



KARL MAYER

Optimization of Fast-Moving, Highly Precise Mechanisms with the Equivalent Static Load Method

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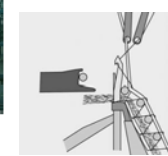
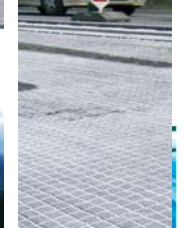
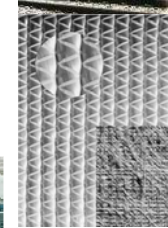
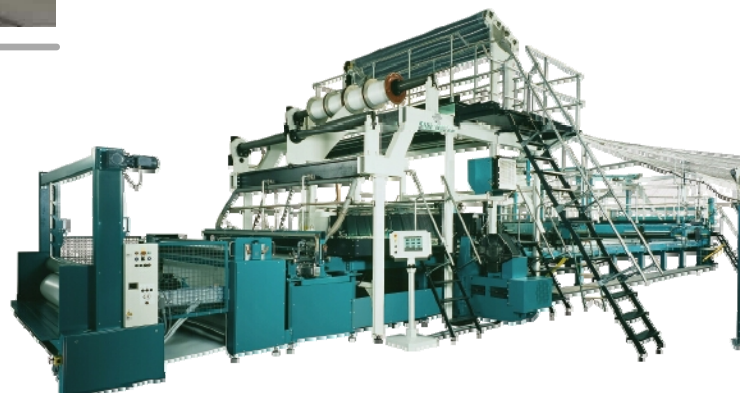
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Karl Mayer Textile Machines



Frequency: up to 70 Hz
Range of motion: 50 mm
Accuracy: 1/1000 mm
Load cycles: 10^{10} p.a.
Forces: 10 KN

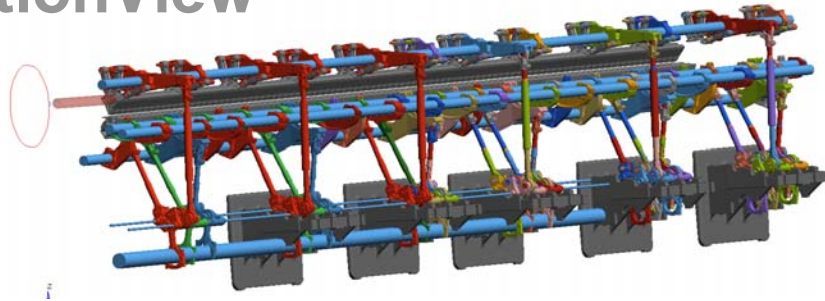



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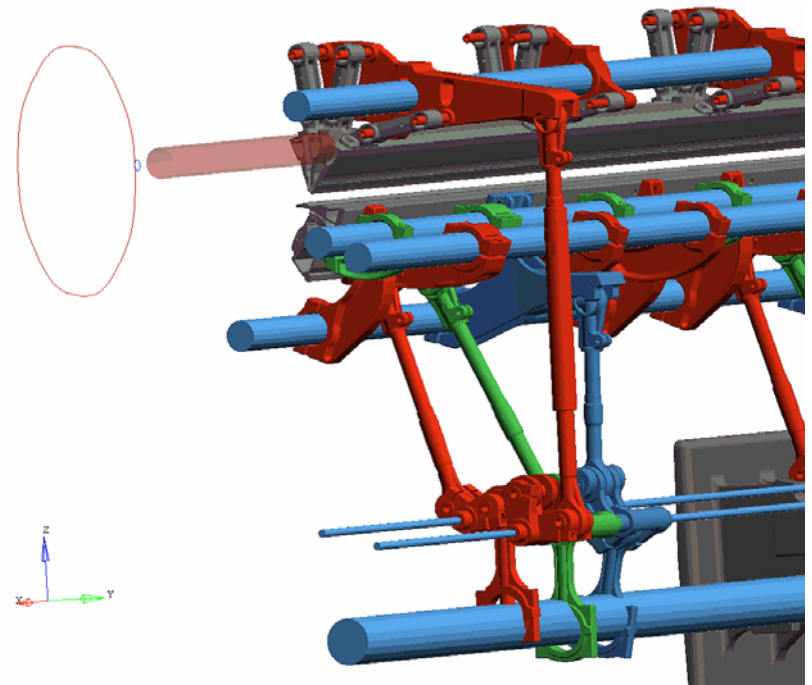


HyperMesh and MotionView

MotionView

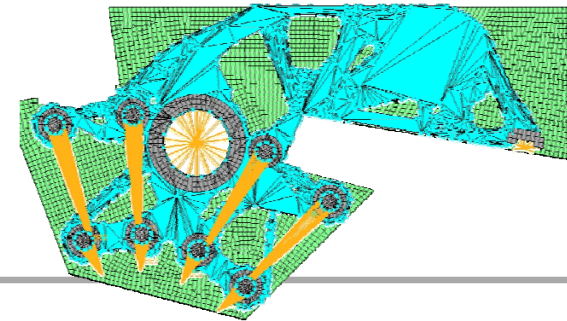
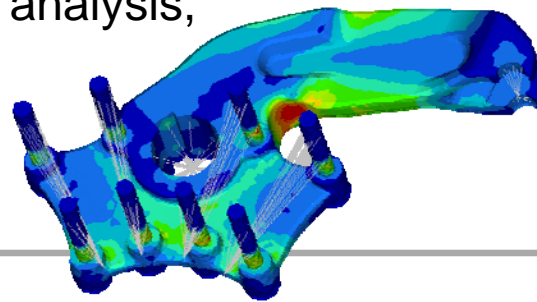
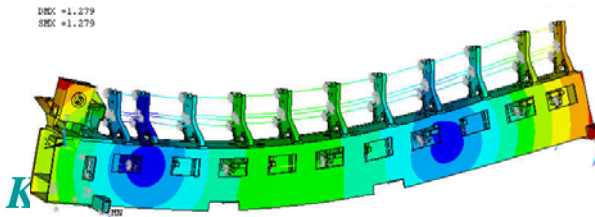


mechanism + electric motor + control
⇒ transient analysis, optimization



HyperMesh

complete structure or single parts
⇒ static or harmonic analysis,
optimization



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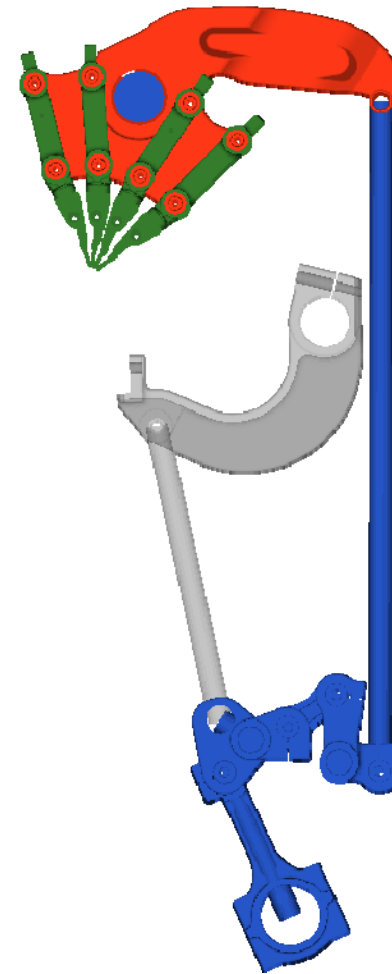
Design Objectives for Mechanisms

Objectives

- Optimization of the motion
- Assure durability (10^{10} load cycles per year)
- Minimization of
 - ✦ vibration and deformation
 - ✦ forces (load on bearings, excitation)
 - ✦ stress in parts
 - ✦ mass

Design parameters

- Shape of the parts
- Kinematic dimensions
- Materials



Optimization Problem

Time variant loads and constraints

Design variables influence loads

e.g. a parts mass influences the load on this part

Manifold interactions between parts

e.g. a parts mass affects the stress in other parts,
e.g. the relevance of a parts deformation depends on
the mechanisms position and transmission behaviour

Dependency between design variables

e.g. shapes influencing the kinematic dimensions

Total mechanisms characteristic is relevant

e.g. excitation forces (partial mass balancing)



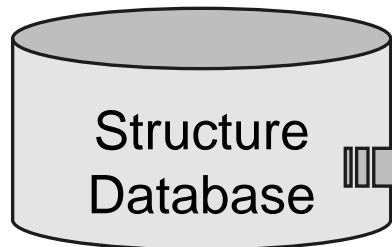
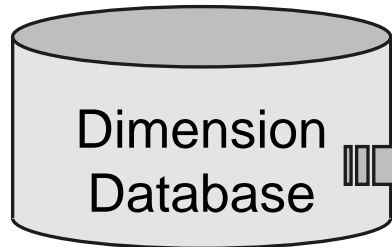
The Design Process

1. Build the rigid-body-model in HyperMesh
 - ⇒ Transient analysis (kinetostatic forces) is possible
 - ⇒ Forces may be used as input for a topology optimization.
2. Build or import the FE-mesh for the flexible bodies
3. Attach the FE-mesh to the bodies
 - ⇒ Transient analysis (deformation, forces, stress) is possible
4. Set up the design variables, constraints and objective for the optimization
 - ⇒ Automatic optimization with consideration of transient motions



Building the Rigid-Body-Model

TCL-script (ASCII-file)



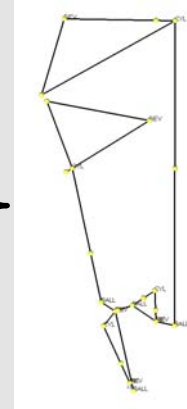
Data definition: kinematic dimensions

```
variable KurbelParameter;  
array set KurbelParameter {  
  sv_DAY 7.777  
  sv_DAZ -12.345  
  ...  
}
```

Function calls: build the kinematic structure

```
*createnodesbetweennodes $p_G4(ID) $p_G4(ID) 1  
set K_ID [expr $K_ID+1]  
*createmark nodes 1 [expr $K_ID]  
*bodycreate "Kurbelwelle" 1 1 53 0 0 0  
*bodyparametersupdate "Kurbelwelle" 1 1000 1000 1000 0 0 0 .....  
*alternatejointcreate 10 [expr $K_ID] $p_G4(ID) 0 0 1 0 0 0 0 0  
*collectorcreate loadcols "Antrieb" "" 30  
*createmark nodes 1 $K_ID  
*loadcreateonentity_curve nodes 1 3 14 -999999 -999999 -999999 6.28 .....
```

```
ViergelenkErzeugen $p_G3(ID) $K_ID [array get KurbelParameter] 4 "Kurbel"  
set Temp_ID2 $Temp_ID  
ViergelenkErzeugen $p_G0(ID) $Temp_ID2 [array get LegellIParameter] 7 "LegellI"  
ViergelenkErzeugen $p_G2(ID) $Temp_ID2 [array get LegelIParameter] 5 "LegelI"  
set Temp_ID2 $Temp_ID  
ViergelenkErzeugen $p_G1(ID) $Temp_ID [array get LegellIParameter] 6 "LegellI"
```



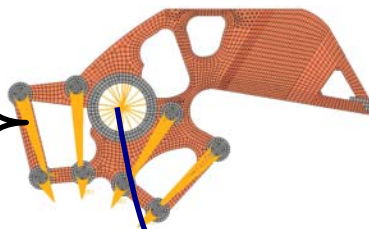
Function calls: create loadsteps, motion, etc.

```
*loadstepscreate "MBSIM" 1  
*attributeupdateint loadsteps 1 4143 1 1 0 1
```



Adding Flexible Bodies

Build (import) the FE-model

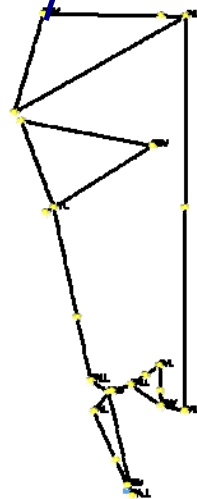


TCL-Script

```

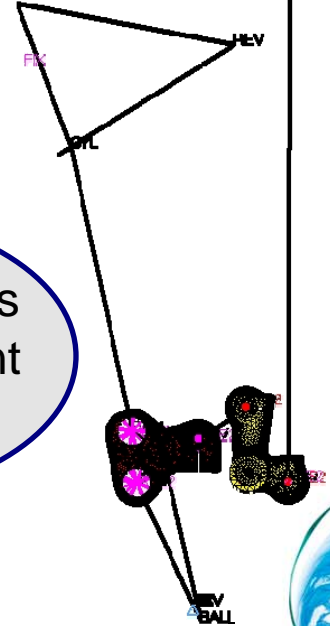
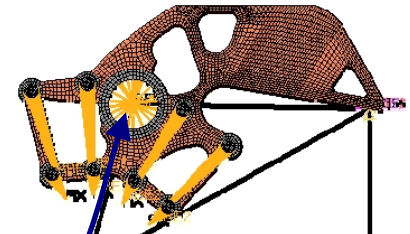
variable KurbelParameter;
array set KurbelParameter {
  sv_DAY 7.777
  sv_DAZ -12.345
  ....
*createnodesbetweennodes $p_G4(ID) $p_G4(ID) 1
set K_ID [expr $K_ID+1]
*createmark nodes 1 [expr $K_ID]
*bodycreate "Kurbelwelle" 1 1 53 0 0 0
*bodyparametersupdate "Kurbelwelle" 1 .....
*alternatejointcreate 10 [expr $K_ID] .....
*collectorcreate loadcols "Antrieb" "" 30
*createmark nodes 1 $K_ID
*loadcreateonentity_curve nodes 1 3 14 .....

ViergelenkErzeugen $p_G3(ID) $K_ID ....
set Temp_ID2 $Temp_ID
ViergelenkErzeugen $p_G0(ID) $Temp_ID2 ....
ViergelenkErzeugen $p_G2(ID) $Temp_ID2 ....
set Temp_ID2 $Temp_ID
ViergelenkErzeugen $p_G1(ID) $Temp_ID ....
...
*loadstepscreate "MBSIM" 1
*attributeupdateint loadsteps 1 4143 1 1 0 1
...
    
```



Attach elements to bodies

Define constraints for the component mode synthesis

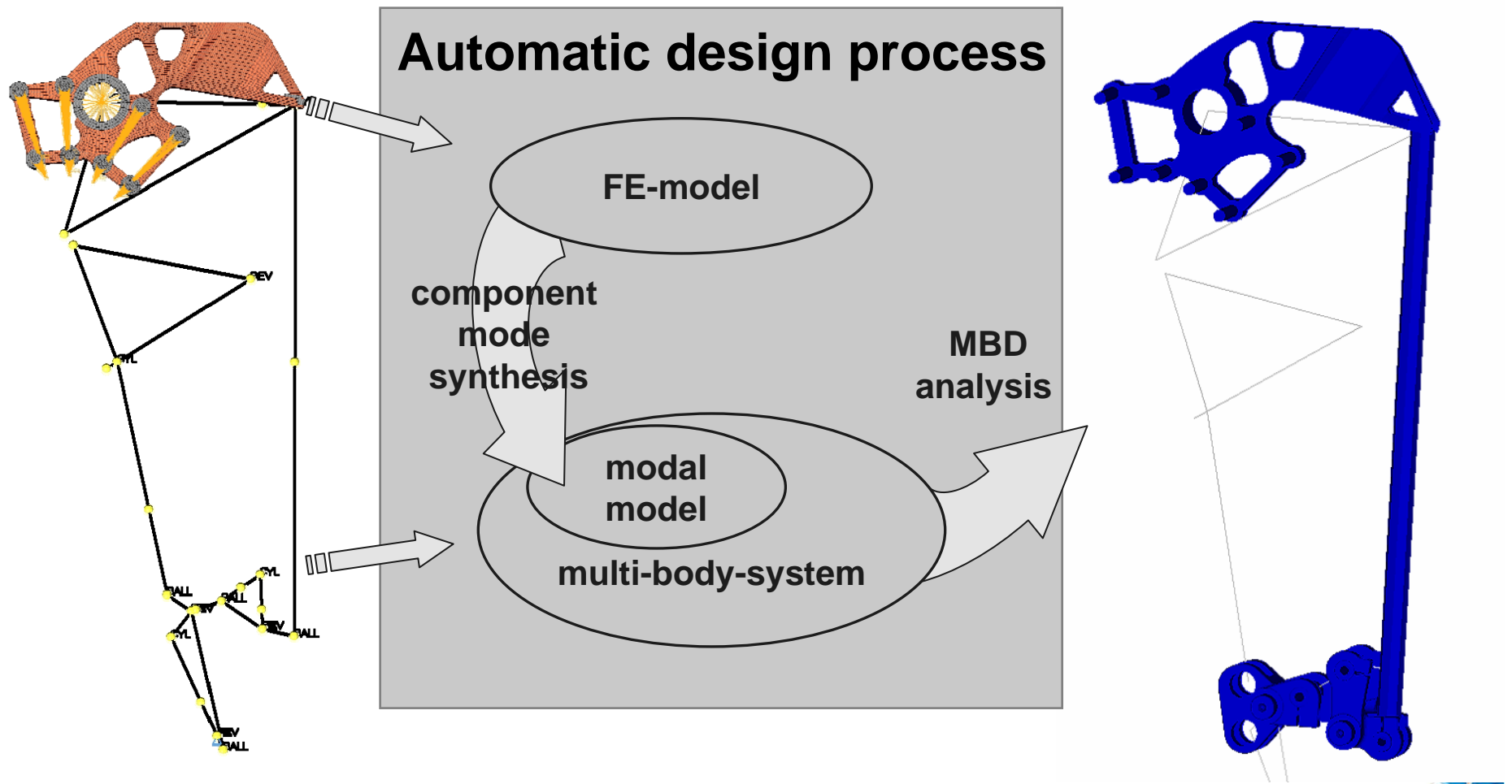


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Performing Transient Analysis



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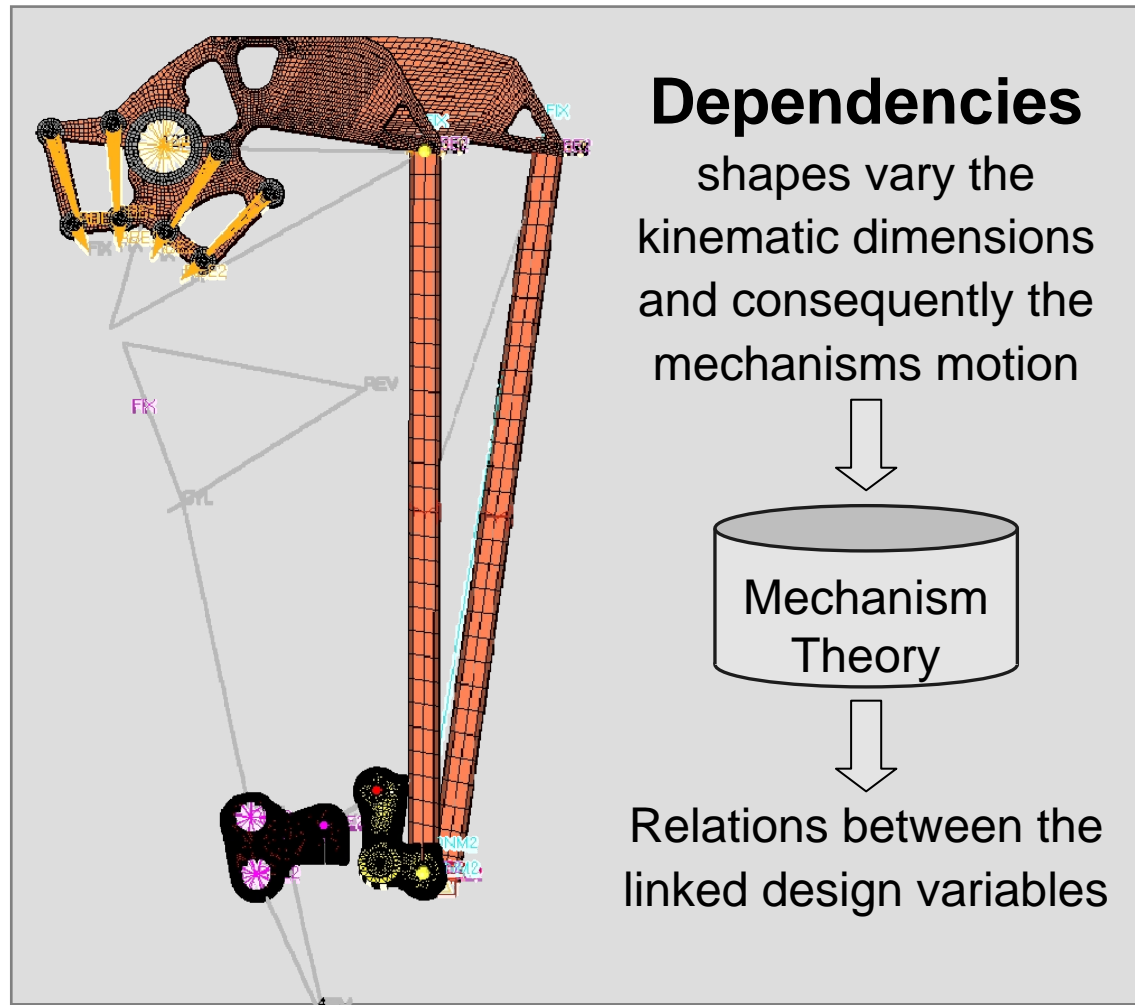
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Setting up the Optimization

Design objective
or constraints on
velocities or accelerations
deformations
joint forces
stress
mass
...

Design variables
size-optimization
freeshape
shape

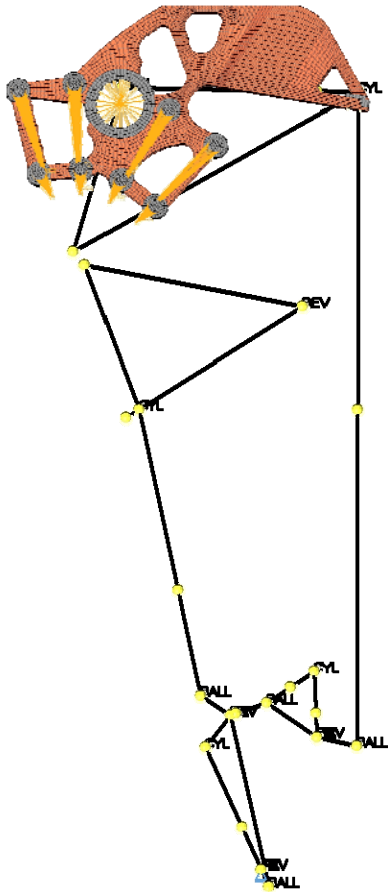


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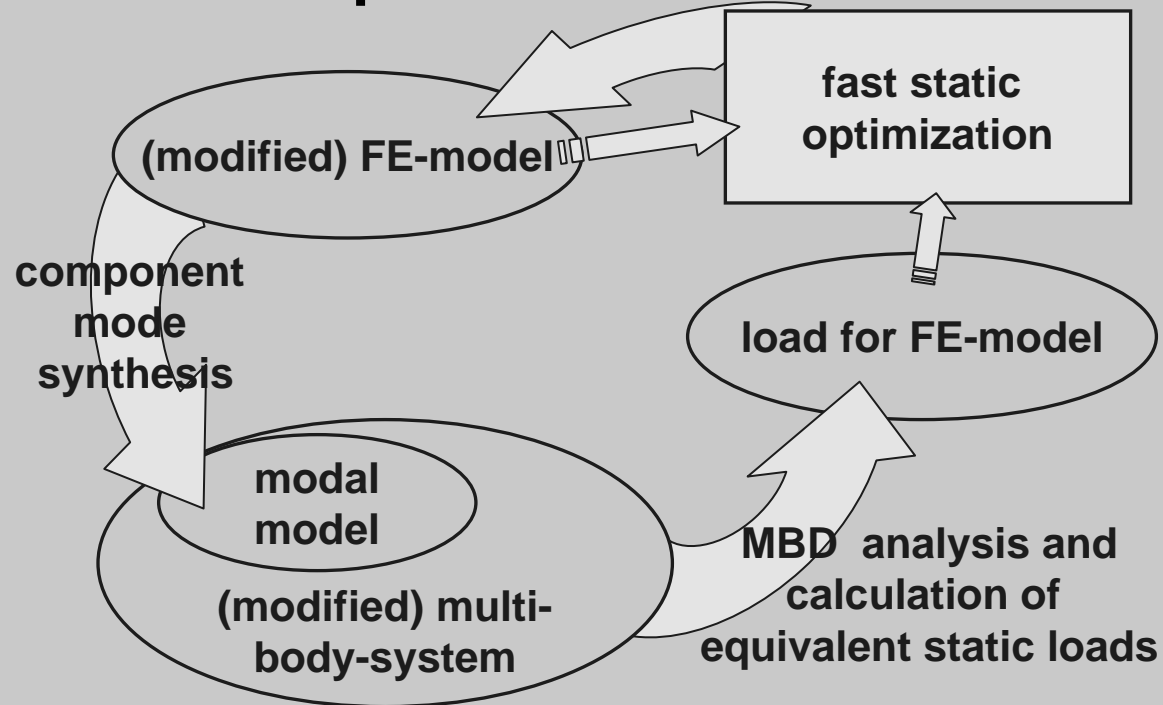
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Performing the Optimization



Automatic optimization



Definition: „Equivalent Static Load“

„when a dynamic load is applied to a structure, the equivalent static load is defined as the static load that makes the same displacement field as that by a dynamic load at an arbitrary time.“



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Summary

Problem: Find the optimal design for a time variant system with numerous interactions between the components

Solution:

1. Partially automated generation of complex multi-body-systems in HyperMesh
 - ⇒ usage of a database with kinematic dimensions
 - ⇒ usage of macros for building basic kinematic structures
2. Adding FE-models for the flexible parts of the system
3. Setting up the optimization problem
 - ⇒ application of mechanism theory to define adequate constraints
4. Start the automatic optimization



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