37TH ANNUAL
BRAKE COLLOQUIUM
& EXHIBITION

IMPROVED MATERIAL DAMPING FOR SQUEAL PREDICTION BY SIMULATION (CEA)

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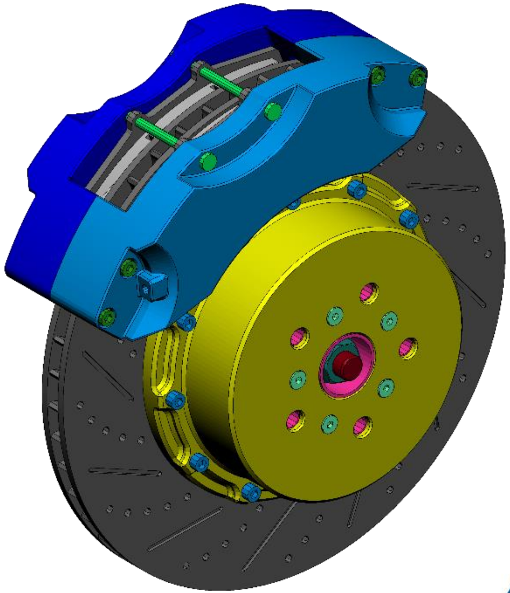

MOTIVATION

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.

MATERIAL DAMPING

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- 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 VERSUS MATERIAL DAMPING

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Viscous damping force

Proportional to the velocity

$$F_{D,visc} \sim \omega d$$

Material damping force

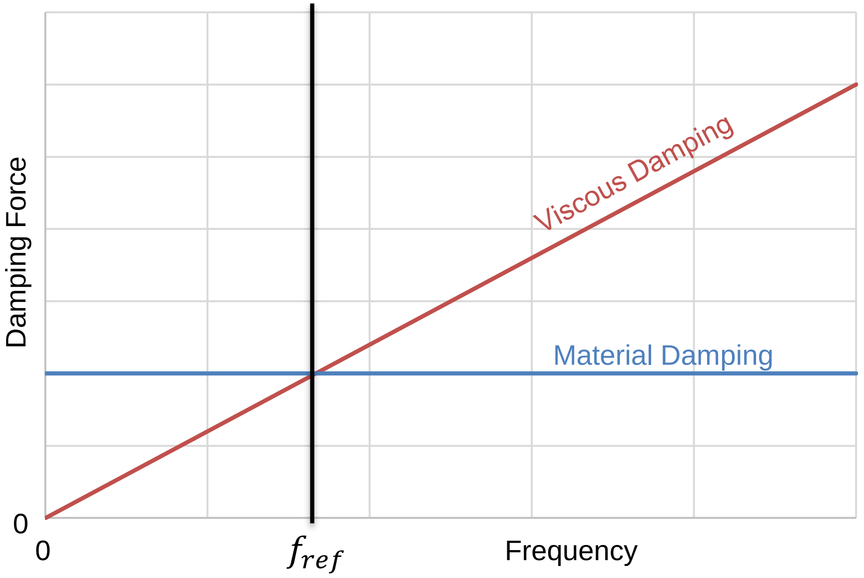
Proportional to the strains (displacements)

$$F_{D,g} \sim gk$$

Equal damping forces at

$$f_{ref} = \frac{kg}{2\pi d}$$

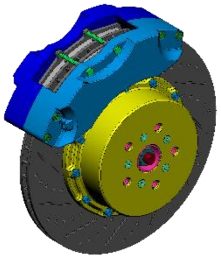
If the eigenfrequency is higher than the reference frequency, the resulting damping is too low, if lower too high.

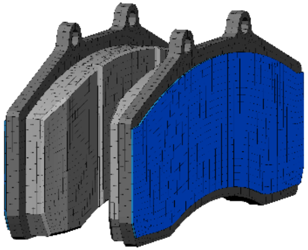


TWO PLACES OF INACCURACIES

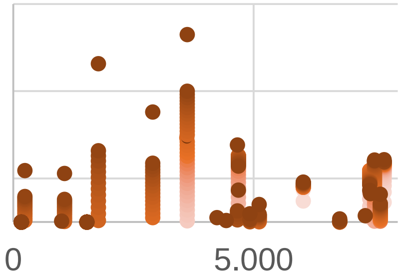
Example: realistic brake model

- Material damping at pad (0.05) and shim elastomer coating (0.05)

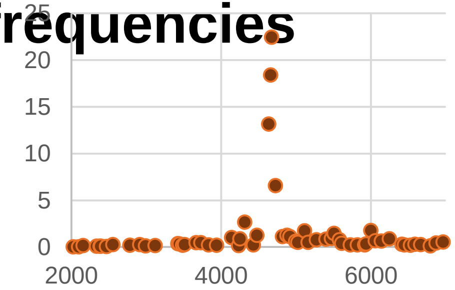




1. **Squeal Modes at different Frequencies**



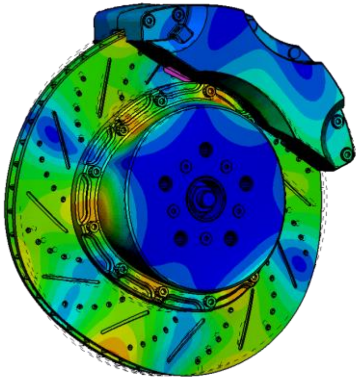
2. **Contribution of Real Modes with different frequencies**



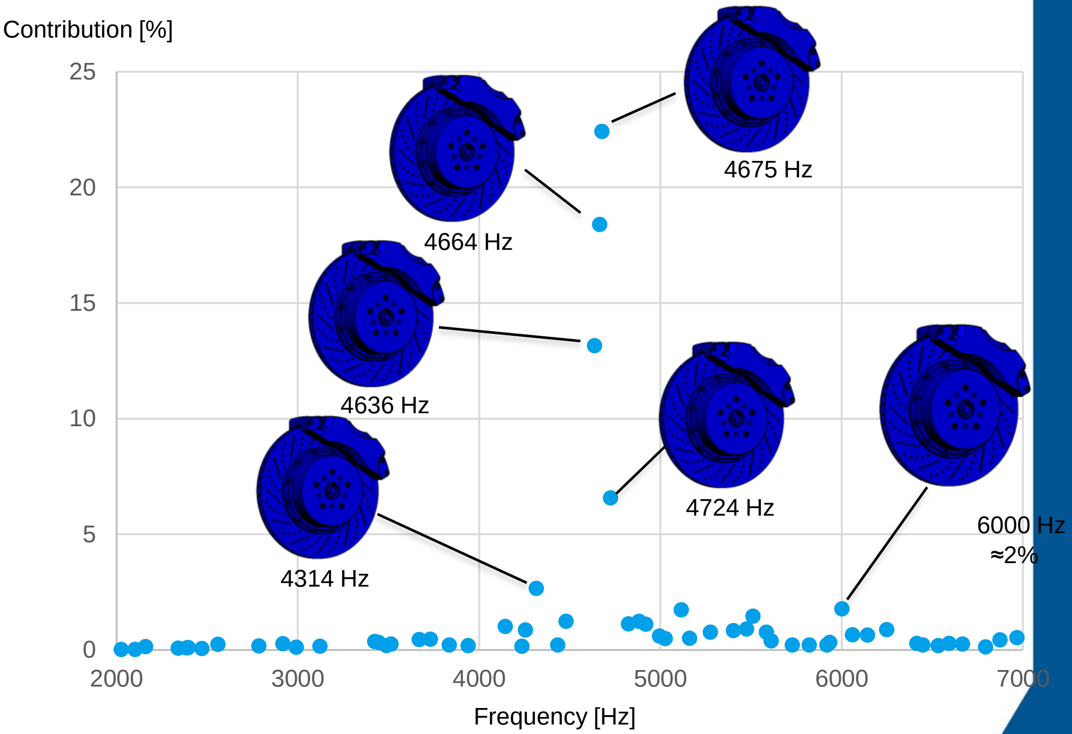
MODE CONTRIBUTION

Squeal modes typically consist on several real modes with contribution between 0% to 30%.

Only one single reference frequency leads to wrong damping for many contributions.



4603 Hz



TRUE TO FREQUENCY – MATERIAL DAMPING

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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 FREQUECY = 1000 Hz

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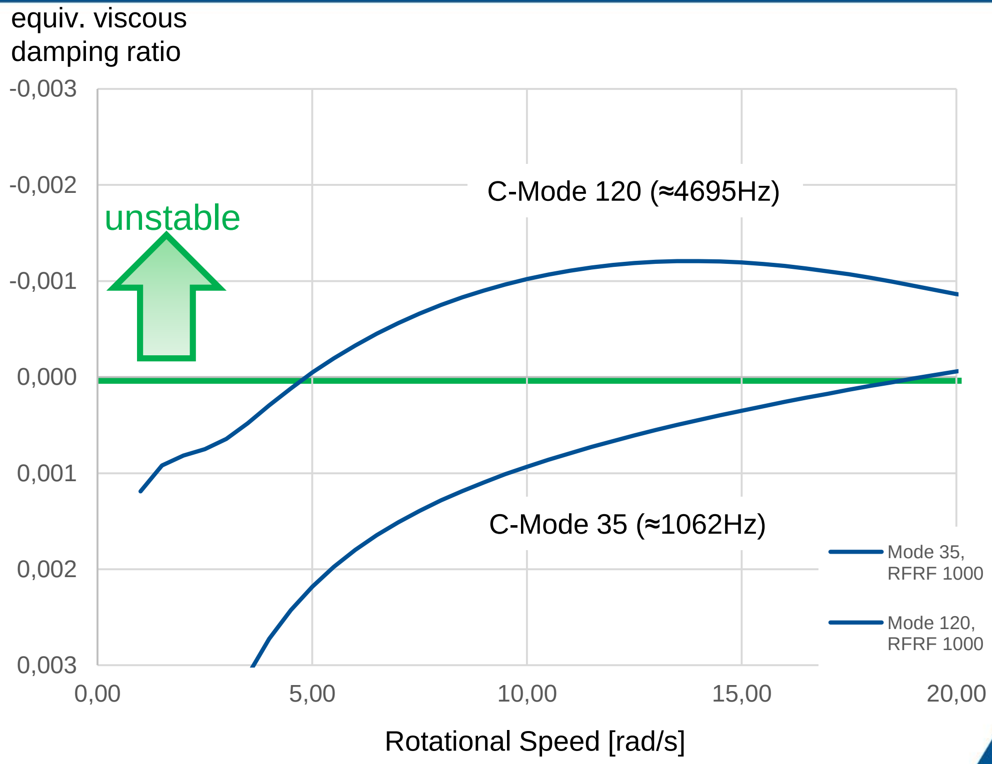
Reference frequency for converting material damping to viscous damping = 1000Hz

Two complex modes with squeal tendency are displayed:

Mode 35 at about 1062 Hz

Mode 120 at about 4695 Hz

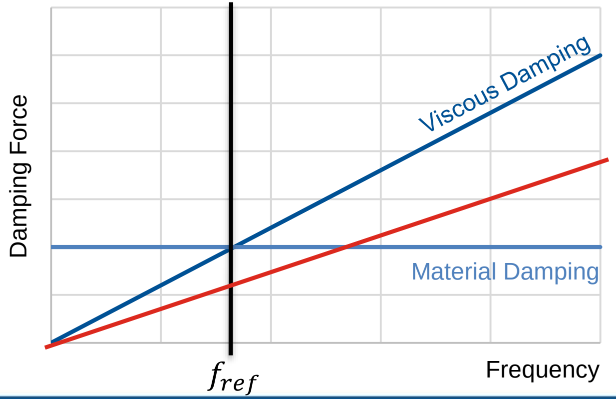


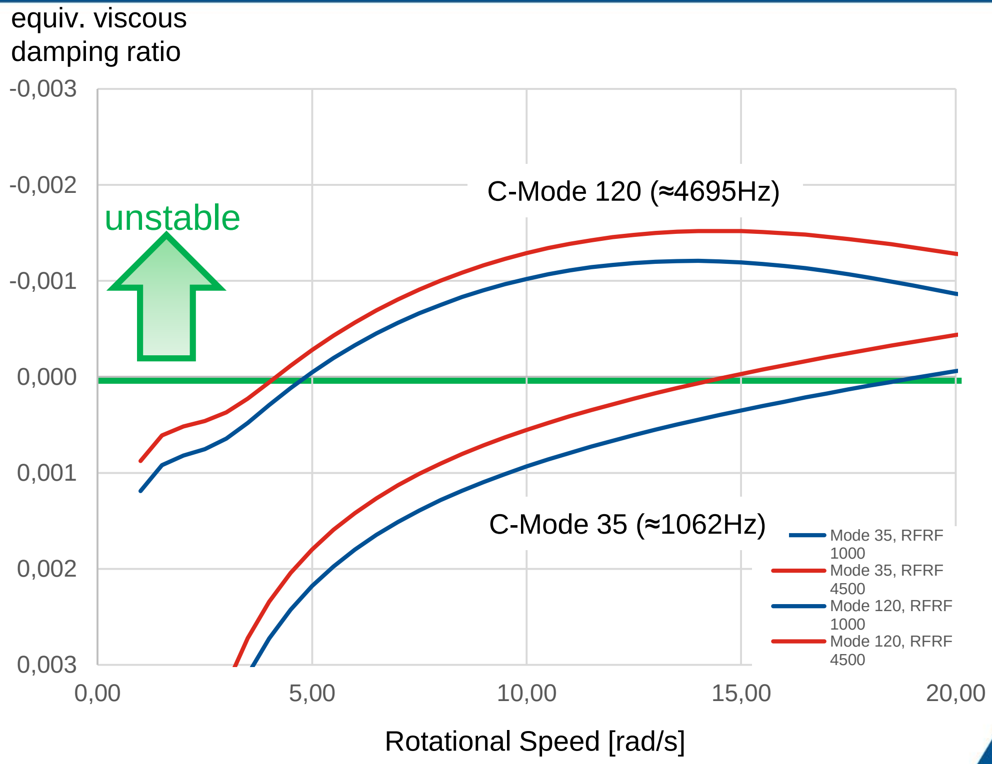
REFERENCE FREQUECY = 1000 Hz vs. 4500 Hz

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





REFERENCE NEW APPROACH

New approach with usage of individual frequencies for converting material damping to viscous damping shows best results

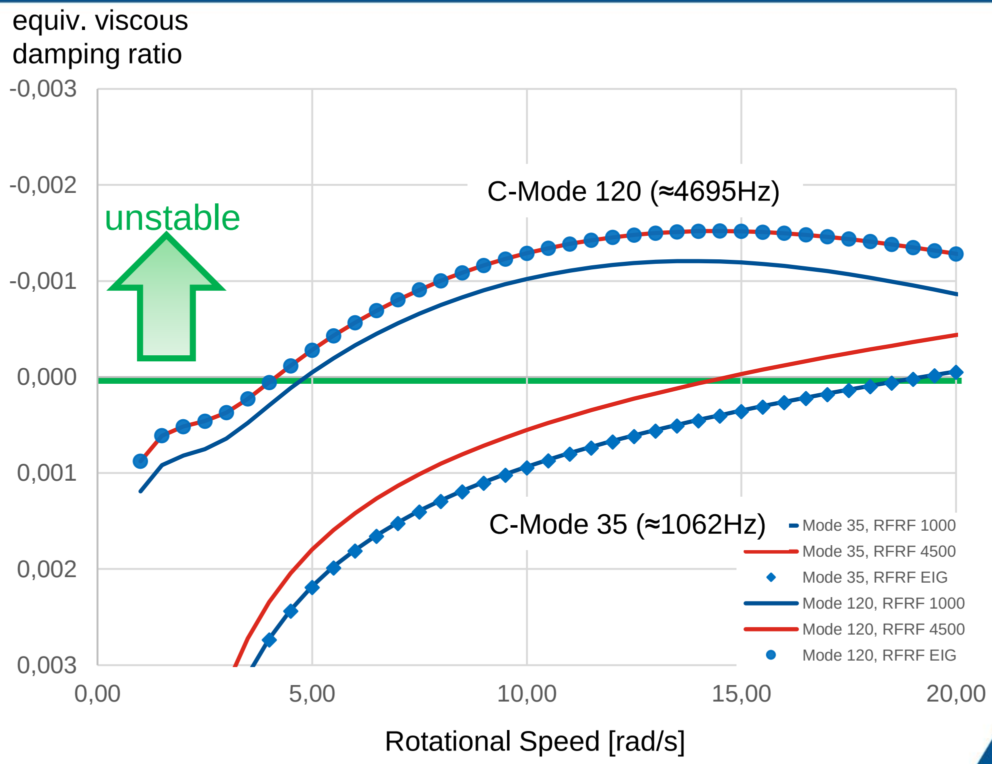
For c-mode 35 the result is same as with reference frequency 1000 Hz

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



EQUIVALENT VISCOUS DAMPIG RATIO

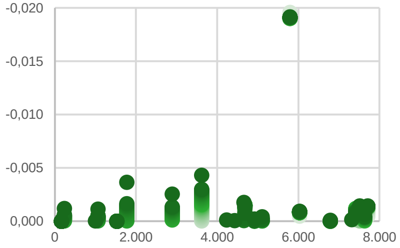
Why INTES always uses this result as indicator?

+Descriptive and corresponds to Lehr‘s damping measure (Lehrsches Dämpfungsmaß) (from single degree of freedom system; 1-Massen-Schwinger)

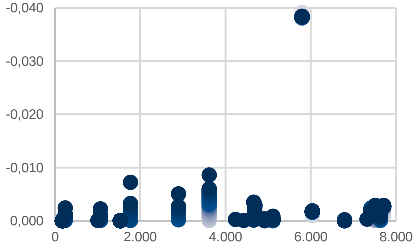
+Equivalent viscous damping ratio (evdr) similar (factor 0.5) results like the often used effective damping ratio (edr)

+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



Equivalent viscous damping ratio



Effective damping ratio

Solution of the homogeneous equation in state space:

$$\bar{q}_i(t) = \bar{x}\exp(\nu t) = \bar{x}_i e^{\delta_i t}(\cos\omega_i t + i\sin\omega_i t)$$

Eigenvalues: $\lambda = \lambda_R + i\lambda_I$

Frequency of harmonic part: ω_i

Damping coefficient: δ_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)

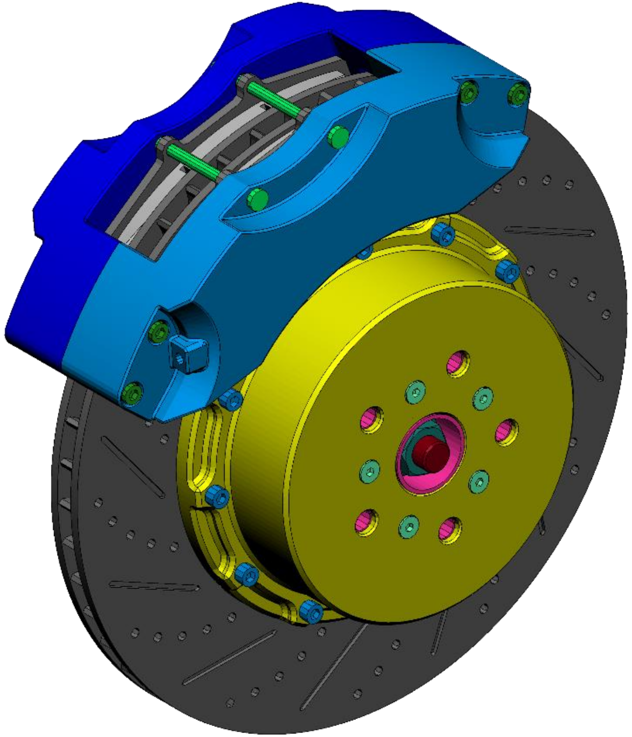
Real Eigenvalues until 10,000 Hz

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



MODEL

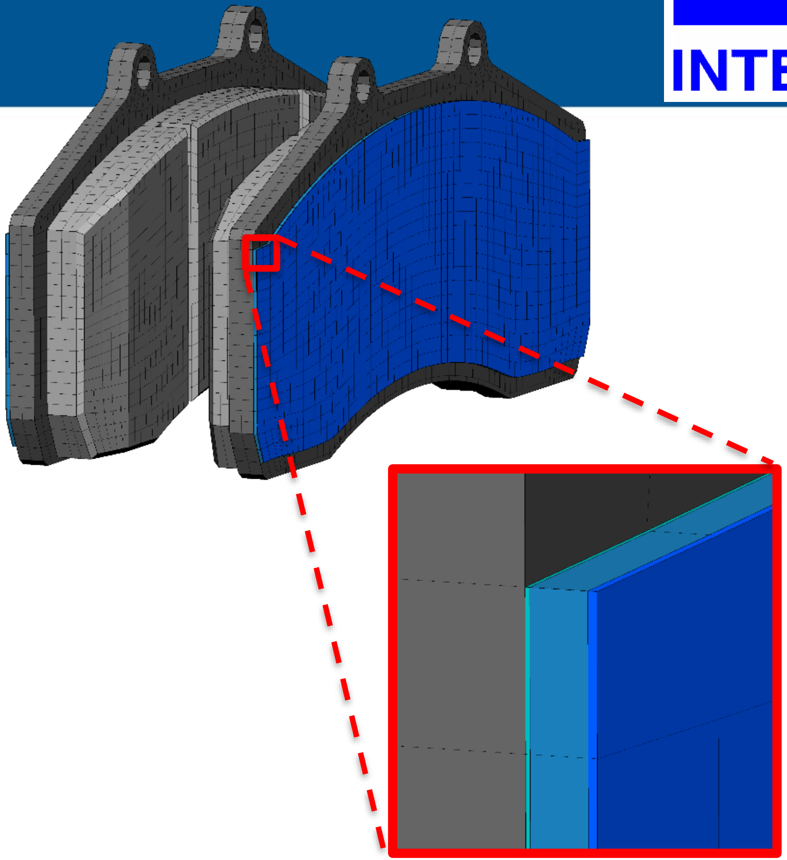
Brake pad model

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

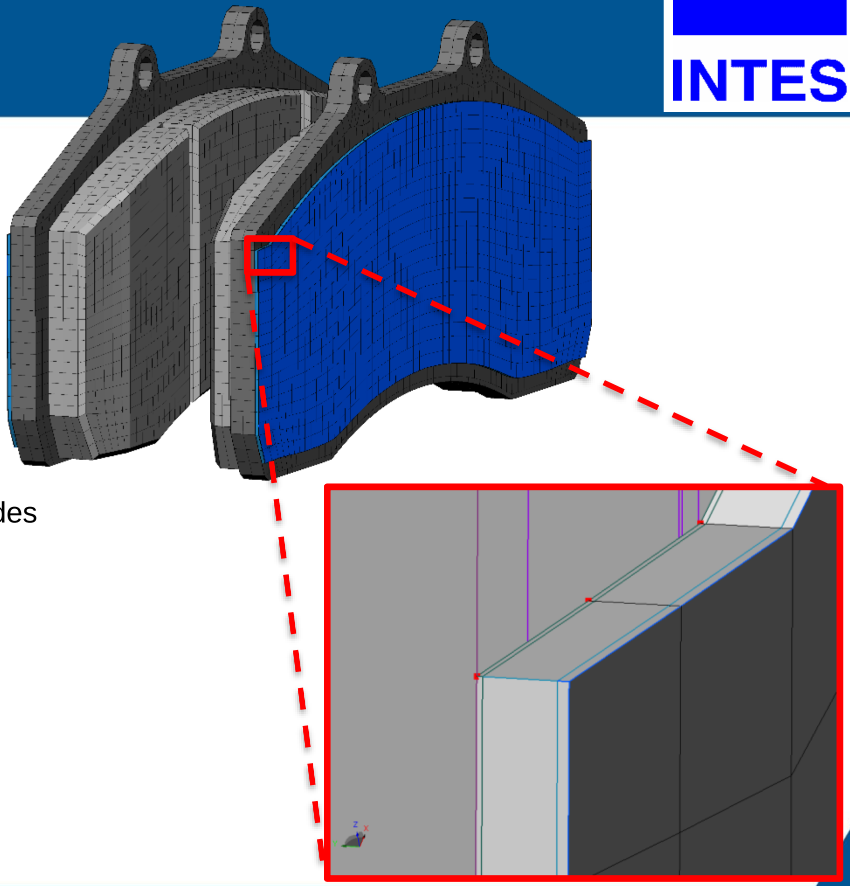
Modify thickness of shim layers

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

SAMPLING LOOP

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.

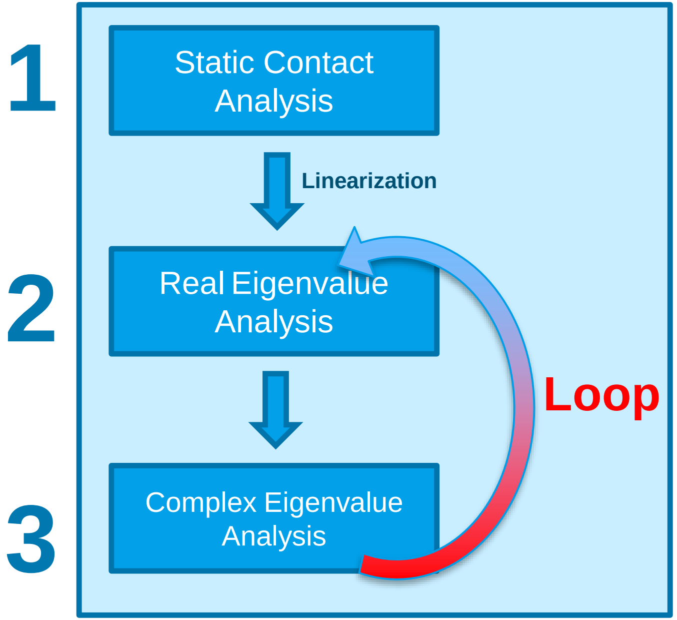
Loop over part 2 and 3 of CEA process is sufficient!

Advantages:

Decision about contents of loop by engineer based on the requirements.

Shorter run times:

- Excluding unnecessary analysis
- Reading of model data only once



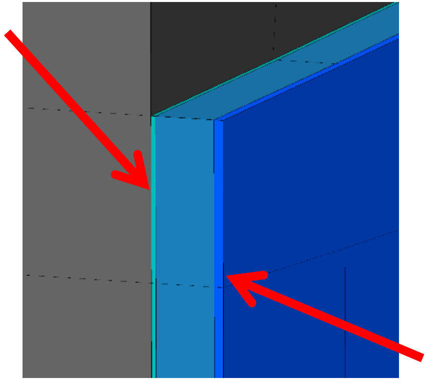
CEA Process

SELECTED SAMPLING RESULTS I

Automatic combination of all parameter values

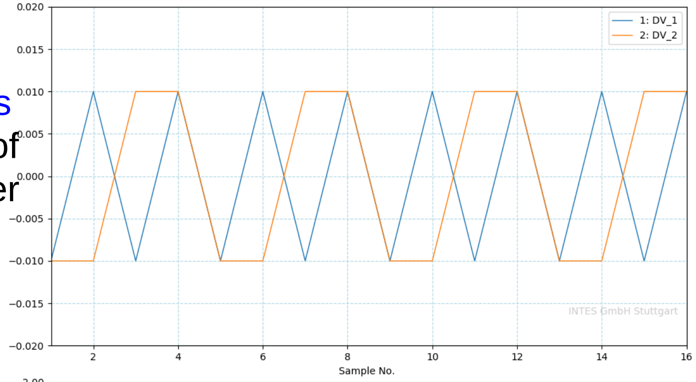
xy-history graph of design variable values

DV_1
DV_101

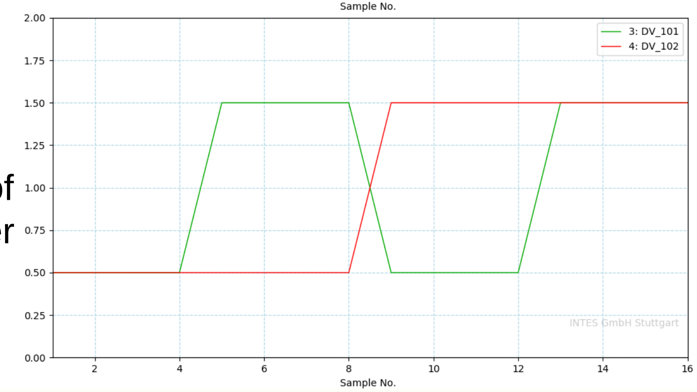


DV_2
DV_102

thickness change of elastomer coating



material damping change of elastomer coating



SELECTED SAMPLING RESULTS II

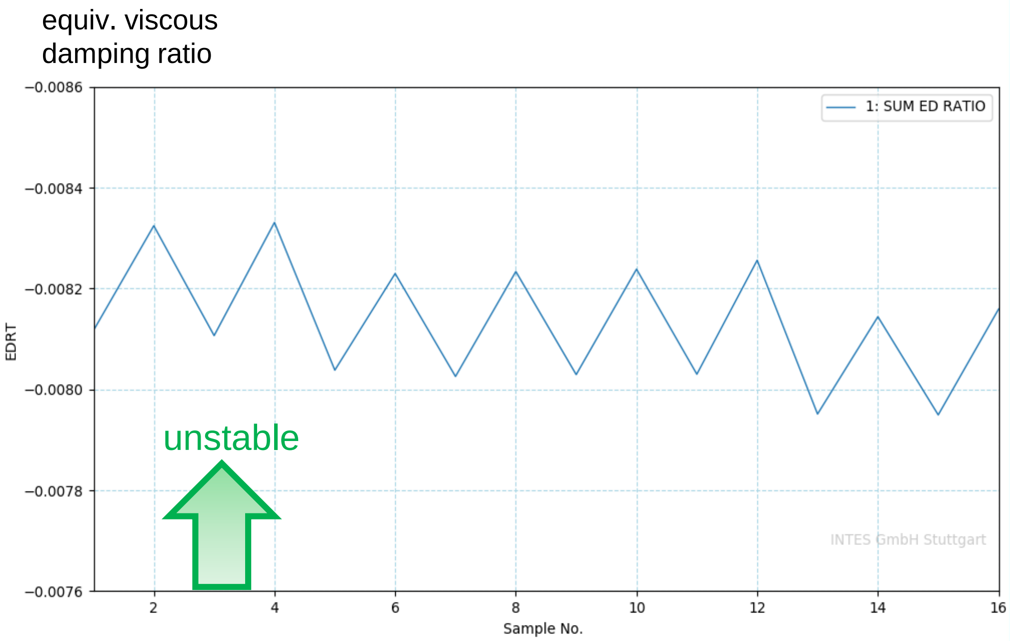
Thickness change of elastomer coating to backplate dominant (biggest changes)(DV_1).

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

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- 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!

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