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Vibrational Fatigue SPECTRAL and Tool Harmonic

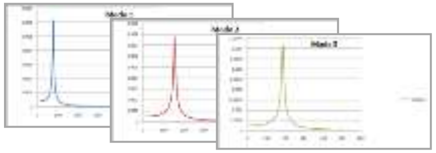
FEMFAT User Meeting NA Oct. 2014

FEMFAT

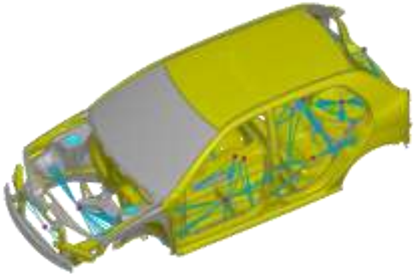
Vibrational Fatigue Analysis

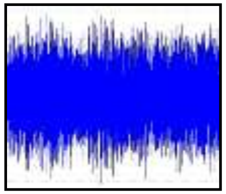
Frequency Response Analysis

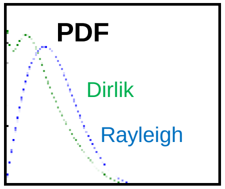
Modal Transfer Functions



Random Load



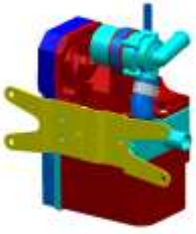


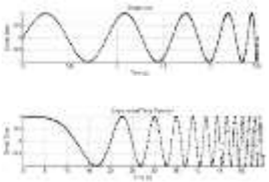


Module SPECTRAL

- ➢ Simple PSD load definition
- ➢ Highly efficient analysis
- ➢ WELD & SPOT future development

Deterministic Load



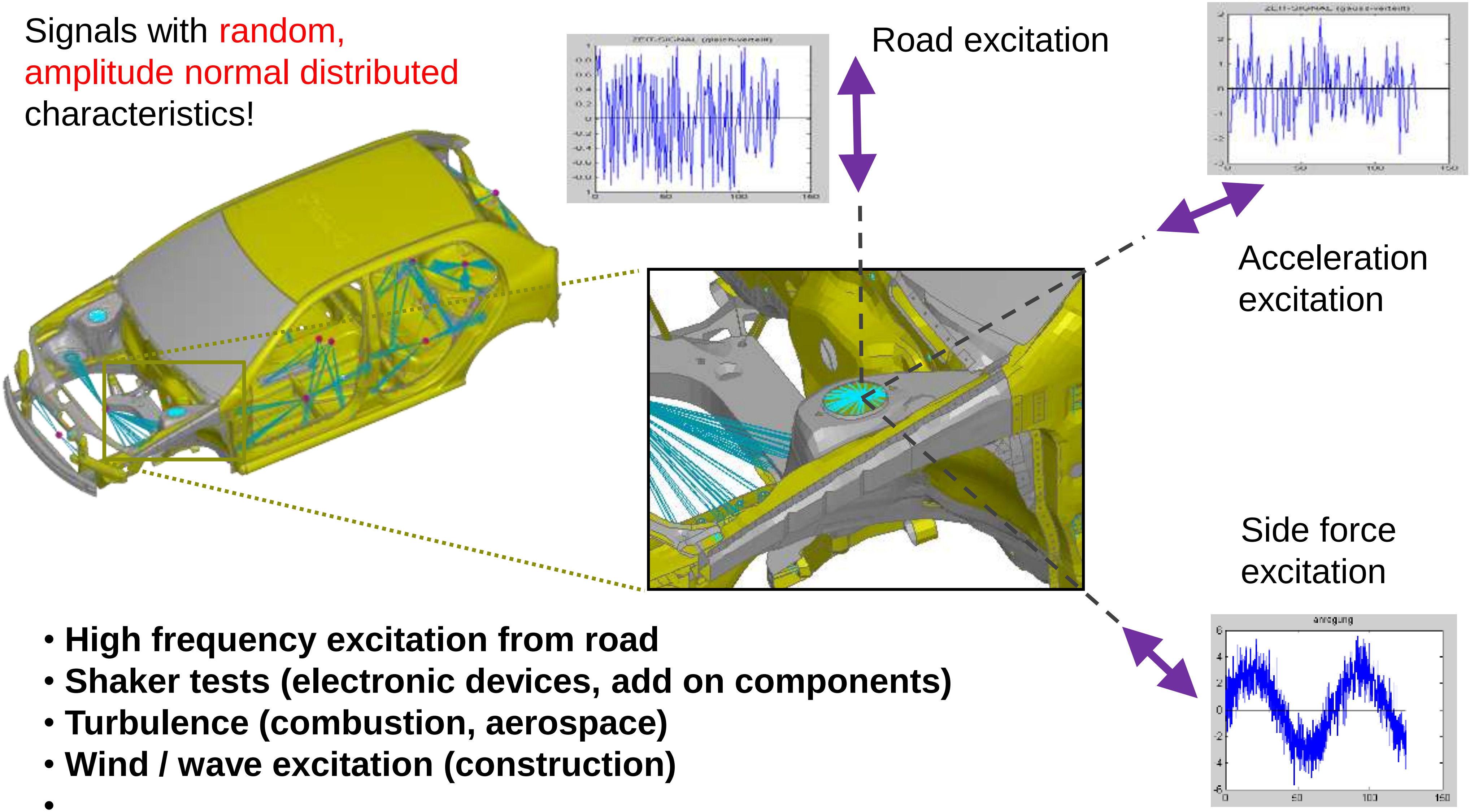


Tool *Harmonic* + ChannelMAX

- ➢ Various load definitions available
- ➢ High accuracy & efficiency
- ➢ Joint assessment WELD & SPOT available

Motivation to Develop SPECTRAL

Signals with random, amplitude normal distributed characteristics!



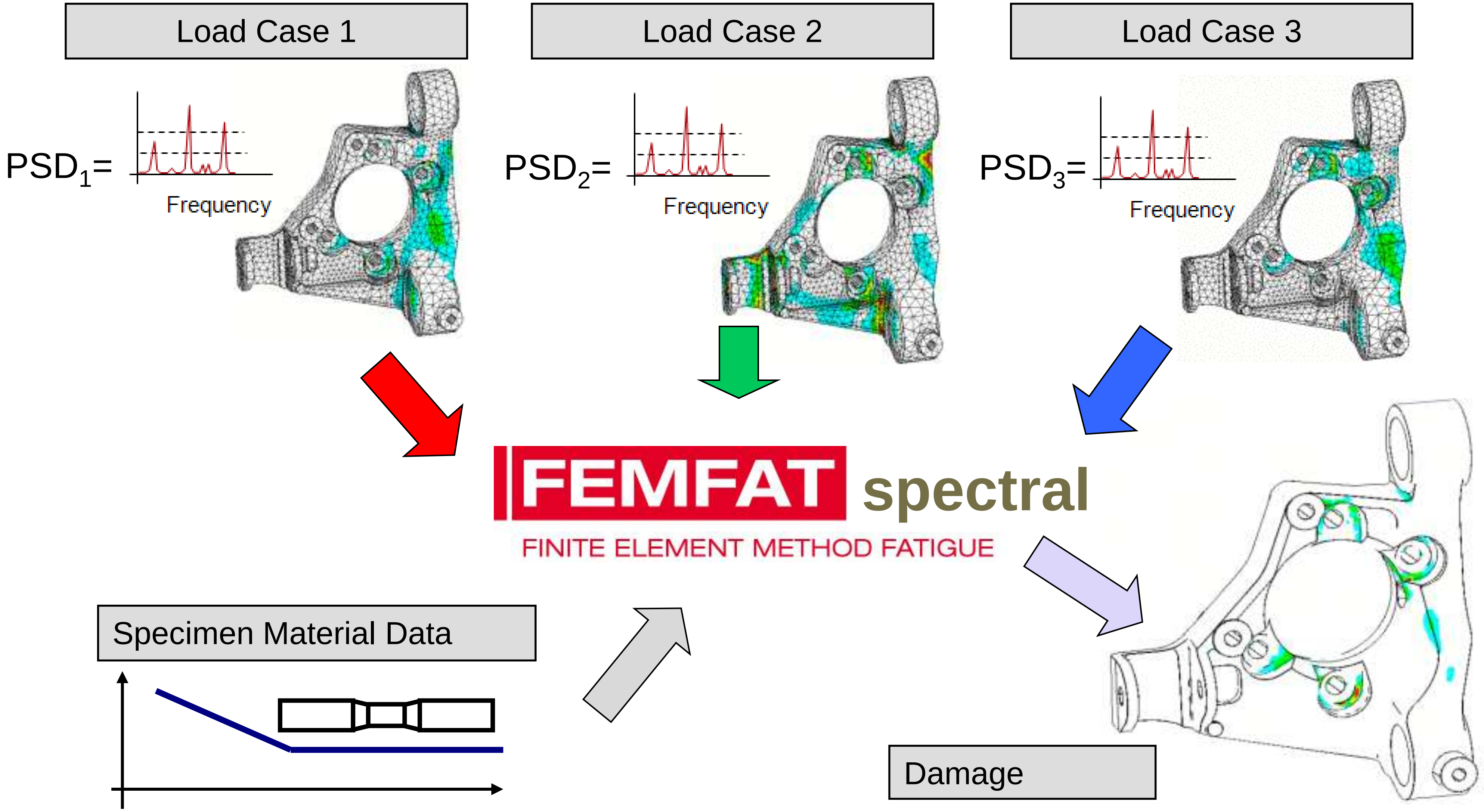
Road excitation

Acceleration excitation

Side force excitation

- **High frequency excitation from road**
- **Shaker tests (electronic devices, add on components)**
- **Turbulence (combustion, aerospace)**
- **Wind / wave excitation (construction)**
- **…**

Data Processing in SPECTRAL



Load Case 1

$PSD_1=$

Load Case 2

$PSD_2=$

Load Case 3

$PSD_3=$

FEMFAT spectral

FINITE ELEMENT METHOD FATIGUE

Specimen Material Data

Damage

Probability Models

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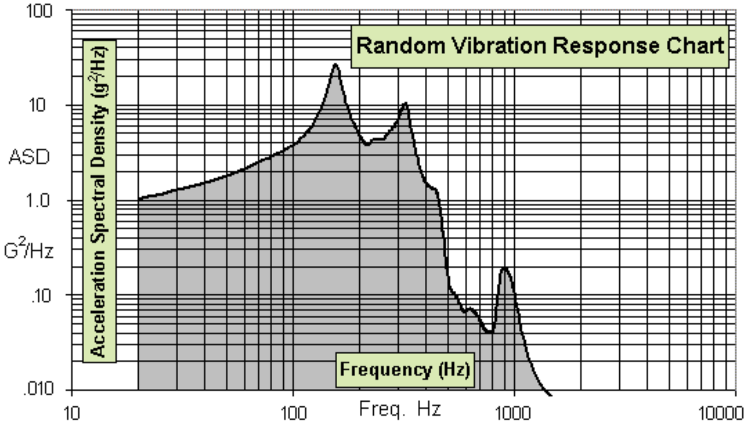
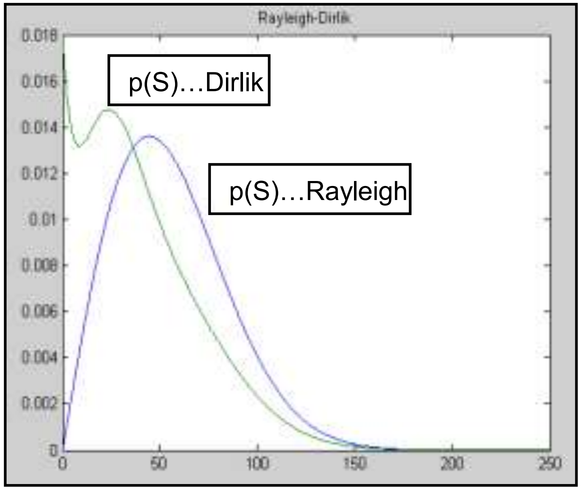
Estimation of stochastic amplitude stress distribution from PSD



PSD



PDF

i-th order moment of density:

$$m_i = \int_{[0,\infty[} \omega^i G_{\sigma\sigma}(\omega)\,d\omega$$

m_0 ... area

m_1 ... center of area

m_2 ... geometric moment of inertia

PROBABILITY MODEL

narrow band signal

→ **Rayleigh**

broad band signal

→ **Dirlik**

Equivalent Stress Methods

- von Mises stress
- Normal stress in critical plane ←default brittle material
- Equivalent stress in critical plane
- Modified equivalent stress in critical plane ←default ductile material

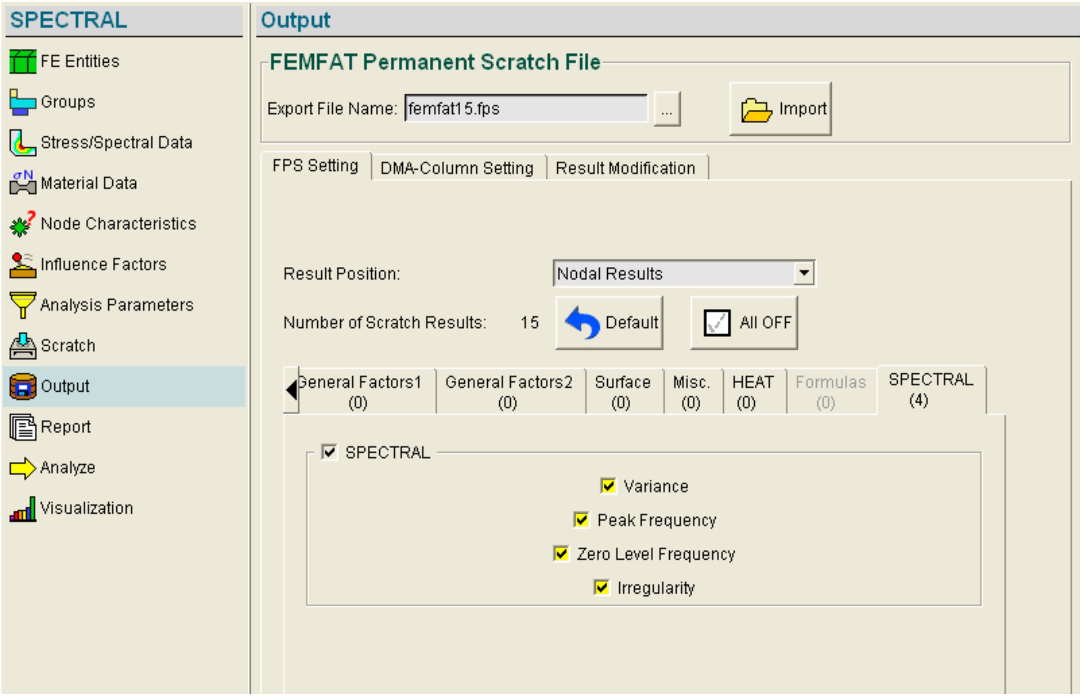
FEMFAT Spectral
uses statistically correct equivalent stress PSDs!

SPECTRAL Related Output

$$m_0 = \int_0^\infty G_{xx}(\omega)d\omega \qquad m_2 = \int_0^\infty \omega^2 G_{xx}(\omega)d\omega \qquad m_4 = \int_0^\infty \omega^4 G_{xx}(\omega)d\omega$$

Variance of Equivalent Stress $\sigma = \sqrt{m_0}$

Peak Crossing Frequency $\nu_p = \dfrac{1}{2\pi}\sqrt{\dfrac{m_4}{m_2}}$



Export File Name: femfat15.fps

Result Position: Nodal Results

Number of Scratch Results: 15

☑ SPECTRAL

☑ Variance

☑ Peak Frequency

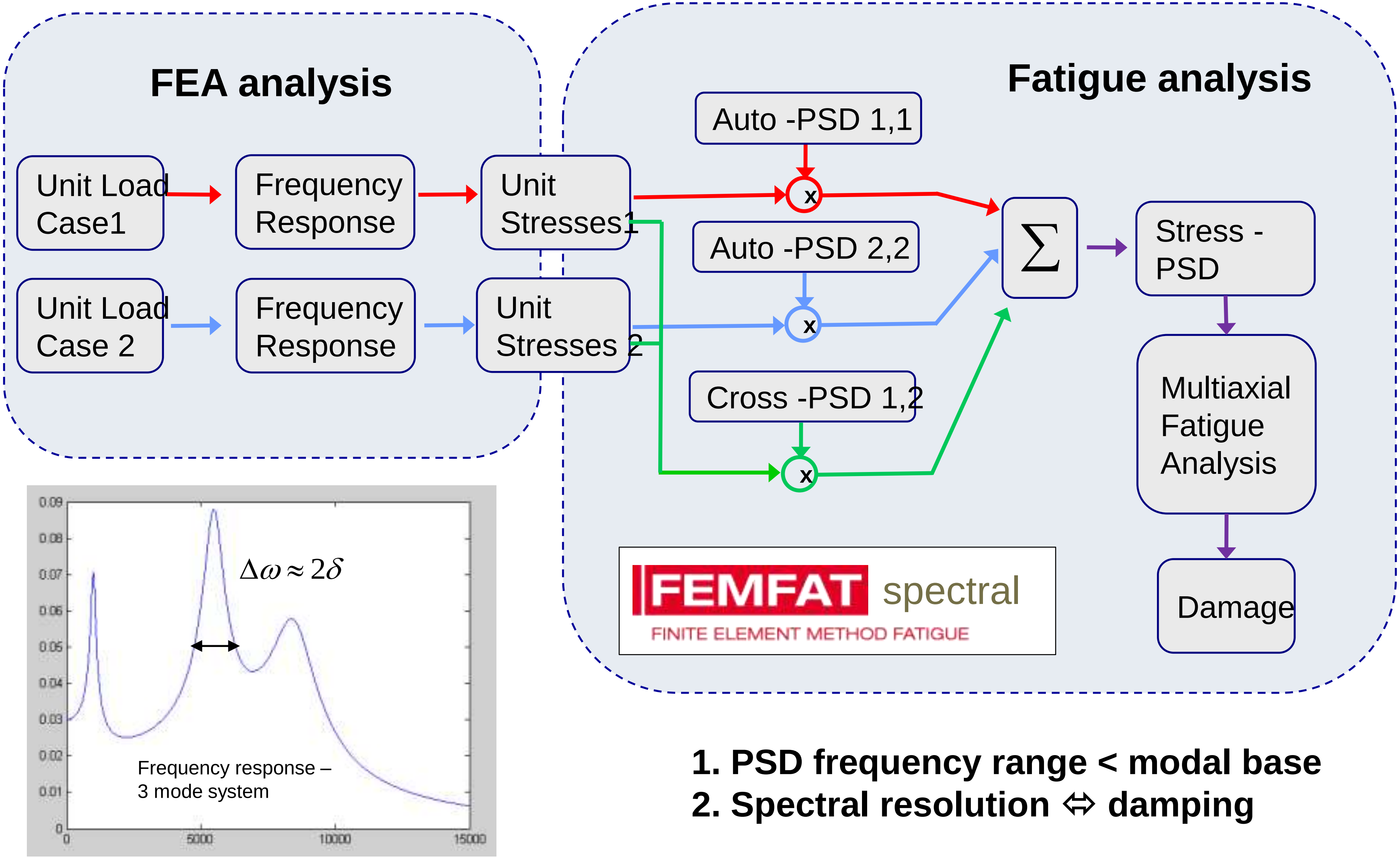
☑ Zero Level Frequency

☑ Irregularity

Irregularity $\gamma = \dfrac{\nu_0}{\nu_p} = \dfrac{m_2}{\sqrt{m_0 \cdot m_4}}$

$$\gamma \rightarrow \begin{cases} 1 & \text{for narrow band} \\ 0 & \text{for broad band} \end{cases}$$

Multiaxial PSD Loading



Frequency response –
3 mode system

1. PSD frequency range < modal base
2. Spectral resolution ⇔ damping

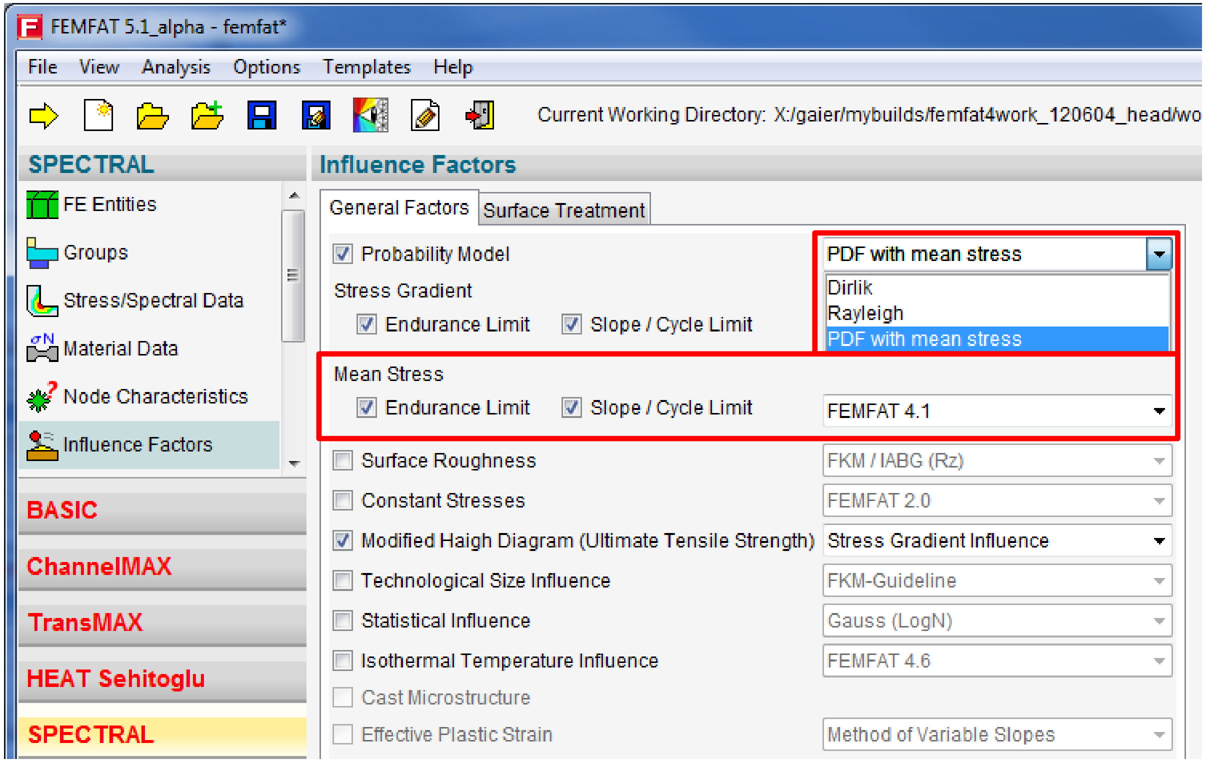
Supported Influence Factors SPECTRAL

- Stress gradient (notch effect)
- Surface roughness & treatment
- Constant stress (e.g. bolt pretention, gravity)
- Isothermal temperature influence
- Technological size influence
- Statistical influence

V 5.1 has additionally features

- Mean stress influence
- Plasticity influence (PLAST)
- ANSYS interface (additionally to NASTRAN and ABAQUS)

SPECTRAL: Mean stress influence



Current Working Directory: X:/gaier/mybuilds/femfat4work_120604_head/wo

☑ Probability Model: PDF with mean stress

Stress Gradient: ☑ Endurance Limit ☑ Slope / Cycle Limit

Mean Stress: ☑ Endurance Limit ☑ Slope / Cycle Limit: FEMFAT 4.1

☐ Surface Roughness: FKM / IABG (Rz)

☐ Constant Stresses: FEMFAT 2.0

☑ Modified Haigh Diagram (Ultimate Tensile Strength): Stress Gradient Influence

☐ Technological Size Influence: FKM-Guideline

☐ Statistical Influence: Gauss (LogN)

☐ Isothermal Temperature Influence: FEMFAT 4.6

☐ Cast Microstructure

☐ Effective Plastic Strain: Method of Variable Slopes

Damage:

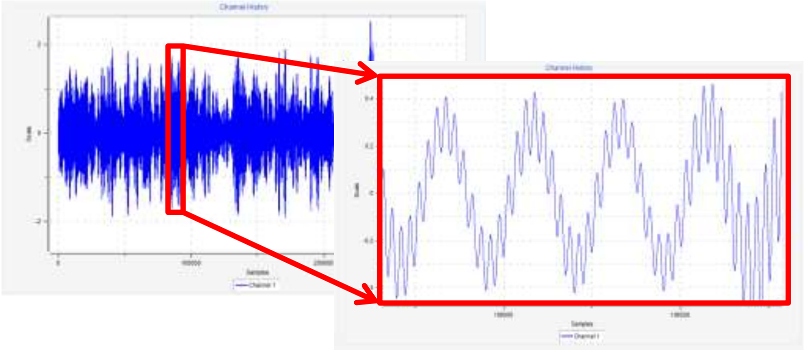
$$D = v_p t \int_{-\infty}^{\infty}\int_{0}^{\infty} p(s,m) * d(s,m) dsdm$$

The probability density function (PDF) is a linear combination of range count and level crossing count distribution.

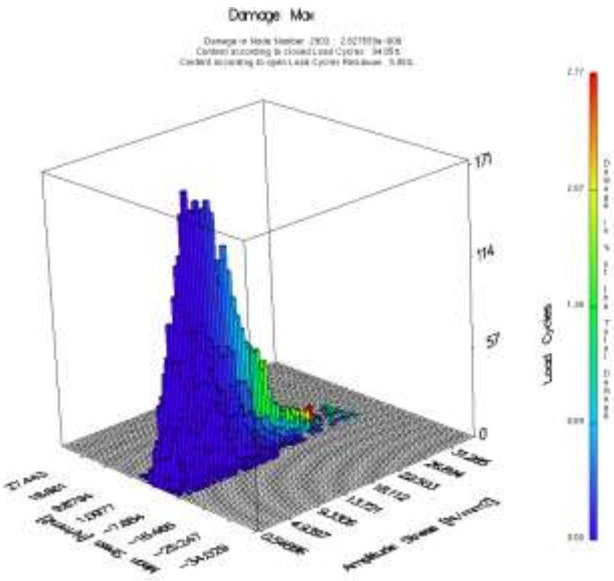
SPECTRAL: Mean stress influence
Comparison Time – Frequency Domain Analysis

MAX analysis in time domain with rainflow counting:

Load signal:

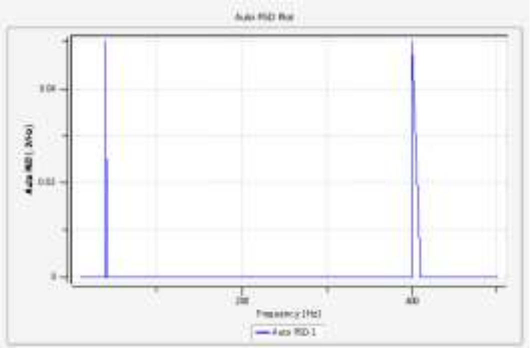


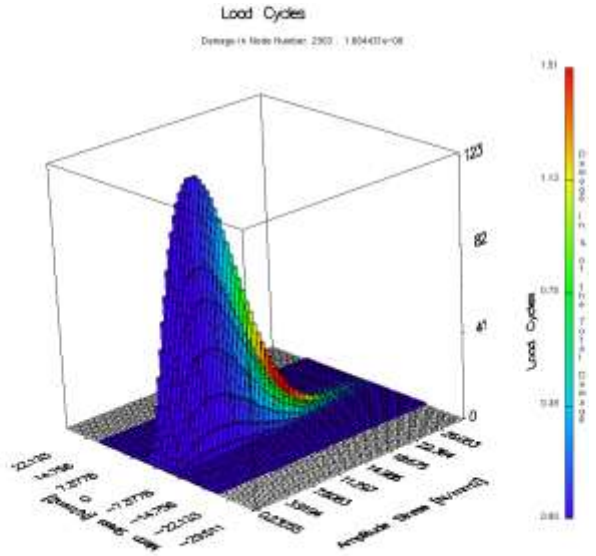
Rainflow matrix:



SPECTRAL analysis in frequency domain:

Load PSD with Irregularity = 0.954 (~ narrow band):

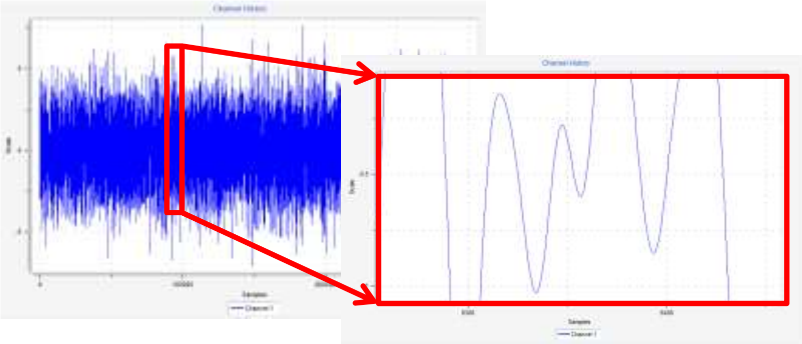




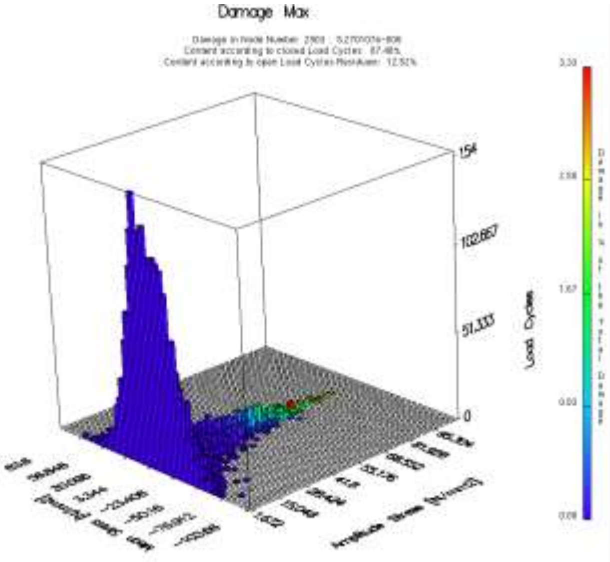
SPECTRAL: Mean stress influence
Comparison Time – Frequency Domain Analysis

MAX analysis in time domain with rainflow counting:

Load signal:

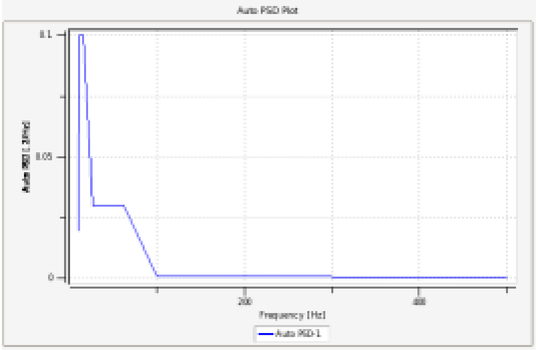


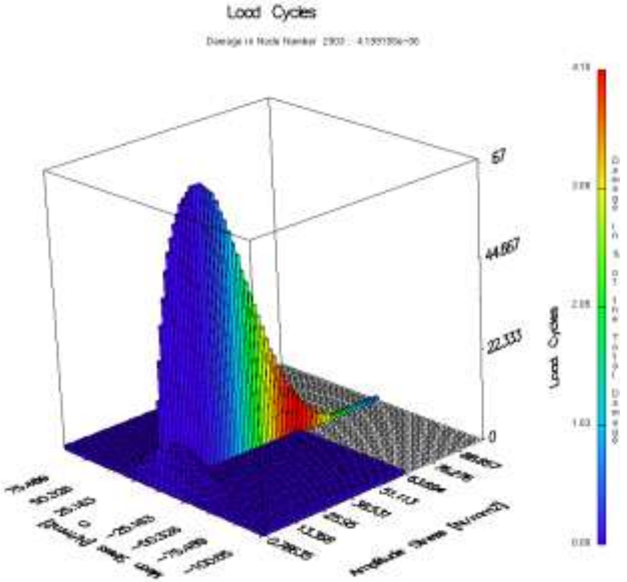
Rainflow matrix:



SPECTRAL analysis in frequency domain:

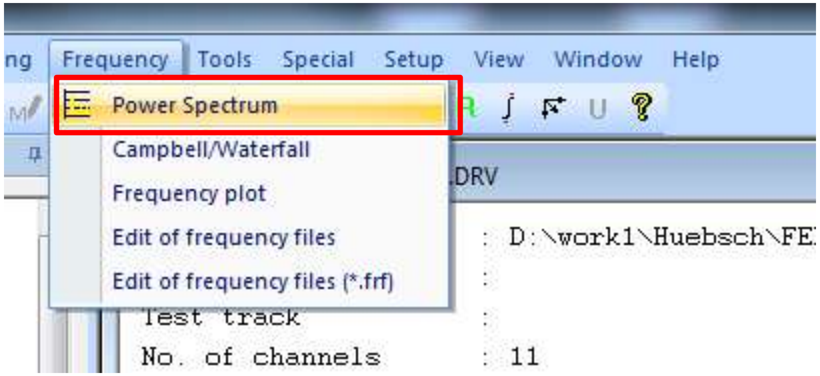
Load PSD with Irregularity = 0.306 (~ broad band):





PSD Export from FEMFAT LAB

1) Choose **Power Spectrum** from the **FREQUENCY** menu



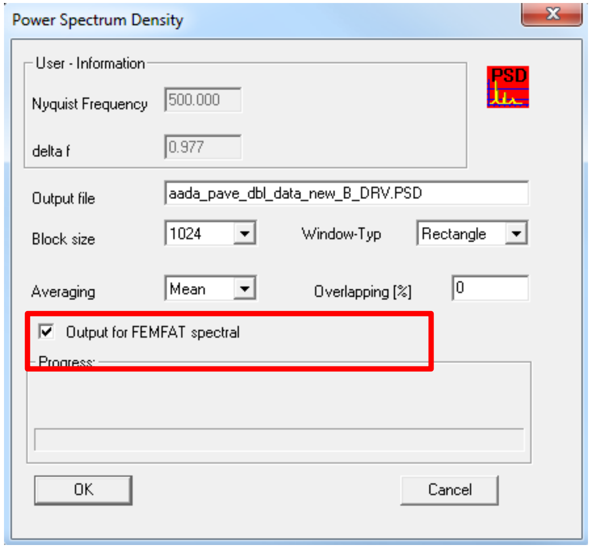
: D:\work1\Huebsch\FE

:

Test track :

No. of channels : 11

2) Activate **OUTPUT FOR FEMFAT SPECTRAL**



Nyquist Frequency 500.000

delta f 0.977

Output file aada_pave_dbl_data_new_B_DRV.PSD

Block size 1024

Window-Typ Rectangle

Averaging Mean

Overlapping [%] 0

☑ Output for FEMFAT spectral

Progress:

LAB exports all auto- and cross-PSDs to a csv file. This file can be directly imported to SPECTRAL.

3) PRESS **OK**

Conclusions / Outlook

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Advantages of SPECTRAL

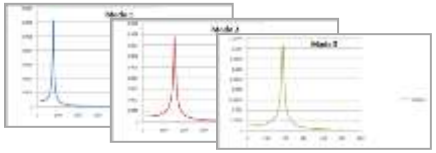
- Dynamic analysis in frequency domain (unit load cases)
- Small amount of data & fast processing
- Accurate numerical implementation
- Multi axial excitation fully available (incl. cross PSDs)
- Maximum compatibility with time-domain analysis

Future development will focus on full functionality like time-domain

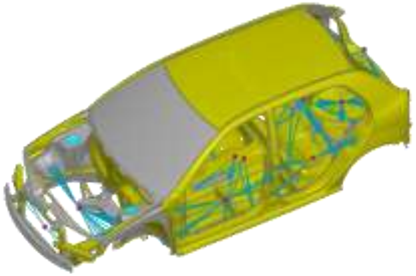
Vibrational Fatigue Analysis

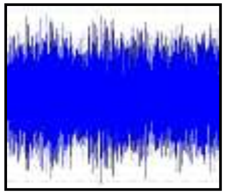
Frequency Response Analysis

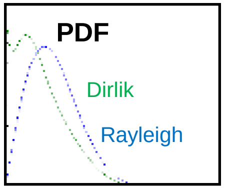
Modal Transfer Functions



Random Load







Module SPECTRAL

- Simple PSD load definition
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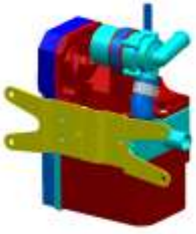
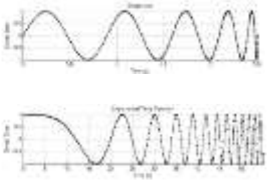
- WELD & SPOT future development

Deterministic Load





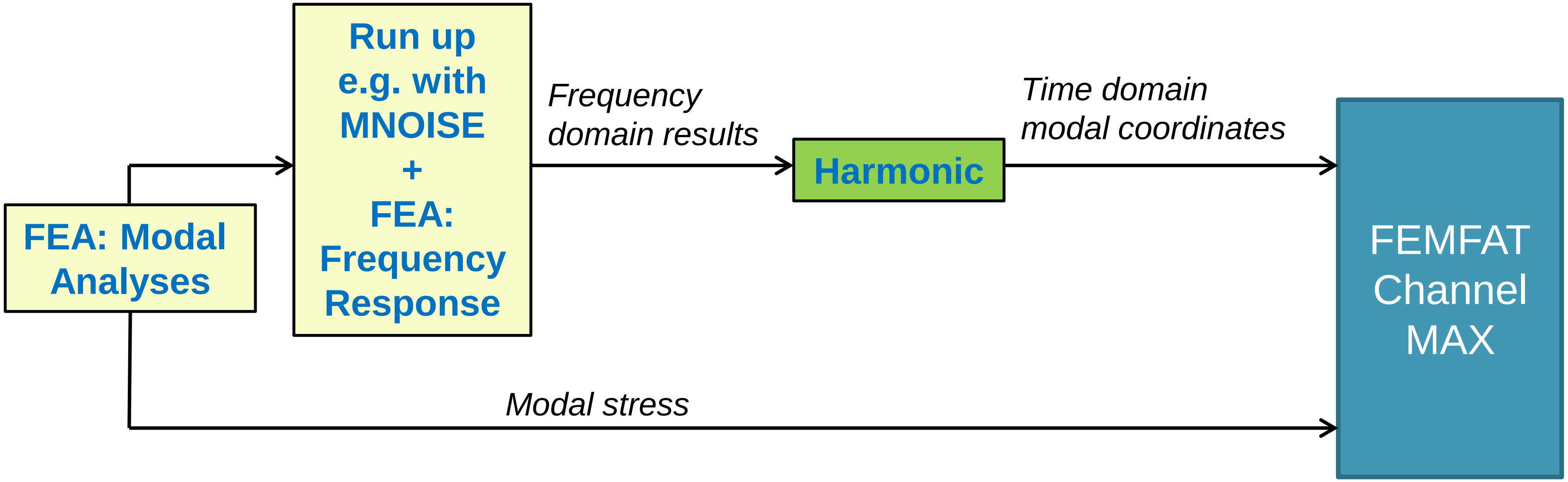
Tool *Harmonic* + ChannelMAX

- Various load definitions available
- High accuracy & efficiency
- Joint assessment WELD & SPOT available

Tool *Harmonic* – Add on to FEMFAT

- Harmonic is a stand alone console application
- It is free of cost for customers with a maintained MAX license
- An additional license entry is needed for this tool
- Available for Windows and Linux 64 bit
- A documentation is available in English
- Interfaces for NASTRAN *.pch, ABAQUS *.dat and ANSYS *.mcf

Tool *Harmonic* – Add on to FEMFAT



FEA: Modal Analyses

Run up e.g. with MNOISE + FEA: Frequency Response

Frequency domain results

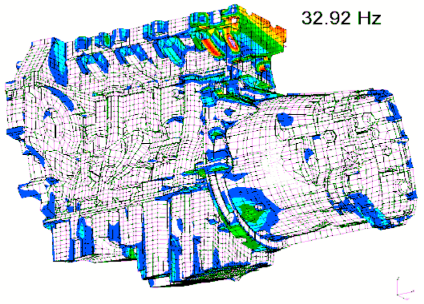
Harmonic

Time domain modal coordinates

FEMFAT Channel MAX

Modal stress

Applications:



- **Engine Run up Simulation**
- **Vibration tests for add on parts e.g. tank (signal from unit load)**

Tool *Harmonic* – Add on to FEMFAT

- **There are currently six different functions for a time domain output, that can be read by FEMFAT**
  - **A constant sinus**
  - **A linear sweep of the frequency**
  - **A logarithmic sweep of the frequency**
  - **A signal form a given time-frequency-amplitude table**
  - **A engine run up**
  - **A signal from a unit load**

Tool *Harmonic* – Constant sine

Possible definition for a constant sine wave:

Const_sin

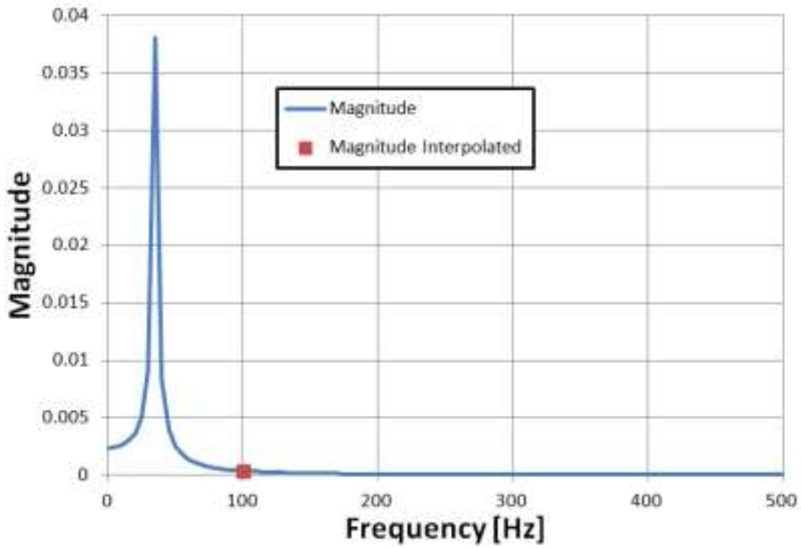
Const_frequ:	Input of Frequency
AmplitudeFactor || AmplitudeFile:	Input either the value (default is 1), or the path to a A(t) file
InterpolationMethodeAmplitude:	1…Linear(default), 2…Akima-Spline
T_max:	Input of Total Running Time
SampleRate:	Input of points per sinus
File:	Input of the file
Filetype:	1…Abaqus || 2…Nastran || 3…Ansys || 4…Permas
InterpolationMethodeTransferFunction:	1…Linear(default), 2…Akima-Spline

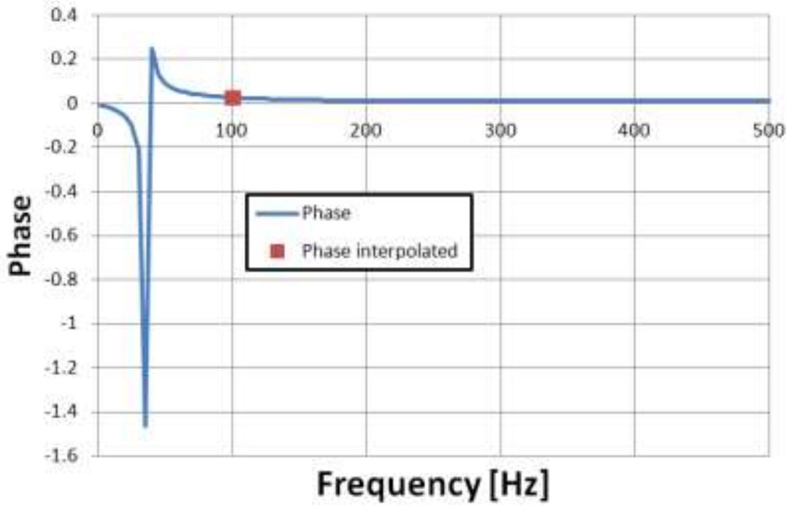
Tool *Harmonic* – Constant sine

Example 1:

Const_sin

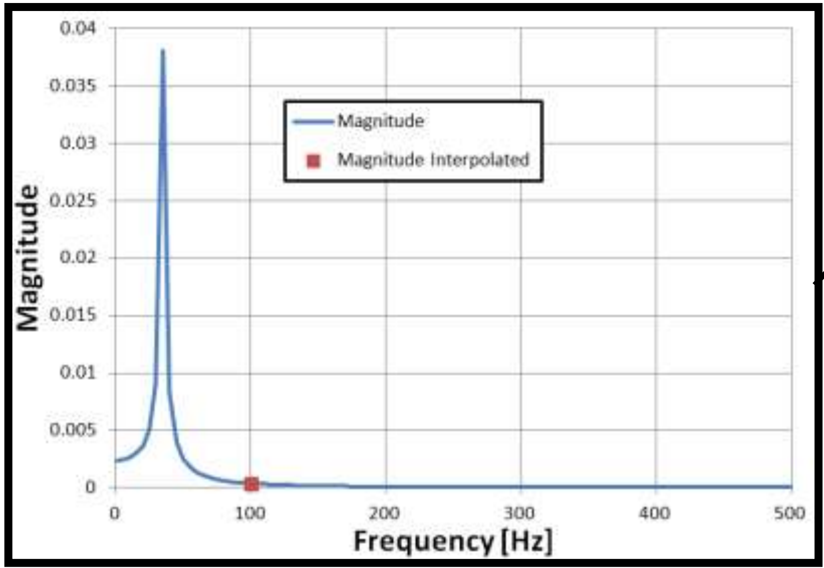
Const_frequ:	100	will generate a constant sine with 100Hz
AmplitudeFactor:	5	Amplitude is constant with a magnitude of 5
T_max:	4	The signal will last for 4 seconds
SampleRate:	20	The signal will be generated with 20 points per wave
File:	test.dat	File definition
Filetype:	1	Definition for a Abaqus-File
InterpolationMethodeTransferFunction:	2	The transfer function is interpolated with an Akima-Spline

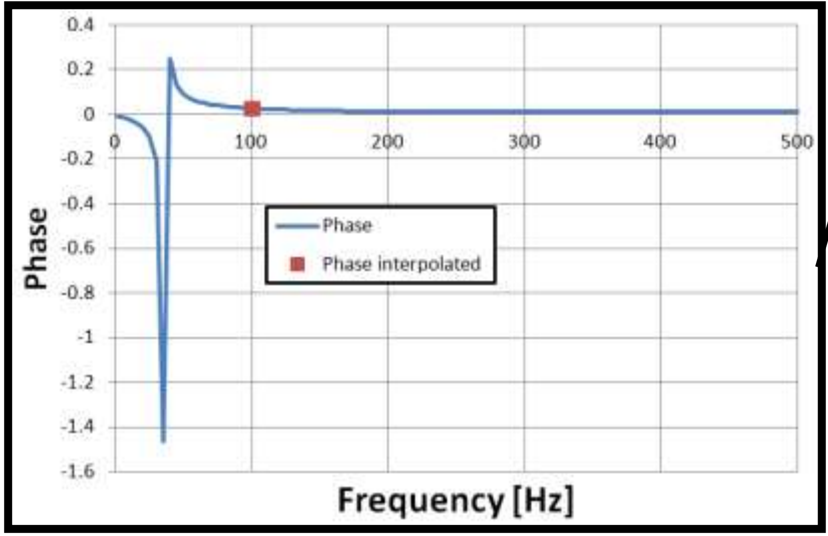




Tool *Harmonic* – Constant Sine

Example 1:





From FE-File

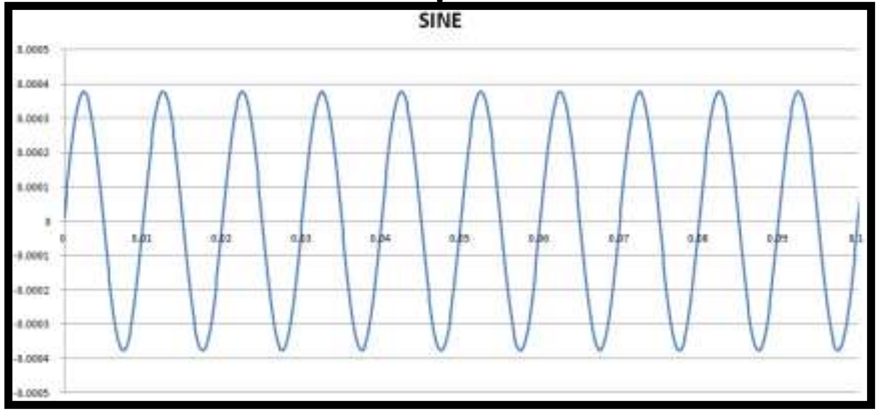
$$G(j\omega)$$

From Control-File

$$\omega = 2 \cdot \pi \cdot f$$

System Response

$$h(t) = A(\omega) \cdot \sin(\omega \cdot t + \varphi(\omega))$$



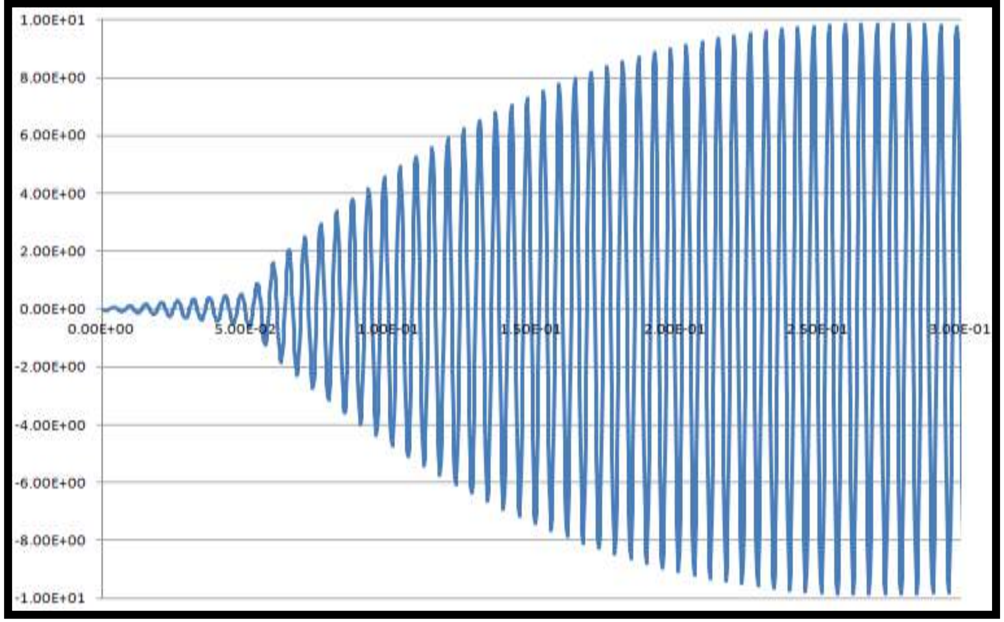
Tool *Harmonic* – Constant Sine

Example 2:

Const_sin:	1………..	will be executed
Const_frequ[Hz]:	150………	will generate a constant sine with 150Hz
Amplitude[1]:	amp.txt….	Amplitude is variable with time
T_max[s]:	5………..	The signal will last for 5 seconds
SampleRate[1]:	10……..…	The signal will be generated with 10 points per wave
Output_Transferfunction:	0…………	The transfer functions of the FEA will not be outputted
Filetype:	1	Definition for a Abaqus-File
InterpolationMethodeTransferFunction:	2	The transfer function is interpolated with an Akima-Spline

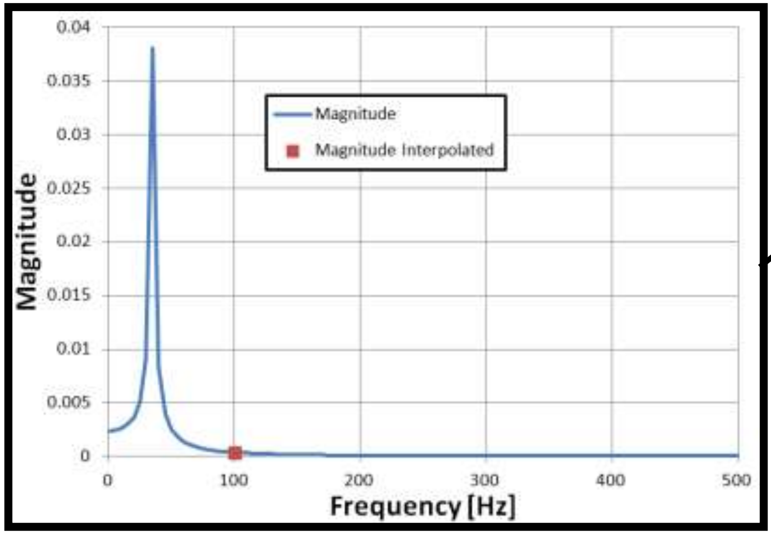
Example ampl.txt:

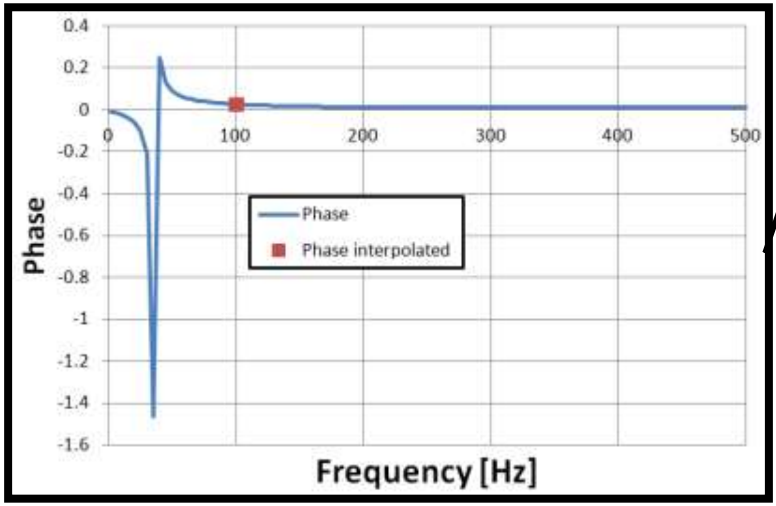
```
# time amplitude
0       100
0.01    200
0.02    400
0.03    600
0.04    800
0.05    1000
0.06    3000
1       5000
2       7000
9       7500
10      8000
```



Tool *Harmonic* – Constant Sine

Example 2:





From FE-File

$$G(j\omega)$$

From Control-File

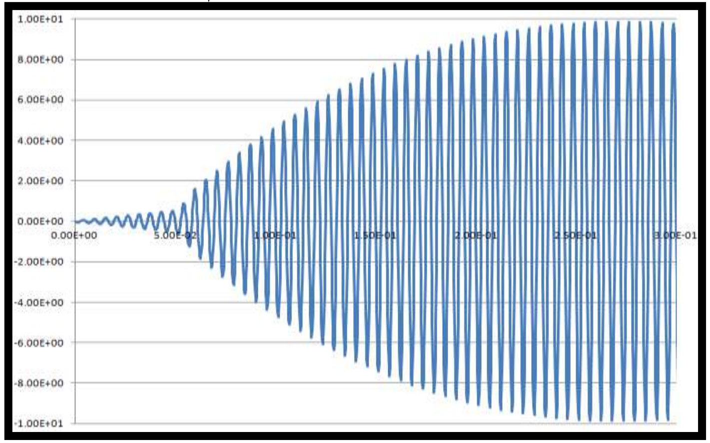
$$\omega = 2\cdot\pi\cdot f$$

System Response

$$h(t) = A(t)\cdot\sin(\omega\cdot t + \varphi(\omega))$$

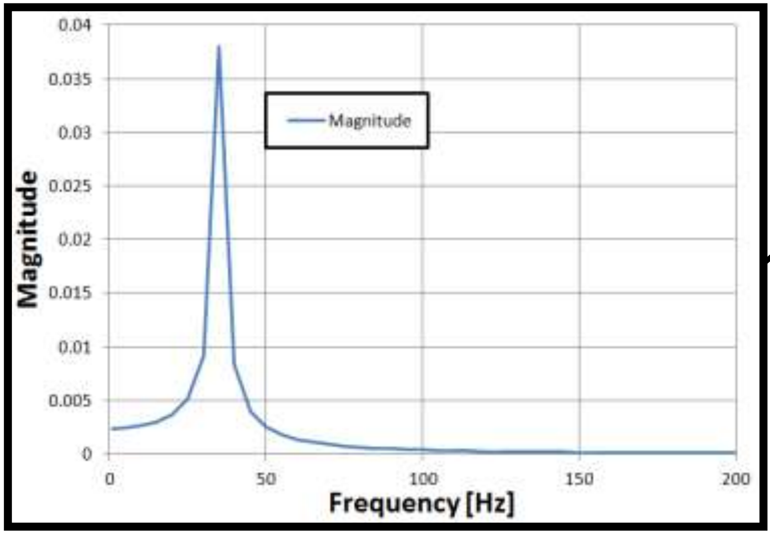
Example ampl.txt:

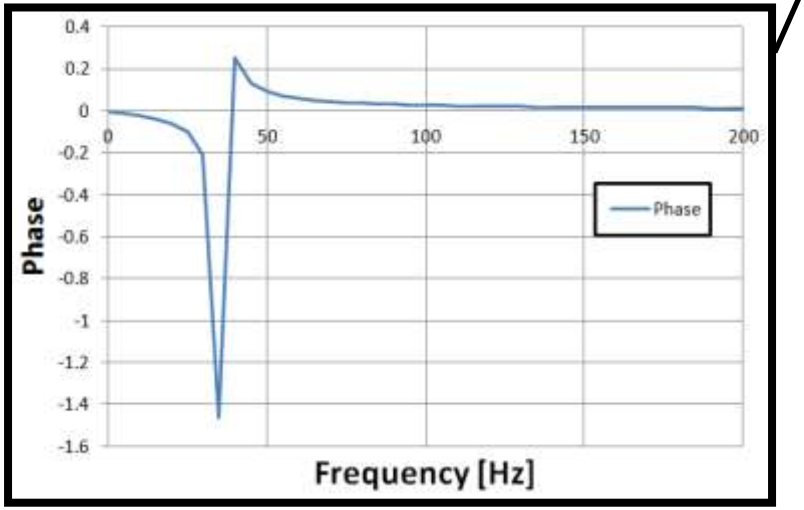
```
# time amplitude
0       100
0.01    200
0.02    400
0.03    600
0.04    800
0.05    1000
0.06    3000
1       5000
2       7000
9       7500
10      8000
```

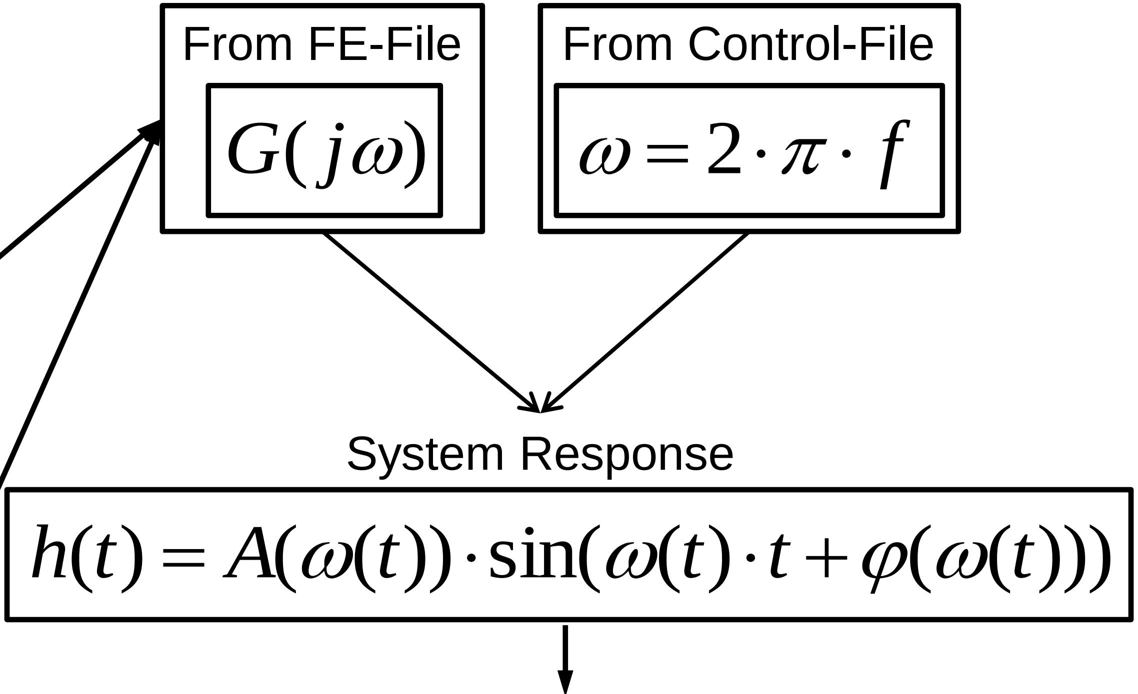


Tool *Harmonic* – Linear Sweep

Example 1:







From FE-File

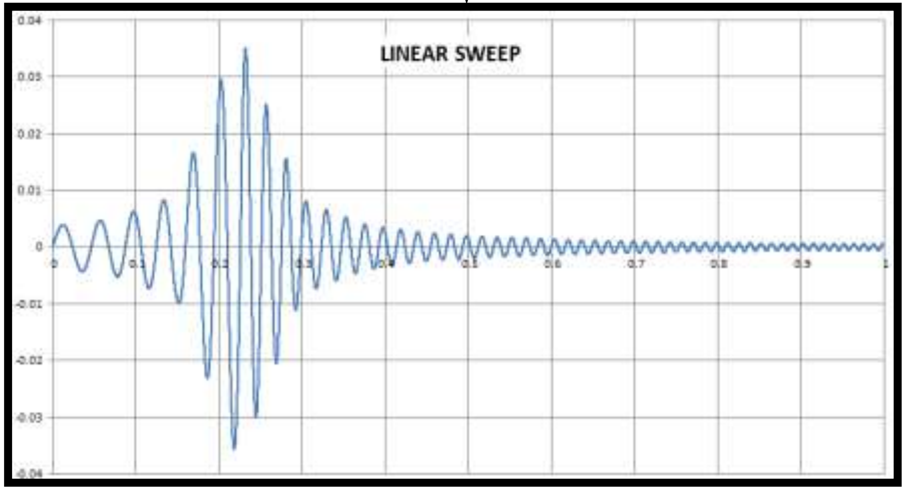
$G(j\omega)$

From Control-File

$\omega = 2 \cdot \pi \cdot f$

System Response

$$h(t) = A(\omega(t)) \cdot \sin(\omega(t) \cdot t + \varphi(\omega(t)))$$



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The future is ours to make.