ACOCAR active suspension

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Contents

- Introduction
- Active suspension hardware
- Quarter car test rig
- Skyhook quarter car control
- Experimental skyhook control results
- Conclusion
Introduction

- Tuning of a **passive** automotive suspension is always a compromise between comfort and road holding performance.
- **Semi-active** suspensions can break this compromise because they can change their characteristics in real time, but can only dissipate energy.
- **Active** suspensions offer increased performance since they can add energy to the system and generate suspension movements if necessary.
- This presentation will compare the performance of a passive suspension with that of the controlled semi-active and active ACOCAR (Actively COnrolled CAR) suspension, developed by Tenneco.
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Acocar system overview

- **Acocar corner consists of:**
  - 1 constant flow pump.
  - 1 damper/actuator with 2 servo-valves to control its force.
  - 1 ultracapacitor to flatten out peak currents.

- **Active mode:**
  pump flow of 5 l/min in normal operation.

- **Semi-active mode:**
  pump is switched off.
Acocar system packaging options

- Lightweight design under development:
  - Aluminium valve block & outer tube
  - Plastic spring seats and dust cover

- 4 separate power packs (1 for each corner), or combine the 2 pumps of 1 axle on 1 electromotor?

- System with or without anti-roll bars?
  - With anti-roll bars:
    - Mechanical fail-safe for roll stiffness
    - Roll stiffness available in semi-active mode
  - Without anti-roll bars:
    - Easier packaging
    - Lower weight
Active suspension hardware

- Semi-active force region only in passive quadrants.
- Active region increases with pump flow rate.
- Actuator force independent of velocity.
- All forces can be generated by adjusting the appropriate servo-valve and keeping the other one open.
Acocar system targets: performance

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Quarter car test rig

- 25 kN hydraulic actuator to apply road inputs.
- Rear left suspension mounted on a sliding frame.
- Sprung mass = 350 kg, unsprung mass = 45 kg.
- Excellent repeatability.
Sensors & real-time control system

- Accelerometers on sprung and unsprung mass.
- Linear displacement sensor to measure relative suspension movement.
- String potentiometer to measure absolute displacement of sprung mass.
- PC with dSpace 1103 board to control test rig and active suspension and to log measurements.
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Skyhook quarter car control

- Pure skyhook damping = proportional to the absolute velocity of the sprung mass.
- Damping as if the car was suspended to a fixed point in the sky.
- Additional term is added to provide some passive damping, proportional to relative suspension velocity.

\[ f_d = b_g \cdot v_b + r_g \cdot v_r \]
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Experimental skyhook control results

- Sine excitation: 1.5 Hz, 0.015 m

passive

active

semi-active
Experimental skyhook control results

- Body displacement peak to peak reduced from 88.5 mm with passive damper to 30.3 mm (34 %) in semi-active mode and 4.7 mm (5.3 %) in active mode (5 l/min)
- Pump flow rate of 5 l/min is sufficient
Experimental skyhook control results

- Pink noise excitation:
  - $f = 1 - 20$ Hz,
  - $x = +/- 0.025$ m,
  - $v = +/- 0.7$ m/s

passive  active  semi-active
Semi-active performance

- Acceleration (measure for comfort) vs. tyre force variation (measure for handling & safety).
- Semi-active skyhook control reduces body acceleration to 85% of the level obtained with the passive reference damper.
- Also tyre force variation is reduced to 70%.
Active performance

- Improved performance for comfort in active mode: reduction of acceleration to 80% of passive level with pump flow rate of 5 l/min.
- Higher pump flow rate (10 l/min) reduces body acceleration even further on rough road profiles: reduction to 62% of passive level!
- Performance for handling comparable to semi-active mode: reduction of tyre force variation to 70% of passive level.
Active performance

5 l/min

10 l/min

0.3 Hz - 30 Hz frequency band

normalized tyre force variation RMS

body acceleration RMS [m/s²]

rg = 0
rg = 500
rg = 1000
rg = 1500
rg = 2000
rg = 3000
rg = 4000

fixed currents
Passive shock

0.3 A
0.8 A
1.6 A

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ACOCAR power consumption

- Full semi-active function possible with pump off
- Pump flow rate of 5 l/min
  - In soft: 60 W (hydr.) avg. / corner
  - 110 W (elec.) avg. / corner
  - (potential to go lower with additional short-cut valve)
  - On worse road profile or in extreme handling conditions:
    - max. avg. 130 W (hydr.) / corner
    - max. avg. 240 W (elec.) / corner
- Pump flow rate of 10 l/min
  - Worst case:
    - max. avg. 420 W (hydr.) / corner
    - max. avg. 760 W (elec.) / corner
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## Acocar Performance: Ultimate comfort & safety

<table>
<thead>
<tr>
<th></th>
<th>Sine 1.5 Hz, 15 mm</th>
<th>Sine 15 Hz, 3 mm</th>
<th>Random bad road</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Body displacement peak to peak [mm]</td>
<td>Tyre force variation peak to peak [N]</td>
<td>Body acceleration RMS [m/s²]</td>
</tr>
<tr>
<td>Passive damper</td>
<td>88.5 (100 %)</td>
<td>4360 (100 %)</td>
<td>1.00 (100 %)</td>
</tr>
<tr>
<td>Semi-active</td>
<td>30.3 (34 %)</td>
<td>1380 (32 %)</td>
<td>0.85 (85 %)</td>
</tr>
<tr>
<td>Active (5 l/min)</td>
<td>4.7 (5.3 %)</td>
<td>1350 (31 %)</td>
<td>1.18 (118 %)</td>
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<tr>
<td></td>
<td></td>
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<td>0.80 (80 %)</td>
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<td>1.05 (105 %)</td>
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<td></td>
<td></td>
<td></td>
<td>0.62 (62 %)</td>
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<td>1.22 (122 %)</td>
</tr>
</tbody>
</table>

- Feasibility proven on 1/4 car
- Ability to control driver inputs:
  - body displacement reduced to **5 %** on sine
  - elimination of body roll & pitch
- Ability to control road inputs:
  - body acceleration reduced to **62 %** of passive level on rough road
Acocar Performance: Ultimate comfort & safety

- Working on production intended design with integrated pump
- Starting to build prototype car
- Target EU platforms (SOP 2012-): top limousines and performance cars