Contents of Work Package 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11: Vehicle Noise and Inovative Semi-Active Damper Design

Coordinator of the WP

Brno University of Technology - Ing. Kamil Řehák, Ph.D.

Participants of the WP

Brno University of Technology – prof. Ing. Václav Píštěk, DrSc., doc. Ing. Pavel Kučera, Ph.D., Ing. Ondřej Blaťák, Ph.D.; Tatra Trucks a.s – Ing. Martin Frait; Technical University Liberec - Ing. Robert Voženílek, Ph.D.; Škoda Auto a.s. – Bohuslav Novotný; KAR group, a.s. – Miroslav Konečný, CTU FME – Ing. Zdeněk Neusser, Ph.D.; UWB RTI – Ing. Pavel Žlábek, Ph.D

Main Goal of the WP

Creation of approach for increase effectivity at future vehicles development.

Partial Goals for the Current Period

Perform sensitivity study and measurement, increase complexity of computational model.

Contents of Work Package 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11: Vehicle Noise and Inovative Semi-Active Damper Design

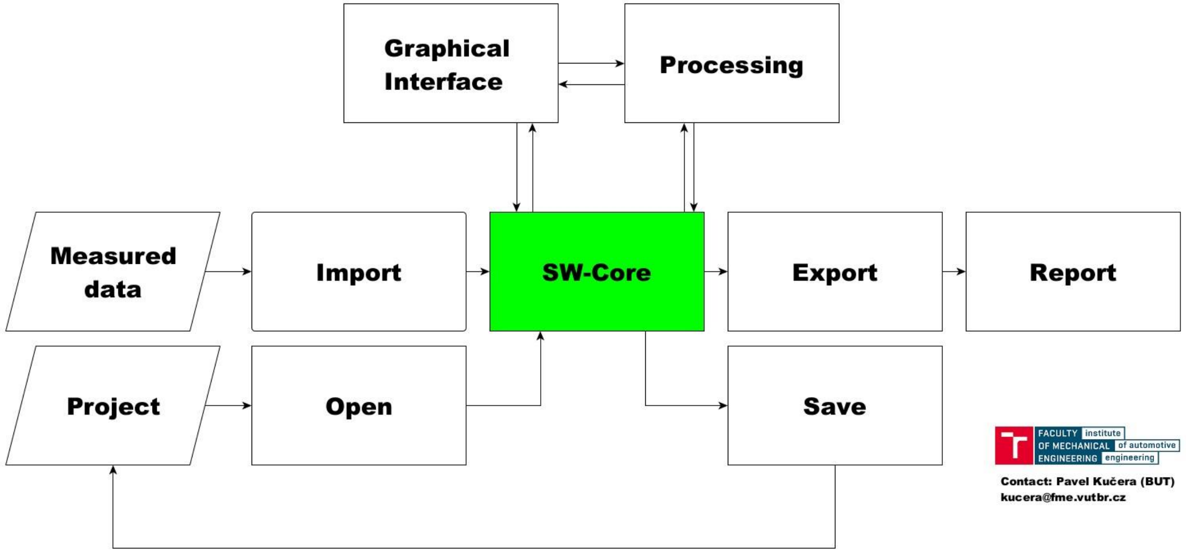
Official 4-WP11 Deliverables:

- 4-WP11-001 | **Software for identification of noise sources of mobile systems**, R-software, BUT 0.9; TATRA 0.05; WBU 0.05
- 4-WP11-002 | **Set for acoustic transmission tests**, G-funk, TUL FME 0.9; Skoda Auto 0.1
- 4-WP11-003 | **Hydraulic damper with new internal architecture for semi-active control,** G-funk, KAR 0.8; BUT 0.15; CTU FME 0.05
- 4-WP11-004 | **Mathematical model of the electronic control system,** O-Ostatní, KAR 0.7; BUT 0.25; CTU FME 0.05
- 4-WP11-005 | **Damping element with innovative damping characteristics**, Gfunk, XII./2025, CTU FME 0.2; BRANO 0.7; BUT 0.1

Activities in 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11-001: Software for identification of noise sources of mobile systems

- Objectives and benefits
  - User-friendly processing of measured data not only in the automotive field
  - Fast processing
  - Import of the project and its modification, completion, replacement of data
  - Evaluation of noise sources
  - Report generation
- Analysis of Wavelet Transform
  - Analysis of noise measurement data
  - Comparison of the method with FFT
  - Problem with evaluating frequencies higher than 250 Hz
- Software
  - beta version programmed
  - software core completed
  - import and export programming
  - project structure programming
  - programming report generation
  - a beta version was created



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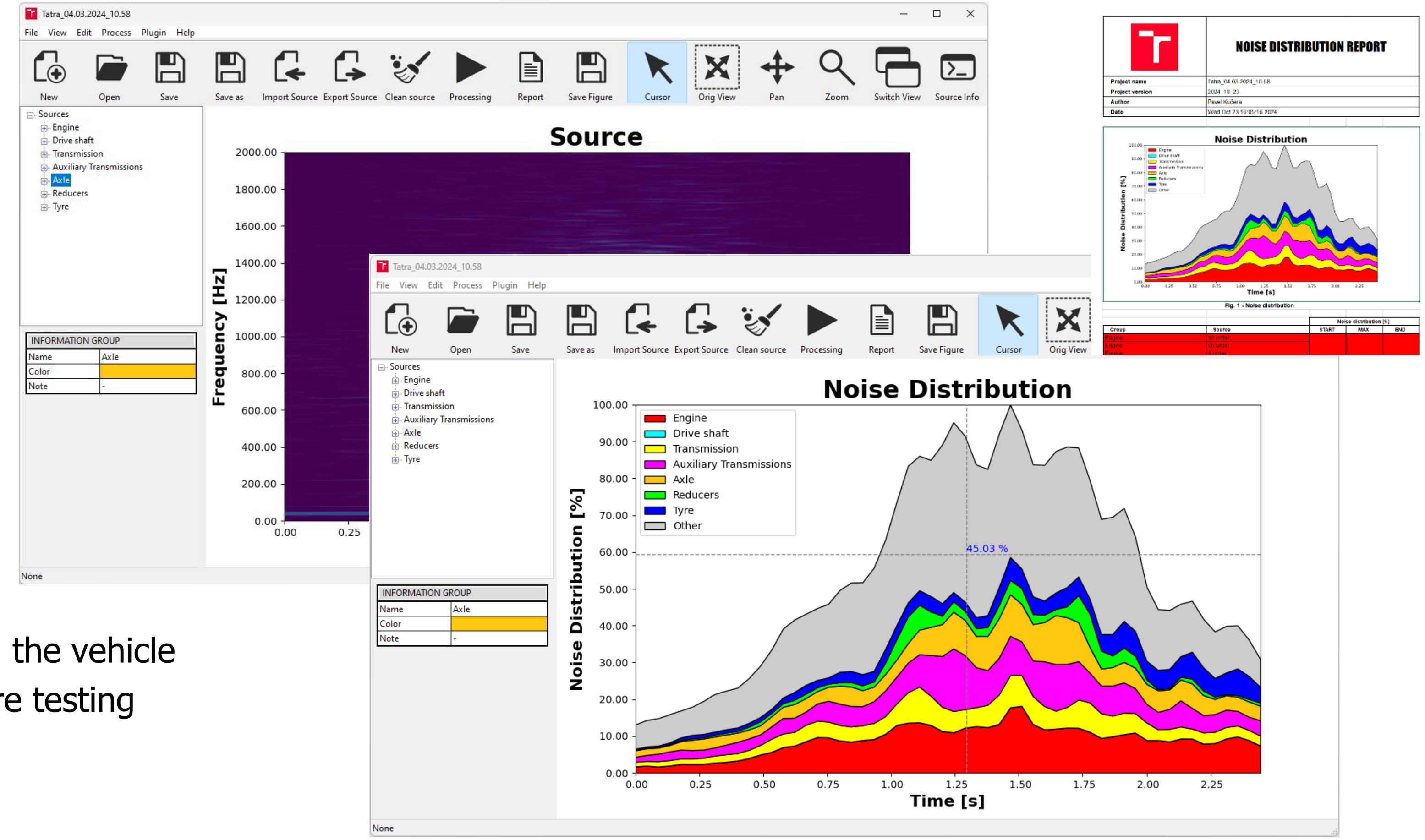
Activities in 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11-001: Software for identification of noise sources of mobile systems

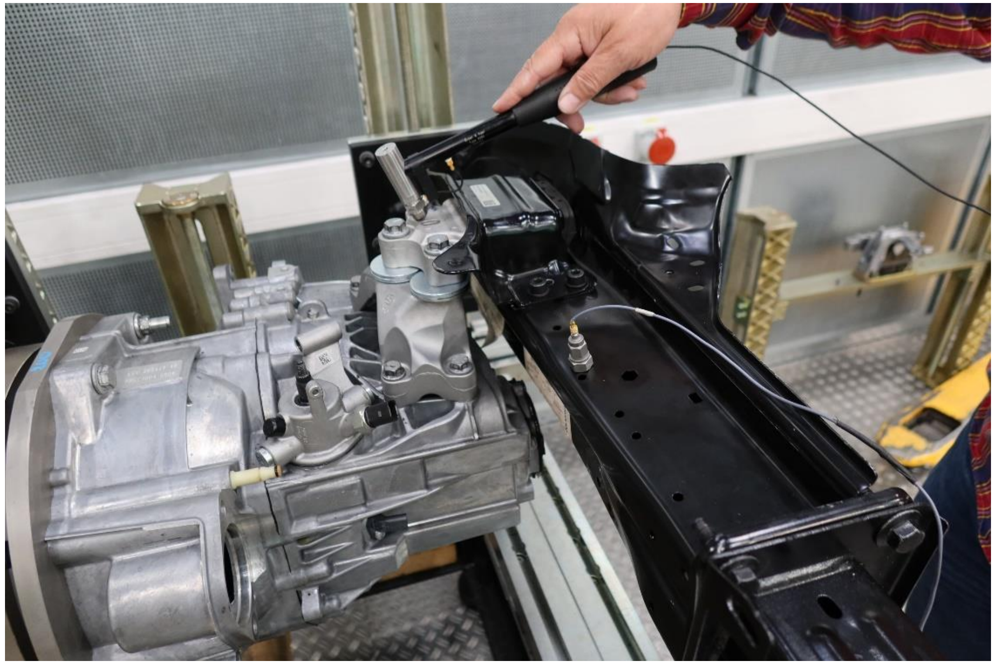
- Graphical interface
- Source
- View
- Noice Distribution
- Report
  - Export to Excel
  - Graph
  - Result of distribution for group
- Next step
  - Creating documentation for users
  - Creating code documentation
  - Carry out a noise measurement on the vehicle
  - Use the measured data for software testing
  - Create the installation file (.EXE)

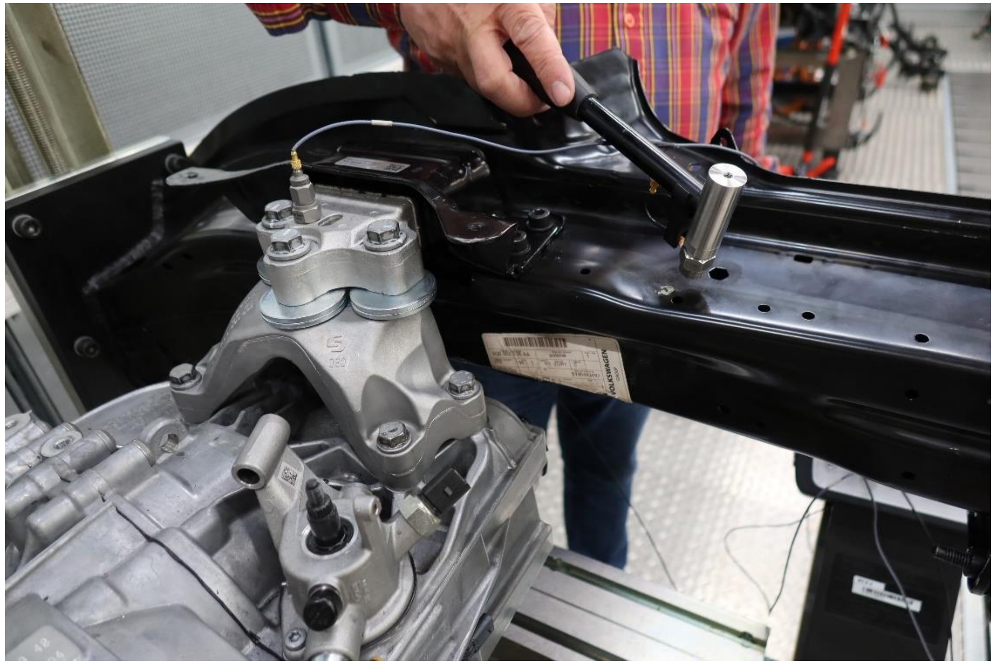


Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

4-WP11-002: Set for acoustic transmission tests

The activity is focused on the creation of a set of parts using the structural parts of a real car to perform acoustic and vibration tests on POWERTRAIN test surfaces. Selected components from the construction of the vehicle will partially be replaced by a universal system for storing drive units in the test facilities. This will achieve a better match between the vibration and noise measurements in the test labs and the real vehicle over a wide range of operating conditions.





Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

4-WP11-002: Set for acoustic transmission tests

Measurement and evaluation procedure:

1. Measurement frequency range 0 Hz (practically about 2 Hz) to 1 kHz
2. The vibration transfer (frequency transfer function H) was determined through the transfer paths - the vehicle storage beds.
3. Shock excitation was performed at the input by a hammer with a built-in force sensor (broadband shock excitation), and the response to this shock was measured at the output using an accelerometer. The measurements were carried out in two variants:

a) input → output

b) output → input

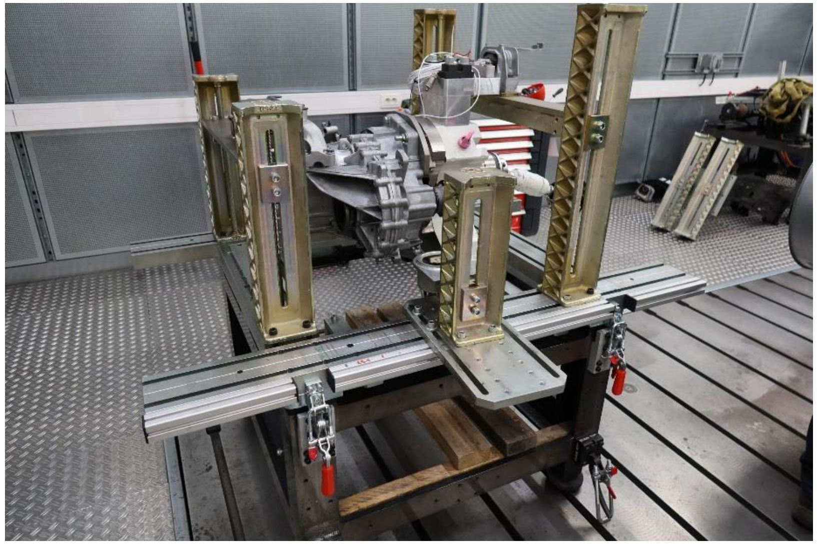
4. The frequency analyser automatically evaluated the frequency transfer function H v $m \cdot s^{-2} \cdot N^{-1}$.

5. The frequency peaks in the H waveform are an indication of the signal amplification at the natural frequencies of the measured system.

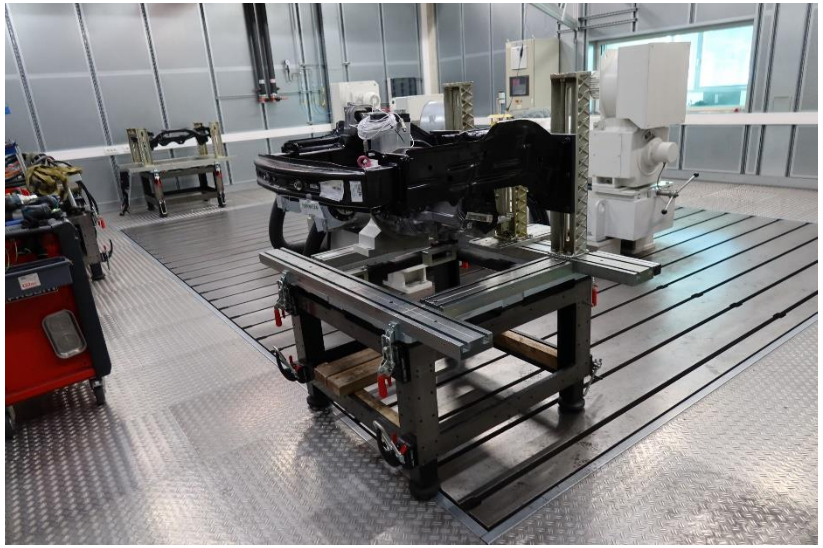
Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

4-WP11-002: Set for acoustic transmission tests

Measurements



original - "hard storage‟
(without combustion engine)



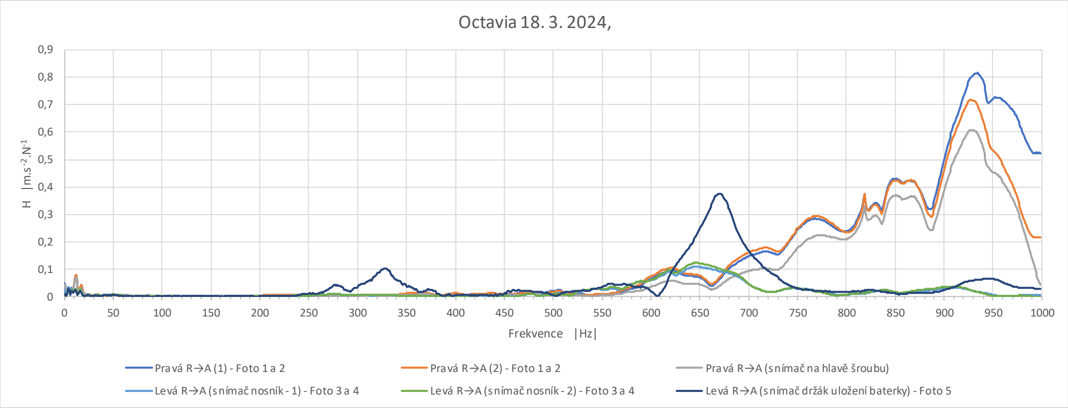
modified - "soft storage‟
(without combustion engine)

storage in the Skoda Octavia

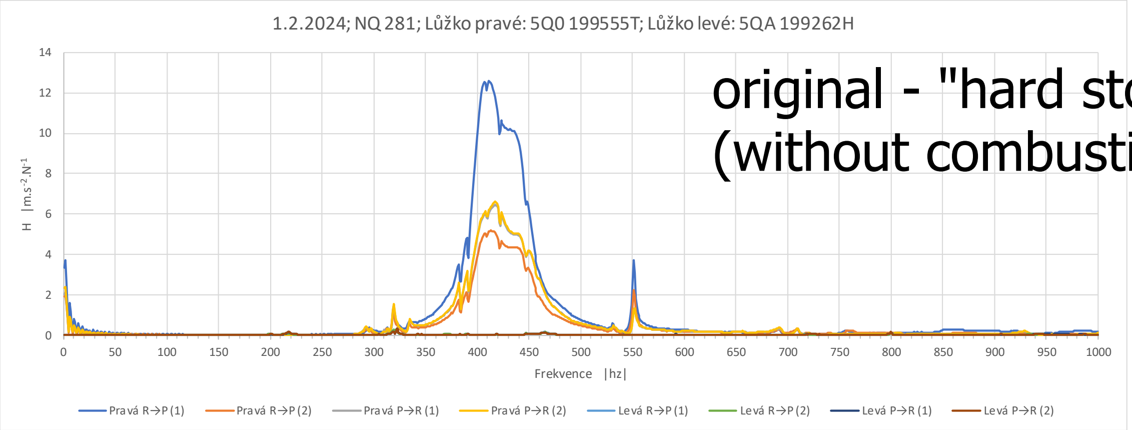
Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

4-WP11-002: Set for acoustic transmission tests

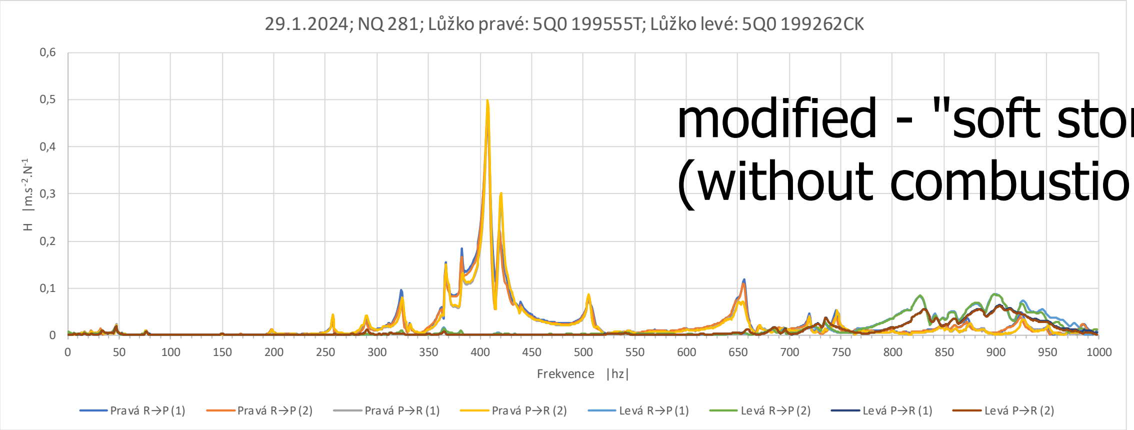
Results



storage in the Skoda Octavia



original - "hard storage‟
(without combustion engine)



modified - "soft storage‟
(without combustion engine)

Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

4-WP11-002: Set for acoustic transmission tests

Current results

It can be seen that the results on the vehicle and the pallet with beams differ mainly in the band where the resonance region is concentrated.Common to all three cases is mainly the band around 350 Hz.The measurements on the pallet are similar to the results on the Octavia vehicle (transmission around 350 Hz).

There is a difference in the results on the palette on the left and right side.While on the vehicle there is a strong resonance band in the region above 600 Hz, which is not fundamentally detrimental in terms of transmission, on the pallet there is a significant difference in the frequency spectrum when measured on the left and right side.The right-hand side of the pallet measurement is significantly similar to the results on the Octavia, while the left-hand side enhances the transmission around 350 Hz.

Left side - engine side (on the palette it is replaced by a rigid block)

Right side - gearbox side

Activities in 4-WP11-003: Hydraulic damper with new internal architecture for semi-active control

4-WP11-003: Hydraulic damper with new internal architecture for semi-active control

- Main goal remains:
  - To build hydraulic damper with semi-active control based on standard vehicle damper (monotube or twin tube design).
  - Rebuild standard passive damper to semi-active (electronic controlled one).
  - The control of the bypass through the damper rod will be used – control of bump and rebound force.

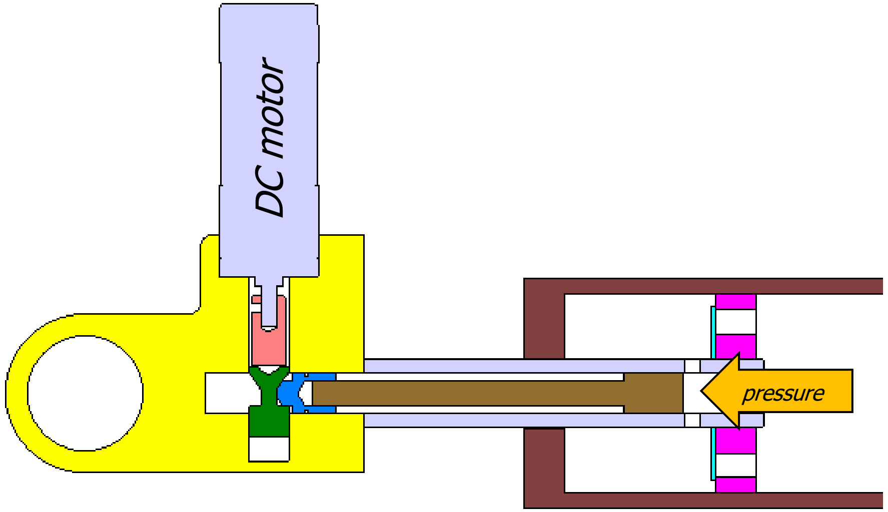
- Decisions made:
  - Rotational actuator will be used – more simple damper design, more energy efficient, easier way to manufacture all parts in-house, lower price (disadvantage – lower operation bandwidth). Activities to integrate the solenoid valve still running.
  - Control algorithm architecture – semi-active damper can be replaced with active system.
  - Damper control will be focused especially on primary ride in this phase of the project, ground hook (skyhook) control for secondary ride will be used where the primary handling conditions won‘t be met (depends on the actuator bandwidth).
  - Vehicle to test the damper prototypes was chosen – SIGMA TN.

Activities in 4-WP11-003: Hydraulic damper with new internal architecture for semi-active control

4-WP11-003: Hydraulic damper with new internal architecture for semi-active control

Design A – DC motor

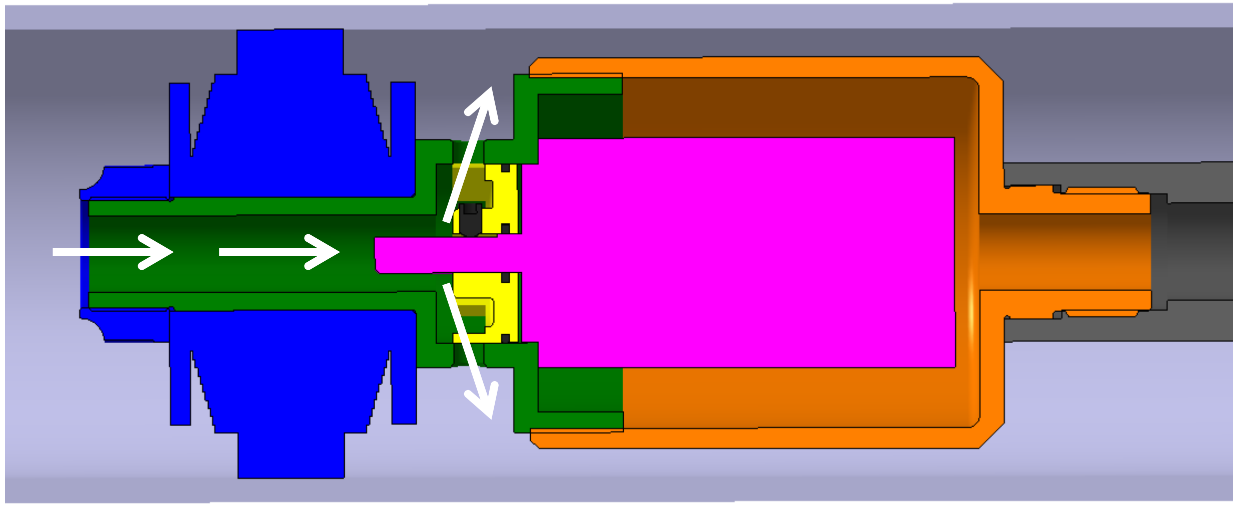
- The main idea was to incorporate faster DC motor (effect of gear ratio to moment) to the outside adjuster of the rebound needle to achieve fast regulation.
- This variant is difficult to use, it would require large motor to overcome the internal pressures during compression (also inertia forces).

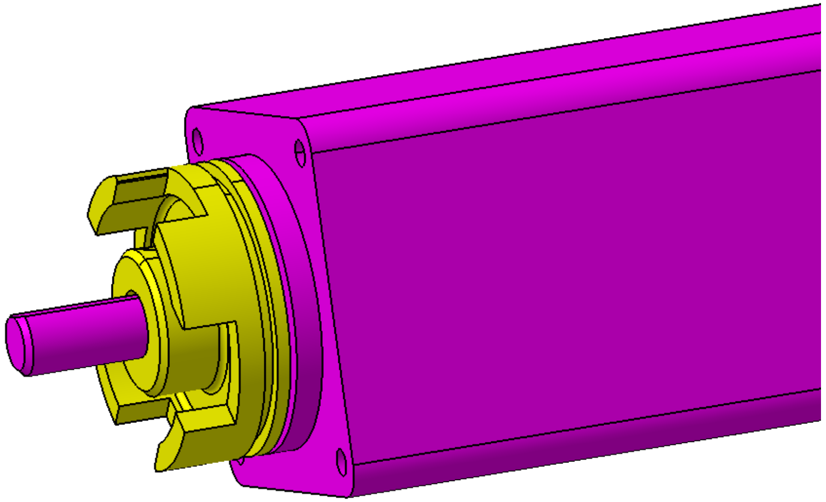


4-WP11-003: Hydraulic damper with new internal architecture for semi-active control

Design B – new architecture

- Change of valve to spool variant, actuator does not need high torque to overcome high pressures.
- Internal actuator, reduced inertia of components, better motor protection, longer damper.



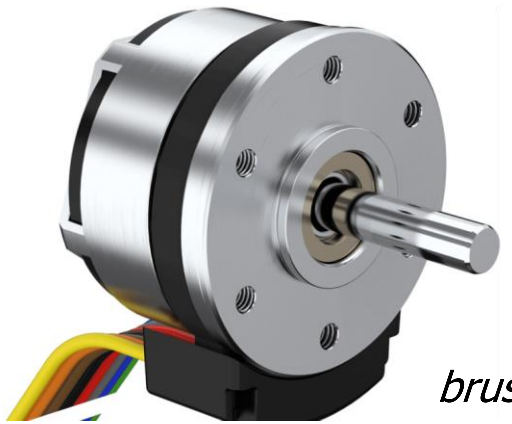


Activities in 4-WP11-003: Hydraulic damper with new internal architecture for semi-active control

4-WP11-003: Hydraulic damper with new internal architecture for semi-active control

- Two designs are created, one with a rotary proportional solenoid drive, the other with a flat DC servo motor. Originally considered stepper motor does not have a fast enough reaction.
- Both variants will be tested mainly with regard to the response speed and accuracy of spool valve position adjustment.

rotary solenoid



brushless flat DC motor

Activities in 4-WP11-004: Mathematical models of electronic control system

4-WP11-004: Mathematical model of the electronic control system

The main innovative part of the damper solution will be the control system. R&D activities focused in:

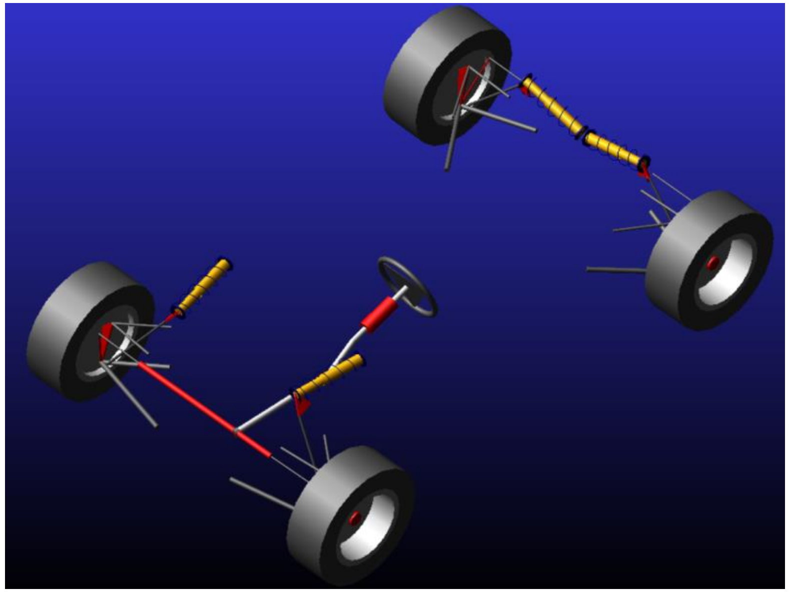
a) Simulations – multibody simulations to understand the effect of damper characteristics on vehicle handling, lookup tables for some type of manoeuvres, model of Sigma TN vehicle
b) Electronic control system – basic architecture was built, feed forward part (based on driver actuation), feedback part (yaw rate controller, wheel speed controller). Some specific functions implemented.
c) Vehicle state observers, estimators of dynamic quantities.
d) Mathematical model of the damper

Activities in 4-WP11-004: Mathematical models of electronic control system

4-WP11-004: Mathematical model of the electronic control system

a) Simulations

- Multibody model of SIGMA TN was built – inputs measured – kinematic points, weight parameters, springs, ARB, etc. – the tyre model is always a problem, solved due to cooperation with Yokohama.
- Basic set of driving manoeuvres was tested – the criterion of transmitted forces, wheel kinematics vs. wheel forces.



Activities in 4-WP11-004: Mathematical models of electronic control system

4-WP11-004: Mathematical model of the electronic control system

b) Electronic control system

- To get the robust solution with fast response, part of the control should be feed forward control (steering wheel velocity, throttle pedal rate). Measured states of the vehicle delays the reaction of the controller – because of tyre relaxation length, system clearances, measured acceleration filtration etc.
- Reference linear single track model – to calculate reference yaw rate (feedback), reference slip angle (feedback), nonlinearity factor, understeer/oversteer detection, reference lateral acceleration
- Longitudinal dynamics model – longitudinal acceleration and longitudinal wheel forces, throttle pedal signal.
- The problem is the limitation of the road friction to the reference values – later in observers, estimators
- Feed forward logic is implemented in the form of lookup tables – where the input is always the driver actuation (rate) and the reference speed.
  - Lookup tables are faster than some mathematical model implemented to the algorithm
  - Lookup table protects the intellectual property

Activities in 4-WP11-004: Mathematical models of electronic control system

4-WP11-004: Mathematical model of the electronic control system

b) Electronic control system

- Feedback control:
  - Reference value of yaw rate, slip angle and slip angle velocity is compared to measured or estimated. This value relates to additional yaw moment needed. Real time sensitivity study of the wheel load effect to the yaw moment to influence the proper wheels (set the damper valve position, or active force demand).
  - Feedback control – the wheel speed difference on the axle or between axles recognized above some dead zone, the control element of the wheel with higher rotational velocity is actuated.
- Additional vertical forces have higher effect in nonlinear range.
- Functions to control vehicle body movement will be implemented – not possible to control the body maximum movement (except high dynamic manoeuvres) with dampers, this set of functions prepared for further active system extension.
  - Feed forward roll moment is calculated
  - Feed forward pitch moment is calculated
  - Heave force is calculated

Activities in 4-WP11-004: Mathematical models of electronic control system

4-WP11-004: Mathematical model of the electronic control system

c) Control system observers and estimators

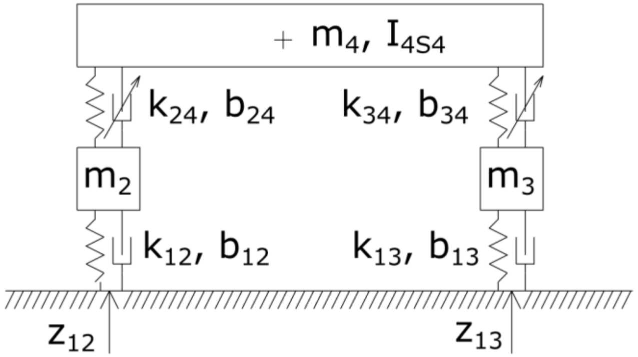
- Vehicle reference speed – input for lookup tables, all the damping characteristics vehicle speed dependent, calculation of the longitudinal wheel slip. Combination of wheel rotational velocity and acceleration integral.
- Vehicle side slip angle (sideslip angle velocity) – side slip angle velocity can be calculated without the known value of sideslip angle , EKF is used. Used also for U/S detection.
- Coefficient of friction – different approaches studied:
  - Based on tyre forces, slip velocities.
  - Based on reference vehicle model – reference and measured lateral acceleration comparison.
- Tyre forces – longitudinal, lateral (split according wheel load or with use of tyre model), normal (load transfer).
- Bank angle, road slope – only some theoretical research, implementation not started.

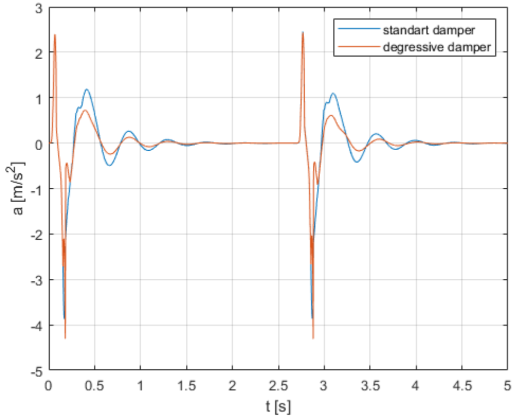
Activities in 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11-005: Damping element with innovative damping characteristics

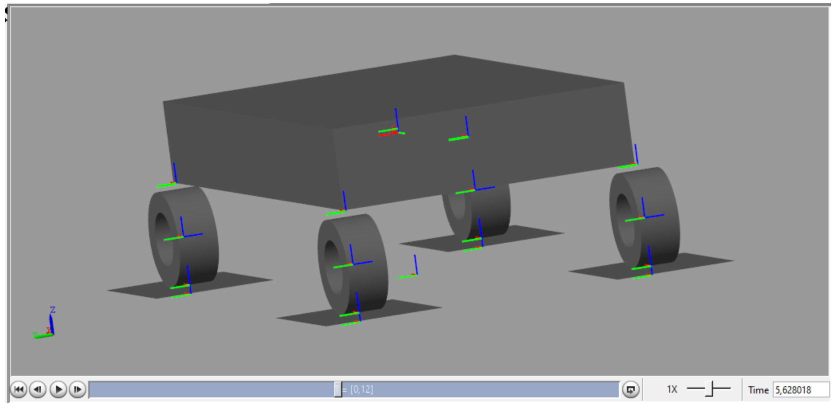
- Simulation experiment proves theoretical advantage of introduced damping element

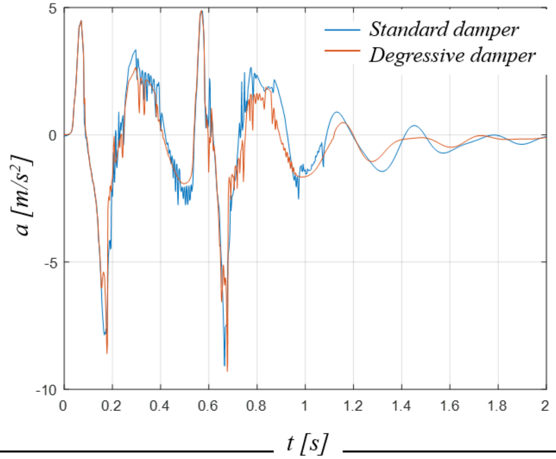
half car model





full car model





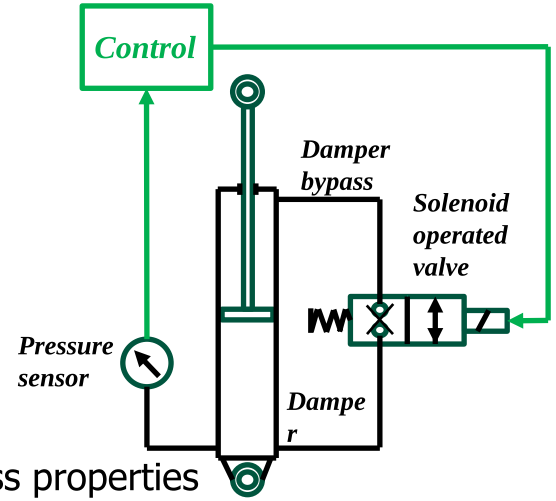
RMS comparison

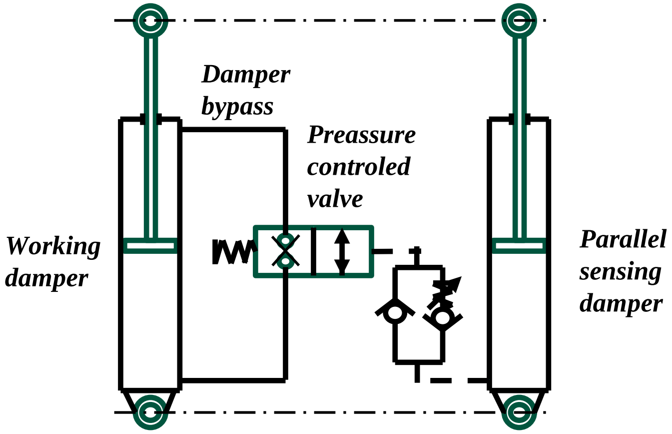
RMS	Standard dampers	Degressive dampers
Half car model	1.78	1.01
Full car model	1.98	1.65

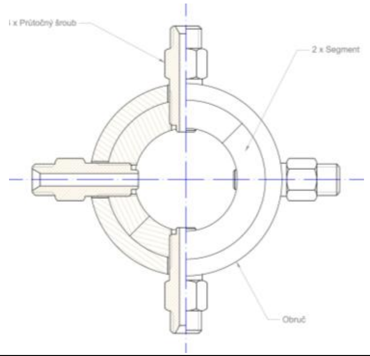
Activities in 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11-005: Damping element with innovative damping characteristics

- Innovative damper
  - Two setups are considered
    - Mechatronic solution
    - Pure mechanic solution
  - Pressure controlled bypass
- Modification of existing damper for testing purposes
  - Existing damper is not suited for high fluid flow
  - Additional adapter is designed to allow suitable bypass properties
  - Increase the volumetric flow of oil through damper bypass channels by reducing the flow resistance by increasing the flow profile area



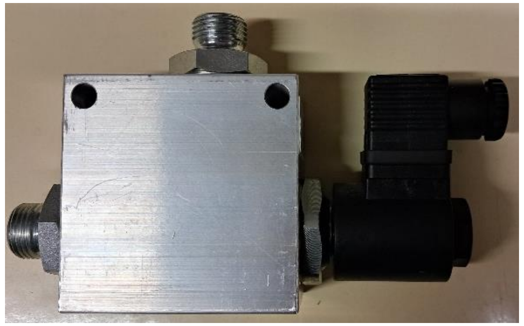


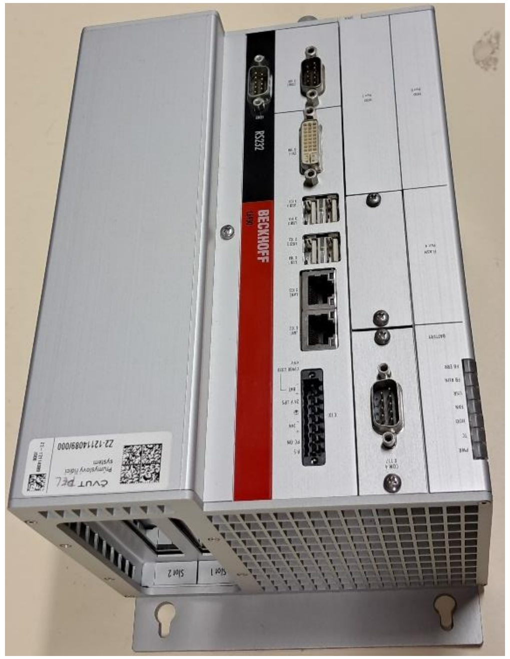


Activities in 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11-005: Damping element with innovative damping characteristics

- Functional sample – laboratory test preparation
  - Damper is equipped with adapters
  - Electrically operated valve and pressure sensor
  - Test bed (hydropulse) will be used for damper testing





Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

Current State of Deliverables and Fulfillment of Goals

- 4-WP11-001 | Software for identification of noise sources of mobile systems, R-software, BUT 0.9; TATRA 0.05; WBU 0.05 **in progress & no major delays:**
  - Designed software concept
  - Programming the beta version of the software
  - Obtaining data to initiate functional verification
- 4-WP11-002 | Set for acoustic transmission tests, G-funk, XII./2025, TUL FME 0,9 ; Skoda Auto 0,1 – **in progress & no major delays:**
  - Measurements were made at the point of storage on the actual drive unit in the vehicle, on the existing pallet system ('hard storage') and on a modified pallet system ('soft storage') with the replacement of the combustion engine.
  - Another modified actual longitudinal profile has been produced and further comparative measurements will be carried out in the near future.
  - The mechanical properties of the new storage system will also be verified in the actual operation of the test cell.
- 4-WP11-003 | Hydraulic damper with new internal architecture for semi-active control, G-funk, KAR 0.8; BUT 0.15; CTU FME 0.05 - **in progress & no major delays:**

Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

- 4-WP11-004 | Mathematical model of the electronic control system, O-Ostatní, KAR 0.7; BUT 0.25; CTU FME 0.05 **in progress & no major delays:**
  - Concept study, selection of proper construction, creation of multibody and mathematical model
- 4-WP11-005 | Damping element with innovative damping characteristics, Gfunk, XII./2025, CTU FME 0.2; BRANO 0.7; BUT 0.1 – **in progress & no major delays**:
  - Simulation experiments – car body force peaks are reduced, RMS value decreases (passenger and payload load is reduced)
  - Functional sample preparation: damper adapter is finished, test bed preparation

Activities in 4-WP11: NVH and Vibration Damping Devices for Future Vehicles

List of Due Deliverables and Their Added Value

- **4-WP11-001** - **Software for identification of noise sources of mobile systems** enables the reduction of costs and the increase of competitiveness of capabilities.
- **4-WP11-002** - deeper inside into testing of drive units of future automotive applications. Close cooperation with industrial partner (Skoda Auto) – both funded R&D projects and commercial ones.
- **4-WP11-003** – concept study of Hydraulic damper for semi-active control
- **4-WP11-004** – creation of mathematical model
- **4-WP11-005** – degresive damper for laboratory testing

Assessment of the Contribution of Deliverables

- MBS simulation of ICE – (4-WP08-003)
- Development of new components for powertrain - (3-WP13-003), (3-WP09-006), (3-WP09-003)
- Software for identification of noise sources of mobile systems – 4-WP11-001.
  - Evaluation of noise sources
  - Easier to focus on a specific source of noise and thus modify the vehicle – 3-WP11-003
  - Improving the ability to compete
- Damping elements – 3-WP10, 4-WP11

Current contribution of 4-WP11 R&D of Knowledge Database: Design Assistance SYstem - DASY

Assessment of the Formal/Administrative Goals of the Work Package

	BUT	ŠKODA AUTO	TATRA TRUCKS	BRANO	WBU	KAR	TUL	CTU FME
Finances (reporting/spending)	OK	OK	OK	OK	OK	OK	OK	OK
Commercialization (the whole organisation)	OK	OK	OK	OK	OK	OK	OK	OK
Deliverables	OK	OK	OK	OK	OK	OK	OK	OK

Current contribution of 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

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).

Výtah z prací 2023-2025 na 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11-001 Software pro identifikaci zdrojů hluku mobilních systémů

(Pavel Kučera – kucera@fme.vutbr.cz)

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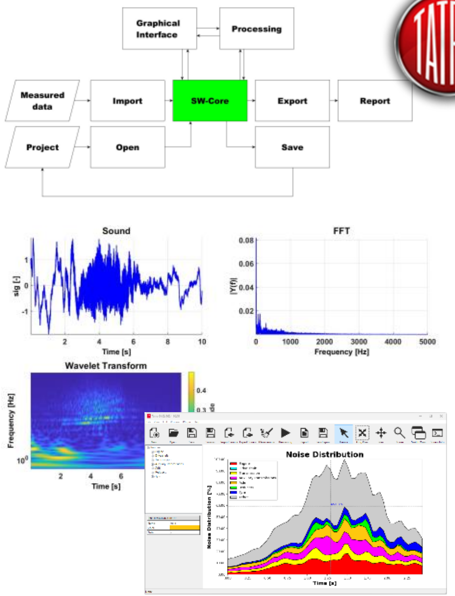
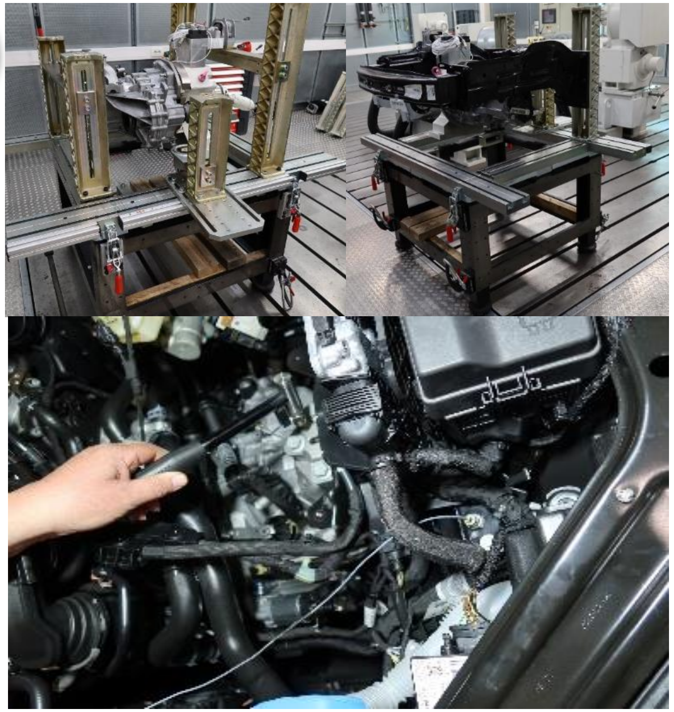


4-WP11-002 Sada pro akustické testování převodovky

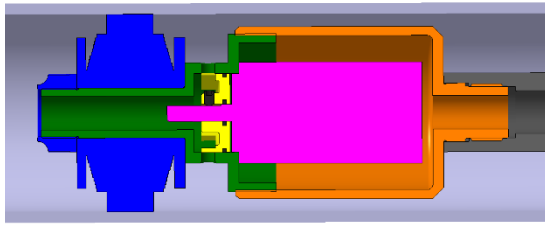
ŠKODA TUL

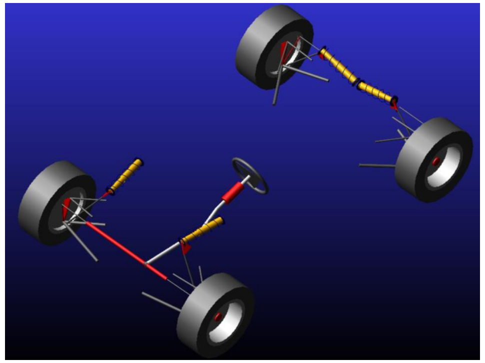


4-WP11-003 Hydraulický tlumič s novou vnitřní architekturou pro semiaktivní ovládání

4-WP11-004 Matematický model elektronického řídicího systému

KAR FAKULTA STROJNÍ ČVUT V PRAZE





4-WP11-005 Tlumicí prvek s inovativní charakteristikou tlumení

Simulační experiment: ověřena funkčnost tlumiče

Funkční vzorek: příprava experimentu, úprava tlumiče

Results of 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design–Achieved 2023-2025

4-WP11-001 Software for identification of noise sources of mobile systems
(Pavel Kučera – kucera@fme.vutbr.cz)

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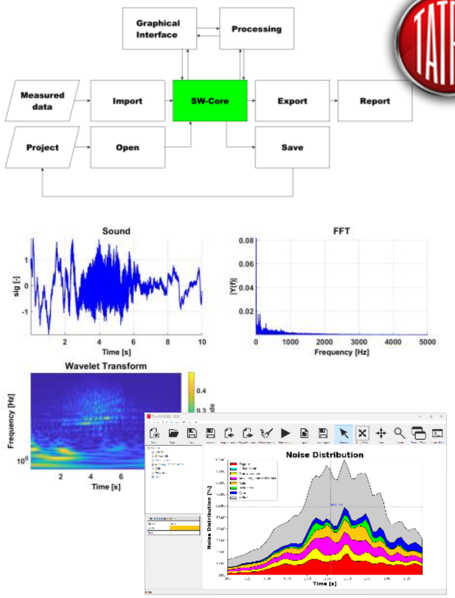
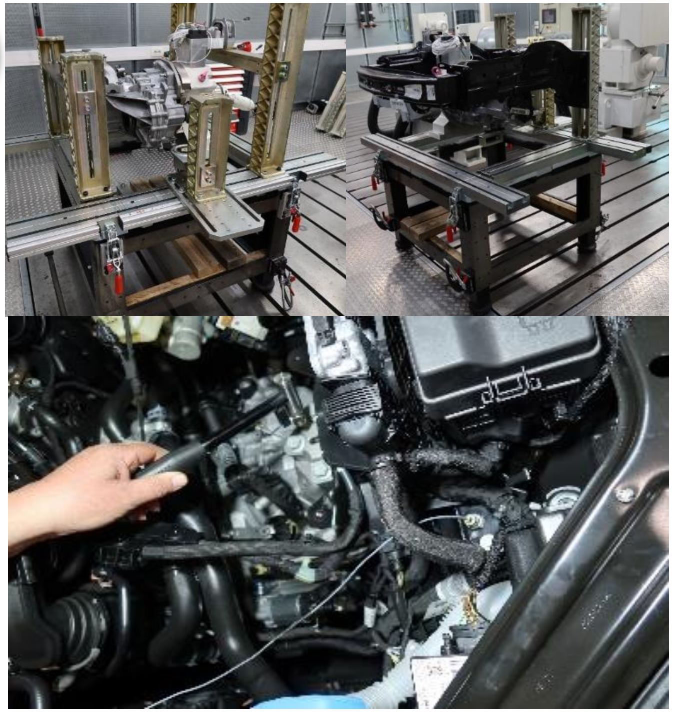


4-WP11-002 Set for acoustic transmission tests

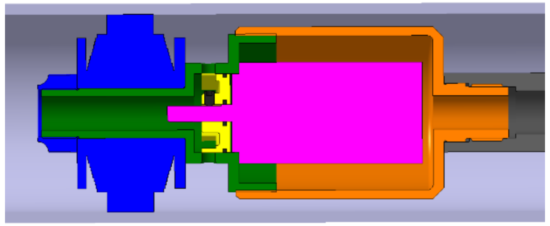
ŠKODA | TUL

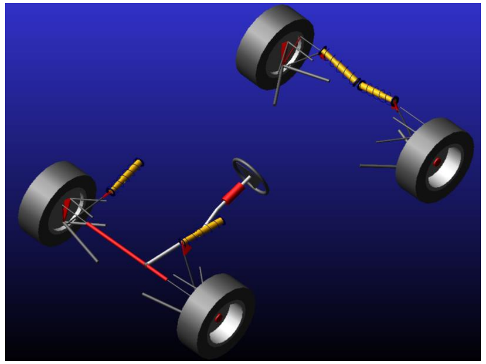


4-WP11-003 Hydraulic damper with new internal architecture for semi-active control

4-WP11-004 Mathematical model of the electronic control system

KAR | FAKULTA STROJNÍ ČVUT V PRAZE





4-WP11-005 Damping element with innovative damping characteristics
Simulation experiments: verifies expected behaviour
Functional sample preparation: test bed preparation, damper adapter

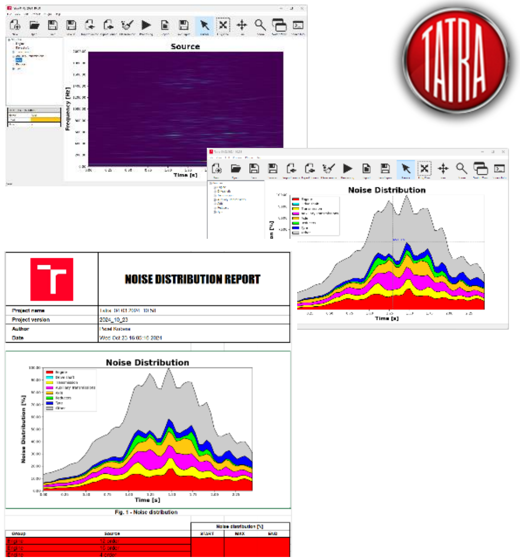
FAKULTA STROJNÍ ČVUT V PRAZE | BRANO GROUP

Výtah z prací 2024 na 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design

4-WP11-001 Software pro identifikaci zdrojů hluku mobilních systémů

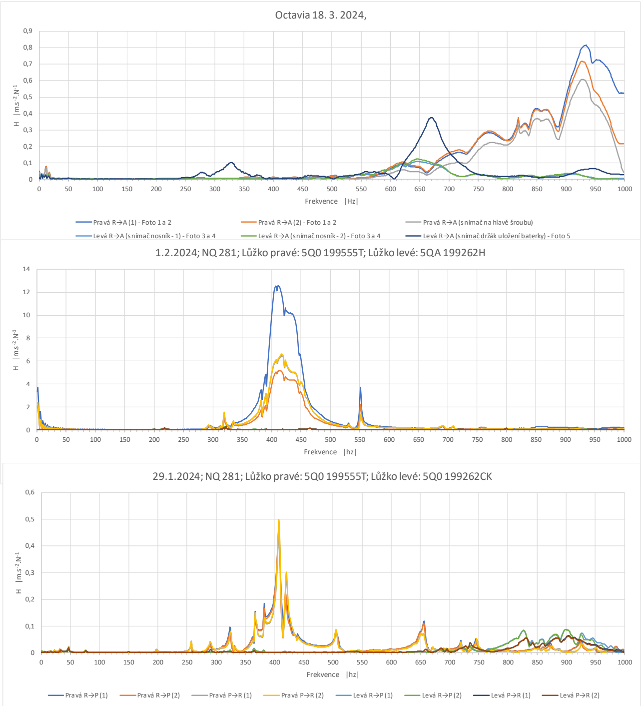
(Pavel Kučera – kucera@fme.vutbr.cz)

FACULTY OF MECHANICAL ENGINEERING institute of automotive engineering



4-WP11-002 Sada pro akustické testování převodovky

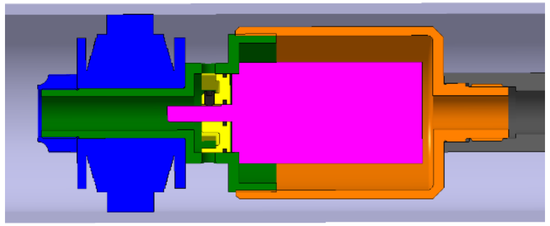
ŠKODA TUL

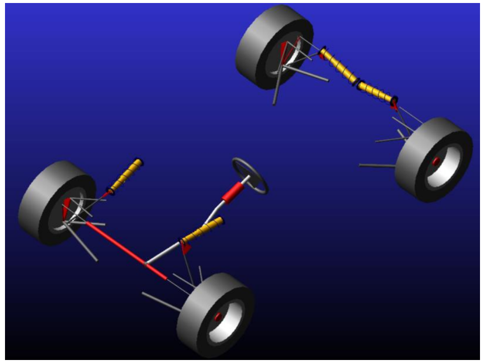


4-WP11-003 Hydraulický tlumič s novou vnitřní architekturou pro semiaktivní ovládání

4-WP11-004 Matematický model elektronického řídicího systému

KAR FAKULTA STROJNÍ ČVUT V PRAZE





4-WP11-005 Tlumicí prvek s inovativní charakteristikou tlumení

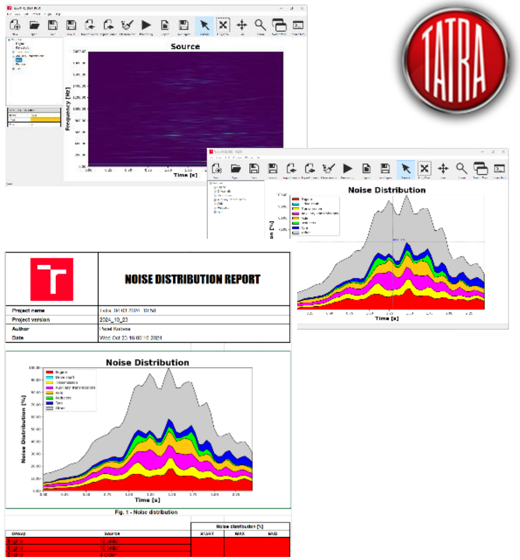
Funkční vzorek: příprava experimentu, úprava tlumiče

FAKULTA STROJNÍ ČVUT V PRAZE BRANO GROUP

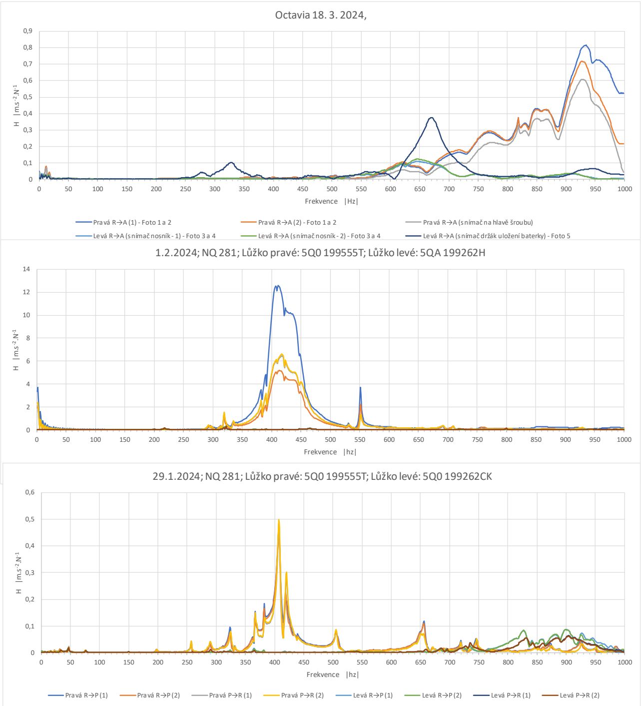
Results of 4-WP11 Vehicle Noise and Inovative Semi-Active Damper Design–Achieved 2024

4-WP11-001 Software for identification of noise sources of mobile systems

(Pavel Kučera – kucera@fme.vutbr.cz)

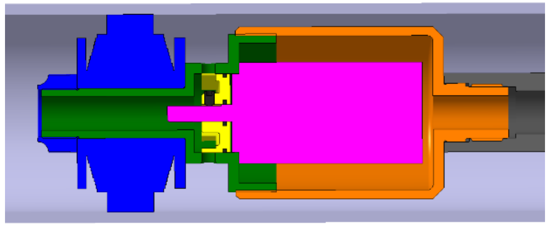


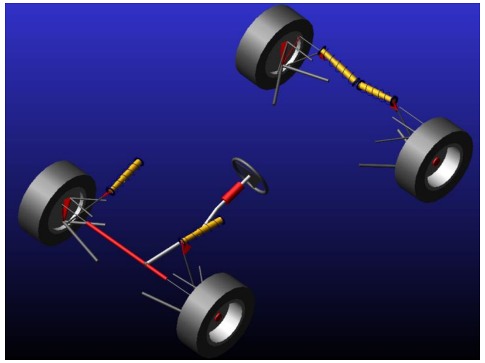
4-WP11-002 Set for acoustic transmission tests



4-WP11-003 Hydraulic damper with new internal architecture for semi-active control

4-WP11-004 Mathematical model of the electronic control system





4-WP11-005 Damping element with innovative damping characteristics

Functional sample preparation: test bed preparation, damper adapter