CONTROLLING AUTOMOTIVE TEST RIGS

A review of industrial control methods for dynamic vehicle and component testing in the laboratory

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Introduction

• The dynamic testing of vehicle structures and components in the laboratory to determine their mechanical properties (dynamic characteristics, durability etc.) is an essential part of automotive R&D.
• Test apparatus designed to replicate real-world forces and motions requires accurate control of actuators.
• Algorithms which are currently used in the testing industry, both new and well established, are reviewed.
• As both the required forces and frequency range are often high, electrohydraulic actuation is typically used.
Automotive testing in the laboratory

• suspension and axle durability testing and characterisation
• tyre and wheel testing
• steering testing
• crash testing to assess occupant safety systems
• pedestrian impact testing
• exhaust system durability testing
• seat, dashboard, and trim vibration testing
• engine and driveline characterisation
• full vehicle testing – characterisation for ride, handling and durability
1960s | 1970s | 1980s | 1990s | 2000 -
---|---|---|---|---
Servohydraulics | Analogue control | Digital control and multi-axis systems
Track testing | Simulation | Lab testing

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• Multi-axis control
  – Motion-compensated load control
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Example actuator response

Total mass $M = M_s + M_a$

Specimen

$K_s$, $C_s$, $f_0$

$P$, $q$, $x_s$

Amplitude (m/s/100%)

Phase

Model

Actual

Frequency (Hz)

Frequency (Hz)
Proportional + Integral (PI) controller

Linear model [1]:

Valve dynamics

Cylinder/specimen dynamics
Hydraulic resonance

e.g. 50Hz hydraulic resonance

Valve bandwidths of:

- 50Hz
- 100Hz
- 200Hz

Resonance compensation:

- acceleration feedback
- differential pressure or load feedback
- a first order lag
- a notch filter
- A cross-port bleed
High performance single-axis control
e.g. pedestrian impact testing
New non-linear model-based closed-loop controller [2]

Required test velocity → Velocity trajectory generator

Command velocity - Partial inverse model → Actuator

Actual velocity - Closed-loop compensator → Predicted velocity

Residual dynamics model

- +

Predicted velocity

- +
Iterative Control

- Target signal vector \( w_t \)
- Initial drive signal vector, \( r_{t,1} \)
- Previous command signal vector, \( r_{t,i-1} \)
- Command signal vector \( r_{t,i} \)
- Error signal vector from previous iteration, \( e_{t,i-1} \)
- Error signal vector for current iteration, \( e_{t,i} \)

Diagram:

- Inverse model
- Gain (<1)
- Closed-loop plant
- Transducers (e.g., acceleration, strain)
- Vehicle response signals

Mathematical expressions:

\[
\begin{align*}
\text{Closed-loop plant} & = w_t + r_{t,1} + r_{t,i-1} + r_{t,i} + e_{t,i-1} + e_{t,i} \\
\text{Response signal vector} & = y_{t,i}
\end{align*}
\]
Frequency domain iteration

- First used for 4-post testing in 1976 [3]

System identification
\[
H(\omega_k) = S_{yr}(\omega_k)S_{rr}^{-1}(\omega_k)
\]
\[
J(\omega_k) = \left[H^T(\omega_k)H(\omega_k)\right]^{-1}H^T(\omega_k)
\]

Start
\[
i=0; \quad y_{t,0} = r_{t,0} = 0
\]

Determine error
\[
e_{t,i} = w_t - y_{t,i}
\]
\[
e_{t,i} \Rightarrow E_i(\omega_k)
\]

Error acceptably small?
Yes → Stop
No → Update drive signal
\[
\Delta R_i(\omega_k) = J(\omega_k)E_i(\omega_k)
\]
\[
\Delta R_i(\omega_k) \Rightarrow \Delta r_{t,i}
\]
\[
r_{t,i+1} = r_{t,i} + \alpha_i \Delta r_{t,i}
\]
Non-linear iterative control
e.g. hydraulic catapult
for occupant restraint testing [4]
Calculating command signal

Target acceleration → Inverse Dynamic Model → Valve command signal

- Target acceleration
- Inverse Dynamic Model
- Valve command signal
Results
Motion compensated load control

Valve cross-compensation
Motion compensated load control

Variable valve cross-compensation
e.g. steering test rig
Motion compensated load control

Specimen motion feedforward [5]
Co-ordinate transformation

e.g. Suspension test rig
Model-in-the-loop testing [6]

Integration of physical testing with real-time computer simulation

e.g. Real axle and road input
linked to virtual chassis
Model-in-the-loop testing

Errors at the interface

- Interface loads
- Disturbances
- E.g. Load controlled actuators

- External loads (virtual)
- Numerical model
- Actuator dynamics

- Measurement noise
- Sensor dynamics
- Physical system
- Interface displacements
- External loads (real)
Summary

Where PI control is inadequate, a variety of techniques are available which:

- use a modified feedback controller
- and/or, shape the command signal

Use of ‘outer-loop’ methods to shape the command signal based on previous trials (iterative control) has proved very successful over many years.

Various ways of cross-coupling individual actuator controllers are routinely used in multi-axis rigs.

Non-linear model-based controllers are now used for specialist applications (both for closed-loop and iterative control).

Model-in-the-loop testing … many applications but challenging for fast dynamics.

Refs