Simulation based
Power Steering Hose
Design and Optimization

Dr. Heiko Baum
FLUIDON GmbH
Jülicher Strasse 336
52070 Aachen
# Table of contents

1. **Introduction**

2. Current situation of hydraulic pipe and hose simulation

3. Development of a library for flexible hose elements

4. A development methodology for automotive lines

5. Presentation of example lines

6. Summary
Historical Highlights of IFAS - Institute for Fluid Power Drives and Controls

As nationally and internationally recognized research institution, the IFAS is and has been pioneering many developments in Fluid Power technology.

60’s: Beginnings of servo hydraulics, fluidics

70’s: Basis of cavitation research, servo pneumatics, pump controlled systems

80’s: Digital control, development of DSHplus (simulation tool), proportional / directional control cartridge valves, secondary control

90’s: Pre-compression chamber in piston pumps, fuzzy control, bio fluids, piezo technology, sealing engineering (bleed-by effect)

present: Coating technology, condition monitoring

The Institute’s Development

1968: IFAS is founded as "Institut für hydraulische und pneumatische Antriebe und Steuerungen" - IHP in short. Under Professor Backe’s direction, two academic and six non-academic staff members are employed in the very beginning.

1977: The Institute now moves into its own large experimental hall with attached office building in the RWTH Expansion Area Seffent-Melaten. Now, there is room for about 50 test-stands, workshops, laboratories, computer rooms and a library.

1994: Concurring with the succession to the direction of the Institute and to the professorship by Professor Murrenhoff is the change of the Institute’s name. Today, about 25 academic staff members, 20 non-academic employees and approx. 40 student assistants are working under the grammalogue IFAS. Founding of FLUIDON as Spin-Off

1998: Opening of the expansion building which offers additional space for offices as well as computer, seminar and conference rooms thus giving more capacity for R&D tasks.
Laboratory and test rig recourses at IFAS

IFAS disposes two experimental laboratory buildings which are equipped with workshops and laboratories and give excellent opportunities to deal effectively with R&D tasks. The newest measuring technology for all fluid power values is available.

- floor space about 1250 m² room for approx. 60 test rigs
- 2 clamping beds (5 x 3m), 70 ton foundation, 2 clamping beds (3 x 2.5m)
- 5 sound proof closets, 35 ton foundations
- anechoic room for sound measurements, (6.5 x 8m), drives 200 kW
- passable climatic test room (4.75 x 3.3 x 3m), -70 °C to +70 °C, 20% to 95% relative humidity
- valve test stand max. 315 bar
- max. 500 l/min. ageing test rigs for hydraulic fluids tribo tester
Introduction

Current situation of hydraulic pipe and hose simulation

Development of a library for flexible hose elements

A development methodology for automotive lines

Presentation of example lines

Summary
Thematic introduction

• The inside noise level of a vehicle represents an essential decision feature for the purchase decision of the customer. To satisfy this consumer expectation, it is nowadays extremely important that a potential source of noise, vibration or harshness (NVH) is identified and eliminated as early as possible in the development process.

• A known source for noise which can lead to NVH problems within the vehicle is the fluid-borne noise, issued by the pump of the hydraulic power steering. Currently the design and optimization of power steering hoses is mainly done by costly hardware tests.

• The adaptation of the automotive hose lines requires a high effort since hardware prototypes are optimized up to the desired maturity degree by means of test rig or vehicle tests. Without the amplified use of CAE tools a cost optimal development on schedule of new automotive hose lines in future can be only handled with difficulty.

• What was missing till now, for a time-domain-based simulation, were suitable models for the flexible hose parts. As a result of the cooperation of FLUIDON GmbH and a manufacturer of automotive hoses these models are available now and a simulation-based development methodology for automotive lines can be presented.
1. The combination of rubber material and cord netting of the hose is responsible for a viscous-elastic behavior that determinates its damping characteristics (Figure 1).

2. The reinforcement material has either a more linear (steel braiding) or viscous-elastic (polyamid yarn) behavior. Due to the relative movement between the reinforcement layers there is moreover a static friction (coulomb friction) in the hose sleeve, which affects the damping characteristics as well. Some literature sources propose linear/viscoelastic damper models that are in a series connection to represent the reinforcement layers (Figure 2).

3. Up to now there is no physical model available that describes such behavior. However there are some approaches available that use measured material properties for simplified replacement models (Figure 3).
Pressure variation of an one-chamber hose line at 60 °C

Druckvariation einer Ein-Kammer-Schlauchleitung bei 60 °C
Temperature variation of an one-chamber hose line at 50 bar

Temperaturvariation einer Ein-Kammer-Schlauchleitung bei 50 bar

Figure 9
Fingerprint of an one-chamber line at 50 bar – 60 °C
Vergleich zweier Ein-Kammer-Leitungen bei 50 bar – 60 °C
Fingerprint of a two-chamber line at 10 bar - 40 °C

Vergleich zweier Zwei-Kammer-Leitungen bei 10 bar und 40 °C

Figure 11

Hose 1 Hose 2

Hose 1 Hose 2

Hose 1 Hose 2

Hose 1 Hose 2
<table>
<thead>
<tr>
<th></th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td>2</td>
<td>Current situation of hydraulic pipe and hose simulation</td>
</tr>
<tr>
<td>3</td>
<td>Development of a library for flexible hose elements</td>
</tr>
<tr>
<td>4</td>
<td>A development methodology for automotive lines</td>
</tr>
<tr>
<td>5</td>
<td>Presentation of example lines</td>
</tr>
<tr>
<td>6</td>
<td>Summary</td>
</tr>
</tbody>
</table>
1. Test rig measurements:
Variation of hose length from 100 mm to 500 mm.
Each hose at 40, 60, 80°C and at 10, 50, 100 bar
Prüfstandsmessungen: Variation der Schlauchlänge von 100 mm bis 500 mm. Jeder Schlauch bei 40, 60, 80 °C und bei 10, 50, 100 bar

2. Identification of Hose Material Characteristic
Identifikation der Schlauchmaterialcharakteristik

3. Calculation of material characteristics
Berechnung der Materialcharakteristik
Example of a steering system model with complex feed line

Beispiel eines Lenksystemmodells mit komplexer Versorgungsleitung

Basic resonator types

Basistypen für Resonatoren

- Helmholtz resonator
- Pipe resonator

Source: DELPHI product data sheet to power steering hoses

This copyrighted document is the property of FLUIDON GmbH and is disclosed in confidence. It may not be copied, disclosed to others, or used for manufacturing, without the prior written consent of FLUIDON GmbH
Examples for fittings and flexible hose elements

Beispiele für Installationen und flexible Schlauchelemente
Flexible hose library and simulation model of a two-chamber line

Dehnschlauchbibliothek und Simulationsmodell einer Zwei-Kammerdehnschlauchleitung
1. Assignment of geometric parameters

Zuweisung von geometrischen Parametern
Introduction

Current situation of hydraulic pipe and hose simulation

Development of a library for flexible hose elements

A development methodology for automotive lines

Presentation of example lines

Summary
Development methodology for automotive hose assemblies

Entwicklungsmethodik für automobile Dehnschlauchleitungen

Start

Obtain CAD Data and Packaging Space Information

Define Power Steering Hose Design

Assemble Hose Model from DSHplus Hose Component Library

Assign Fluid Properties from DSHplus Fluid Data Base

Prepare Parameter Sets for Batch Processing

Assign Material Specific Properties from DSHplus Hose Material Data Base

Review Results

Is Design Criterion Met?

Use Design

Modify Design

End

Obtain CAD Data and Packaging Space Information

Define Power Steering Hose Design

Assemble Hose Model from DSHplus Hose Component Library

Assign Fluid Properties from DSHplus Fluid Data Base

Prepare Parameter Sets for Batch Processing

Assign Material Specific Properties from DSHplus Hose Material Data Base

Review Results

Is Design Criterion Met?

Use Design

Modify Design

End
Development methodology for automotive hose assemblies

Entwicklungsmethodik für automobile Dehnenschlauchleitungen

Start

Define Power Steering Hose Design

Assemble Hose Model from DSH plus Hose Component Library

Assign Fluid Properties from DSH plus Fluid Data Base

Assign Material Specific Properties from DSH plus Hose Material Data Base

Prepare Parameter Sets for Batch Processing

Conduct Simulation Analysis (Single PC or Simultaneously on Multiple PC-Systems)

Compute Transfer Matrixes (If Hose Optimization, Compare with Hardware Measurements)

Review Results

Is Design Criterion Met?

Use Design

Modify Design

End

Obtain CAD Data and Packaging Space Informations

Conduct Simulation Analysis (Single PC or Simultaneously on Multiple PC-Systems)

Compute Transfer Matrixes (If Hose Optimization, Compare with Hardware Measurements)

Review Results

Is Design Criterion Met?

Use Design

Modify Design

End
<table>
<thead>
<tr>
<th></th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Introduction</strong></td>
</tr>
<tr>
<td>2</td>
<td>Current situation of hydraulic pipe and hose simulation</td>
</tr>
<tr>
<td>3</td>
<td>Development of a library for flexible hose elements</td>
</tr>
<tr>
<td>4</td>
<td>A development methodology for automotive lines</td>
</tr>
<tr>
<td>5</td>
<td>Presentation of example lines</td>
</tr>
<tr>
<td>6</td>
<td>Summary</td>
</tr>
</tbody>
</table>
Simulation model of a two-chamber line

Simulationsmodell einer Zwei-Kammer-Leitung
Example for an optimization of a two-chamber line

Beispiel für die Optimierung einer Zwei-Kammer-Leitung

Configuration A

Configuration B

Figure 23
Simulation model of a one-chamber line with steel tuner

Simulationsmodell einer Ein-Kammer-Leitung Stahltuner
Example for a robustness analysis of the steel tuner line

Example für eine Robustheitsanalyse der Stahltunerleitung

\( T_{11} \) represents the transfer function of pressure input (pump side) to pressure output (steering gear side)

**Blue:** Measured transfer function

**Red:** Simulation with exact geometrical values

**Grey:** Simulation with tolerated geometrical values
Sensitivity analysis of the tuner length

Sensitivitätsanalyse der Tunerlänge

\[ l_{\text{Tuner}} = 170 \text{ mm (} +50 \text{ mm)} \]
Sensitivity analysis of hose and pipe length

Sensitivitätsanalyse der Schlauch- und Rohrlänge

\[ l_{\text{Tuner}} = 170 \text{ mm}, \ l_{\text{Hose} \cdot 1a} = +500 \text{ mm}, \ \Sigma l_{\text{Pipe} 1, 2} = -500 \text{mm} \]
Sensitivity analysis of hose and pipe length

Sensitivitätsanalyse der Schlauch- und Rohrlänge

\[ l_{\text{Tuner}} = 170 \text{ mm, } l_{\text{Hose}, 1b} = +500 \text{ mm, } \Sigma l_{\text{Pipe}, 1, 2} = -500 \text{ mm} \]
Sensitivity analysis of hose and pipe length

$T_{\text{11}}$

$T_{\text{12}}$

$T_{\text{21}}$

$T_{\text{22}}$

$|l_{\text{Tuner}}| = 170\text{ mm}$, $|l_{\text{Hose}\cdot 1c}| = +500\text{ mm}$, $\Sigma |l_{\text{Pipe}\ 1, 2}| = -500\text{ mm}$
Sensitivity analysis of throttle diameter

Sensitivitätsanalyse des Drosseldurchmessers

$l_{Tuner} = 170 \text{ mm}, \quad d_{Throttle} = 5 \text{ mm}$
Sensitivity analysis of throttle position

Sensitivitätsanalyse des Drosselposition

$l_{\text{Tuner}} = 170 \text{ mm}, \ l_{\text{Hose}\cdot 1a} = + 50 \text{ mm}, \ l_{\text{Hose}\cdot 1b} = - 50 \text{ mm},$
1 Introduction

2 Current situation of hydraulic pipe and hose simulation

3 Development of a library for flexible hose elements

4 A development methodology for automotive lines

5 Presentation of example lines

6 Summary
Summary

• By means of the new DSH\textsuperscript{plus} automotive hose library it is now possible to start the design of automotive lines using a virtual prototype. Based on a set of basic line elements the optimization of such lines can be automated using computer simulation.

• About variations of the geometry parameters a sensitivity and robustness analysis can very comfortably be carried out for the line design, e.g. by means of Doe techniques. The custom-designed application of automotive hose lines is not only accelerated by this, effort and costs for final tests with hardware prototypes are also reduced considerably.