The Synaptic Damping Control System:
increasing the drivers feeling and perception by means of controlled dampers
From ‘passive’ to ‘controlled’ suspension

Vehicle suspension systems should guarantee:

Comfort
Safety & handling

Passive suspension

Suspension tuning

Comfort vehicle
Soft suspension
Low damping suspension

Sport Vehicle
Rigid suspension
High damping suspension

Controlled suspension

Adapt its behavior to different running conditions and to driver requests

Stuttgart, 6 May 2008
The Synaptic Damping Control system

Synaptic Damping Control (SDC) is the continuous damping system by Magneti Marelli suited to control vertical vehicle dynamics and body motions, caused by road surface and by driver inputs (steering wheel, accelerator, brake, gears,..), through controlled shock absorbers.

The system is made up of the following components:

- 4 Electronically controlled shock absorbers
- 1 Electronic Control Unit (ECU)
- 3 Body Accelerometers
- 2 Front Hub Accelerometers
- Embedded SW Control strategies
- CAN node connection

Electronically controlled shock absorbers include proportional electro-valves which continuously vary their characteristics from a minimum (low command current) to a maximum (high command current) damping curve.
The Synaptic Damping Control system architecture

- Rear shock absorbers
- CAN network
- Engine control node;
- Gear-shift control node;
- ABS, EBD, ASR, VDC control node;
- Steering wheel control node;
- Body computer node.

Stuttgart, 6 May 2008
Vehicle dynamics control functionalities

Which functionalities for a controlled shock absorbers system?

- Ride comfort on uneven roads
  - Sky-Hook control
- Ride comfort in case of impulsive event
  - Hole/bump management control
- Longitudinal dynamics transients
  - Control of body pitch
- Lateral dynamics transients
  - Control of body roll
  - Control of under-oversteer

Ride comfort on uneven roads
- Sky-Hook control

Ride comfort in case of impulsive event
- Hole/bump management control
**Modal Sky-Hook control.** Function purpose is to adjust suspension damping level to optimise control of body motion and vibrations caused by road irregularities. The control law is based on the “Sky-Hook” theory.

\[
F_{\text{ref}} = C_{\text{sky}} \ddot{z} + C_{\text{rel}} (\ddot{z} - \dot{y})
\]

Optimization performed on a 3D vehicle model.
Lateral dynamics control

The function is deputed to control vehicle behaviour during lateral dynamic transients.

✓ **Basic functionality** → damping levels of shock absorbers are set in order to smooth body roll motion.

✓ **Advanced functionality** → control of the understeer - oversteer behaviour of the vehicle by adjusting the front / rear damping level balance

  ▪ as a function of the **actual turn phase** (entry, stationary, exit);

  ▪ as a function of the **acceleration (throttle-on) or deceleration (throttle-off)** requested by the driver.
The basic idea: during lateral dynamics transients the control logic increases damping level of shock absorbers.

- The front / rear damping level balance has a strong influence on the understeer / oversteer behaviour.
- The SDC control logic adjusts in real time the front / rear damping level balance as a function of:
  - actual turning phase → steering wheel angle
  - acceleration/deceleration request → gas pedal

* signals form CAN bus
Control of body roll motion

Steering wheel step input at 100 km/h (simulation results).
Control of body roll motion

Sine sweep at 120 km/h – 40° steering wheel angle (simulation results).

Frequency response diagrams
Control of body roll motion

Sine sweep at 120 km/h – 40° steering wheel angle (simulation results).
Control of understeer and oversteer during transient cornering

Introduction to the problem

Steering wheel step manoeuvre at 100 km/h (simulation results)

The front / rear damping level balance has a strong influence on the directional behaviour of vehicles.

Stuttgart, 6 May 2008
Control of understeer and oversteer during transient cornering

Sine sweep at 120 km/h – 40° steering wheel angle (simulation results)
The SDC control philosophy:

the front / rear damping level balance is adjusted in real-time during cornering.

The logic intervention is highly tunable:

it is possible to comply to different drive styles and different drivers expectations.
Control of understeer and oversteer during transient cornering

For instance, a possible goal may be: the higher promptness in turning, with the higher damping of yaw movement.

Steering wheel step manoeuvre at 100 km/h (simulation results)

- Steering angle
- Yaw rate
- Body slip angle
- Roll angle

First phase of the entry: more damping to the rear dampers.

Second phase of the entry: more damping to the front dampers.
Control of understeer and oversteer during transient cornering

SDC offers high tuning possibility → different set up for the logic intervention can be implemented in order to comply to different goals.

Theoretical graphs……..

Steering angle

Tuning parameter

Intermediate solution → it also guarantees good steer feeling

Stuttgart, 6 May 2008
Control of understeer and oversteer during transient cornering

Steering wheel step manoeuvre at 100 km/h (experimental results)

Steering angle

……experimental graphs

Yaw rate
Control of understeer in throttle-on manoeuvres

Without understeer control

With understeer control

Experimental results, front-wheel drive car
Control of oversteer in throttle-off manoeuvres

Without oversteer control

Oversteer effect

Counter steer action needed

Experimental results
Control of oversteer in throttle-off manoeuvres

With oversteer control: Strong reduction of oversteer

Without oversteer control

Experimental results

US-OS control ON

US-OS control off
The goal of the hole/bump management module is to optimize comfort and road holding in case of wheels impact against an obstacle (positive or negative) on the road.

- During rectilinear path, the main goal is to optimize comfort.
- During cornering, the main goal is to optimize road holding.
  - by reducing hubs vibrations;
  - and so reducing yaw rate disturbances and guaranteeing good trajectory control.
- The SDC hole/bump management module is able to
  - rapidly recognize the presence of the event by monitoring vertical accelerations of front wheels;
  - recognize the sign of the event (hole or bump);
  - act on the rear dampers in a predictive way;
  - differently manage symmetrical and asymmetrical events;
  - differently manage events during rectilinear path and during cornering.
Hole and bump management during rectilinear path

Good comfort → reduction of peak to peak of seat guide vertical acceleration

Positive obstacle 100 x 25 mm at 30 km/h. Seat guide vertical acceleration. Experimental results.
Hole and bump management during cornering

Cornering manoeuvre at 40 km/h with 80° steering wheel angle. Positive obstacle on the external wheel. Experimental results.

Good trajectory control → reduction of yaw rate disturbances

-19% Increment of yaw rate caused by the impact against the rear wheel

- A strong reduction of the increment of yaw rate is possible with SDC control
- A strong reduction of hubs vibrations is possible with SDC control
Longitudinal dynamics control

- This function controls body pitch movement caused by longitudinal acceleration jerk induced by driver actions on
  - gas pedal
  - clutch pedal
  - gearbox
  - brake pedal.

- Damping levels of shock absorbers are set in order to control dive and squat body motion.

The basic idea: during longitudinal dynamics transients the control logic increases damping levels of shock absorbers.
Control of body pitch movement

Tip in/tip out in 1\textsuperscript{a} gear @ 100\% gas pedal

Stuttgart, 6 May 2008
Control of body pitch movement

Braking from 100 km/h

Input driver

Brake pressure

Vehicle Speed

Pitch Angle

Pitch Velocity

Passive

Controlled

Max pitch velocity

Average on different tests

Stuttgart, 6 May 2008
Conclusions

- Control strategies, based on the classical Sky-Hook theory, allow a perceptible improvement of comfort performance in case of controlled dampers.

- The ride comfort application represents only a first step in the use of controlled dampers.

- The Synaptic Damping Control strategies are designed in order to increase the drivers feeling and perception.

  ✓ Improvement of handling characteristics of vehicles

    - Control of body roll
    - Control of understeer and oversteer during transient cornering
    - Control of understeer and oversteer caused by throttle-on and throttle-off
    - Minimization of yaw rate disturbances caused by impacts against obstacles during cornering
    - Control of body pitch

  ✓ All these control strategies give the vehicle more stability and allow greater driving pleasure, without compromising vertical comfort.
Thank You!