Potential of Vehicle Dynamics Control Systems to laterally control a Vehicle in Case of a Steering System Failure

October 2020, Steven Grall, Peter Lenz
Outline Bertrandt

1974
Foundation Bertrandt

Overall performance FY 2018/19: 1 bn Euro

About 13,600 employees

More than 50 locations in Europe, the USA and China

From the initial idea to production readiness

Design  Vehicle Body  Interior  Electronics  Powertrain  Chassis  Simulation  Testing  Engineering Services

In different Industries

Cars  Aircraft  Motorcycles  Tractors  Ships  Medical Devices  Industrial Machinery  Wind Turbines
Range of Services

Trends
- Digitalisation
- Autonomous Driving
- Connectivity
- Electric Mobility
- Vehicle Safety
- IT Services
- Virtualisation

Design Services
- Interior
- Vehicle Body
- Powertrain
- Chassis
- Simulation
- Electronics
- Modelling-/Rapid Technologies
- Simulation
- Engineering Services

Industries
- Automotive Industry
- Aerospace
- Commercial Vehicles
- Agriculture
- Motorcycle
- Electric Industry
- Mechanical-/Plant Engineering
- Medical Engineering
- Energy Management
We Want to Be Close to Our Customers – Decentralised Organisation

Round 13,000 employees at more than 50 locations in Europe, the USA and China.
Motivation

**Where we are today**

"Mechanical" steering systems

- Megatrends:
  - Electrification
  - Autonomous driving

- Regulations:
  - ECE-R 79

**Where we want to go**

Steer-by-Wire

- Key technology to autonomous driving
- New functions
- Package
- Less complexity

- Synthetic steering feel
- Risk of failure

**What is challenging us**

- Minimization of Risks
- Back up: Redundancy
- Remaining Risk

**Use of existing systems as back up systems to laterally control the vehicle in case of a steering system failure**
What could go wrong?

Failure Scenarios

- **Scenario „Loose“**
  - SbW-System without function
  - No torque on the steering rack
  - No lock of current position
  - Front Wheels can turn freely

- **Scenario „Locked“**
  - SbW-System without function
  - Front wheels will be turned into neutral position
  - Defined steering angle velocity
  - Front wheel angle gets locked at neutral position
How do we test?

**Driving Manoeuvres** *(excerpt)*

- **Steady-State circular test**
  - Driving in a circle with constant radius and constant speed

- **Slalom**
  - Consecutive left and right turns

**Test Execution:**

- Speed should be kept constant during each test
- Given trajectory should be followed
- Parameters to be varied from test to test:
  - Vehicle Speed
  - Radius
  - (lateral acceleration)

**Assumptions:**

- Friction coefficient = 1
- Parameters chosen according to Standard highway and rural roads
- Ideal actuator behaviour

**Objective:** General statement about the ability of backup systems to lateral control of the vehicle
Testing Environment

- Simulation Software: IPG Carmaker
  > Setup of test cases
  > Vehicle with electro mechanic steering system

- Development Software: Matlab/Simulink
  > Control systems
  > Simulation of steer-by-wire failure
Using longitudinal forces

1) Steer by **brake torque**
   - Using the ESP-System to brake selected wheels individually
   - Asymmetric braking creates a torque about the z-axis of the vehicle
   - *Vehicle will slow down*

2) Steer by **torque vectoring**
   - Transferring engine torque to selected wheels individually
   - Asymmetric engine torque creates a torque about the z-axis
   - *Vehicle might accelerate*

3) **Combination** of brake torque and torque vectoring
   - Required torque about the z-axis can be generated
   - Vehicle speed can be kept constant
After the switch from conventional steering to steering by longitudinal forces at 500m the brake and drive torque are applied to the related wheels to lateral control the vehicle.

The vehicle speed is increasing slightly (from 50 kph to ~53 kph)
The yaw rate stays constant after the switch from conventional steering to steering by longitudinal forces at 500m.

When the backup-system is working, most of the lateral force is generated by the rear axle.

Steady State Circular Test – Scenario “Loose”
Longitudinal Steering

<table>
<thead>
<tr>
<th>$r = 800 &amp; 1000 , m$</th>
<th>$a_y = 0,96 , m/s^2$</th>
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<tbody>
<tr>
<td>$v = 100 , km/h$</td>
<td>$\dot{\psi} = 2 , ^\circ/s$</td>
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</table>
Longitudinal Steering - Test Results

Klothoide - 'Loose'

Steer by
Longitudinal Forces

Conventional
Steering System
σ = 0° results in 45 % less required drive and brake torque in comparison to the base model
Using Rear Wheel Steering

– rear wheels turn opposite to the front wheels
– Steering torque will be mainly generated at rear axle
– Assumptions:
  > Rear axle steering angle up to 15° (comparable to front axle)
  > This system will only be used if the front wheels are locked in neutral position
Rear Wheel Steering - Results

- Rear wheel steering is taking over the lateral control at ~750m
- Difference between wheel and wheel hub angle is based on toe angle depending on the suspension position
- The peak of yaw rate and lateral acceleration are caused by the delay of 0.15s between the failure of the steering system and the takeover of the backup system at ~750m
Rear Wheel Steering - Slalom

Comparison of standard front wheel steering and Rear wheel steering
– Same radius and so following the same path
– Very similar steering angles of the affected wheels
  > Just the sign is the opposite

<table>
<thead>
<tr>
<th>Radius [m]</th>
<th>Time [s]</th>
<th>Rear Wheel Steering</th>
<th>Front Wheel Steering</th>
<th>Wheel angle [°]</th>
<th>Time [s]</th>
<th>Rear Wheel Steering</th>
<th>Front Wheel Steering</th>
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</table>

\[ r = 30 \text{ m} \quad a_y = 1,54 \text{ m/s}^2 \]
\[ v = 30 \text{ km/h} \quad \dot{\psi} = 15,9 \text{ °/s} \]
Both tested backup systems (Steer by brake & drive torque and rear wheel steering) have a potential to laterally control a vehicle with a non-functional steering system.

> Working in almost any situation we tested, when the lateral acceleration is $< 4 \text{ m/s}^2$.

> The appropriate backup systems is depending on the error case.

- Steering by brake and drive torque is more complex than steering with rear axle.

- Steering by brake and drive torque has a higher system demands.

- Torque vectoring and rear wheel steering are not available in most of the vehicles.
What is next?

- **Get closer to Reality**
  - More detailed models for the actors
  - More detailed suspension models
  - More Scenarios (e.g. “random position locked”)

- **More Simulation & Testing**
  - New driving manoeuvres
  - Wider range of curvature and speed to be looked at
  - More parameters to vary (friction coefficient)
  - Sensitivity analysis of more suspension parameters

- **Human-in-the-Loop Testing**
  - Implementing the backup systems an our dynamic driving simulator
  - Subjective evaluation of the steering feel of backup systems
Ihr Kontakt

Bertrandt Ingenieurbüro GmbH, Köln
Oskar-Schindler-Str. 10 50769 Köln
Tel.: +49 221 / 7022 - 275
Mobil: +49 175 / 325 07 09
Bennet.Gedan@bertrandt.com
www.bertrandt.com

Peter Lenz
Lead Engineer
Chassis & Vehicle Dynamics

Bennet Gedan
Team Manager
ADAS

Bertrandt Ingenieurbüro GmbH, Köln
Oskar-Schindler-Str. 10 50769 Köln
Tel.: +49 221 / 7022 - 543
Mobil: +49 151 / 147 153 32
Peter.Lenz2@bertrandt.com
www.bertrandt.com