

# Integration Of Flexible Structures In Multibody Systems: Reliable Model Generation And Automated Modeselection

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## 1. Process FEM / MBS Interfacing

1. Overview
2. Optimization And Automization Potentials

## 2. A New Process For Integrating Flexible Structures

1. Overview
2. Model Preparation Within MBS-Environment
3. Single Process Steps

## 3. Flexible-Body System Analysis And Automatic Modeselection

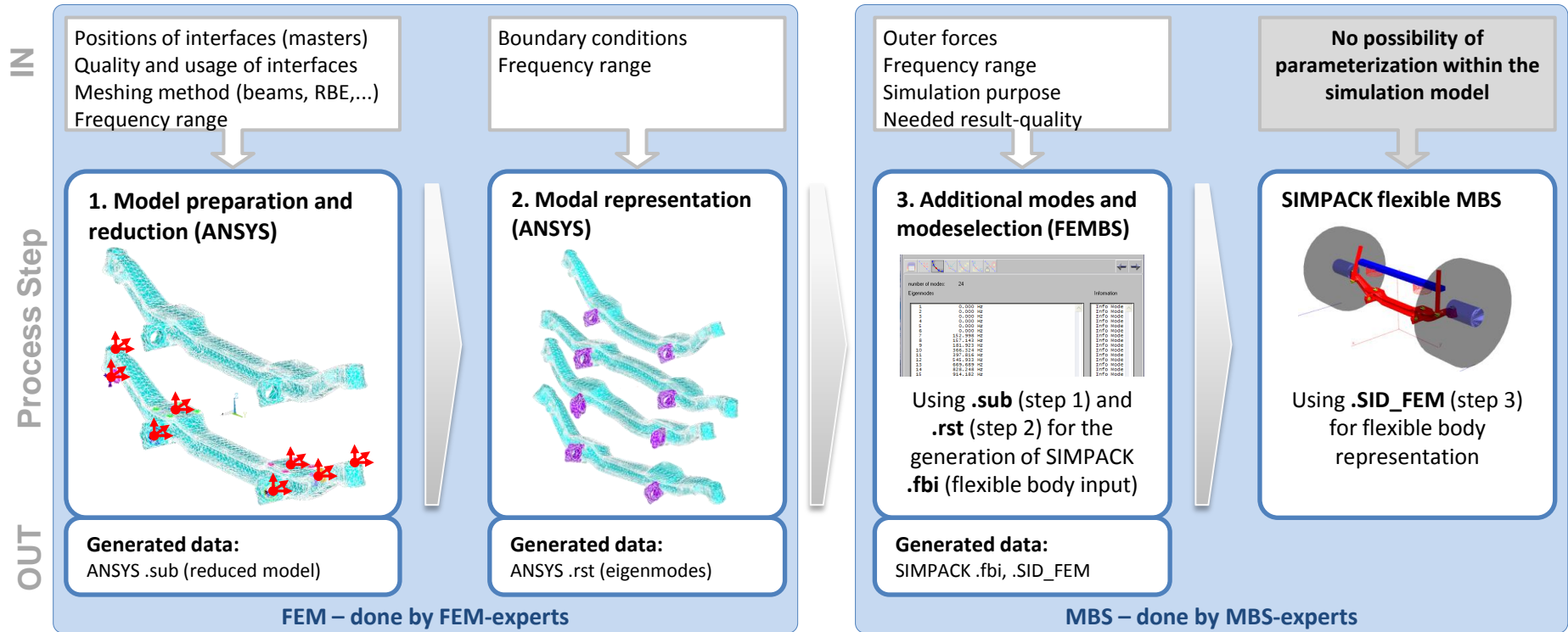
1. Available Selection-Criterias
2. Global selection recommendation

## 4. Summary And Perspective



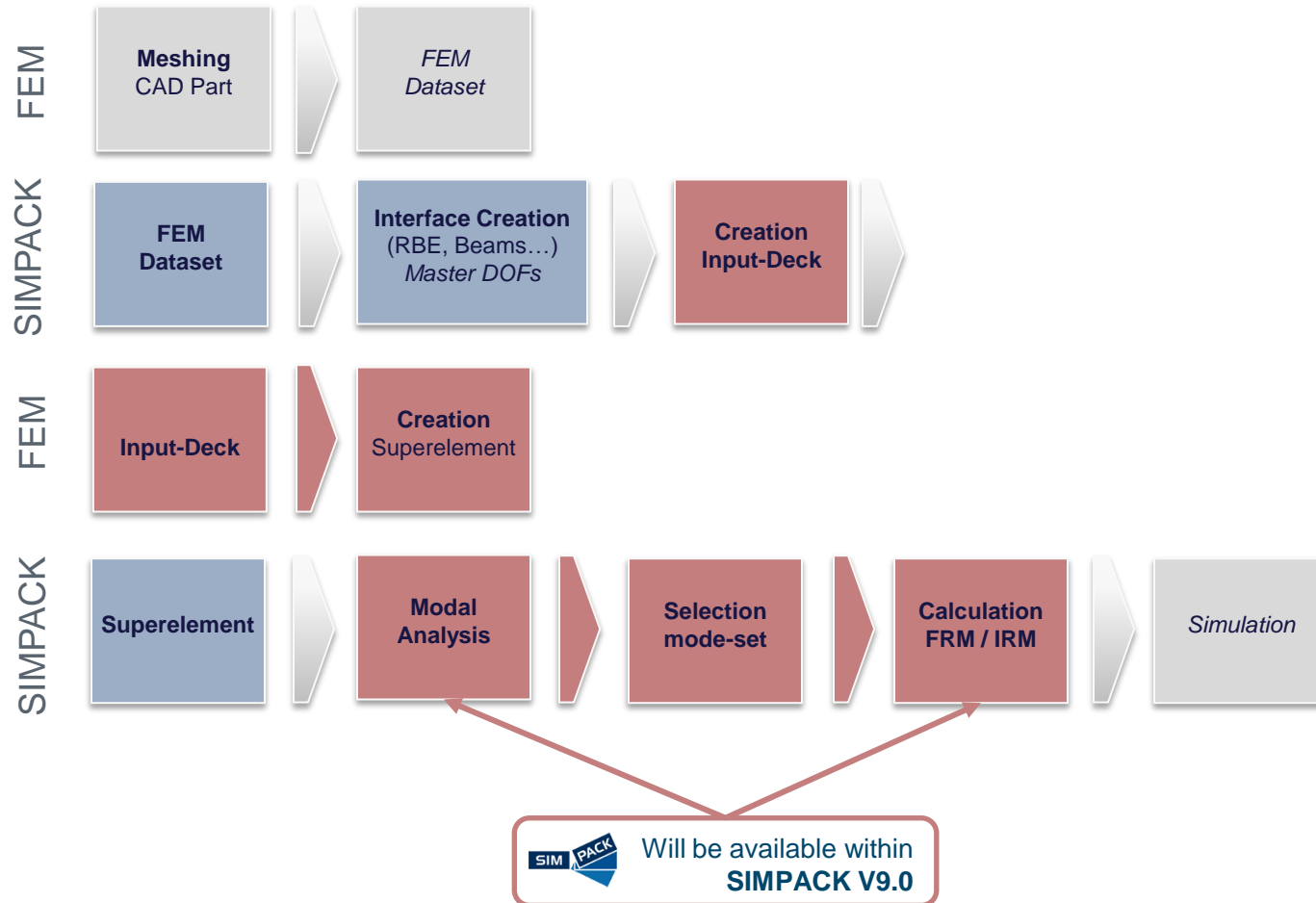
# Process FEM / MBS Interfacing

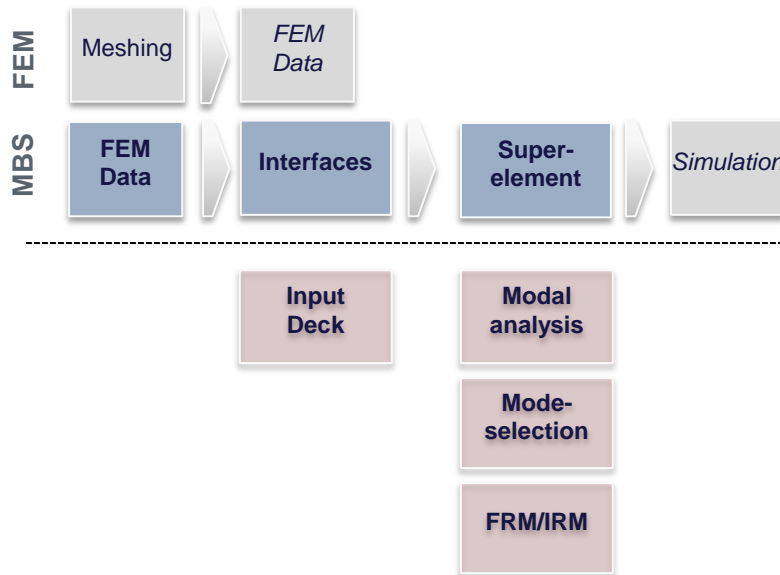
## (ANSYS + SIMPACK 8.9)



Model requirements?

Model quality? (passed as Blackbox)





### → Preparation of FE-Mesh within the Multibody-Simulation-(MBS)-Environment

- Interface generation
- Datamanagement for interfaces and flexible-body data
- Generation of Input-Deck, automated model-reduction

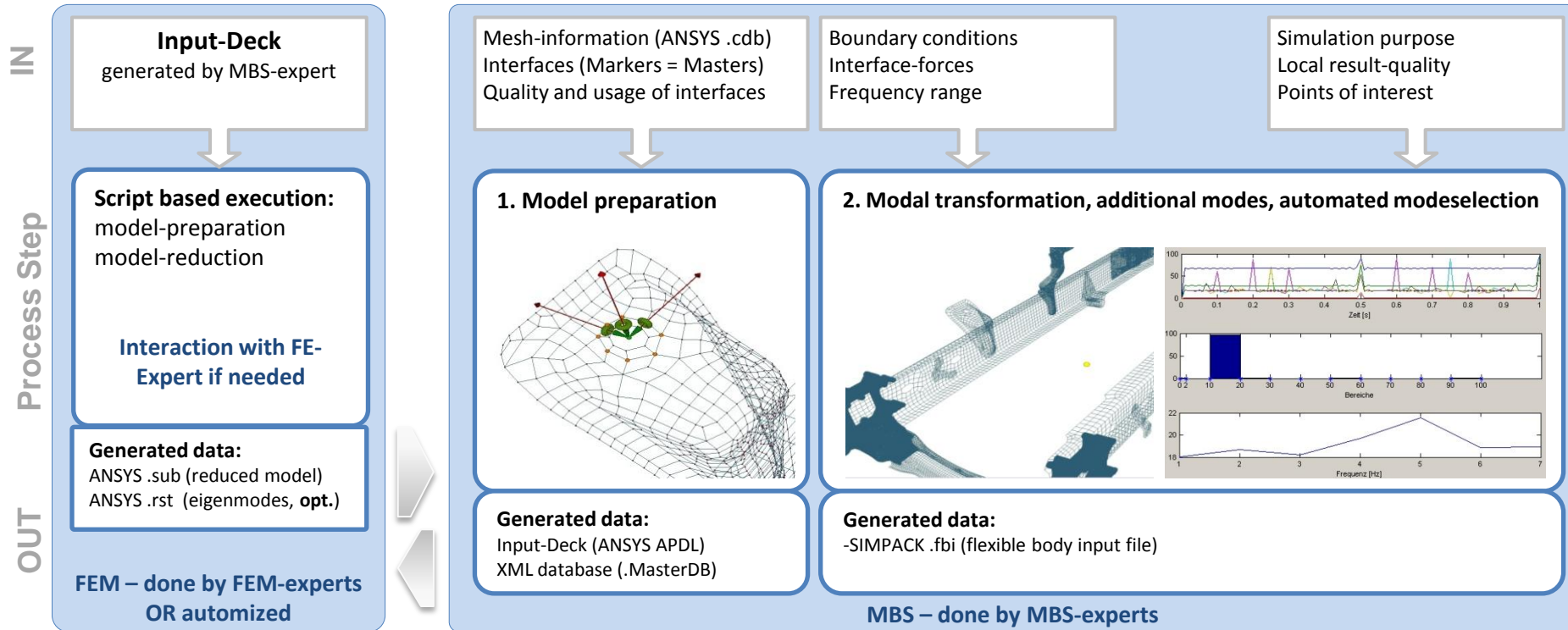
### → Calculation of modes and FRM / IRM within the MBS-environment – automated modeselection based on simulation scenario and loadcase

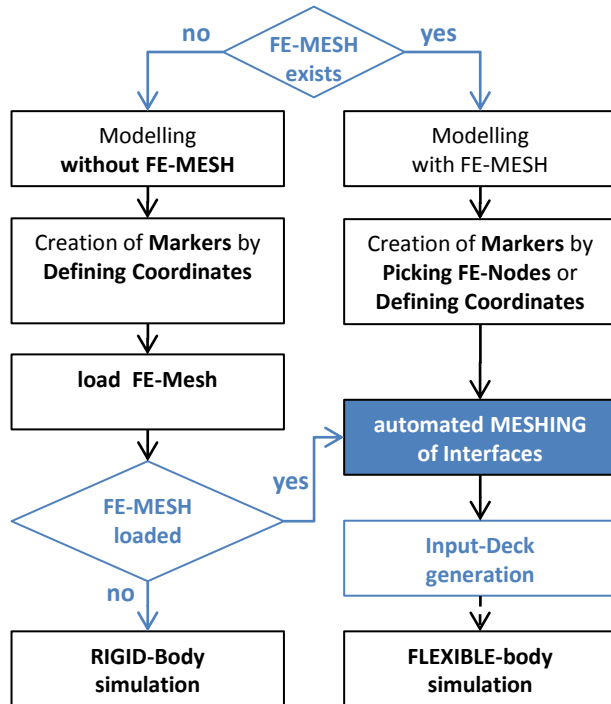
- Modal analysis
- Calculation of modeselection criterias

By transferring key-tasks of the model-preparation to MBS-environment a huge range of data is directly available:

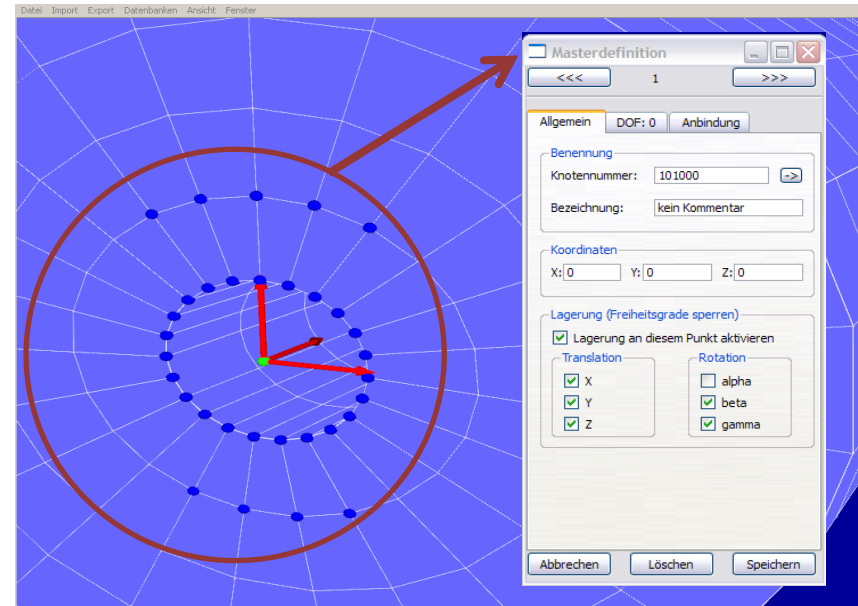
- Interface forces / torques
- Interface usage and requirements
- Frequency ranges
- Boundary conditions
- ...

# A New Process For Integrating Flexible Structures





→ ANSYS Input-Deck  
 → XML interface database



### Saving important data like

- Interface purpose (measuring, force-input, inactive)
- Interface description
- Boundary conditions
- Connections to FE-mesh (RBE2/3, Beams, ...)

# New Process For Integrating Flexible Structures

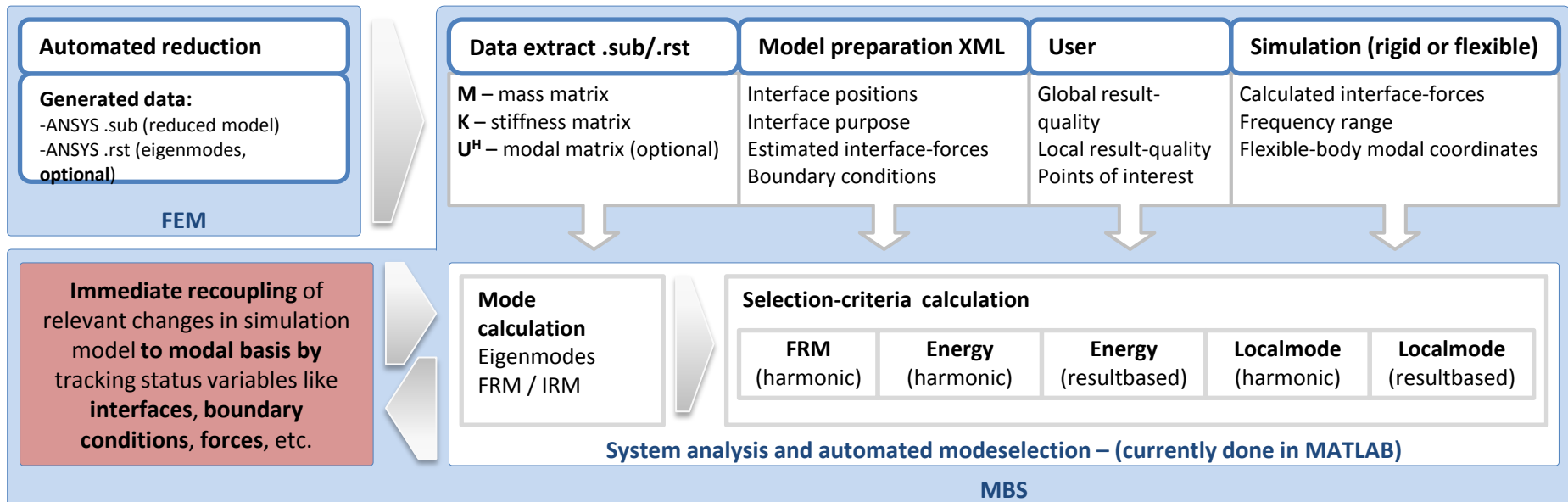
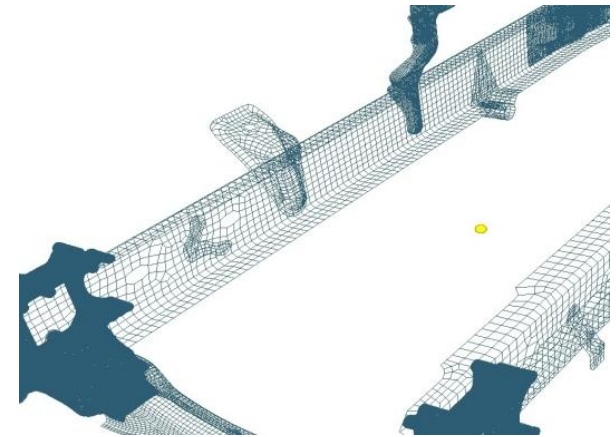
## Process Steps

### Available data about interfaces and model-setup can be used

- Interface positions, DOF
- Estimated interface-forces (FRM calculation)
- Boundary conditions

### Available data of simulation run can be used

- Calculated interface-forces
- Frequency Ranges



# Flexible-Body System Analysis And Automatic Modeselection

Parameters for modeselection-routines given by user or derived from result-data  
forces, frequencies, thresholds and limits, ...

### Selection-criteria calculation

<b>FRM</b> (harmonic)	<b>Energy</b> (harmonic)	<b>Energy</b> (resultbased)	<b>Localmode</b> (harmonic)	<b>Localmode</b> (resultbased)
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<b>STAGE 1</b> <i>(before simulation)</i>
<b>STAGE 2</b> <i>(after simulation)</i>

#### FRM (harmonic)

Based on FRM calculation:  
-Forces  
-Excitation frequency band

Type:  
-Frequency domain

- Principal:
1. Displacement for one force at one frequency differs from displacement at other frequency
  2. Selection of the eigenmode which compensates the error best

**STAGE 1 criteria**

#### Energy (harmonic)

Based on energy balance:  
-Forces  
-Excitation frequency band

Type:  
-Time domain

- Principal:
1. Calculation of modal coordinates for all input value combinations
  2. Calculation of energy balances
  3. Selection of the mode if energy is greater than threshold

**STAGE 1 criteria**

#### Energy (resultbased)

Based on energy balance:  
- modal coordinates directly imported from SIMPACK

Type:  
-Time domain

- Principal:
1. Calculation of energy balance using modal coordinates
  2. Selection of the mode if energy is greater than threshold

**STAGE 2 criteria**

#### Localmode (harmonic)

Based on displacements:  
-Forces  
-Excitation frequency band

Type:  
-Maximum value

- Principal:
1. Calculation of modal coordinates for all input value combinations
  2. Calculation of displacement maxima
  3. Selection if the mode has only effects on active interfaces

**STAGE 1 criteria**

#### Localmode (resultbased)

Based on displacements:  
- modal coordinates directly imported from SIMPACK

Type:  
-Maximum value

- Principal:
1. Calculation of displacement maxima using modal coordinates
  2. Selection if the mode has only effects on active interfaces

**STAGE 2 criteria**

FRM  
(harmonic)

1. Formulation of basic FEM equation and harmonic excitation of the system leads to

$$\underline{\underline{M}}\ddot{\underline{u}} + \underline{\underline{K}}\underline{u} = \underline{p} \quad \Rightarrow \quad (\underline{\underline{K}} - \omega_0^2 \underline{\underline{M}})\underline{u}_{FRM} = \underline{p}$$

M: mass matrix / K: stiffness matrix / p: force / u = displacement vector /  $u_{FRM}$ : displacement vector FRM /  $\omega_0$ : excitation frequency

2. Displacement is only exact for the used combination of force + frequency, generally flexible body motion consists of displacements calculated by FRM + eigenmodes

$$\underline{u}_{FRM}(\omega_0) \neq \underline{u}_{FRM}(\omega_0 + \Delta\omega) \quad \underline{u} = \underline{u}_{FRM} + \underline{u}_H$$

$u_H$ : displacement vector eigenmodes

3. The „error“ made at different frequency has to be „compensated“ by eigenmodes

$$\underbrace{(\underline{\underline{K}} - (\omega_0 + \Delta\omega)^2 \underline{\underline{M}})\underline{u}_H}_{\text{compensation by eigenmodes}} = \underbrace{-(2\omega_0\Delta\omega + \Delta\omega^2)\underline{\underline{M}}\underline{u}_{FRM}}_{\text{error at different frequency}}$$

4. Modal transformation and separation of the equations due to diagonal mass and stiffness matrices (orthogonality of eigenmodes!) leads to

$$q_{H,i} = \frac{-(2\omega_0\Delta\omega + \Delta\omega^2)\hat{m}_i}{\hat{K}_{ii} - (\omega_0 + \Delta\omega)^2\hat{M}_{ii}}$$

**The coordinate  $q_H$  for each mode  $i$  indicates the ability of the mode to compensate the error at excitation frequencies different from  $\omega_0$**

Energy  
(harmonic)

1. Formulation of basic FEM equation and harmonic excitation of the system leads to

$$\underline{\underline{M}}\ddot{\underline{u}} + \underline{\underline{K}}\underline{u} = \underline{p}(t) \quad \Rightarrow \quad \underline{\underline{\hat{M}}}\ddot{\underline{q}} + \underline{\underline{\hat{K}}}\underline{q} = \underline{\hat{p}}e^{i\omega t} \quad (\text{modal transformed})$$

M: mass matrix / K: stiffness matrix / p(t): force / u = displacement vector / q: modal coordinate / ω: excitation frequency

2. Assuming sinusoidal excitation and separation of equations due to diagonal mass and stiffness matrices (orthogonality of eigenmodes!) leads to

$$q(t)_i = \frac{\hat{p}_i}{\hat{K}_{ii}^2 - \omega^2} \left( -\frac{\omega}{\hat{K}_{ii}} \sin(\hat{K}_{ii}t) + \sin(\omega t) \right)$$

$$\dot{q}(t)_i = \frac{\omega \hat{p}_i}{\hat{K}_{ii}^2 - \omega^2} \left( -\cos(\hat{K}_{ii}t) + \cos(\omega t) \right)$$

3. Energy levels for each mode and the whole system are calculated

$$E_{ges}(t) \equiv E_{pot}(t) = \sum_{i=1}^n \frac{1}{2} q(t)_i \hat{K}_{ii} q(t)_i + E_{kin}(t) = \sum_{i=1}^n \frac{1}{2} \dot{q}(t)_i \hat{M}_{ii} \dot{q}(t)_i$$

4. Energy levels of each mode are related to the system energy

$$\lambda_i(t) = \frac{E_{pot,i}(t) + E_{kin,i}(t)}{E_{ges}(t)}$$

λ: energy criteria

**λ represents the energy level for each mode *i* with respect to the global system energy**

### Localmode (harmonic)

1. Energy criteria results (modal coordinates) are used for calculation:

$$q(t)_i = \frac{\hat{p}_i}{\hat{K}_{ii}^2 - \omega^2} \left( -\frac{\omega}{\hat{K}_{ii}} \sin(\hat{K}_{ii}t) + \sin(\omega t) \right)$$

2. Modal coordinates are expanded using modal matrix, resulting in displacement vector

$$\underline{u}(t) = \underline{U}^H \underline{q}(t)$$

3. Maximum displacements over time are stored and analysed

**Analysis of resulting displacements for each mode  $i$  on all active interface DOFs**

### Energy (resultbased)

1. Import of modal positions and velocities directly from SIMPACK

$$q(t) \quad \dot{q}(t)$$

2. Energy levels for each mode and the whole system are calculated

$$E_{ges}(t) \equiv E_{pot}(t) = \sum_{i=1}^n \frac{1}{2} q(t)_i \hat{K}_{ii} q(t)_i + E_{kin}(t) = \sum_{i=1}^n \frac{1}{2} \dot{q}(t)_i \hat{M}_{ii} \dot{q}(t)_i$$

3. Energy levels of each mode are related to the system energy

$$\lambda_i(t) = \frac{E_{pot,i}(t) + E_{kin,i}(t)}{E_{ges}(t)}$$

**$\lambda$  represents the energy level for each mode  $i$  with respect to the global system energy**

$\lambda$ : energy criteria

### → Criteria can be used as quality index for final modeselection

- If all included modes have high energy levels, deselection is probably too strong
- If some modes have very low energy levels, deselection is probably too weak

**Localmode**  
(resultbased)

1. Import of modal positions and velocities directly from SIMPACK

$$q(t)$$

2. Modal coordinates are expanded using modal matrix, resulting in displacement vector

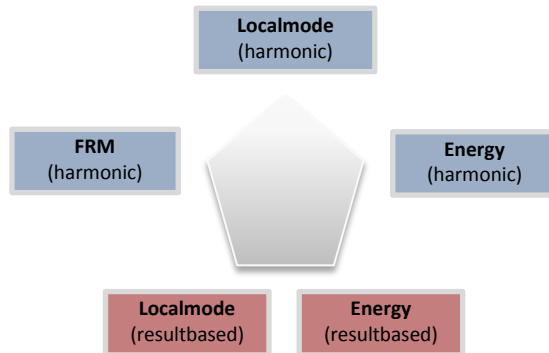
$$\underline{u}(t) = \underline{U}^H \underline{q}(t)$$

3. Maximum displacements over time are stored and analysed

**Analysis of resulting displacements for each mode  $i$  on all active interface DOFs**

→ **Criteria can be used as quality index for final modeselection**

- If simulation results include unused interfaces no mode should be marked as localmode by the criteria



### Stage 1 criterias (before simulation)

- 1. Input:
  - Forces
  - Excitation frequency band (e.g. 1-50 Hz, 5Hz steps)
  - Thresholds and limits
- 2. Calculation
  - all combinations force + frequency
  - local criterias (focused on current loadcase)
  - global criterias (full resultbase analysis)

### Stage 2 criterias (after simulation)

- 1. Input:
  - SIMPACK modal positions and velocities
- 2. Calculation
  - global criterias based on result-data

→ **Combination of single selection criterias results in one Boolean global criteria**

# Summary And Perspective





### **SIMPACK V9.0 offers a new method for FE/MBS integration**

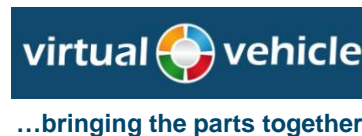
- Internal mode calculation
- Boundary-conditions are taken into account
- FRM calculation dependent on interfaces to flexible-body

### **Parts of this project will be integrated into SIMPACK**

- Flexible-system analysis
- Calculation of modeselection criterias
- Selection proposals for adequate mode-set
- Recoupling of simulation results and flexible-system analysis

# Have a good time at SIMPACK Usermeeting 2011

## Questions?



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