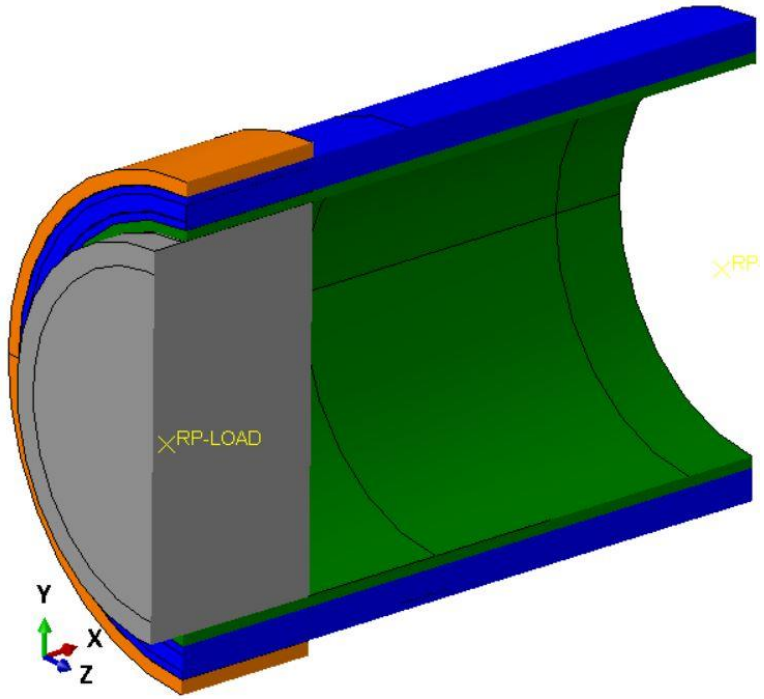
$$\begin{pmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{pmatrix} \cdot \begin{pmatrix} p_{01} \\ p_{12} \\ p_{23} \end{pmatrix} = \begin{pmatrix} \delta/R_0 \\ 0 \\ 0 \end{pmatrix}$$

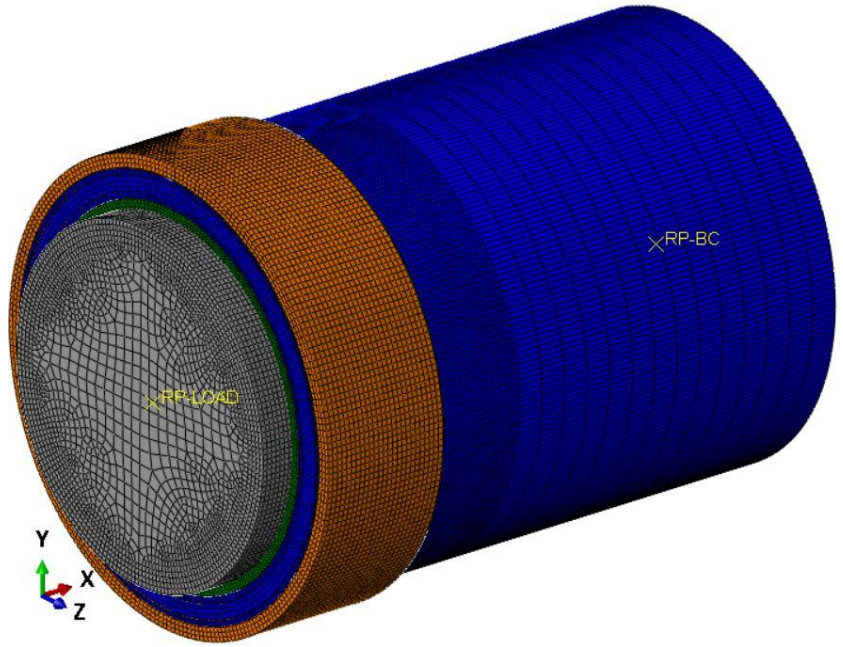


Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- FEM validation

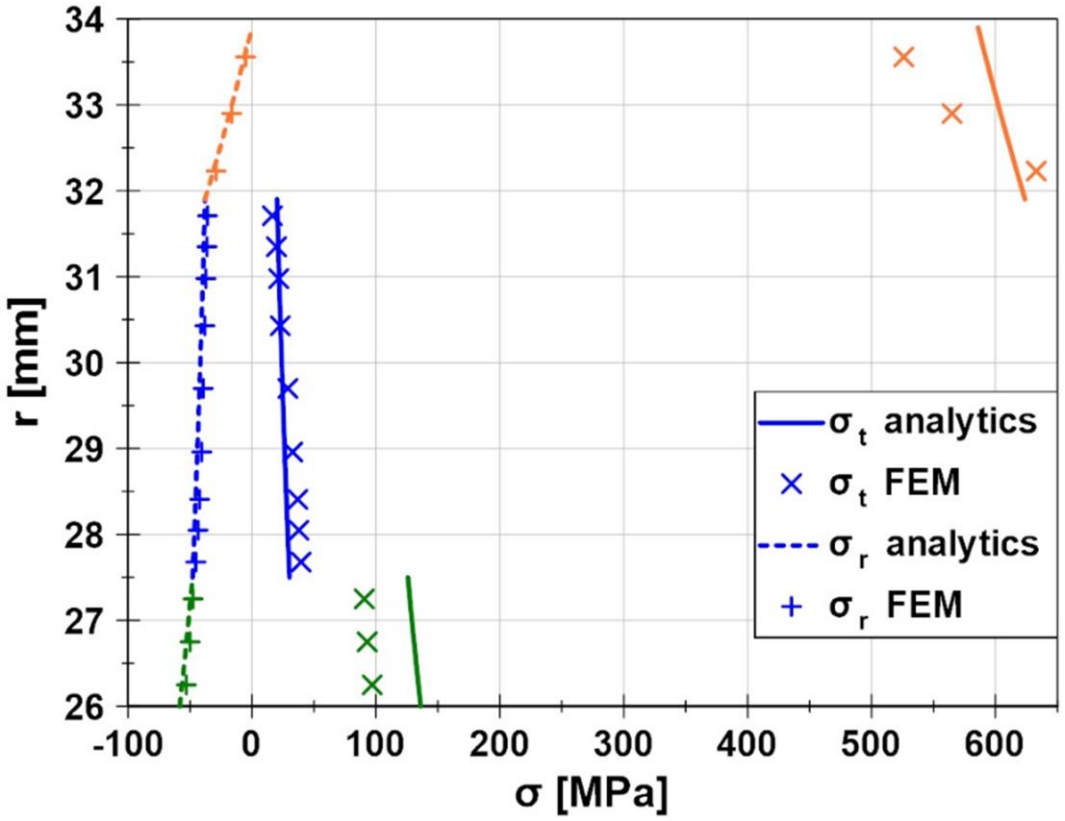


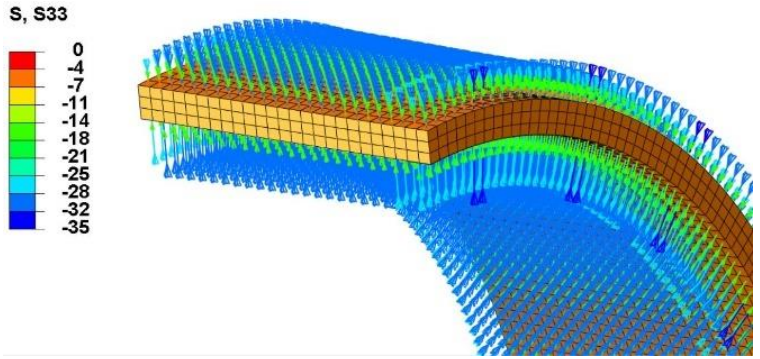


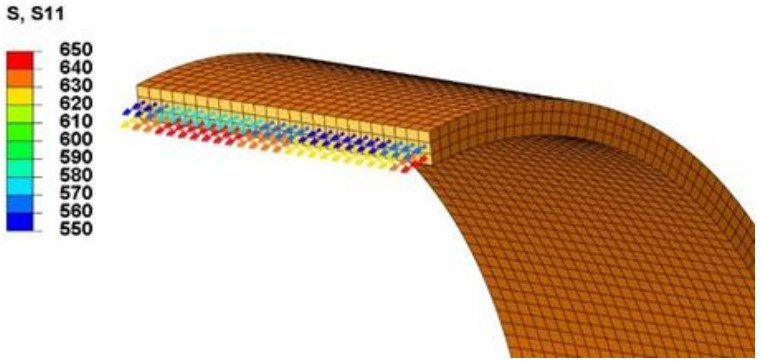
Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- FEM validation



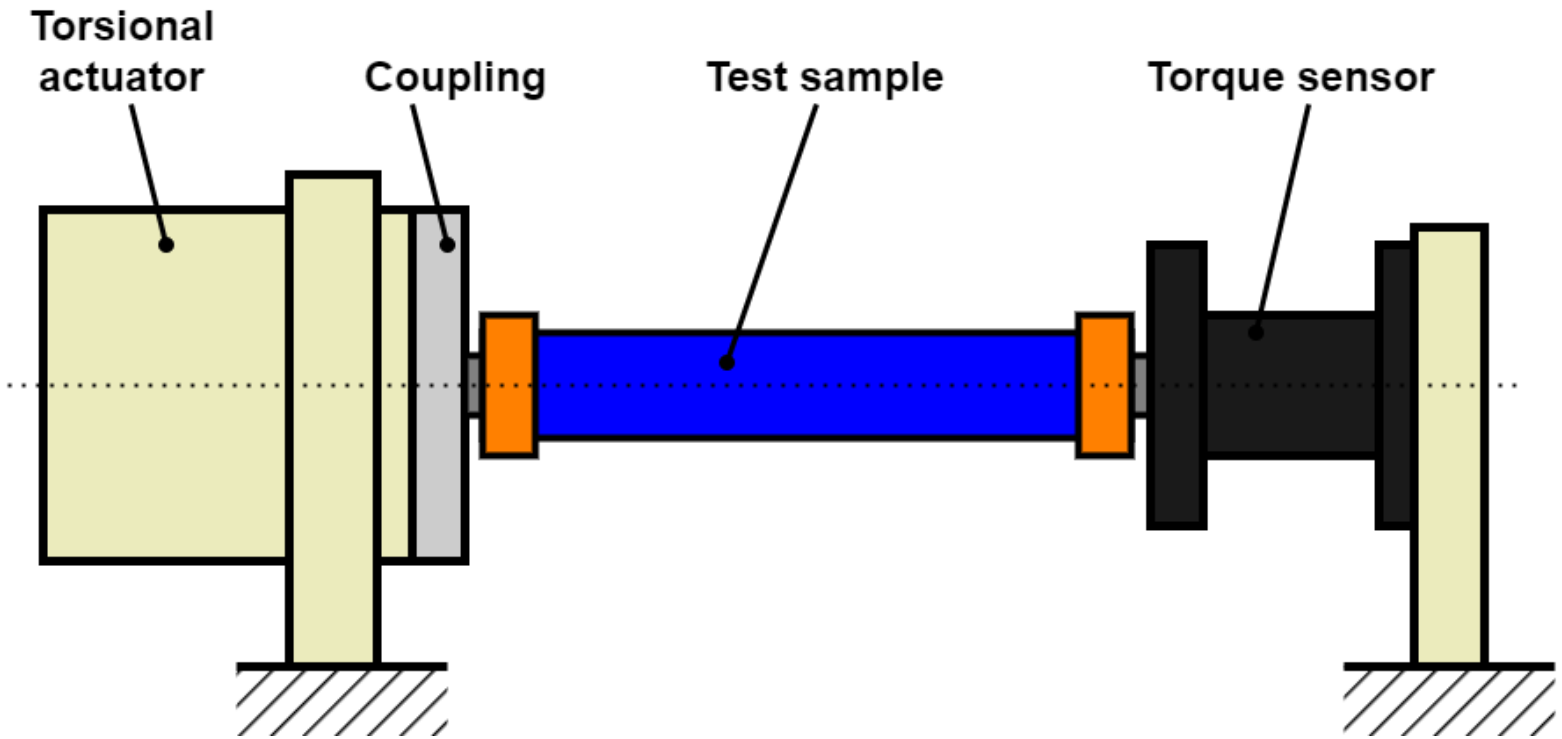




Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

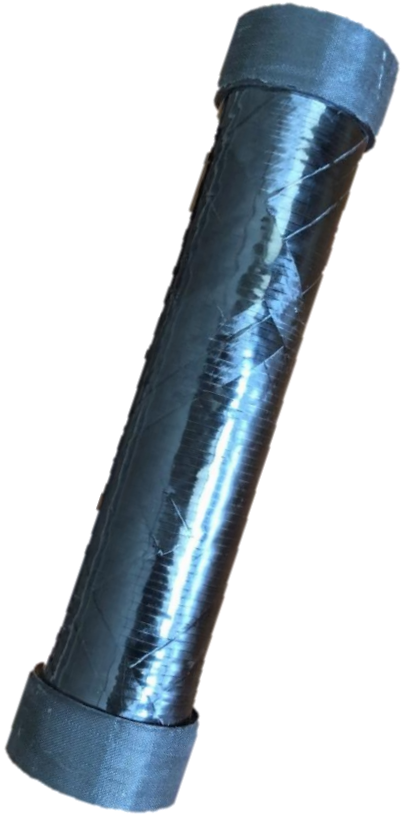
- Experiment torsion test

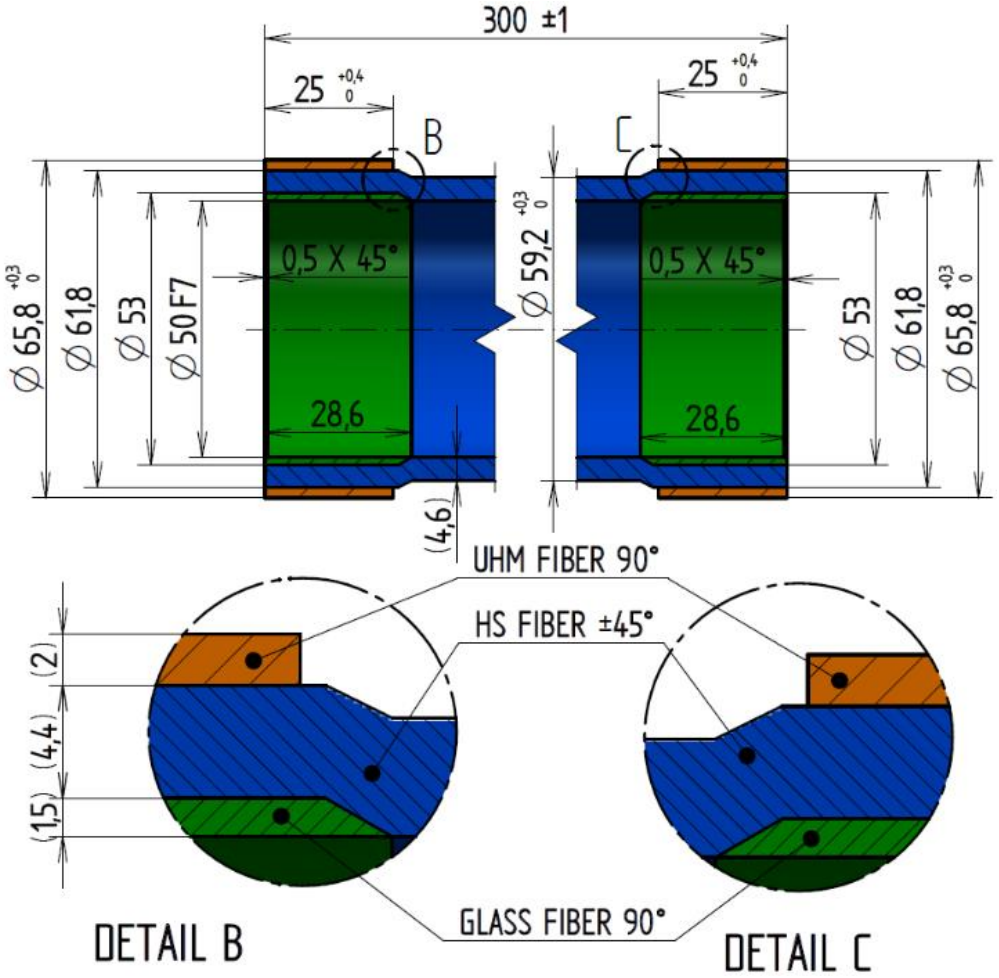


Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Experiment sample

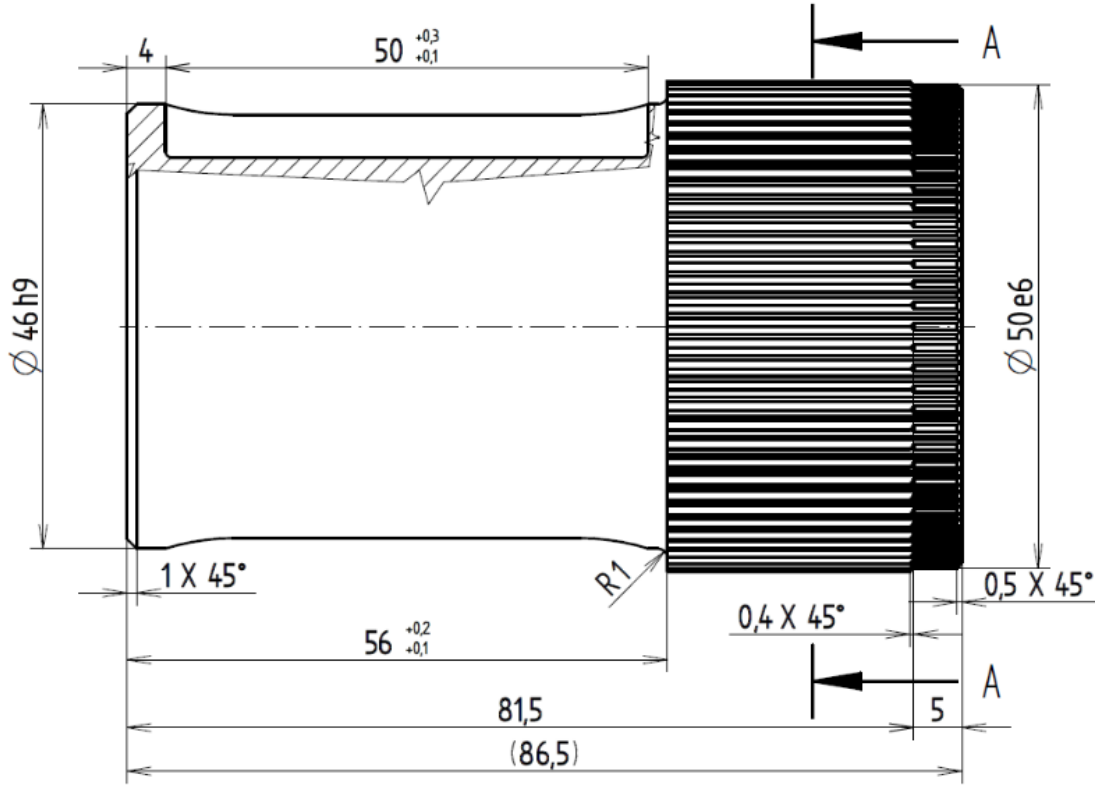


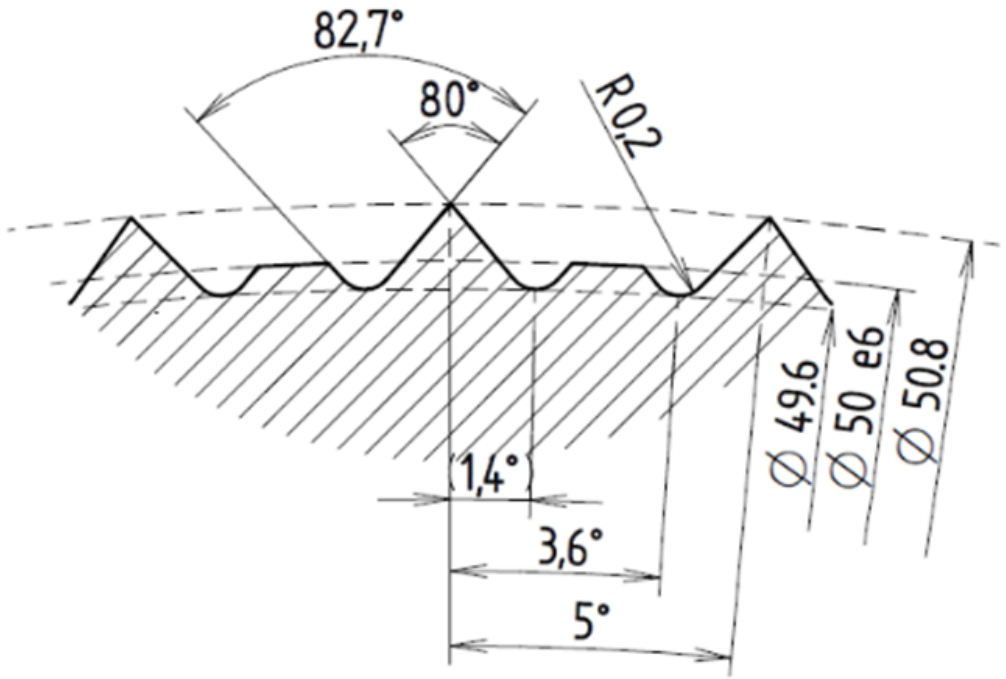


Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Experiment sample





Activities in 3-WP09 New Solutions for Automotive Transmissions

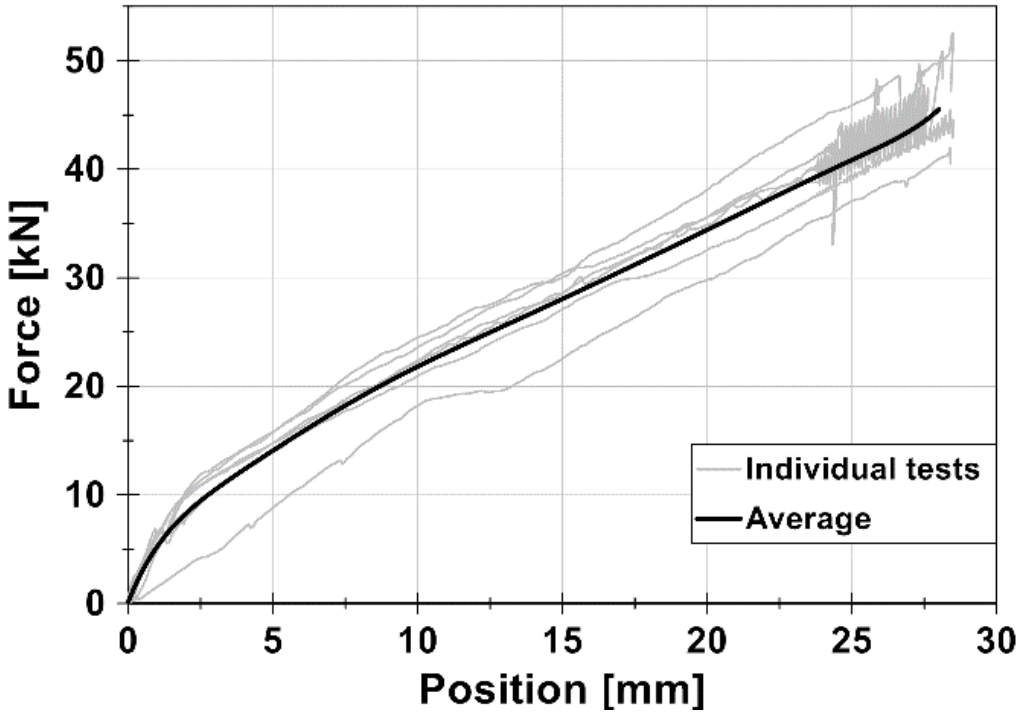
3-WP09-003: Composite joint shaft

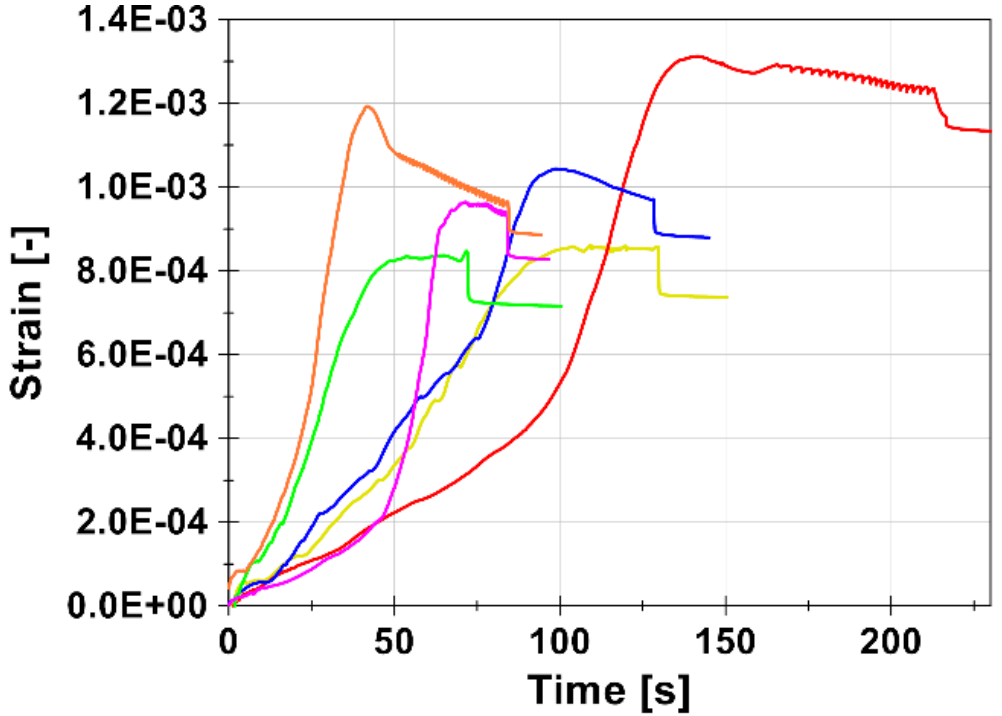
- Press fitting

Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Press fitting

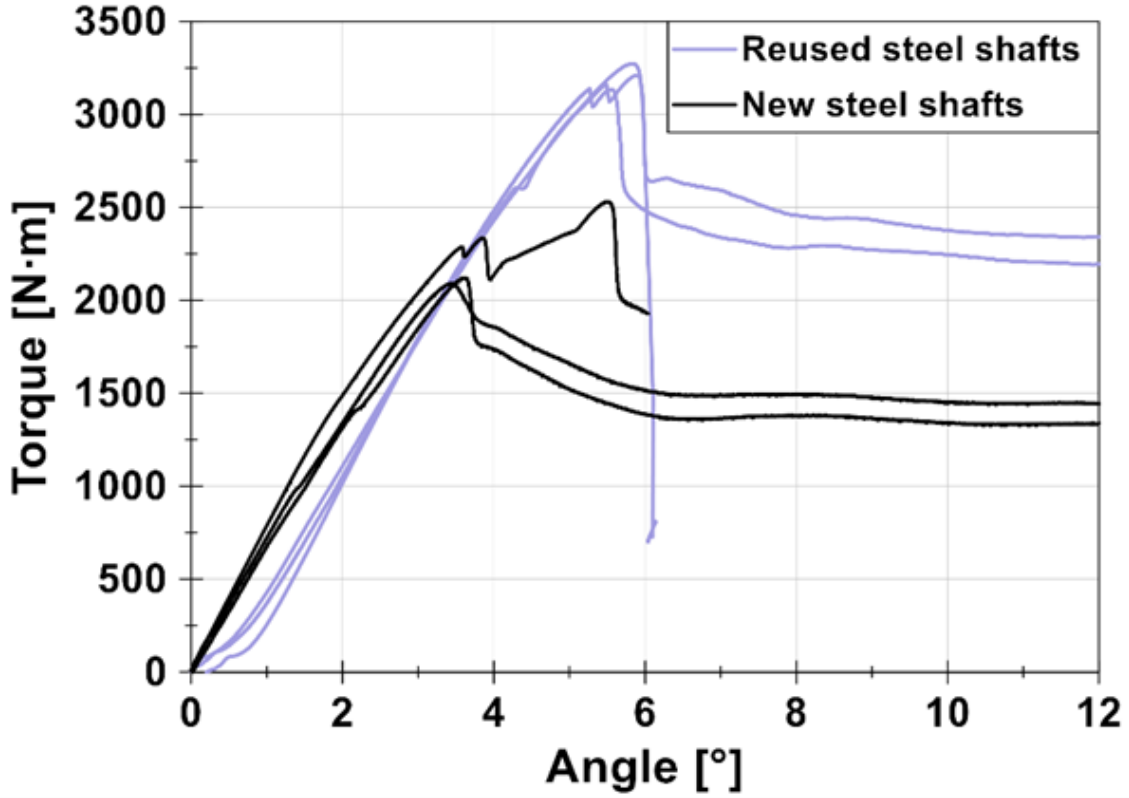




Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Torsion test

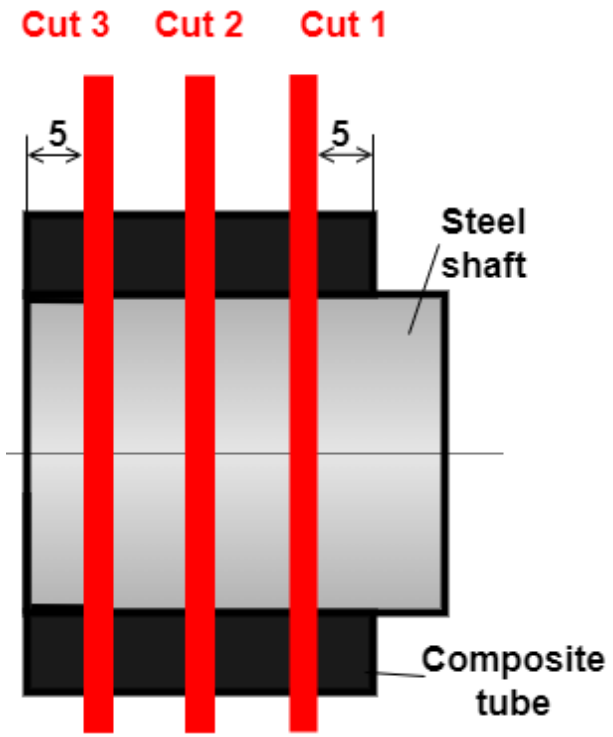


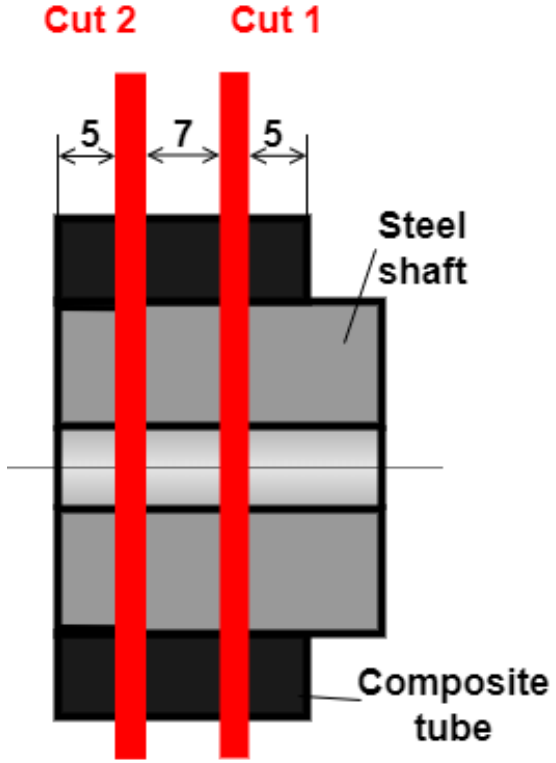
State	M_{max} [N.m]	M_{res} [N.m]
New	2250	1530
Reused	3200	2260

Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Microscope

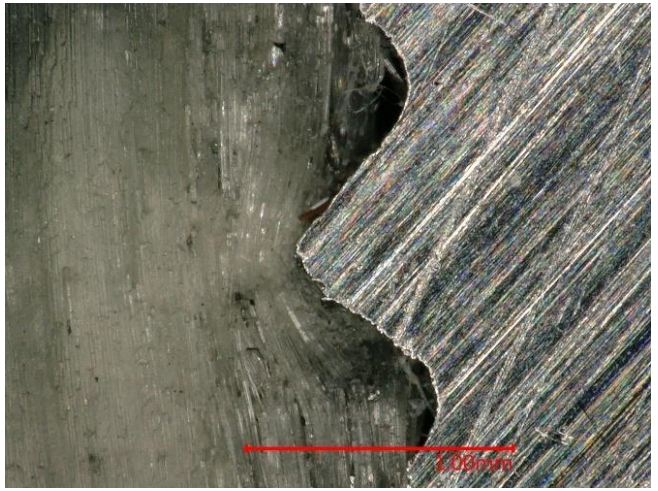


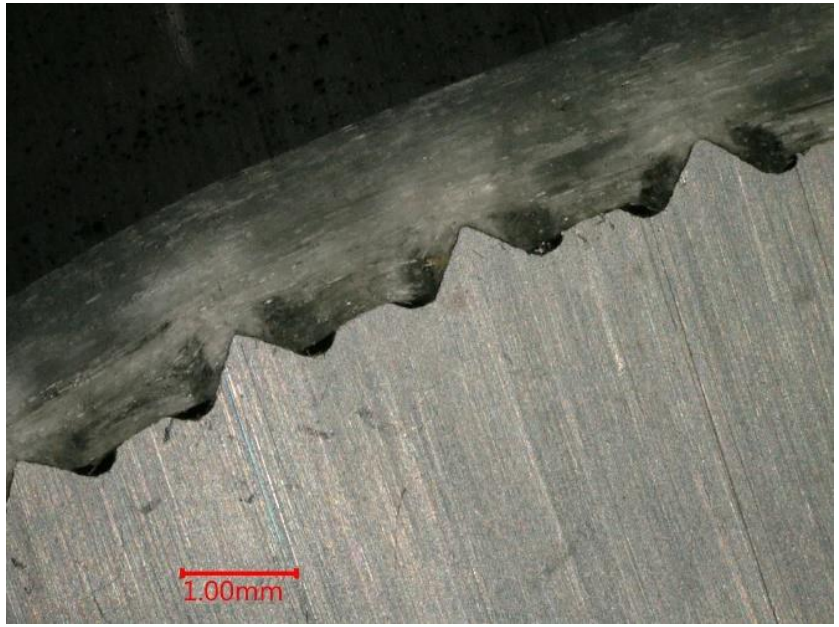


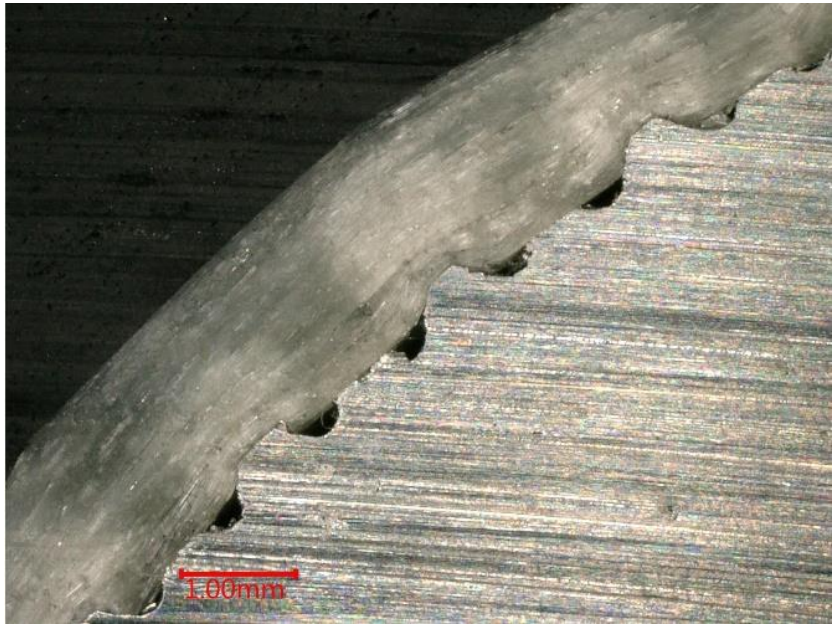
Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Microscope new sample
- Fibers sometimes uncut
- Deformed teeth



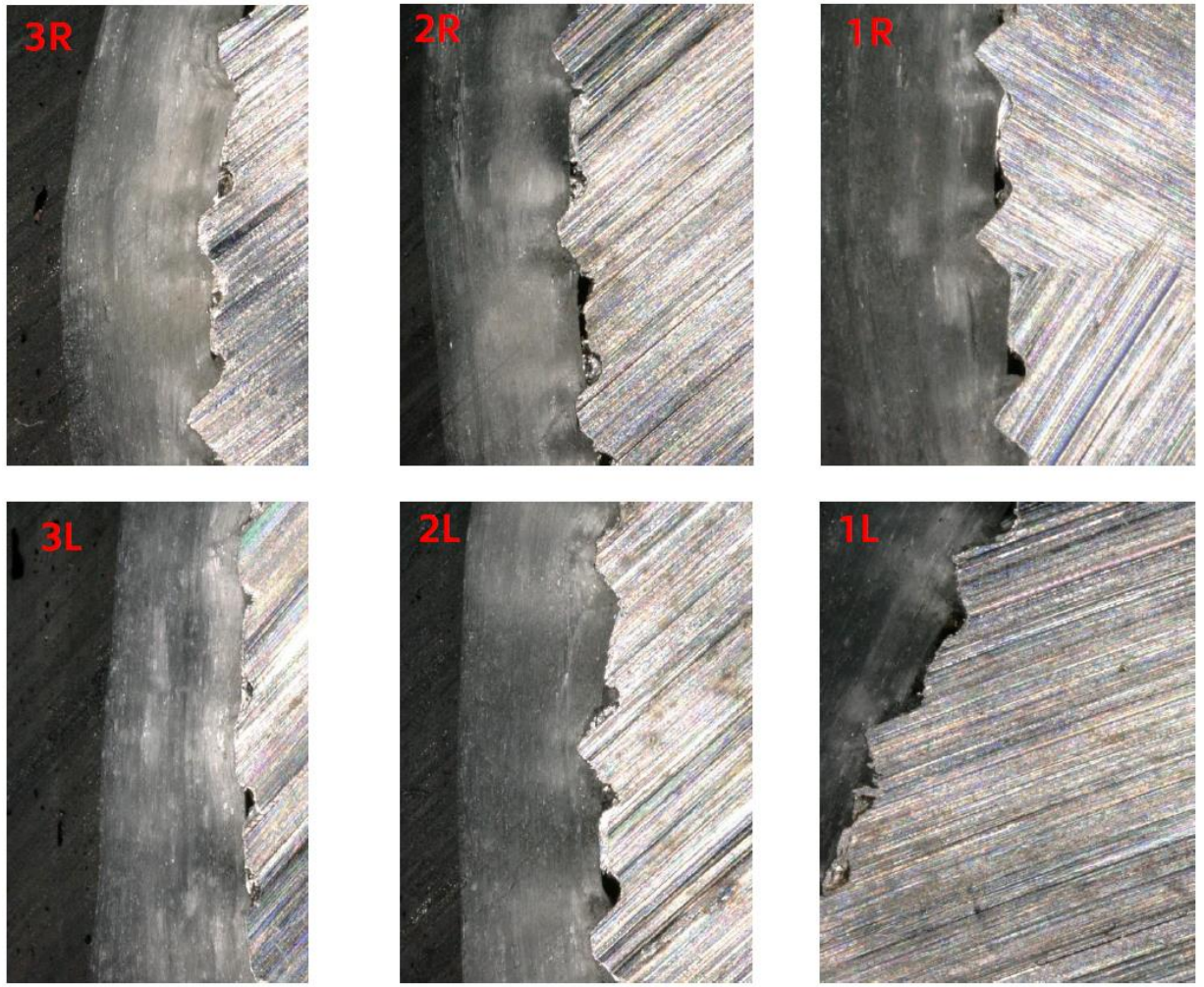




Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

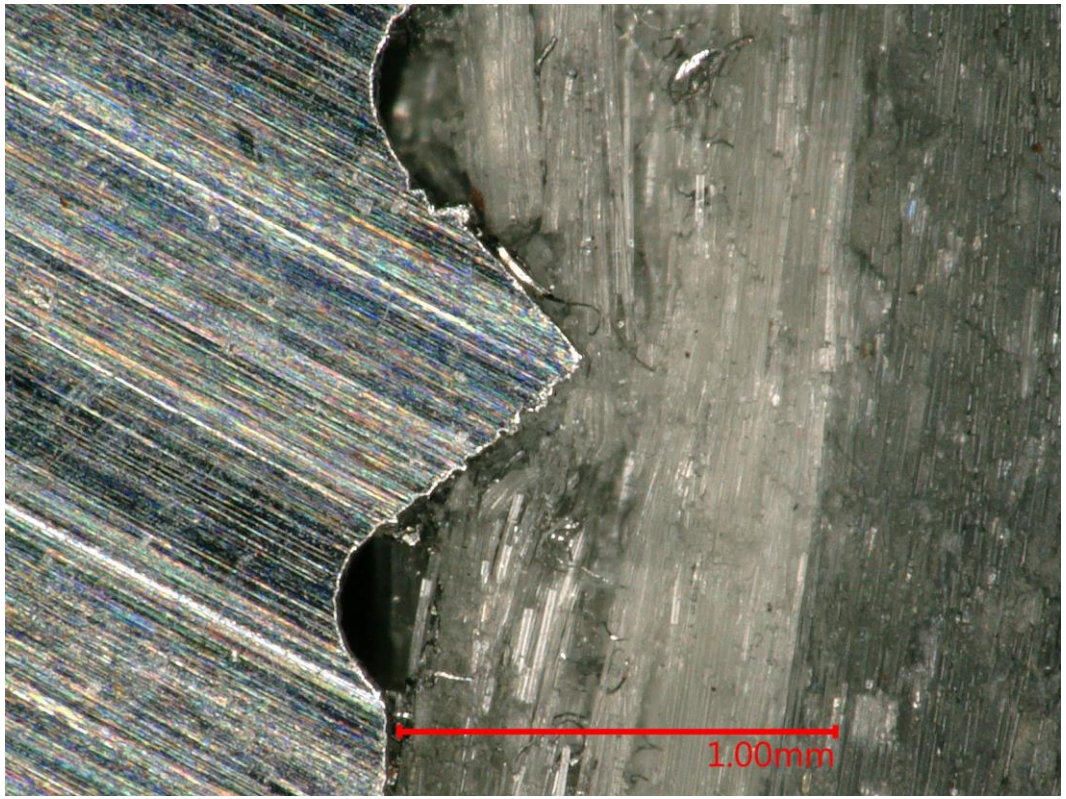
- Microscope – reused
- Less fiber breakage

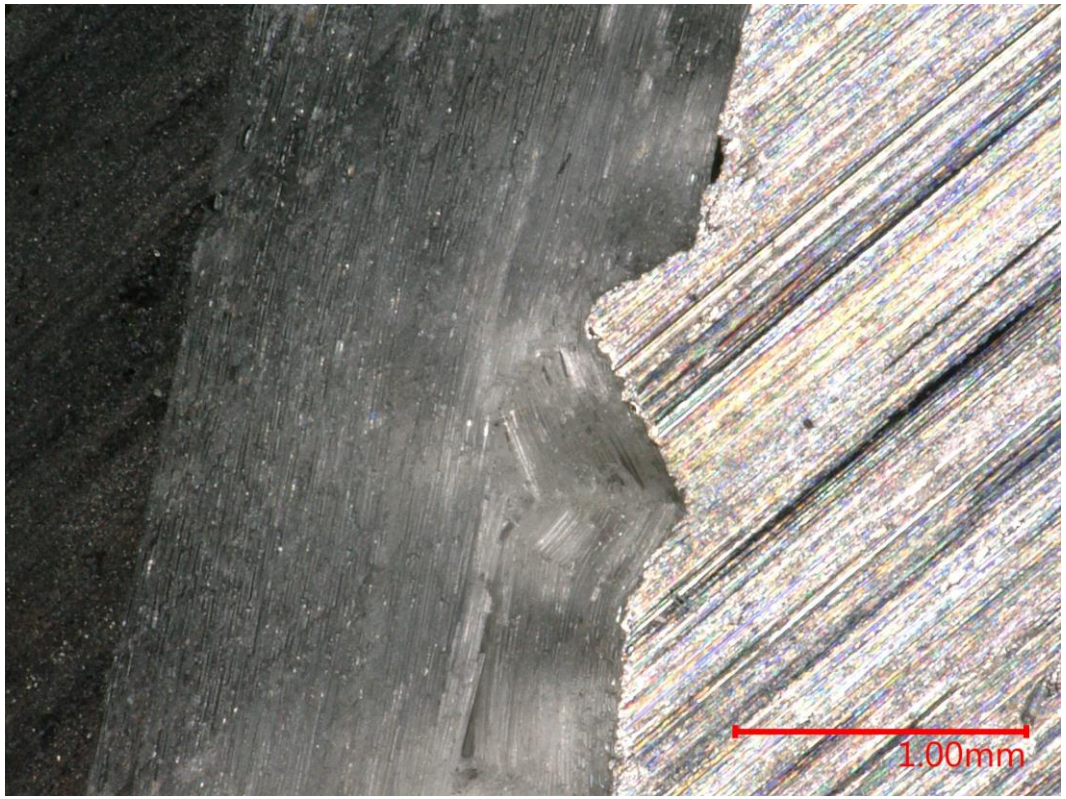


Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- Microscope – new vs reused

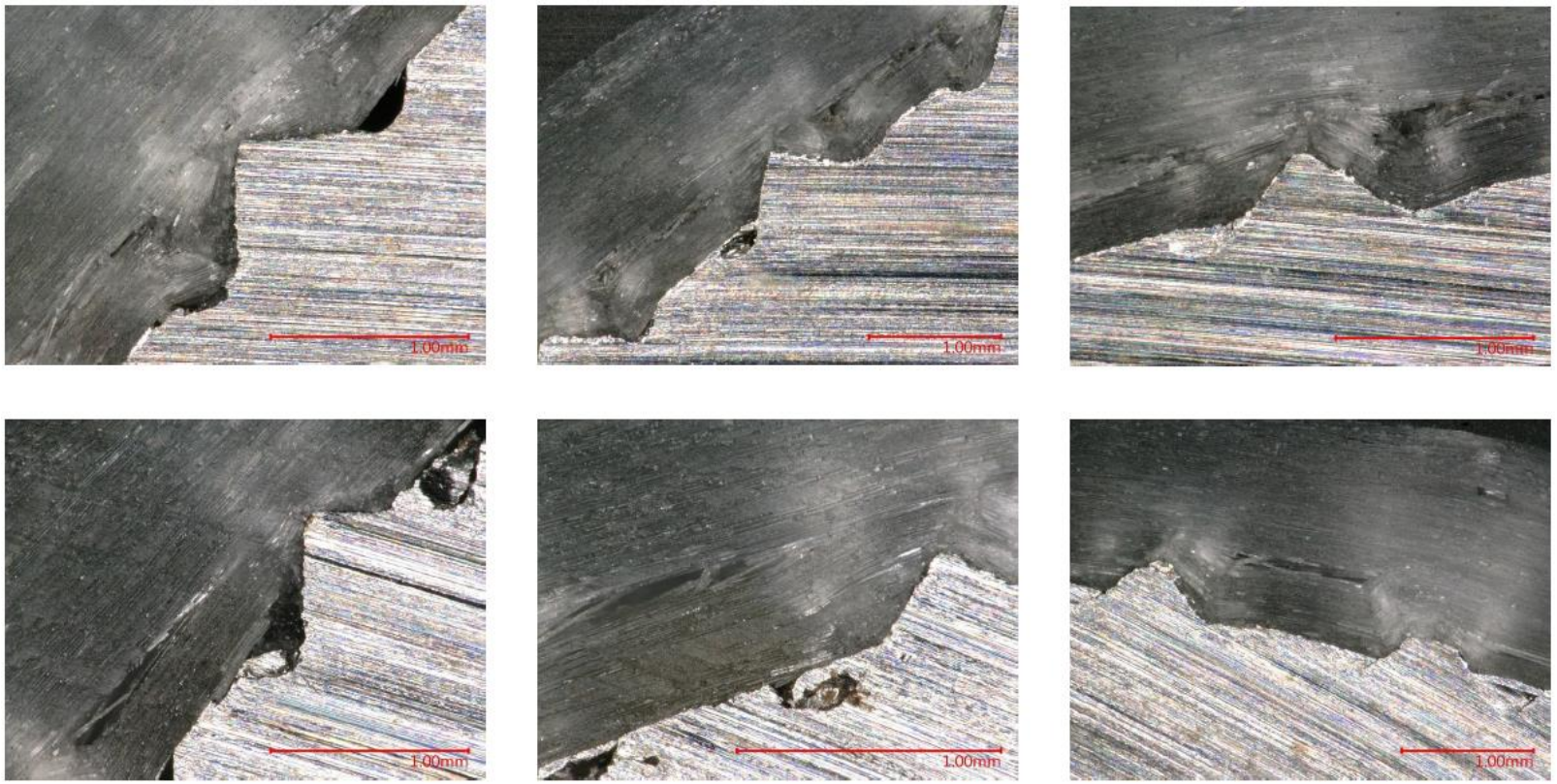




Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

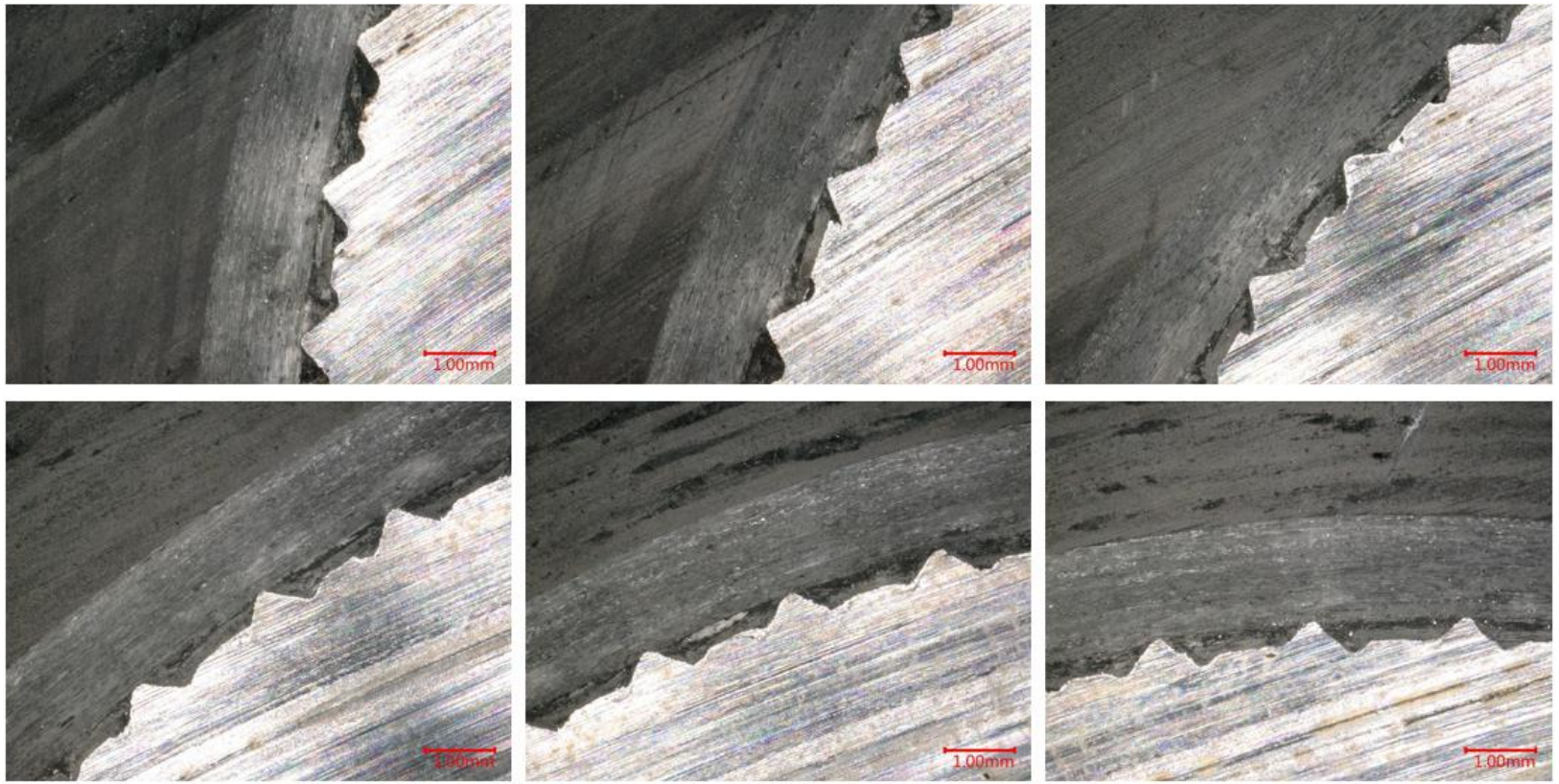
- Microscope –reused, local cracks



Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

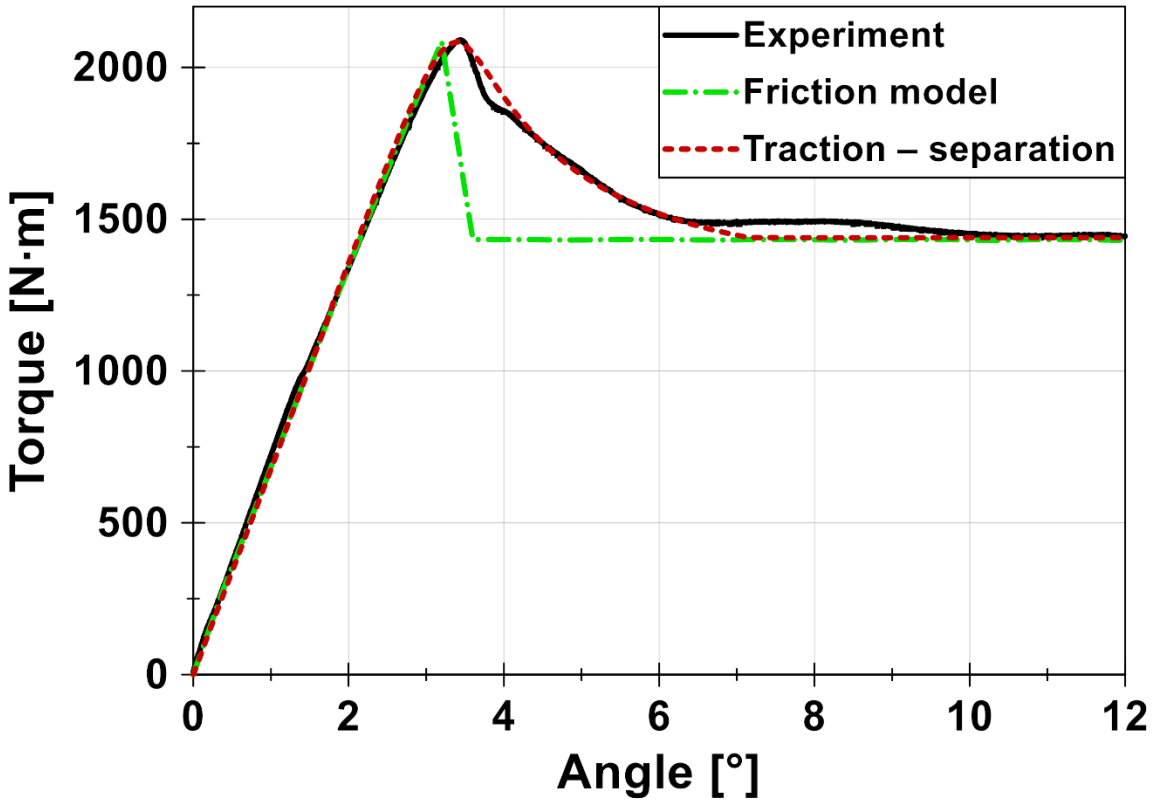
- Microscope –reused, damage

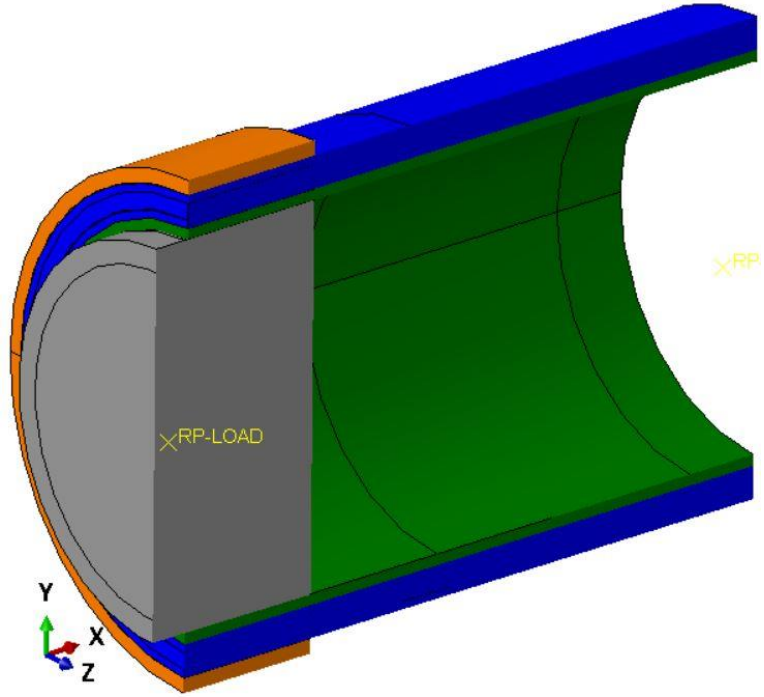


Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- FEM – load bearing capacity

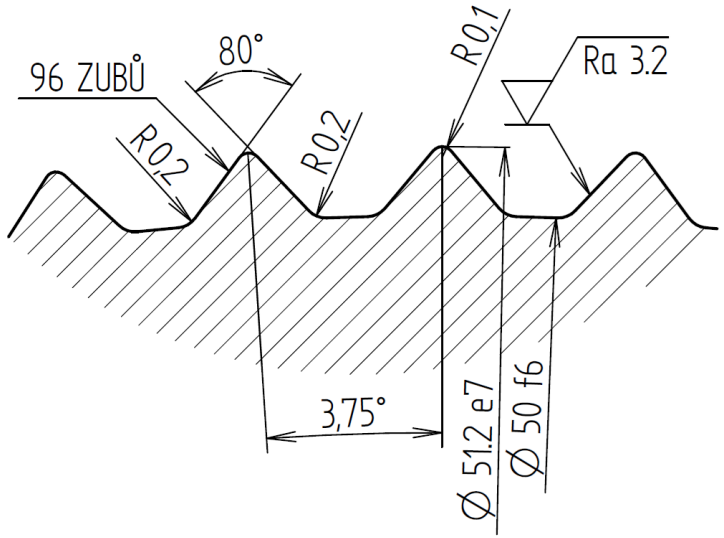


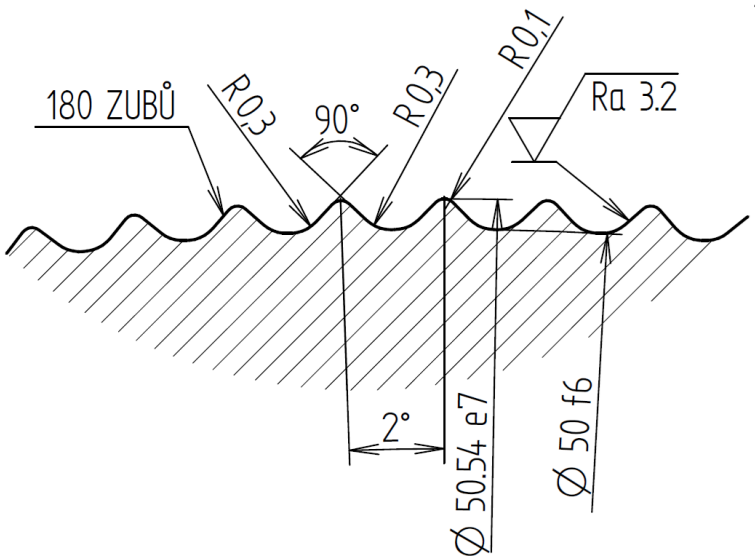


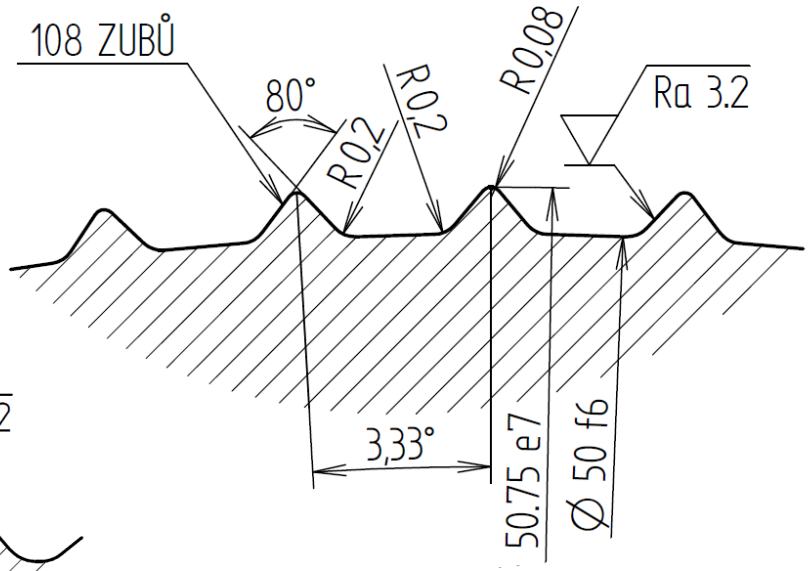
Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-003: Composite joint shaft

- New geometry







Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-004: Composite Joint Shaft dedicated and optimised for usage in passenger car's powertrains, Torque – 3200 Nm

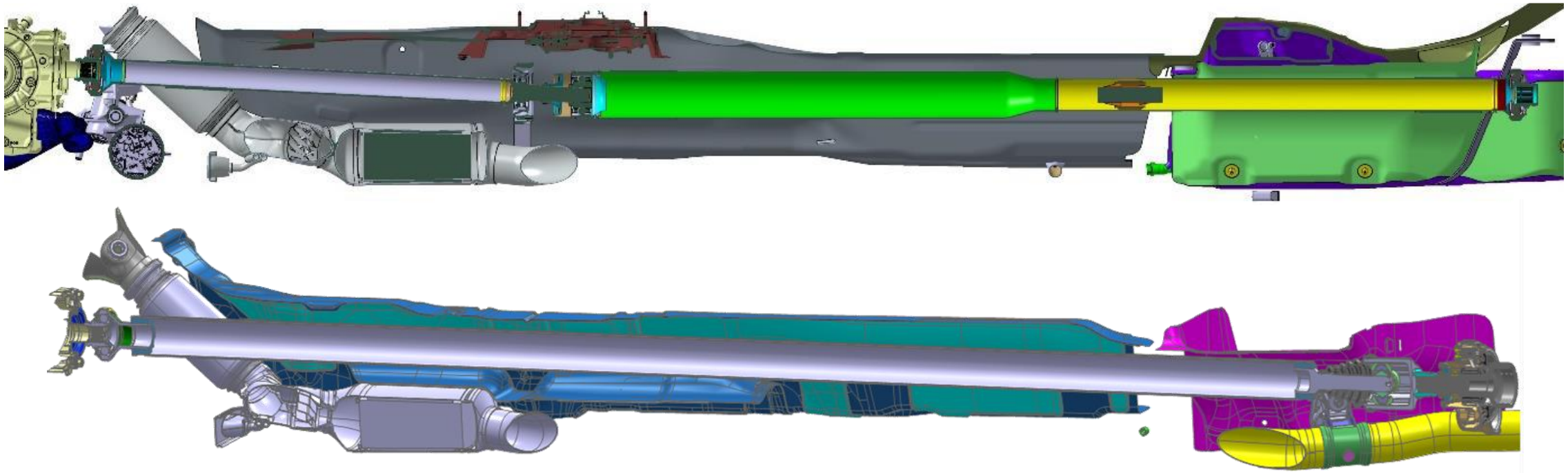
- Max speed – 3600 rpm (60 Hz)
- Weight reduction (currently 11 059 g)
- Maintain fatigue life, temperature and chemical resistance and price

Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-004: Composite Joint Shaft dedicated and optimised for usage in passenger car's powertrains,

- Critical speed
  - Higher diameters, higher stiffness → higher critical speed
  - Lower density, lower length → higher critical speed

$$n_{krit} = \frac{30\pi}{4} \cdot \sqrt{\frac{E}{\rho}} \cdot \frac{\sqrt{D^2 + d^2}}{L^2}$$



Activities in 3-WP09 New Solutions for Automotive Transmissions

3-WP09-004: Composite Joint Shaft dedicated and optimised for usage in passenger car's powertrains,

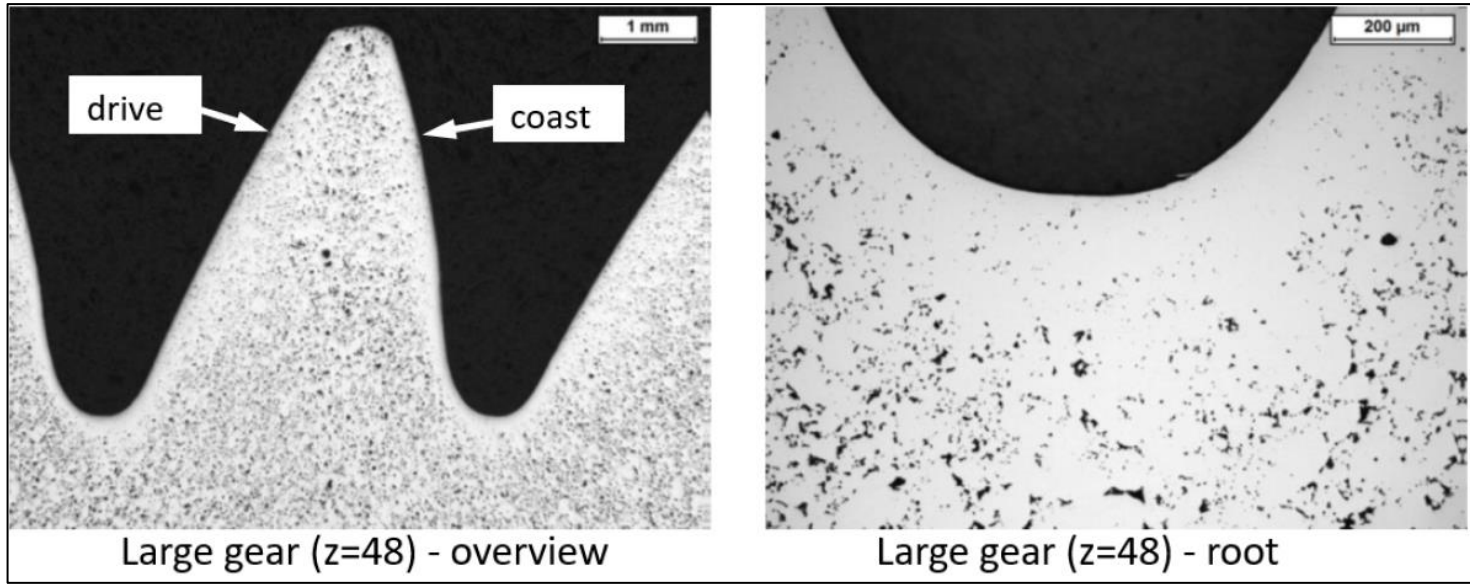
- Variants

							celokompozit
			Varianta 1 (60x2)	**Varianta 2 (62x2)**	**Varianta 3 (65x1,5)**	**Varianta 4 (55x2)**	**Varianta 5**
		vlákno	K13916/T700 24K	K13916/T700 24K	K13916/T700 24K	K13916/T700 24K	K13916/T700 24K
Ocel	d0	(mm)	56	58	62	51	56
	t	(mm)	2	2	1,5	2	7,7
	dtrub	(mm)	60	62	65	55	71,4
	tcelk	(mm)	7,0	6,9	6,2	7,4	-
	dkomp	(mm)	70,0	71,8	74,4	65,8	71,4
	L	(mm)	2084	2084	2084	2084	2084
	tkomp	(mm)	5,0	4,9	4,7	5,4	7,7
	mtrub (L=2084mm)	(kg)	5,9	6,2	4,9	5,5	-
	mkomp	(kg)	3,6	3,6	3,6	3,5	5,2
	mcelk	(kg)	9,5	9,8	8,5	9,0	5,2
	cena komp	(€)	192	193	192	192	241
	f1	(Hz)	382	389,5	428,95	361,9	513
	f2	(Hz)	1503	1532	1679,7	1426,3	1966
	n1	(min^{-1})	3 648	3 719	4 096	3 456	4 899
	n2	(min^{-1})	14 353	14 630	16 040	13 620	18 774

Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-005: Powder metal Asymmetric gearwheels

- In cooperation with our partner SKODA AUTO and other partners were in frame of PhD thesis fabricated asymmetric powder metal gearwheels with the rolling technology
- The structure of produced gearwheels was analysed with help of Light Optical Microscops



Large gear (z=48) - overview

Large gear (z=48) - root

Source: Miláček O. New Possibilities for Gearwheels in Automotive Gearboxes. CTU PhD Thesis. 2023

Activities in **3-WP09:** New Solutions for Automotive Transmissions

3-WP09-005: Powder metal Asymmetric gearwheels

- The first proposal for microgeometry was defined.
- The grinding is planned for the first week of December 2024 in Swiss company. To tune precisely the machine the presence of CTU and Skoda Auto is expected.
- The closed-loop test stand will be used for first set of tested gearpairs.
- The main outcomes of this workpackage will be explored during next year

Activities in 3-WP09 New Solutions for Automotive Transmnissions

3-WP09-006: Gearboxes for electric vehicles

- Definition of requirements for search of new designs for gearboxes of electric vehicles:
  - Usage of new materials (e.g. Composite, powder metal)
  - New materials = new technology of fabrication => nontraditional approach
  - Combination of several tasks (e.g. Diferential and ratio reduction)
  - Low amount of gears
  - High reduction ratio
  - Dog clutch shift (optional)
  - Possibility of hybrid usage (several sources)

- Chosen category of the vehicle
  - Small vehicle (Gross weight 1500 kg)

Activities in 3-WP09 New Solutions for Automotive Transmnissions

3-WP09-006: Gearboxes for electric vehicles

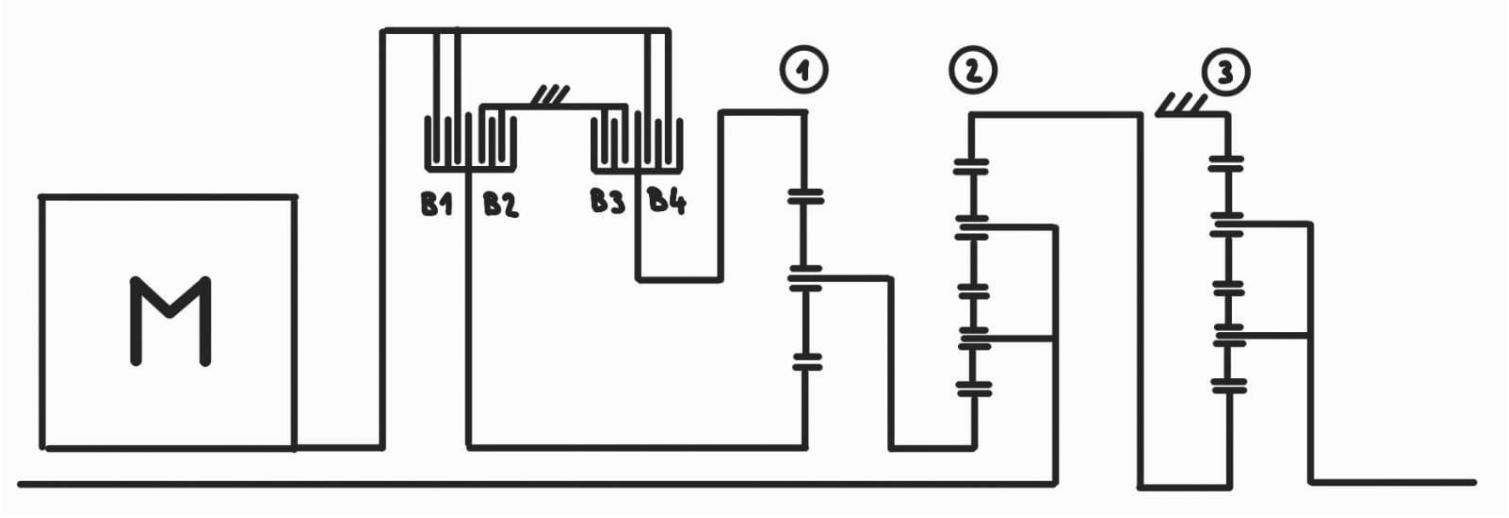
- First approach – design requirements:
  - Hollow electric motor
  - Minimal two speed gearbox, integrated function of differential and final drive
  - Usage of single planetary sets (optional; preferable)
  - Prefered solution without internal gearmesh
  - One shift element opens, one shift element is engaging
  - Low amount of opened clutches/brakes
  - Base ratios in limits of manufacturability, good efficiency
  - Fullfilled conditions of assembly

	Ratio
1st speed	+/- 15
2nd speed	+/- 7,5

Activities in 3-WP09 New Solutions for Automotive Transmnissions

3-WP09-006: Gearboxes for electric vehicles

Variant 1



	B1	B2	B3	B4
i_{p1}	X		X	
i_{pn}		X		X

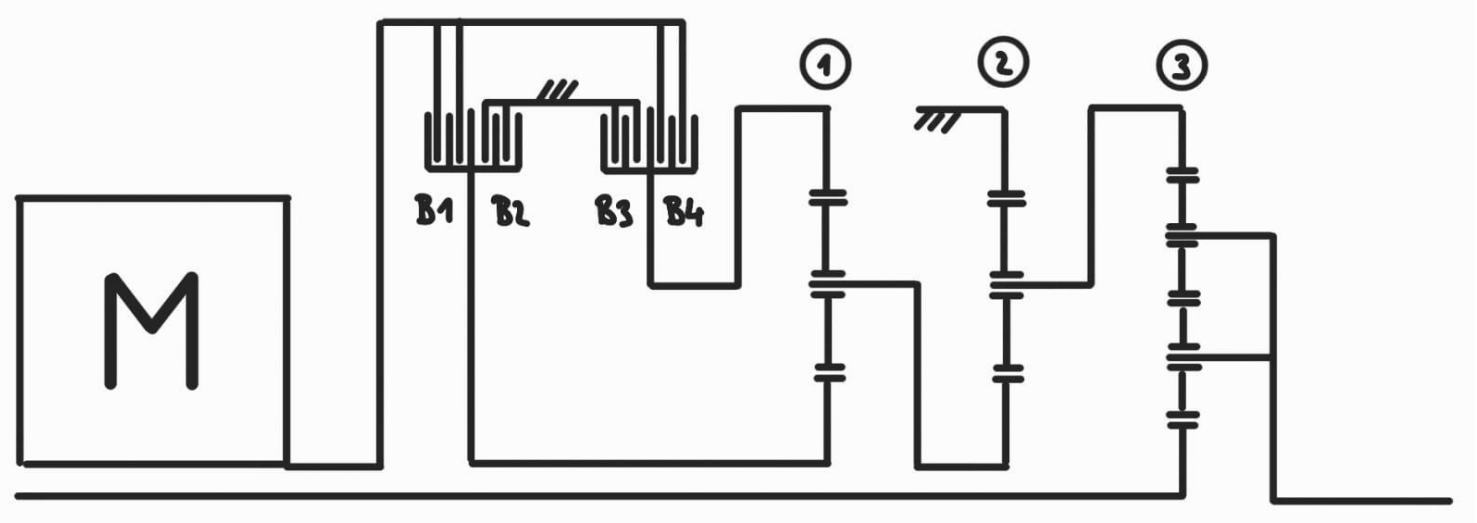
Source: Pelant Š. Diploma project, CTU in Prague, 2023

Set 1	Set 2	Set 3
$z_{p1} = 34$ [1]	$z_{p2} = 18$ [1]	$z_{p3} = 30$ [1]
$z_{k1} = 68$ [1]	$z_{k2} = 63$ [1]	$z_{k3} = 72$ [1]
$z_{s1} = 17$ [1]	$z_{s2max} = 22{,}5$ [1]	$z_{s3max} = 21$ [1]

Activities in 3-WP09 New Solutions for Automotive Transmnissions

3-WP09-006: Gearboxes for electric vehicles

Variant 2



	B1	B2	B3	B4
i_{p1}	X		X	
i_{pn}		X		X

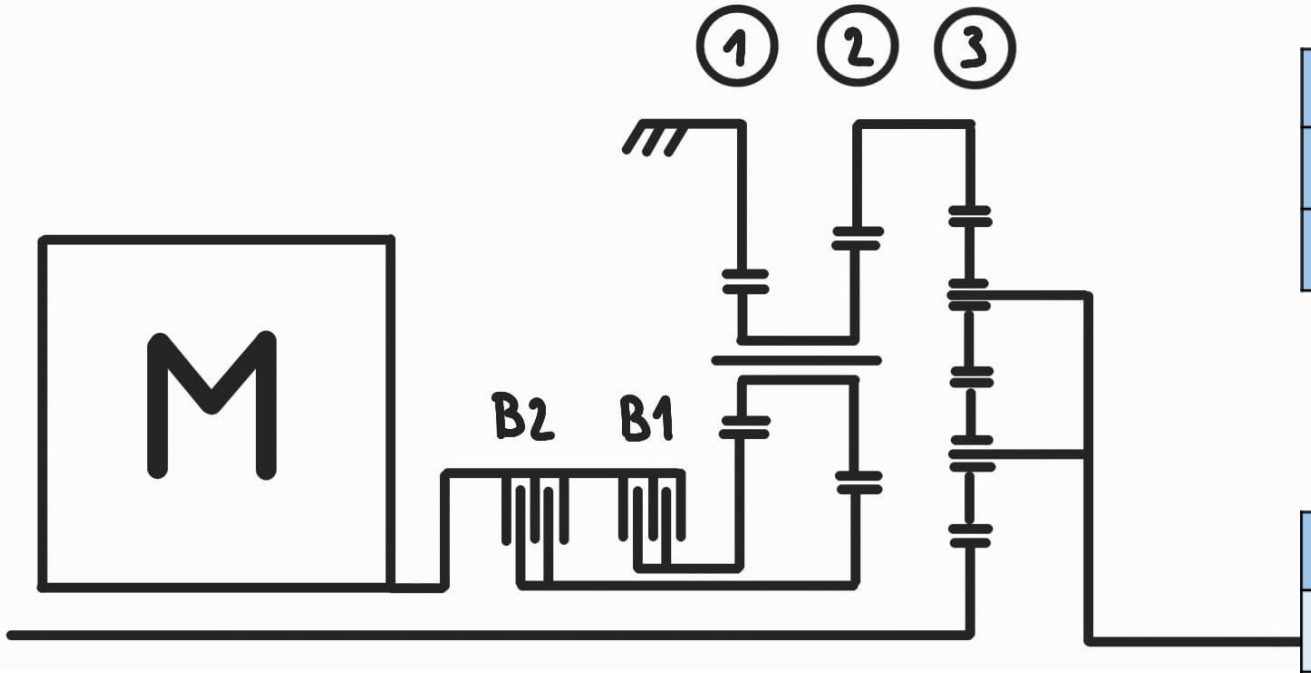
Set 1	Set 2	Set 3
$z_{p1} = 34\ [1]$	$z_{p2} = 18\ [1]$	$z_{p3} = 38\ [1]$
$z_{k1} = 68\ [1]$	$z_{k2} = 72\ [1]$	$z_{k3} = 76\ [1]$
$z_{s1} = 17\ [1]$	$z_{s2} = 27\ [1]$	$z_{s3max} = 19\ [1]$

Source: Pelant Š. Diploma project, CTU in Prague, 2023

Activities in 3-WP09 New Solutions for Automotive Transmnissions

3-WP09-006: Gearboxes for electric vehicles

Variant 3



	B1	B2
i_{p1}		X
i_{pn}	X	

Set 1	Set 2	Set 3
$z_{p1} = 32$ [1]	$z_{p2} = 21$ [1]	$z_{p3} = 38$ [1]
$z_{k1} = 66$ [1]	$z_{k2} = 77$ [1]	$z_{k3} = 76$ [1]
$z_{s1} = 17$ [1]	$z_{s2} = 28$ [1]	$z_{s3max} = 19$ [1]

Source: Pelant Š. Diploma project, CTU in Prague, 2024

Fulfillment of goals and deliverables of **3-WP09:** New Solutions for Automotive Transmissions

Current State of Deliverables, Milestones and Fulfillment of Goals

- 3-WP09-001 | **Gear with low transmission error**, G-funk, VI./2026, BUT 0.3; TUO 0.3; SA 0.4 **in progress & no major delays:**
  - Increase complexity of computational model, performed sensitivity study, design and manufactured gears for validation.
- 3-WP09-002 | **Digital twin of the test bench for monitoring gear mesh** , O, VI./2026, BUT 0.3; TUO 0.3; SA 0.4 **in progress & no major delays:**
  - Perform comlex technical experiment, increase comlexity of computational model, data processing, design and manufacturing of assembly to increase repeatability of technical experiment.
- 3-WP09-003 | **Composite Joint Shaft** , G-funk, XII./2025, CTU FME 0.4; SA 0.1, Compotech 0.5 **in progress & no major delays:**
  - Composite joint shaft – search for microsplined jopint between steel and composite part
- 3-WP09-004 | **Composite Joint Shaft dedicated and optimised for usage in passenger car`s powertrains**, O, VI./2026, CTU FME 0.4; SA 0.1, Compotech 0.5 **in progress & no major delays:**
  - Definition of paramters for vehicle usage
- 3-WP09-005 | **Powder Metal assymetric gearwheels**, G-funk, XII/2025, CTU FME 0.6; SA 0.4 **in progress & no major delays:**
  - Grinding of assymetric grearwheels. Experimental tests.
- 3-WP09-006 | **Gearboxes for electric vehicles**, O, VI/2026, CTU FME 0.9; SA 0.1 **in progress & no major delays:**

Fulfillment of goals and deliverables of **3-WP09:** New Solutions for Automotive Transmissions

Current State of Deliverables, Milestones and Fulfillment of Goals

- 3-WP09-006 | **Gearboxes for electric vehicles**, O, VI/2026, CTU FME 0.9; SA 0.1 **in progress & no major delays:**
  - Definition of main parameters, and search for possible scheme combining several functions

Fulfillment of goals and deliverables of **3-WP09:** New Solutions for Automotive Transmissions

List of Due Deliverables and Their Added Value

3-WP09-001 – deeper understanding of gear microgeometry on transmission error.

3-WP09-002 – deeper inside into testing of gears of future automotive applications.

3-WP09-003 – deep research of new ways of joining composite and steel material

3-WP09-004 – investigation of possible simplification for vehicle joint shaft

3-WP09-005 – deeper knowledge of possibility of inovative gear design and new gearwheel materials

3-WP09-006 – investigation of new designs for e-vehicle gearboxes

Current contribution of **3-WP09:** New Solutions for Automotive Transmissions

Assessment of the Formal/Administrative Goals of the Work Package

	VŠB - TUO	Skoda	BUT	CTU	Compotech
Finances (reporting/spending)	OK	OK	OK	OK	OK
Commercialisation	OK	OK	OK	OK	OK
Deliverables	OK	OK	OK	OK	OK

Current contribution of **3-WP09:** New Solutions for Automotive Transmissions

Acknowledgment

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

Appendices to **3-WP09:** New Solutions for Automotive Transmissions

Appendices

Pokud jsou zapotřebí pro elektronickou formu sborníku. Nebudou prezentovány při přednášce.

Rozsah libovolný do celkového pdf rozsahu presentace 15 MB.

Výtah z prací 2023-2025 na **3-WP09:** Nová řešení automoibilových převodovek

TOTO JSOU VÝTAHY: **ZA LÉTA 2023-2025 v ČEŠTINĚ**

Uveďte jméno hlavního autora a kontakt na něj.

Hlavní výstupy (pokud možno graficky vyjádřené) ve formě abstraktu pro souhrn z projektu za dané období, tj. od začátku projektu (2023) až do aktuálního stavu, nejdéle do konce 2025 (konce první části projektu) s uvedením účastníků – původců výstupů (stačí zkráceně - např. VUT v Brně).

Abstrakt bude součástí elektronického podkladu Kolokvia, ale neprezentuje se. Jde spíše o podklad pro různé souhrnné materiály (např. pro oponenturu) za NCK2.

Ale sestavte jej už pro kolokvium!

Results of **3-WP09:** New Solutions for Automotive Transmissions – Achieved 2023-2025

The main results (mostly in graphical form and in English, with reference to the participant – author of the result). **Everything in English (including description of pictures)**.

Tento snímek je anglickou verzí předchozího snímku!

Abstrakt bude součástí elektronického podkladu Kolokvia, ale není třeba jej prezentovat. Jde spíše o podklad pro různé souhrnné materiály (např. pro oponenturu) za NCK2.

Ale sestavte jej už pro kolokvium!

Výtah z prací 2024 na **3-WP09:** Nová řešení automobilových převodovek

TOTO JSOU VÝTAHY: **za běžný rok 2024 (v návaznosti na předchozí roky) v ČEŠTINĚ**

Uveďte jméno hlavního autora a kontakt na něj.

Hlavní výstupy (pokud možno graficky vyjádřené) ve formě abstraktu pro souhrn z projektu za dané období do konce 2024 s uvedením účastníků – původců výstupů (stačí zkráceně - např. VUT v Brně).

Abstrakt bude součástí elektronického podkladu Kolokvia, ale neprezentuje se. Jde spíše o podklad pro různé souhrnné materiály (např. pro oponenturu) za NCK2.

Ale sestavte jej už pro kolokvium!

Results of **3-WP09:** New Solutions for Automotive Transmissions – Achieved 2024

The main results 2024 following those of previous year(s) (mostly in graphical form and in English, with reference to the participant – author of the result). **Everything in English (including description of pictures)**.

Tento snímek je anglickou verzí předchozího snímku!

Abstrakt bude součástí elektronického podkladu Kolokvia, ale není třeba jej prezentovat. Jde spíše o podklad pro různé souhrnné materiály (např. pro oponenturu) za NCK2.

Ale sestavte jej už pro kolokvium!