Modeling and Factor Analysis of Hydraulic Power Steering Systems for Rotational Steering Vibration by Using MSC.ADAMS

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This presentation presents a study on the rotational vibration sensitivity of automotive hydraulic power steering systems by using MSC.ADAMS. The results are used to predict the effect of specification change and provide countermeasure ideas for reducing the level of steering rotational vibration.
Contents

- Introduction
- Modeling approach
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- Application
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Introduction

Steering vibration is a major NVH issue that affects overall NVH comfort in passenger cars.

Two types of fundamental steering vibrations:

- Vertical/lateral translational vibration
- Rotational vibration

Focus of this study
Introduction

**Rotational steering vibration:**
mainly caused by excitation force acting on the steering rack due to:
- tire/wheel imbalance → “Steering shimmy”
- braking torque fluctuation → “Brake judder”

Normal frequency range: 15Hz – 20Hz

Steering system behaves exactly the same for both steering shimmy and brake judder
Introduction

**Purposes:**

- Analyze the sensitivity of steering rotational vibrations to the excitation force acting on steering rack;
- Guide steering system tuning for reducing steering vibration;
- Achieve an important step toward full transmissibility analysis of vibration from road wheel to steering wheel.

**Challenge:**

- Non-linear dynamic coupling between the steering rack-pinion mechanism and the hydraulic sub-system.
Modelling Approach

Hydraulic power steering system

Hydraulic system

Mechanical mechanism

PRODUCT DEVELOPMENT CONFERENCE

2004 Virtual Huntington Beach, California
Modelling Approach

Mechanical rack-pinion mechanism

- Rigid bodies model
- Non-linear elements: friction, damping, backlash
- Coupling with hydraulic sub-system
Modelling Approach

Hydraulic sub-system

- Include fluid compressibility & inertia
- Can include steering damper, as needed
- Each component model is pre-validated with test data (0-30Hz)
Modelling Approach

Model built on ADAMS/View & ADAMS/Hydraulics

Coupled vibrations between mechanical & hydraulic sys.

Customized friction
For hydraulic rubber sealing

Non-linearity
Stiction, sliding friction & backlash
Modelling Approach

**Gearbox friction**
- Based on inverted sliding test
- Velocity-friction function was identified

**Control valve characteristics**
- Based on gearbox torque-pressure test
- Relative opening function was identified

**Rubber parts stiffness & damping**
- Based on excitation measurement
- Data at proper range of frequency were used

**Friction profile**
- Customized for hydraulic rubber sealing
- Created by using “STEP” functions
Model Validation

*Bench test system*

- Steering rack
- Steering wheel
- Steering column
- Steering rack
- Hydraulic supply
- Data acquisition
- Vibration shaker

**Exciting amplitude:**

- 100N-360N

**Exciting frequency:**

- 10Hz-25Hz

Produce repeatable data for model validation
Model Validation

Comparison of measured & simulated results – time domain

Different amplitudes, same frequency

Excitation force

Steering rack acceleration

Input shaft acceleration

Cylinder differential pressure

Steering wheel acceleration

Excellent agreement between simulation and measurement, even for different exciting force levels
Model Validation

Comparison of simulated & measured results – frequency domain

- Excitation force
- Steering rack acceleration
- Input shaft acceleration
- Cylinder differential pressure
- Steering wheel acceleration

Frequency domain data show an excellent agreement.
The model can predict the nonlinear vibration behavior very well.
Model Validation

Comparison of measured & simulated results

Different frequencies, same amplitude

Excellent agreement between simulation and measurement for exciting frequency range 10-20Hz
## Application

**Factor analysis by using ADAMS/Insight**

### Chart: Change of steering wheel vibration with SPEC variation from 75% to 125%

- **Vibration decrease**
- **Vibration increase**

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<th>Factor</th>
<th>Vibration Effect</th>
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- Quantify the effect of steering factors
- High efficiency, without actual tests
Application

Sensitivity analysis

Steering wheel vibration sensitivity to rack excitation force

Excitation frequency (Hz)

1st order
2nd order
Improved

Improve the steering vibration sensitivity by the virtual tuning of critical factors
The simulation tool is used to predict the effect of specification change on steering rotational vibrations.
Conclusions

✓ A simulation tool for analyzing the fluid-mechanically-coupled, rotational steering vibration sensitivity of hydraulic power steering systems has been created, by using MSC.ADAMS.

✓ The simulation model was well correlated with an actual steering system under various excitation conditions corresponding to steering shimmy and brake judder.

✓ It has been proven to accurately predict the non-linear, coupling vibration behavior of steering mechanical and hydraulic sub-systems within the frequency range of interest.

✓ The tool has been used to identify the most influential steering factors, provide countermeasure ideas, predict the effect of steering part change, and integrate with the models of other sub-systems to perform full transmissibility analysis.