Von Mises Stress PSD using MSC.Random

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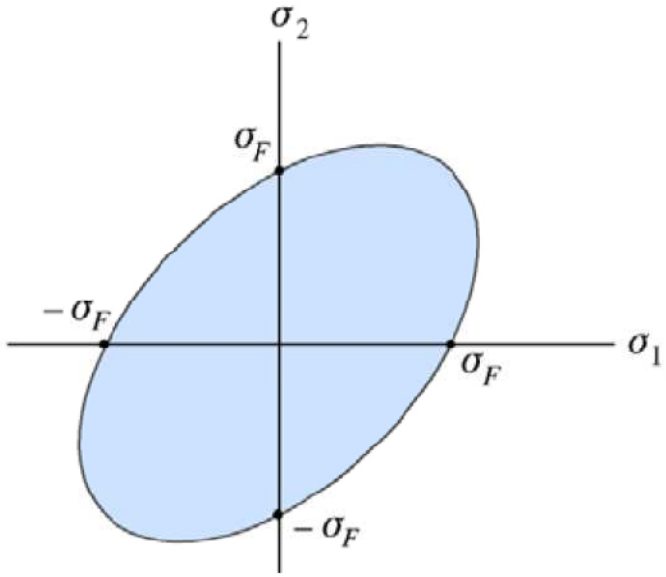
Introduction

- Von Mises is the most widely used stress equivalent in static analysis
- Is valid for ductile materials
- Useable for 2-dimensional and 3-dimensional stress fields



- Typical parameter for durability analysis
- Customers often request it, also in multi-frequency dynamic analysis

- *For random analysis the standard von Mises formula gives wrong results*

Calculation of von Mises PSD

- Under dynamic load the von Mises stress is not centered about zero

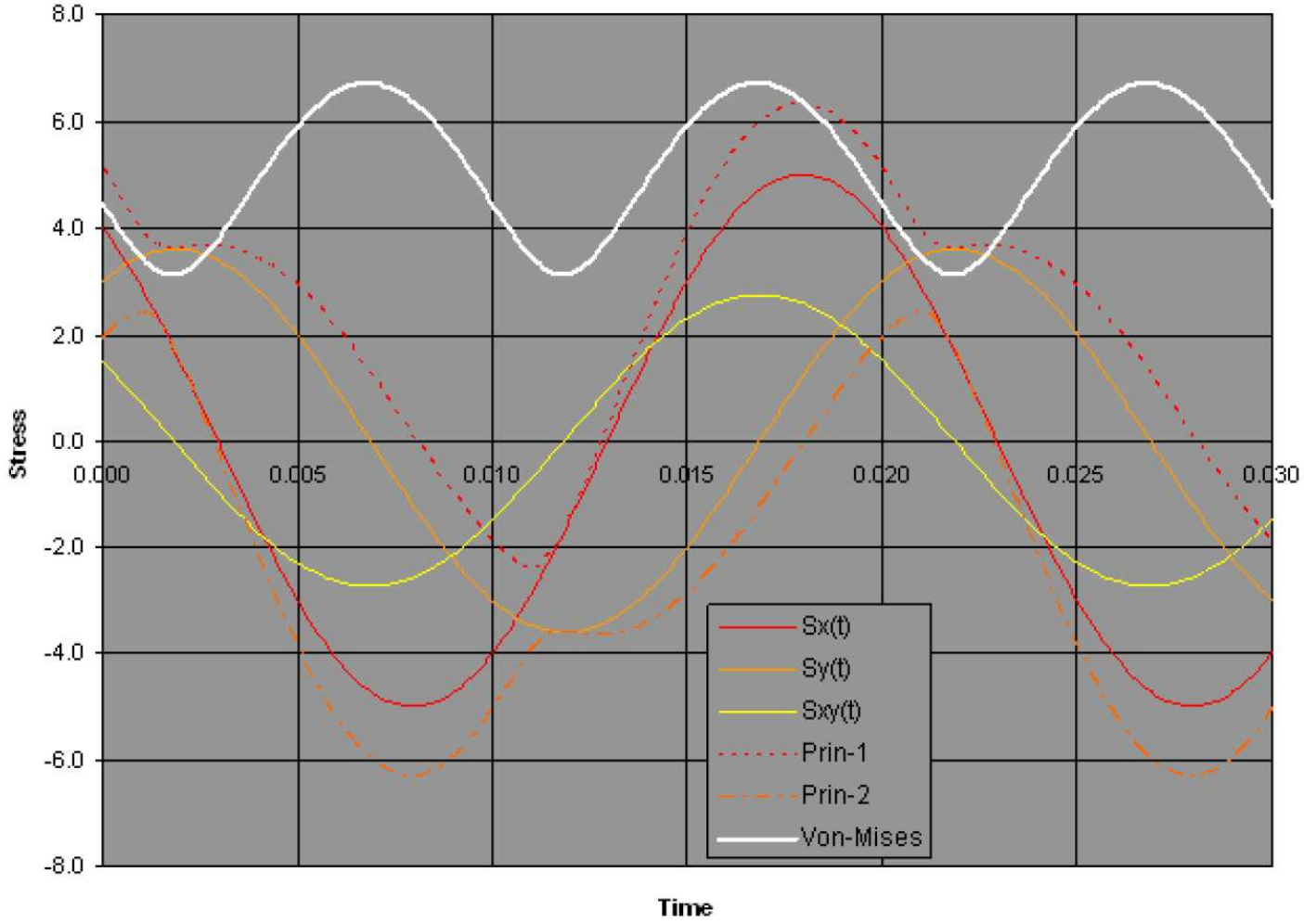


Figure from: MSC.Patran Documentation - Basic Functions, Chapter 11, Random Analysis

Calculation of von Mises PSD

- Probability distribution of von Mises stress is neither Gaussian nor centered about zero
- Therefore, the RMS of basic stress tensor cannot be used
- The von Mises formula is correct only in its complex version and phase information is needed
- In a random analysis there is no phase information and so the correct von Mises can't be calculated
- Pitoiset e.a. [1] showed a method to derive von Mises PSD response, which is implemented in MSC.Random based on the deterministic frequency response
- MSC.Random is part of MSC.Patran

[1] X. Pitoiset, A. Preumont, A. Kernilis: Tools for a Multiaxial Fatigue Analysis of Structures Submitted to Random Vibrations. ESA SP-428, February 1999

Calculation of von Mises PSD

- The formula given in [1] to derive von Mises PSD reads:

$$G_{\sigma_{vM}}(f_m) = \text{trace}\{[A][G_{\sigma\sigma}(f_m)]\}$$

with:

$$G_{\sigma\sigma}(f_m) = \bar{s}\, s^T$$

and the complex stress components

$$s^T = \begin{bmatrix} H_{s_x} & H_{s_y} & H_{s_z} & H_{s_{xy}} & H_{s_{xz}} & H_{s_{yz}} \end{bmatrix}$$

$\bar{s}$ contains the conjugate complex values of the stress components

[1] X. Pitoiset, A. Preumont, A. Kernilis: Tools for a Multiaxial Fatigue Analysis of Structures Submitted to Random Vibrations. ESA SP-428, February 1999

Calculation of von Mises PSD

➢ Matrix [A] is derived from the quadratic formulation of von Mises stress and for the 3-dimensional case reads:

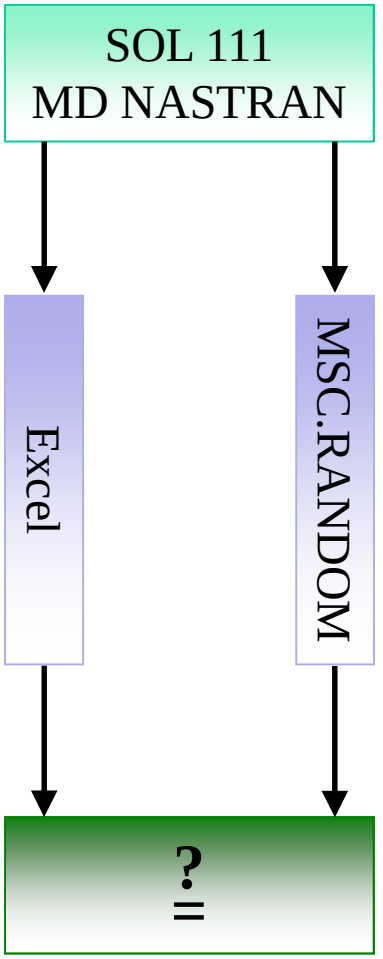
$$[A]=\begin{bmatrix} 1 & -0.5 & -0.5 & & & \\ -0.5 & 1 & -0.5 & & & \\ -0.5 & -0.5 & 1 & & & \\ & & & 3 & & \\ & & & & 3 & \\ & & & & & 3 \end{bmatrix}$$

and so for the 2-dimensional case reads:

$$[A]=\begin{bmatrix} 1 & -0.5 & \\ -0.5 & 1 & \\ & & 3 \end{bmatrix}$$

Verification of MSC.Random results

- The PSD von Mises stress is verified using a model of a flat plate (One solid and one shell model)
- Input to the formula are deterministic frequency response results from Nastran
- Results of MSC.Random are compared with those derived in Excel using above mentioned formula



Verification of MSC.Random results

- Two solid elements with high and low stresses are chosen

Element 41

Elm 41									**Theory**		**MSC.Random**
Hz		S_x	S_y	S_z	S_xy	S_xz	S_yz		v_Mises		v_Mises
30	Re	2.44E-01	6.38E-02	3.93E-02	1.84E-02	3.25E-03	9.75E-04		3.87268E-02		3.87268E-02
	Im	-3.16E-03	-8.11E-04	-4.93E-04	-2.56E-04	-4.28E-05	-2.84E-05				
40	Re	2.54E-01	6.62E-02	4.07E-02	1.92E-02	3.37E-03	1.06E-03		4.17892E-02		4.17892E-02
	Im	-4.57E-03	-1.17E-03	-7.12E-04	-3.70E-04	-6.19E-05	-4.12E-05				
50	Re	2.67E-01	6.96E-02	4.28E-02	2.03E-02	3.55E-03	1.19E-03		4.63120E-02		4.63120E-02
	Im	-6.38E-03	-1.64E-03	-9.93E-04	-5.17E-04	-8.64E-05	-5.78E-05				

Element 50

Elm 50									**Theory**		**MSC.Random**
Hz		S_x	S_y	S_z	S_xy	S_xz	S_yz		v_Mises		v_Mises
30	Re	1.32E-03	-2.04E-03	-6.17E-05	-1.15E-03	-1.13E-04	-2.39E-04		1.27154E-05		1.27155E-05
	Im	-2.60E-05	3.47E-05	1.51E-06	1.93E-05	1.90E-06	4.52E-06				
40	Re	1.40E-03	-2.15E-03	-6.66E-05	-1.21E-03	-1.18E-04	-2.54E-04		1.41516E-05		1.41516E-05
	Im	-3.78E-05	5.04E-05	2.21E-06	2.80E-05	2.76E-06	6.57E-06				
50	Re	1.52E-03	-2.30E-03	-7.35E-05	-1.29E-03	-1.27E-04	-2.74E-04		1.63131E-05		1.63131E-05
	Im	-5.31E-05	7.07E-05	3.11E-06	3.92E-05	3.87E-06	9.23E-06				

Verification of MSC.Random results

- Two shell elements with high and low stresses are chosen

Element 10

Elm 10	S_x		S_y		S_xy			**Theory**		**MSC.Random**
Hz	Re	Im	Re	Im	Re	Im		v_Mises		v_Mises
30	-2.64E-03	5.25E-05	3.90E-03	-6.70E-05	2.22E-03	-3.77E-05		4.73121E-05		4.73121E-05
40	-2.81E-03	7.65E-05	4.11E-03	-9.74E-05	2.34E-03	-5.49E-05		5.27718E-05		5.27718E-05
50	-3.05E-03	1.08E-04	4.41E-03	-1.37E-04	2.50E-03	-7.71E-05		6.10231E-05		6.10231E-05

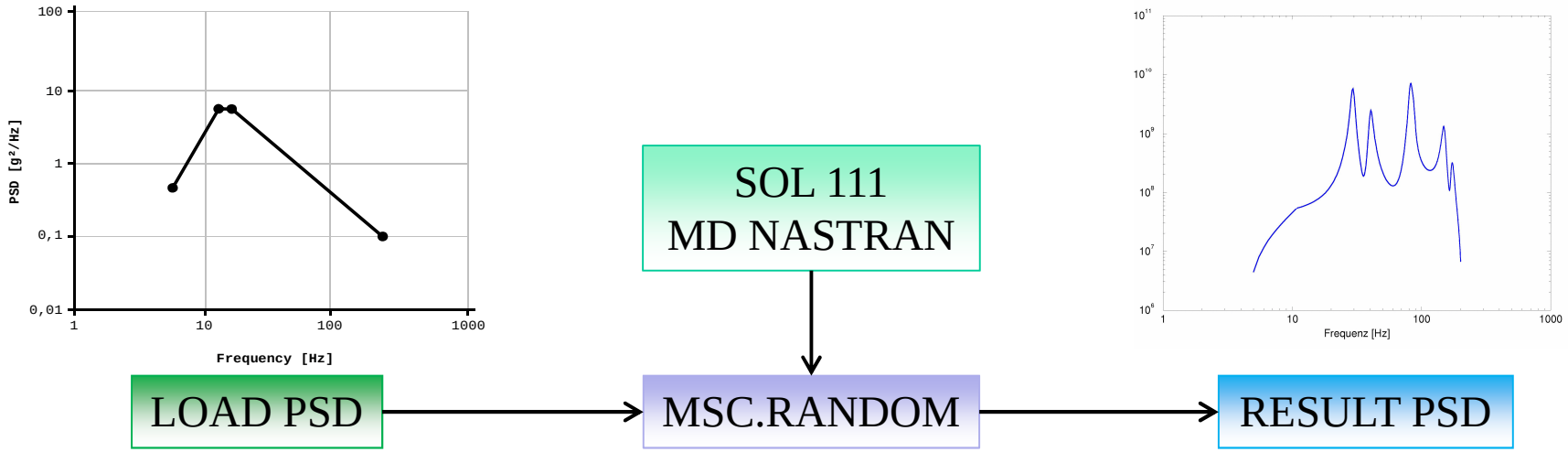
Element 11

Elm 10	S_x		S_y		S_xy			**Theory**		**MSC.Random**
Hz	Re	Im	Re	Im	Re	Im		v_Mises		v_Mises
30	-5.51E-01	7.30E-03	-1.57E-01	2.07E-03	-5.20E-03	7.88E-05		2.42096E-01		2.42096E-01
40	-5.73E-01	1.06E-02	-1.63E-01	2.99E-03	-5.44E-03	1.14E-04		2.61690E-01		2.61690E-01
50	-6.04E-01	1.48E-02	-1.72E-01	4.19E-03	-5.78E-03	1.60E-04		2.90820E-01		2.90820E-01

- The results of MSC.Random compare very well with those derived manually

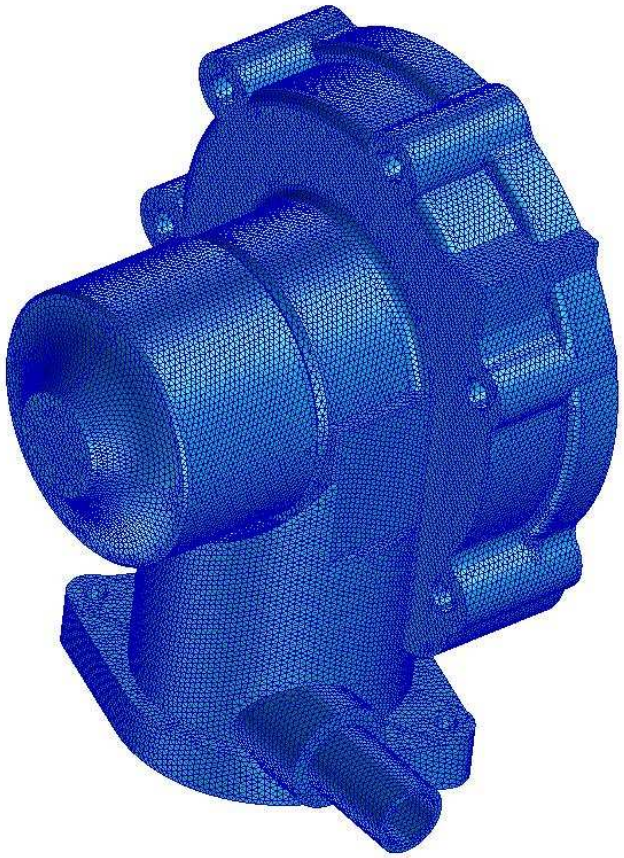
Application at a big model

- A standard frequency response analysis with unity load is done using MD Nastran
- The results are attached to MSC.Random
- Load PSD is put in to MSC.Random
- Random response results are derived in MSC.Random

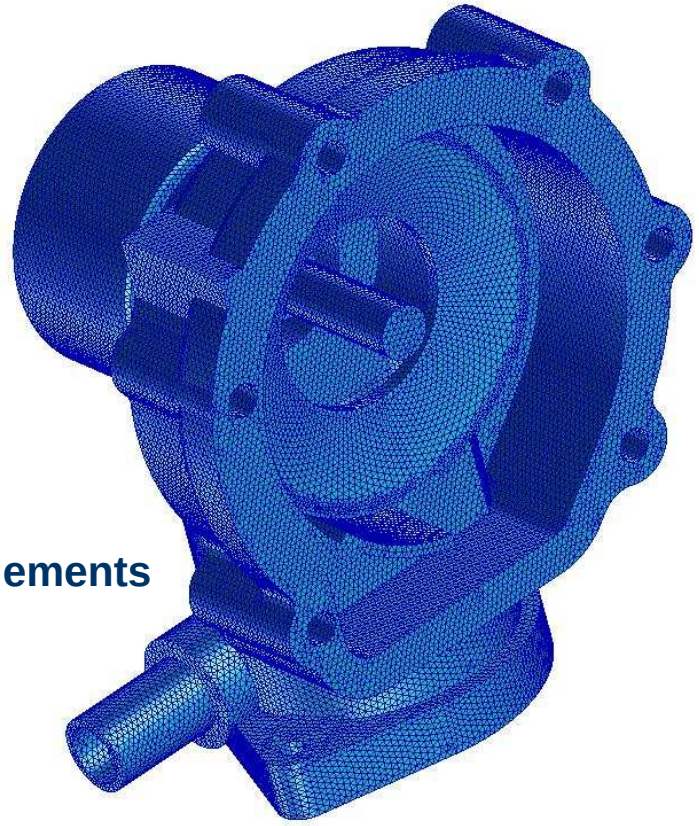


Application at a big model

- Cooling Water Pump for car – FE Model



911 882 Nodes
582 879 Tet10-Elements



- Shaker test with random excitation

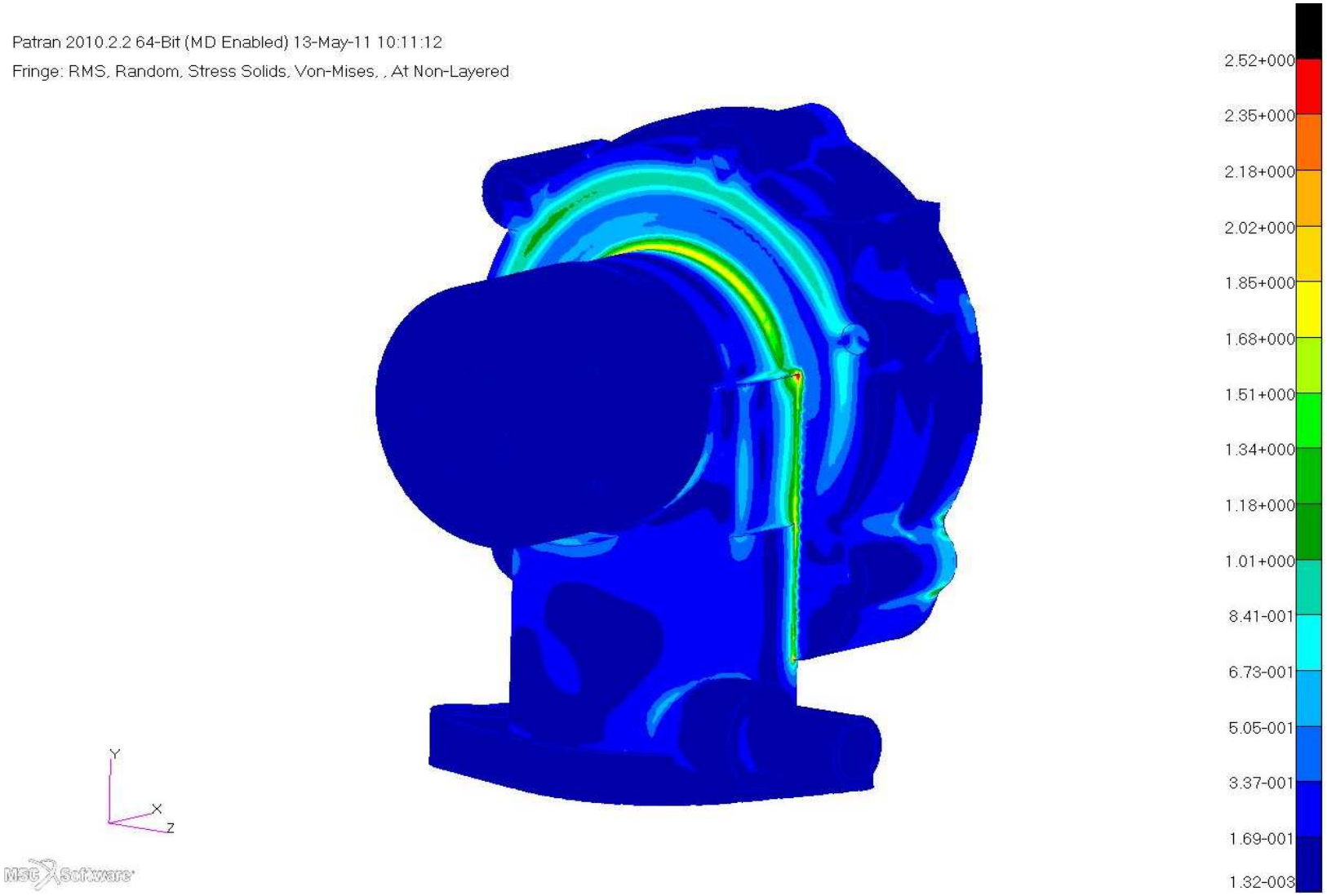
Application at a big model

Performance Data (911 882 nodes, 582 879 Tet10, displacement and stress)

- Nastran Frequency Response:
  - 27h 22min (elapsed), 14h 56min (CPU), 206GB disk space
  - Results: xdb file of 57.5GB
- Creating RMS Results using MSC.Random:
  - 2h 19min – run in background via Patran batch mode
- Plotting RMS Results and generating PSD plots takes only seconds
- All data derived on AMD Opteron under Windows 64bit

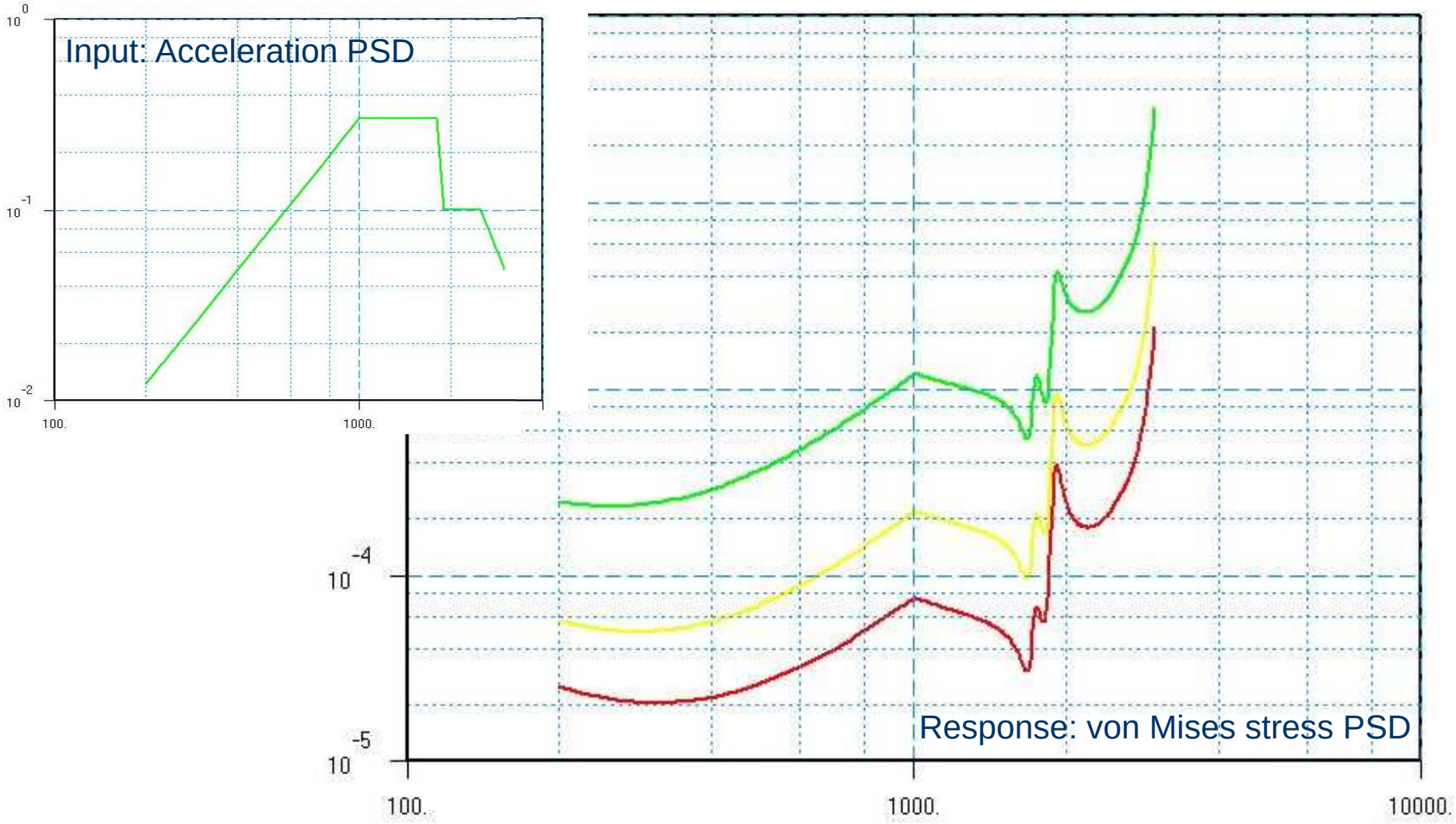
Application at a big model

- RMS-Data for "Hot Spot" identification delivers a fast overview of critical areas



Application at a big model

- PSD-Data for finding responsible resonances



Conclusion

- Often von Mises stresses are requested in dynamic analysis

- Phase information needed is only available in a frequency response simulation
- Von Mises cannot be computed correctly out of a random analysis because the phase is missing
- *But most postprocessors offer this option!*

- The only way to calculate the von Mises stress PSD is based on the deterministic frequency response
- A correct and fast way to get valid von Mises stresses is to use MSC.Random

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