IMPROVED MATERIAL DAMPING FOR SQUEAL PREDICTION BY SIMULATION (CEA)

Michael Klein, Bertold Kirchgäßner

www.INTES.de
IMPROVED MATERIAL DAMPING FOR SQUEEAL PREDICTION BY SIMULATION (CEA)

MICHAEL KLEIN, BERTOLD KIRCHGAESSNER
WWW.INTES.DE
CONTENTS

• Motivation
• Damping - Why Material Damping?
• Material Damping in COMPLEX EIGENVALUE ANALYSIS (CEA)
• NEW ACCURATE METHOD FOR MATERIAL DAMPING
• EXAMPLE
  – INVESTIGATION SHIM AND BRAKE MATERIAL
  – BY SAMPLING
• Conclusion
Stiffness and mass is represented in FEA model for CEA very good:
• Easy to input, long time experience about modeling.

Damping mechanisms are more complex to represent in FEA model:
• More Difficult to measure,
• Many different sources like: mechanisms, properties and geometry.

That is why some analysts neglect damping, but better methods provide the chance to increase accuracy and to improve predictability a lot.

Objective:
• excluding “wrong” potential squeal frequencies of CEA and
• higher accuracy of results (equivalent viscous damping ratio).

With higher accuracy of damping, investigations with focus on damping becomes more meaningful.
• Many damping models: Rayleigh damping, material damping, viscous damping, modal damping, damping by friction (interfaces).
• Besides the damping in friction interface between pad and disk, material damping has the biggest influence.
• Material damping is characteristic and main damping factor for elastomer coatings of shims and also brake pad material.

Why material damping is not widely used today?
Material damping is defined for harmonic motion only.

State of the art: material damping is replaced by one equivalent viscous damping which produces at one specific frequency, the reference frequency $f_{ref}$, the equal damping force as material damping.
Viscous damping force
Proportional to the velocity
\[ F_{D,\text{visc}} \sim \omega d \]

Material damping force
Proportional to the strains (displacements)
\[ F_{D,g} \sim g k \]

Equal damping forces at
\[ f_{\text{ref}} = \frac{kg}{2\pi d} \]

If the eigenfrequency is higher than the reference frequency, the resulting damping is too low, if lower too high.
Example: realistic brake model
- Material damping at pad (0.05) and shim elastomer coating (0.05)

1. Squeal Modes at different Frequencies
2. Contribution of Real Modes with different frequencies
Squeal modes typically consist of several real modes with contribution between 0% to 30%. Only one single reference frequency leads to wrong damping for many contributions.
New approach:
Individual reference frequency derived from each real Eigenmode
Viscous damping is derived from material damping by individual reference frequency

Advantages:
Equivalent damping force is the same for material damping and viscous damping for all individual frequencies
No underestimation or overestimation of damping
Higher accuracy of damping
Higher accuracy of results
Old approach - several runs with different reference frequency – no longer necessary, new approach saves time, by single run!
Reference frequency for converting material damping to viscous damping = **1000Hz**

Two complex modes with squeal tendency are displayed:
- Mode 35 at about 1062 Hz
- Mode 120 at about 4695 Hz
Reference frequency for converting material damping to viscous damping = 4500Hz

According to theory the equivalent damping force is lower at higher reference frequency for all modes

This results in higher risk of squeal followed by CEA

\[ f_{ref} \]

<table>
<thead>
<tr>
<th>Reference Frequency</th>
<th>Equiv. Viscous Damping Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 Hz</td>
<td></td>
</tr>
<tr>
<td>4500 Hz</td>
<td>unstable</td>
</tr>
</tbody>
</table>

**C-Mode 35**: \( \approx 1062 \text{Hz} \)

**C-Mode 120**: \( \approx 4695 \text{Hz} \)
New approach with usage of individual frequencies for converting material damping to viscous damping shows best results

For c-mode 35 the result is same as with reference frequency 1000 Hz

For c-mode 120 the result is same as with reference frequency 4500 Hz

Damping force is correct for each complex mode

No longer several analyses are required to get correct results

Potential complex modes disappear or appear dependent on former material damping settings
Why INTES always uses this result as indicator?
+ Descriptive and corresponds to Lehr’s damping measure 
(Lehrisches Dämpfungsmaß) (from single degree of freedom 
system; 1-Massen-Schwinger)
+ Equivalent viscous damping ratio (evdr) similar (factor 0.5) 
results like the often used effective damping ratio (edr)
+ Evdr works also good for supercritical damping (general view 
on rotor dynamics), and delivers similar picture as edr for 
lower damping
+ All other results also available: frequency, real part, imaginary 
part, damp coefficient, circular frequency

Solution of the homogeneous equation in state space:
\[ \ddot{x}(t) = \ddot{x} \exp(\nu t) = \ddot{x}_i e^{\delta_i t} (\cos \omega_i t + i \sin \omega_i t) \]

Eigenvalues:
\[ \lambda = \lambda_R + i \lambda_I \]
Frequency of harmonic part:
\[ \omega_i \]
Damping coefficient:
\[ \delta_i \]
Equivalent viscous damping ratio*:
\[ \xi_i = \frac{-\delta_i}{\sqrt{\delta_i^2 + \omega_i^2}} \]
Effective damping ratio:
\[ \zeta_i = \frac{-2\delta_i}{|\omega_i|} \]
Complex modes:
\[ X_c = X_{c,R} + iX_{c,I} \]
EXAMPLE APPLICATION

Realistic brake model
1.0 million Elements
3.8 million DOF
12.000 CA DOFs

Complex Eigenvalue Analysis (CEA)
Real Eigenvalues until 10,000 Hz
Complex Eigenvalues until 6,700 Hz
40 Rotational speeds

Investigation Shim
Now with higher accuracy material damping and thickness of elastomer coating it is worth to study by simulation
Brake pad model

3 layer shim 0.8mm
- 1. layer elastomer coating 0.05mm, material damping 0.05
- 2. layer steel 0.65mm
- 3. layer elastomer coating 0.1mm, material damping 0.05

Backplate 5mm
Brake material 10mm (material damping 0.05)

Investigation by Sampling

Modify thickness of shim layers
Keep overall thickness of shim (0.8mm), keep same design space
Modify material damping of the two shim elastomer coatings
Sampling is used to investigate in the influences!
DEFINITIONS

4 Design Variables:
Material damping
   1. Coating to backplate (mat damp 0.05) +/- 50%
   2. Coating to piston (mat damp 0.05) +/- 50%
Thickness of shim layer
   - Overall thickness kept the same
   3. Coating to backplate (0.05mm) +/- 0.01mm
   4. Coating to piston (0.1mm) +/- 0.01mm

Result check:
Sum of equivalent viscous damping ratios for lowest six squeal modes

Investigations:
2 values per design variable
16 analysis loops (all possible combinations)
Run time: only 12 minutes for one analysis loop*
   - 10,000 Hz real Eigenvalues
   - 7,000 Hz complex Eigenvalues
   - 3,800,000 DOF
   - 40 rotational speeds
Definition of loop:
Damping has no influence on static contact analysis ⇒ not included in the loop.
Change of layer thickness by keeping the overall shim thickness has nearly no influence, too.
Loop over part 2 and 3 of CEA process is sufficient!

Advantages:
Decision about contents of loop by engineer based on the requirements.
Shorter run times:
• Excluding unnecessary analysis
• Reading of model data only once
Automatic combination of all parameter values
xy-history graph of design variable values

DV_1
DV_101

DV_2
DV_102

thickens change of elastomer coating

material damping change of elastomer coating
Thickness change of elastomer coating to backplate dominant (biggest changes) (DV_1).
Thickness change of outer elastomer coating nearly neglectable (DV_2).
Material damping changes on both sides show equivalent changes.
Lowest indication of squeal noises shown by sample 13 and 15.
0.075% damping for both coatings and thick inner coating to backplate.
CONCLUSIONS

Material damping is important.
New approach for considering material damping in CEA shows improved accuracy for all frequencies simultaneously.
Repetition of CEA with different reference frequencies no longer required to get accurate results. Run time saved!
Possible reduction of potential squeal modes by simulation, makes it easier to identify the ‘true’ squeal modes. Better predictability!

Adjustment of shim material damping behavior by CEA now meaningful.
Integrated sampling reduces run time in contrast to separate solutions (e.g. model input only once, small loop).
Our (INTES) mission is to improve accuracy and reduce run time for virtual development with PERMAS!
CONTACT INFORMATION

Michael Klein
INTES GmbH
Stuttgart, Germany

www.intes.de
klein@intes.de