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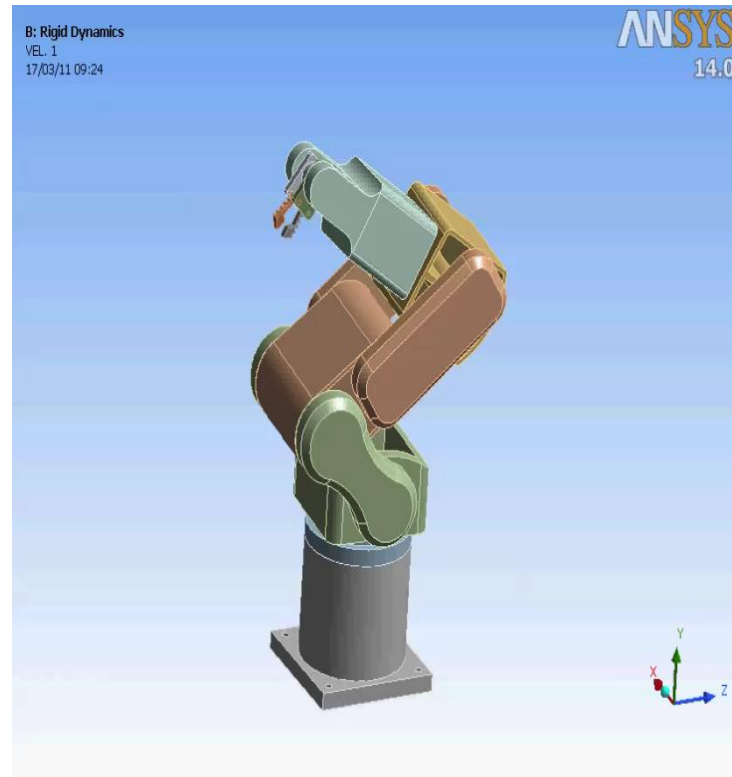
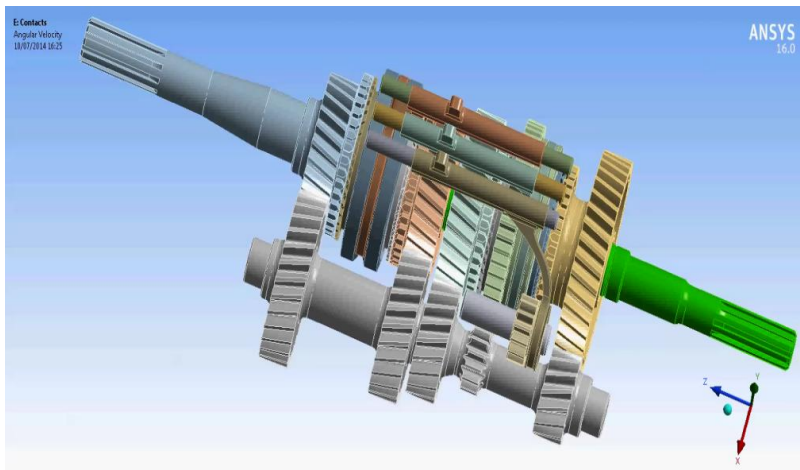
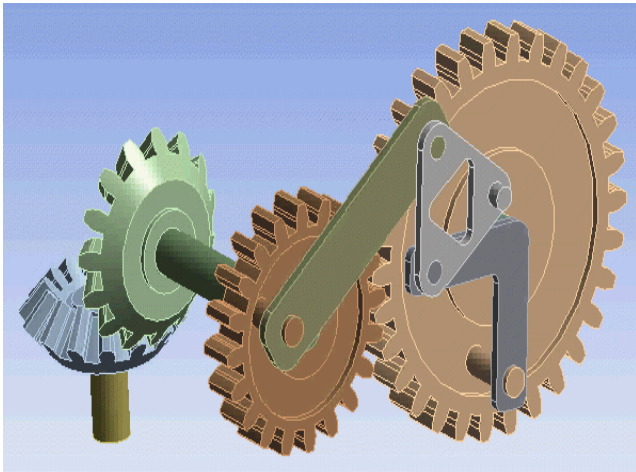


# ANSYS 刚柔混合多体动力学分析专题培训

- 李桂花/ 应用工程师

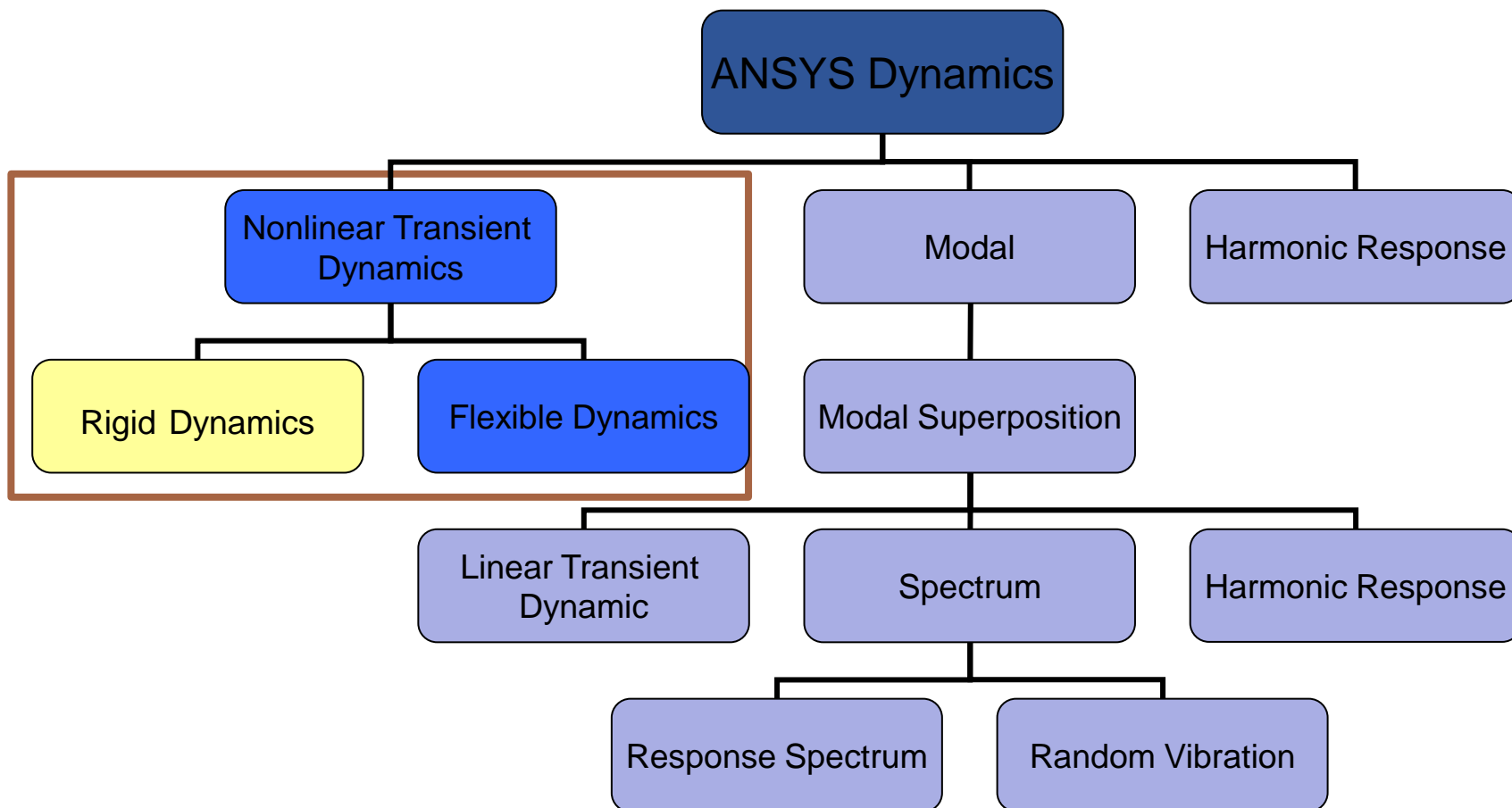
# 什么是多体动力学 (Multibody Dynamic, MBD) ?

- 多体运动学是研究多体系统 (一般由若干个柔性和刚性物体相互连接所组成)运动规律的科学。



# A. 多体动力学简介

- ‘刚体动力学’ 是ANSYS 动力学分析中的一个分支



# A. 多体动力学简介

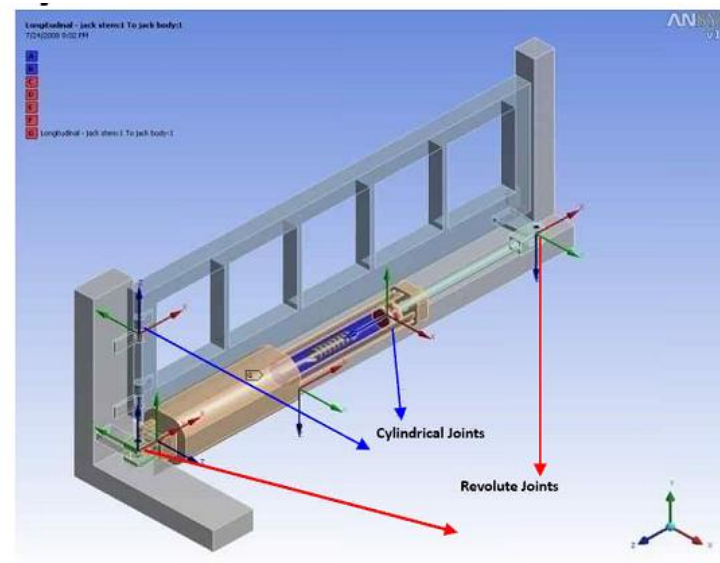
## Ansys中有两种多体动力学分析:

### 多刚体系统运动分析

- 只包含刚性体
- 求解快
- 由于接触或者运动副产生运动
- 主要求解各个零部件的位移、速度、加速度和反作用力/力矩等历程曲线。
- 支持大变形大旋转效应
- 通过 “Rigid Dynamics” 分析模块实现

ANSYS MECHANICAL: 1min

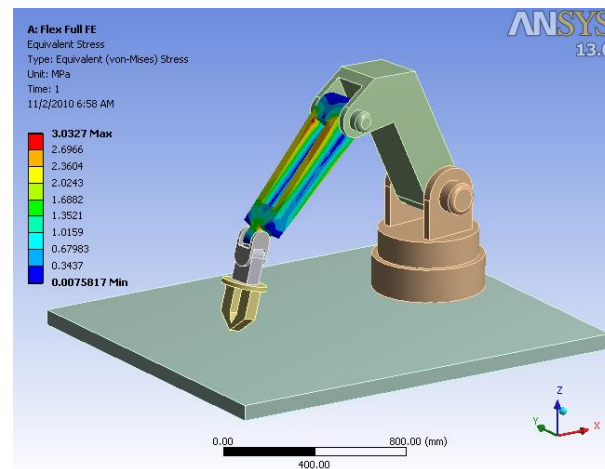
RIGID DYNAMIC: 1s



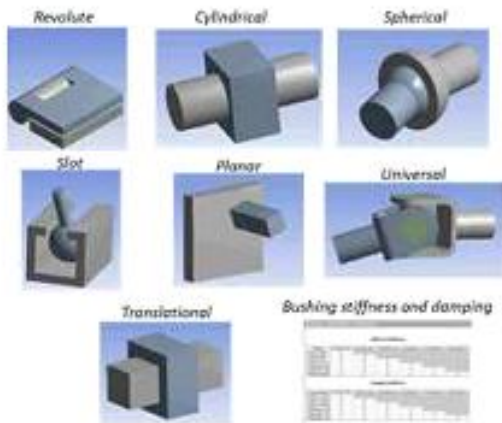
# A.多体动力学简介

柔性体或者刚柔混合多体动力学

- 包含柔性体和刚体
- 求解时间长
- 允许所有的非线性效应
- 不仅可以求解系统当中刚体的动力学特性；同时还可以输出柔性体的动力学特性：包括柔体的应力、应变、变形、接触压力等等。
- 通过 “Transient Structural” 模块求解

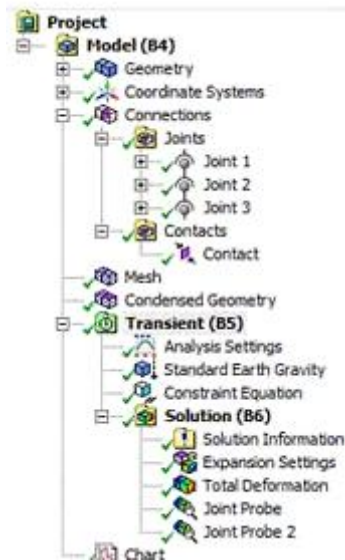


# 大纲



## • 多体动力学分析组成

## • 多体动力学分析流程

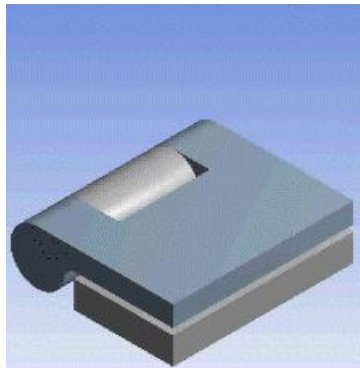


## • 多体动力学和其他模块的连接

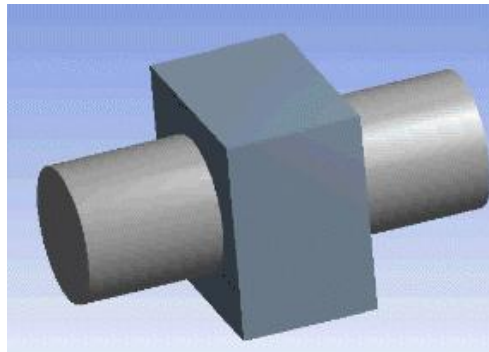


# 运动副

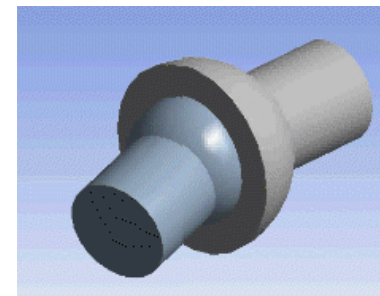
- Revolute
- Cylindrical
- Spherical
- Translational
- Slot
- Planar
- Universal
- General
- Bushing



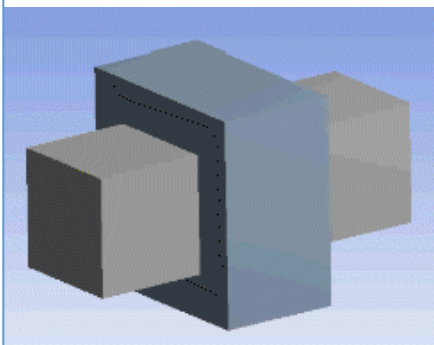
Revolute



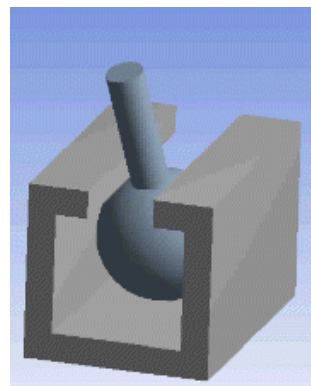
Cylindrical



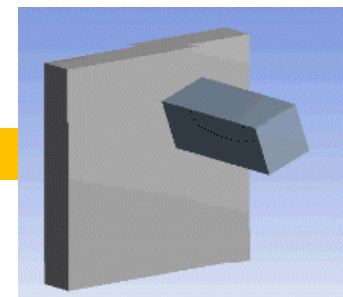
Spherical



Translational



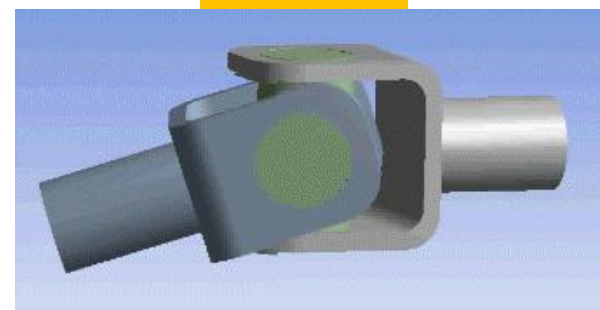
Slot



Planar

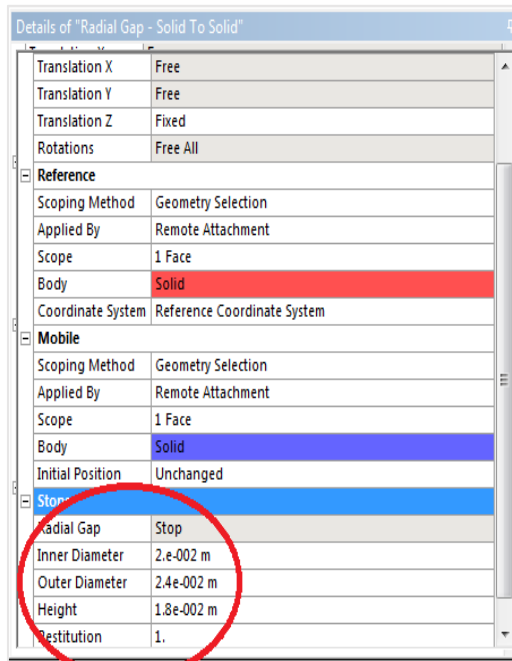
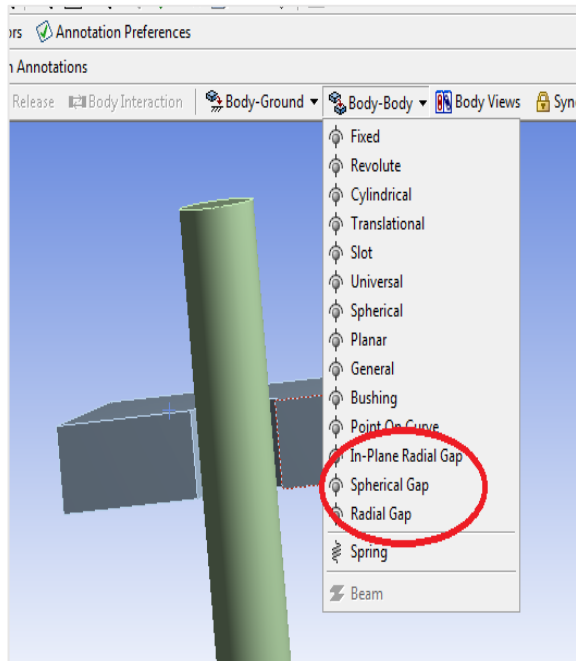


Universal



# 运动副—有间隙:

- 提供三种考虑间隙的运动副:
  - In-plane radial gap
  - Spherical gap
  - Radial gap



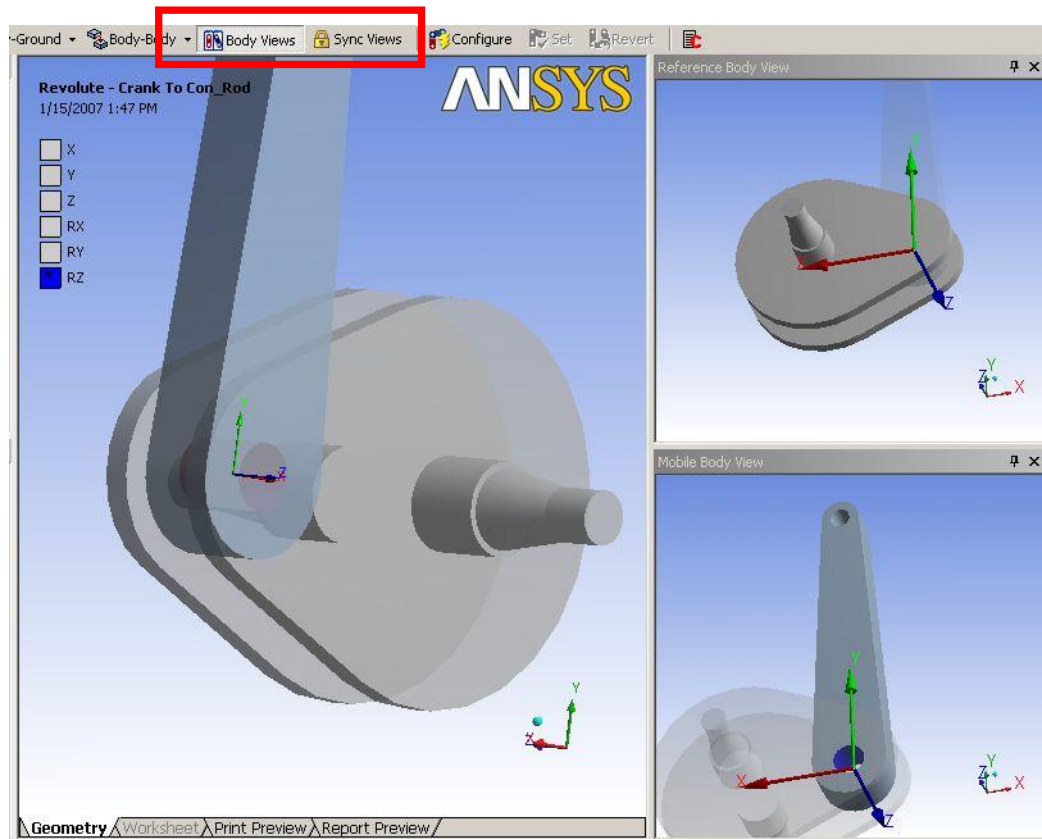


# Joints—Body Views

- 自动探测建立 joint
- “Body Views”
  - 辅助窗口显示运动副
- “Sync Views”
  - 窗口同步



Details of "Connections"	
<b>Auto Detection</b>	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	0.5517 mm
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Same Body Grouping	Yes
Revolute Joints	Yes
Fixed Joints	Yes
<b>Transparency</b>	
Enabled	Yes



# Joint Features—Reference Coordinate Systems

## • 参考坐标系:

- 自动位于joint分支下.
- 可以手动更改



Details of "Reference Coordinate System"	
<b>Definition</b>	
Type	Cartesian
<b>Origin</b>	
Define By	Geometry Selection
Geometry	Click to Change
Origin X	0. mm
Origin Y	300. mm
Origin Z	1. mm
<b>Principal Axis</b>	
Axis	Z
Define By	Geometry Selection
Geometry	Click to Change
<b>Orientation About Principal Axis</b>	
Axis	Y
Define By	Default
<b>Directional Vectors</b>	
X Axis Data	[ 1. 0. 0. ]
Y Axis Data	[ 0. 1. 0. ]
Z Axis Data	[ 0. 0. 1. ]
<b>Transformations</b>	
Base Configuration	Absolute
Transformed Configuration	[ 0. 300. 1. ]

# Joint Features—Stops

- **Stops**或者 **Lock**设置运动副的运动极限或条件.
- 当达到相对运动，**Stops**限制条件会有冲击发生，**Lock**则是锁定在固定
- **SECSTOP**
- **SECLOCK**

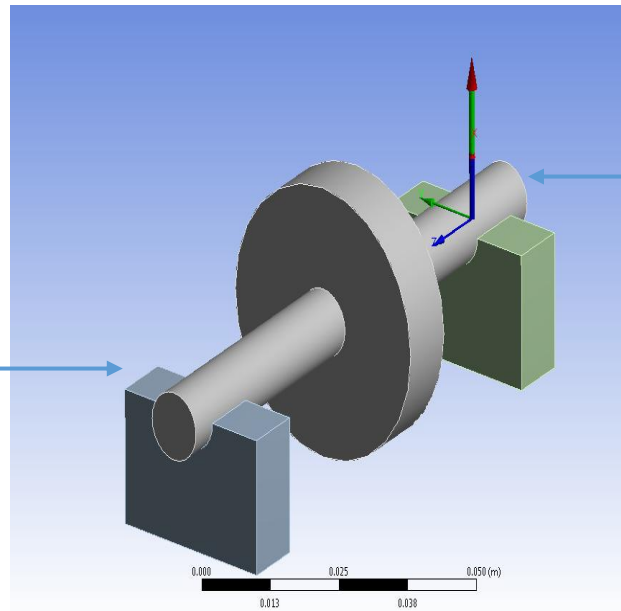
Details of "Revolute - Ground To Part 1"

<b>Definition</b>	
Connection Type	Body-Ground
Type	Revolute
Torsional Stiffness	0. N·m/°
Torsional Damping	0. N·m·s/°
Suppressed	No
<b>Reference</b>	
Coordinate System	Reference Coordinate System
<b>Mobile</b>	
Scoping Method	Geometry Selection
Scope	1 Face
Body	Part 1
Initial Position	Unchanged
<b>Stops</b>	
RZ Min Type	None
RZ Max Type	None
	Stop
	Lock
Behavior	Rigid
Pinball Region	All
<b>Mobile</b>	
Scoping Method	Geometry Selection
Scope	1 Face
Body	PendulumAxis:1
Initial Position	Unchanged
Behavior	Rigid
Pinball Region	All
<b>Stops</b>	
Y Min Type	Stop
<input type="checkbox"/> Y Min	-65. mm
Y Max Type	Stop
<input type="checkbox"/> Y Max	65. mm
Restitution	0.5

# Joint Features—DOF Checker (Background)

- 存在过约束问题，也可以计算，但是结果变得不准确。
- **Question**：模型对称，为什么支反力不对称？

Revolute joint  
 $F_x=0$  N  
 $M_y=0$  N-m



Revolute joint  
 $F_x=1.51$  N  
 $M_y=6.05 \times 10^{-2}$  N-m

# Joint Features—Redundancy Analysis

- Answer** : 模型存在过约束，使用过约束分析，更改运动副类型。

过约束分析显式多余约束

Data View

Redundancy Analysis

Number of free degrees of freedom: 1

Name	Type	Scope	X Displacement	Y Displacement	Z Displacement	Rotation X	Rotation Y	Rotation Z
Revolute - Solid To Solid	Revolute	Body-Body	Redundant	Redundant	Redundant	Redundant	Redundant	Free
Revolute - Solid To Solid	Revolute	Body-Body	Fixed	Fixed	Fixed	Fixed	Fixed	Free
Fixed - Ground To Solid	Fixed	Body-Ground	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Fixed - Ground To Solid	Fixed	Body-Ground	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed

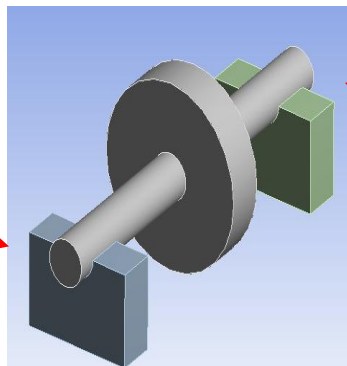
Redundancy Analysis

更改revolute joint为  
spherical joint 和 slot  
joint

Number of free degrees of freedom: 1

Name	Type	Scope	X Displacement	Y Displacement	Z Displacement	Rotation X	Rotation Y	Rotation Z
Spherical - Solid To Solid	Spherical	Body-Body	Fixed	Fixed	Fixed	Free	Free	Free
General - Solid To Solid	General	Body-Body	Fixed	Fixed	Free	Free	Free	Free
Fixed - Ground To Solid	Fixed	Body-Ground	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Fixed - Ground To Solid	Fixed	Body-Ground	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed

**Spherical joint**  
Fx = 0.76 N  
My = 0 Nm



**Slot joint**  
Fx = 0.76 N  
My = 0 Nm

# Joint Features—DOF Checker

- 接触的 Worksheet 可以显示 “Joint DOF Checker.”
- 如果总自由度数小于1，则可能有过约束问题，表格会给出提示信息：

## Joint DOF Checker

4 Bodies x 6 DOF	= +24
4 Revolute joint x 5 DOF	= -20
1 Translational joint x 5 DOF	= -5
<b>Free DOF</b>	<b>= -1 DOF</b>

### Warning:

This model is possibly over constrained. Consider modifying joint definitions.

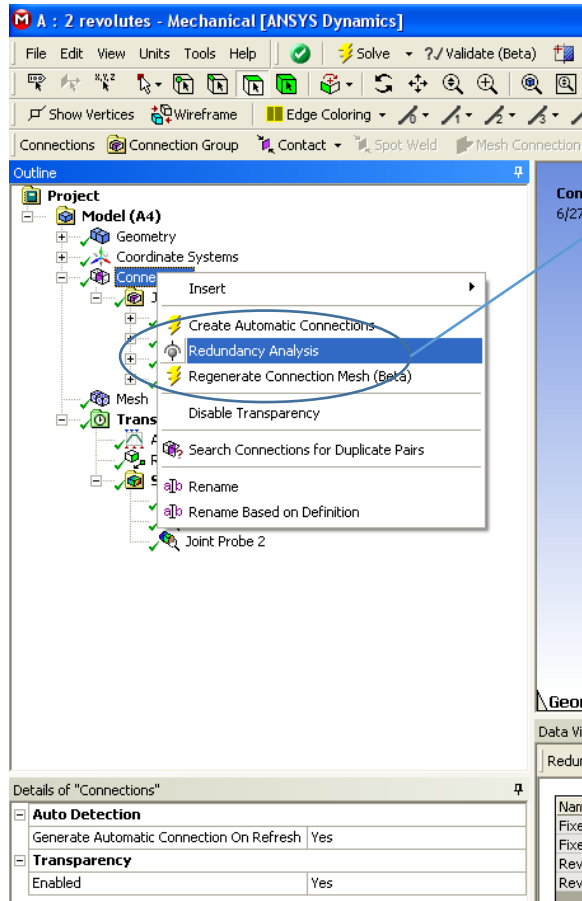
### Analysis of model redundancies:

```
Joint Revolute - Part 4 To Part 3 shows some constraint redundancies
X Translation constraint equation was at time redundant
Y Translation constraint equation was at time redundant
Z Translation constraint equation was at time redundant
X Rotation constraint equation was at time redundant
Y Rotation constraint equation was at time redundant
```



# Joint Features—Redundancy Analysis

- 进行过约束分析，改善约束条件



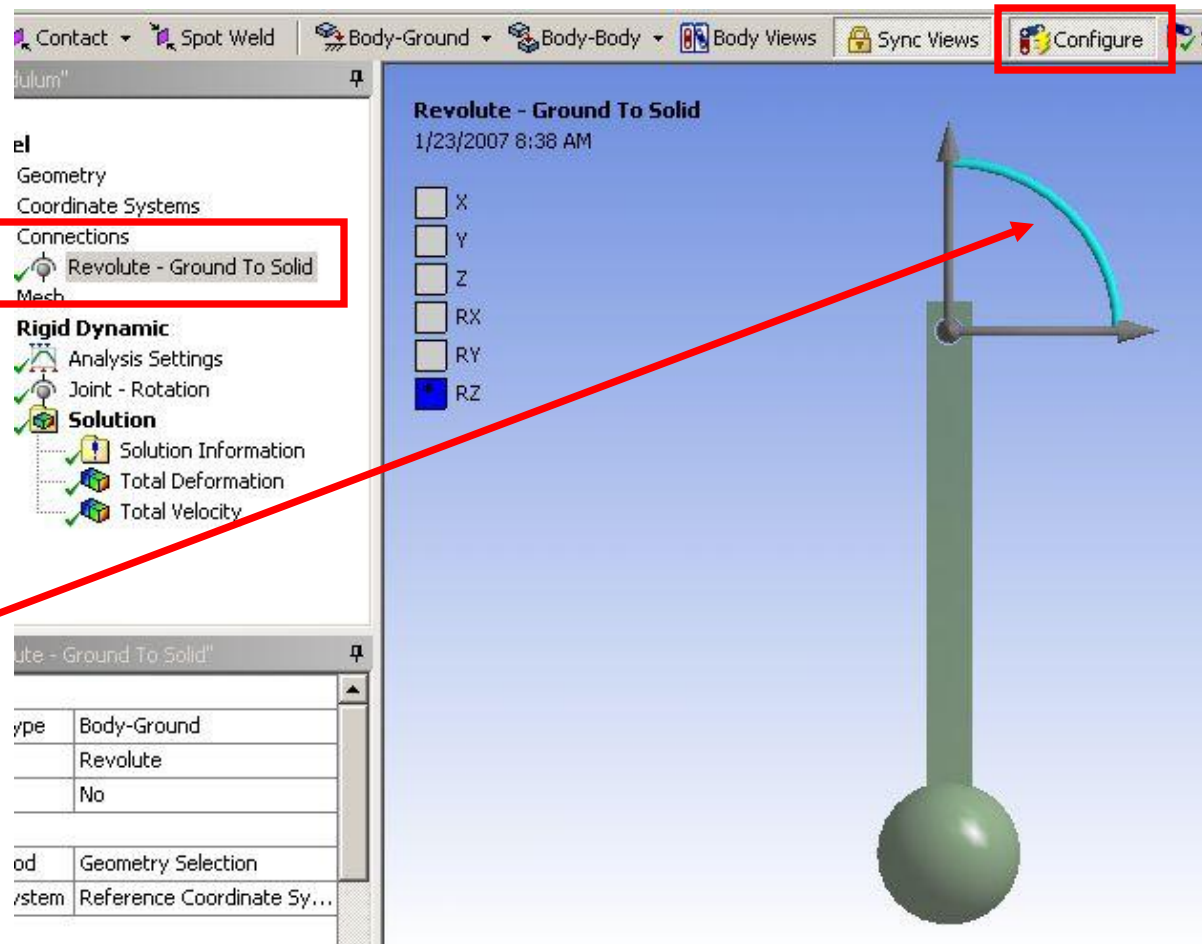
Data View

Redundancy Analysis

Name	Type	Scope	X Displacement	Y Displacement	Z Displacement	Rotation X	Rotation Y	Rotation Z
Fixed - Ground To Left Bearing	Fixed	Body-Ground	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Fixed - Ground To Right Bearing	Fixed	Body-Ground	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Revolute - Left Bearing To Shaft	Revolute	Body-Body	Fixed	Fixed	Fixed	Fixed	Fixed	Free
Revolute - Right Bearing To Shaft	Revolute	Body-Body	Redundant	Redundant	Redundant	Redundant	Redundant	Free

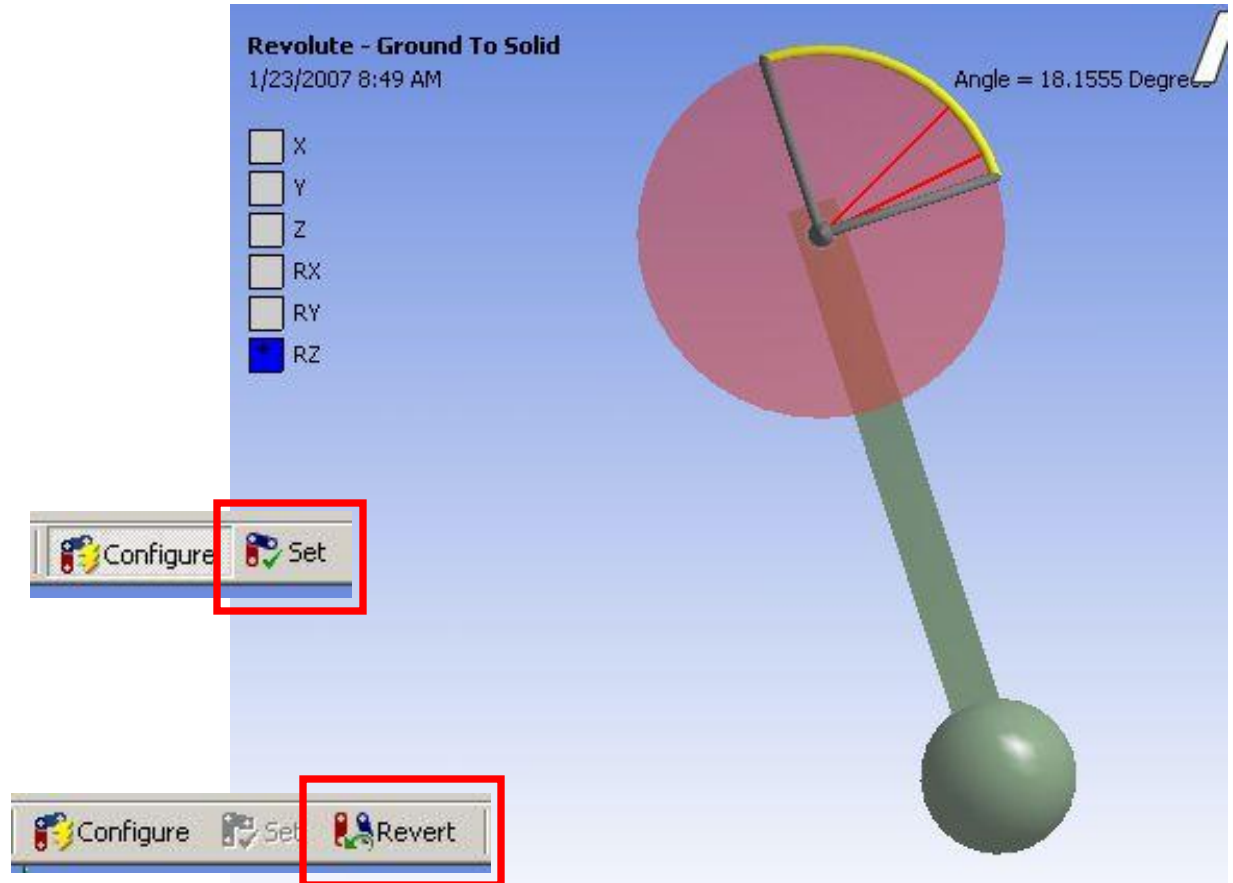
# Joint Features—Configuration Tool

- 单摆处于自由状态的位置.
- 通过 “Configure” 可改变初始位置.
- 先选择configure，然后选择具体运动副，出现调整的坐标



# Joint Features—Configuration Tool

- 选择具体调整自由度坐标，  
拖曳鼠标到具体位置。
- 通过 “Set” 确定初始位置。
- 通过 “Revert” 还原到最初状态。



# Joint Features—Assemble Tool

- 装配体组合工具允许客户通过定义连接的方式去组装装配体。

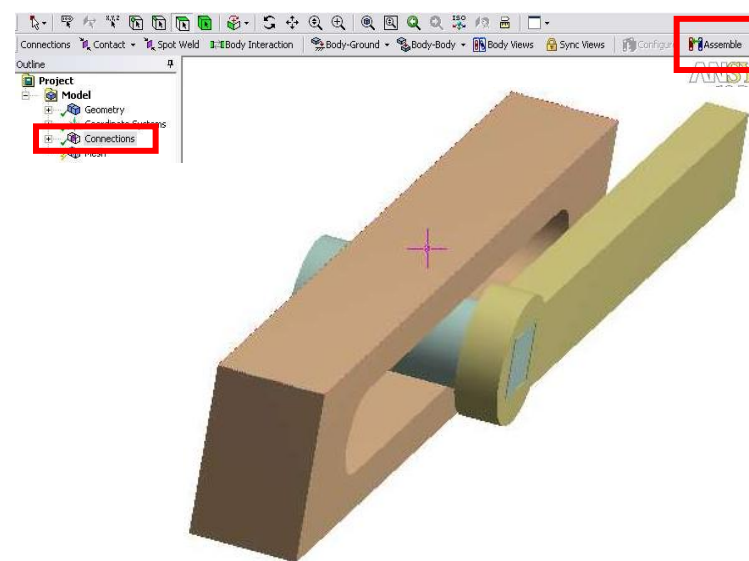
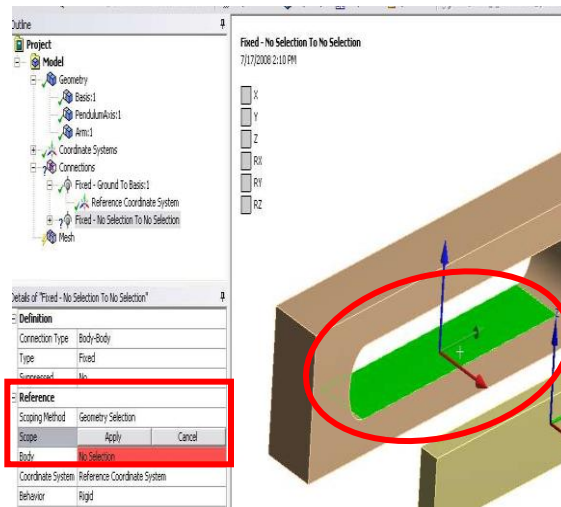
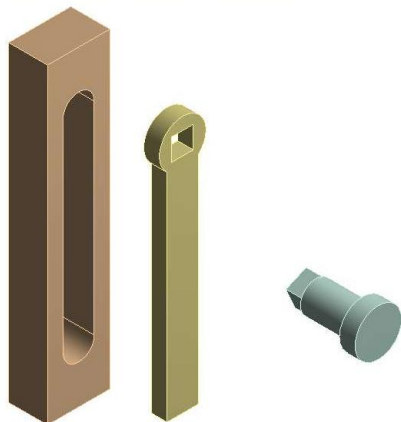
CAD parts



Define Connections

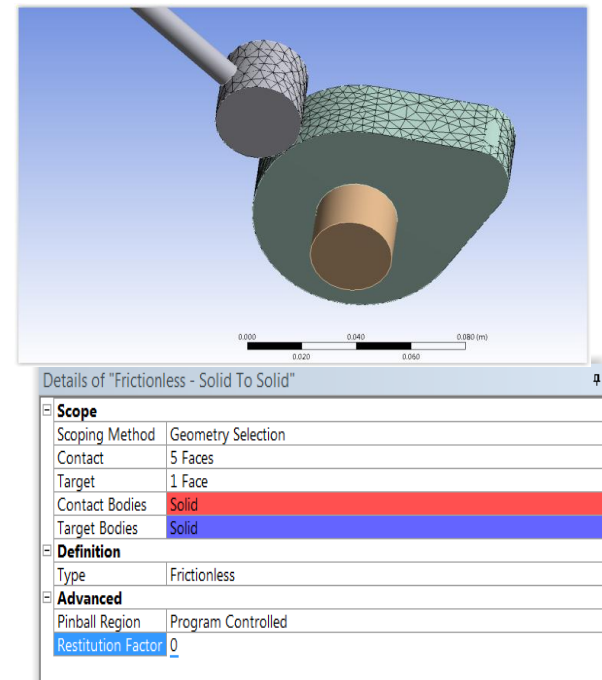
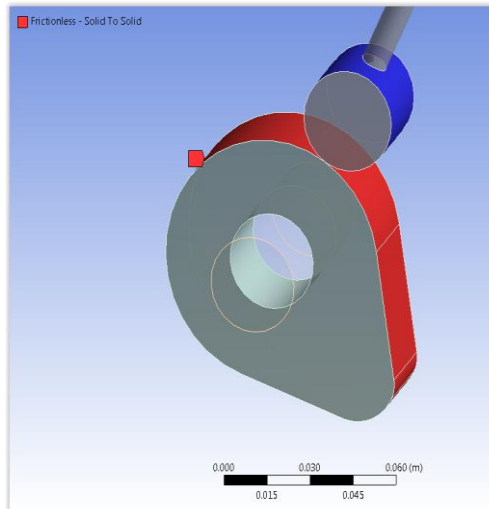
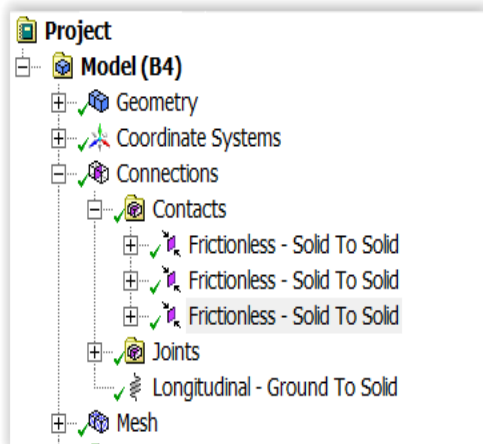


Assemble



# 接触

- 可自动或者手动生成
- 可定义不同接触类型(bonded, no separation, frictionless, frictional).
- 只在接触表面生成网格
- 网格不必太细
- 可定义接触表面能量损失因子(pure elastic = 1, pure plastic = 0)



# 边界条件和载荷

- 边界条件或者载荷可定义常数，表格或者函数
- 可以抑制某一载荷步的边界

Details of "Joint - Moment"

**Scope**

Joint: Revolute - Ground To Drive

**Definition**

DOF: Rotation Z

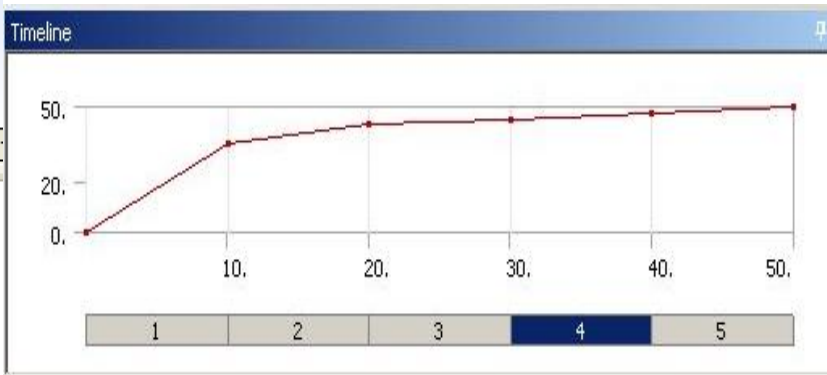
Type: Moment

Magnitude: Tabular Data

Suppressed: No

Import...

Export...



Tabular Data

Steps	Time [s]	Moment [N*mm]
1	0.	0.
2	10.	35.
3	20.	43.
4	30.	45.
5	40.	47.
6	50.	50.
*		

Details of "Joint - Moment"

**Scope**

Joint: Revolute - Ground To Drive

**Definition**

DOF: Rotation Z

Type: Moment

Magnitude:  $= \sin(\text{time} * 10)$

Lock at Load Step: Never

Suppressed: No

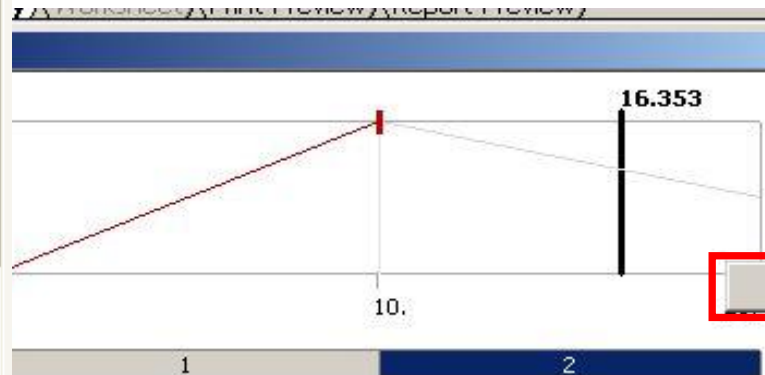
**Function**

Unit System: Metric (m, kg, N, s, V, A)

Angular Measure: Degrees

**Graph Controls**

Number Of Segments: 200.



Tabular Data

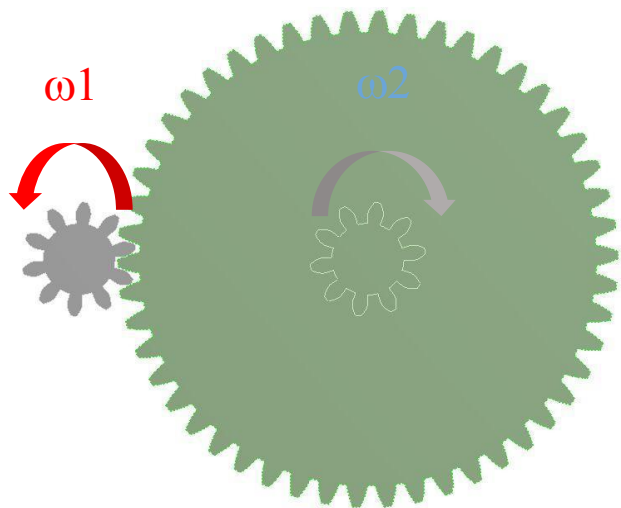
Steps	Time [s]	Moment [N*mm]
1	0.	0.
2	10.	100.
3	20.	50.
*		

Activate/Deactivate at this step!



# 约束方程

- 用于创建运动副之间的关系:
- - 可以是位移, 速度, 角速度等
- 例如对图中齿轮减速机构:  $\omega_1 + 5 \omega_2 = 0$
- - 小齿轮10个齿, 大齿轮50个齿



Outline

- Contacts
- Joints
  - Fixed - Ground To Stator
  - Revolute - Stator To Rotor
  - Fixed - Rotor To Motor Shaft
  - Revolute - Ground To Secondary Shaft
  - Revolute - Ground To Cam Shaft
  - General - Cam Shaft To Plunger
  - General - Ground To Carriage
  - Fixed - Valve To Plunger
  - General - Ground To Cylindrical
- Longitudinal - Ground To Solid
- Mesh
- Named Selections
- Transient (A5)
  - Analysis Settings
  - Constraint Equation
  - Constraint Equation 2
  - Joint - Moment

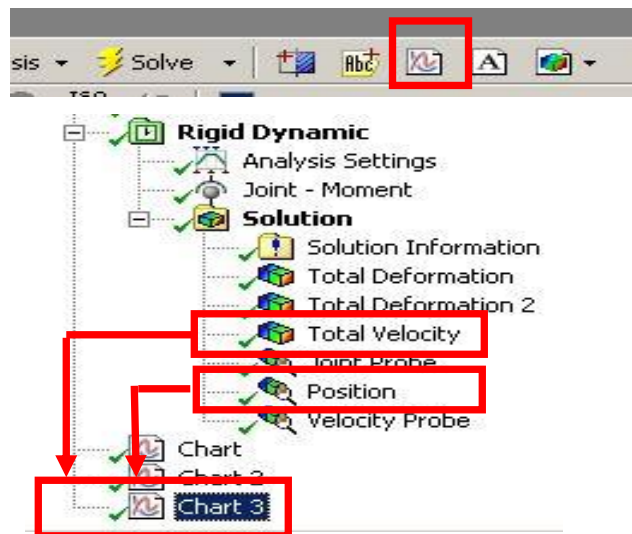
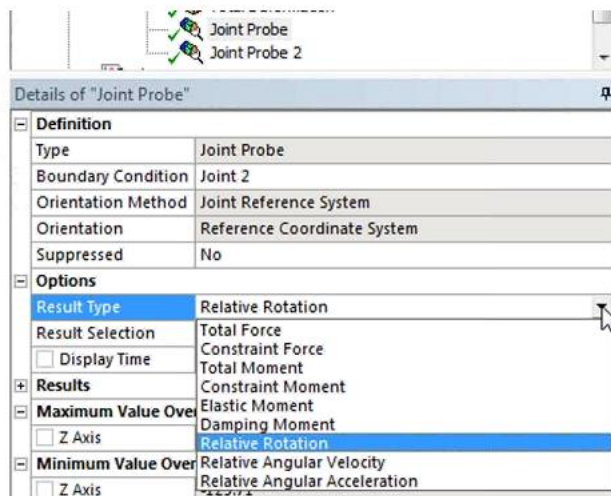
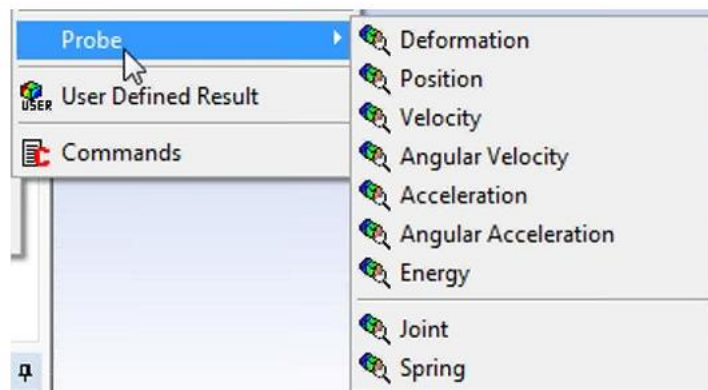
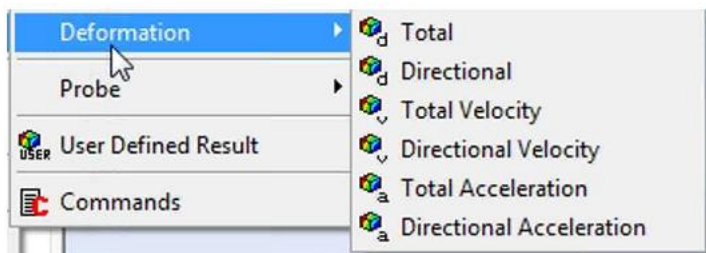
Worksheet

### Constraint Equation

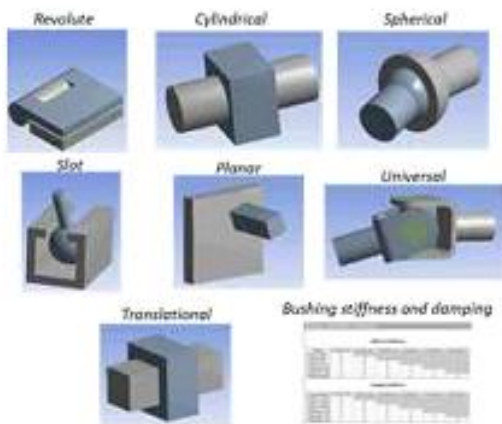
$0 = 1 (1/^\circ) * \text{Revolute - Stator To Rotor}(\text{Omega Z}) + 5 (1/^\circ) * \text{Revolute - Ground To Secondary Shaft}(\text{Omega Z})$

Coefficient	Units	Joint	DOF Selection
1	1/°	Revolute - Stator To Rotor	Omega Z
5	1/°	Revolute - Ground To Secondary Shaft	Omega Z

# 后处理

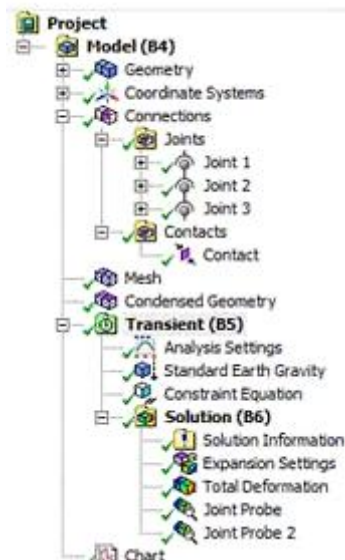


# 大纲



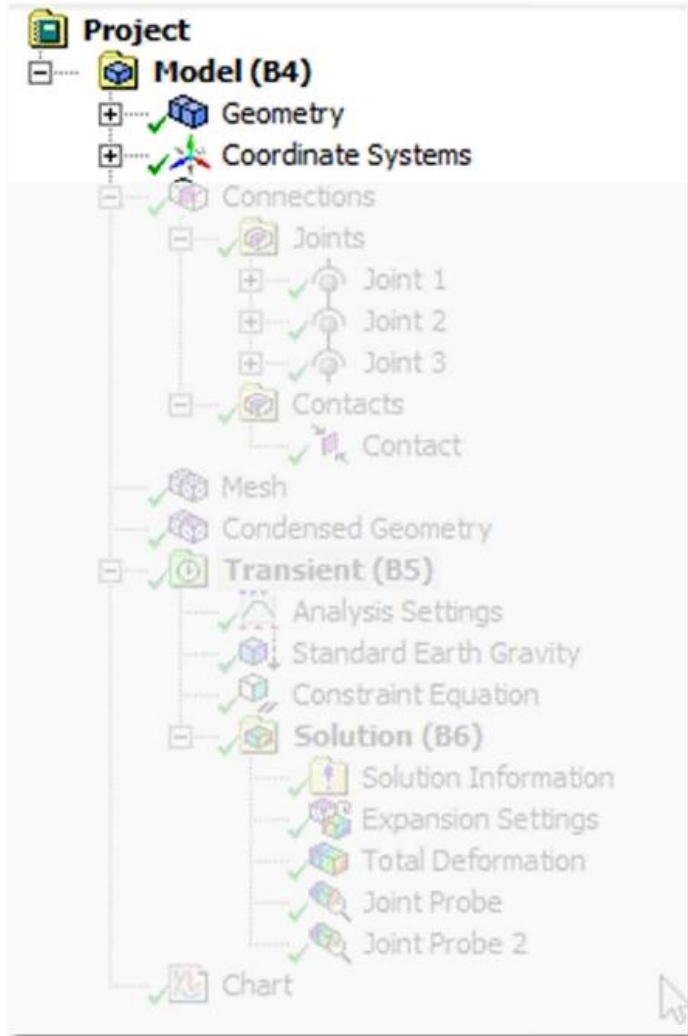
## • 多体动力学分析组成

## • 多体动力学分析流程



## • 多体动力学和其他模块的连接

# Step1 : 导入几何



PTC® Creo®

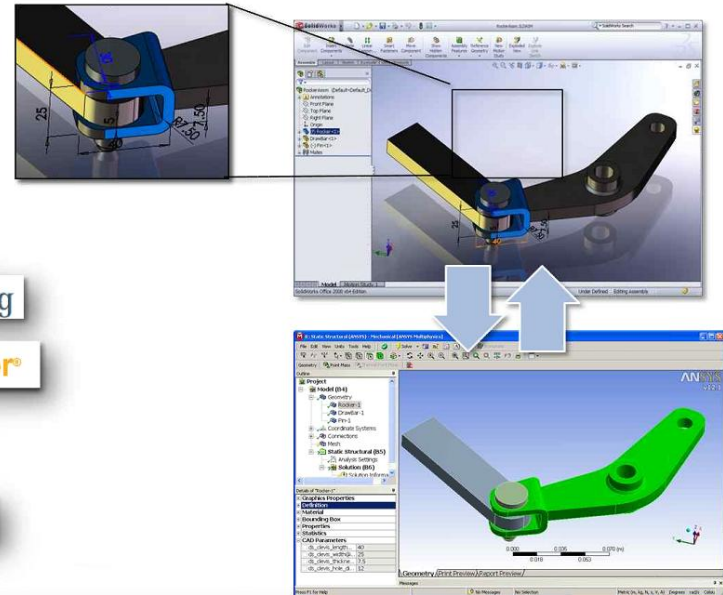
CoCreate® Modeling

Autodesk® Inventor®



NX SIEMENS

Solid Edge

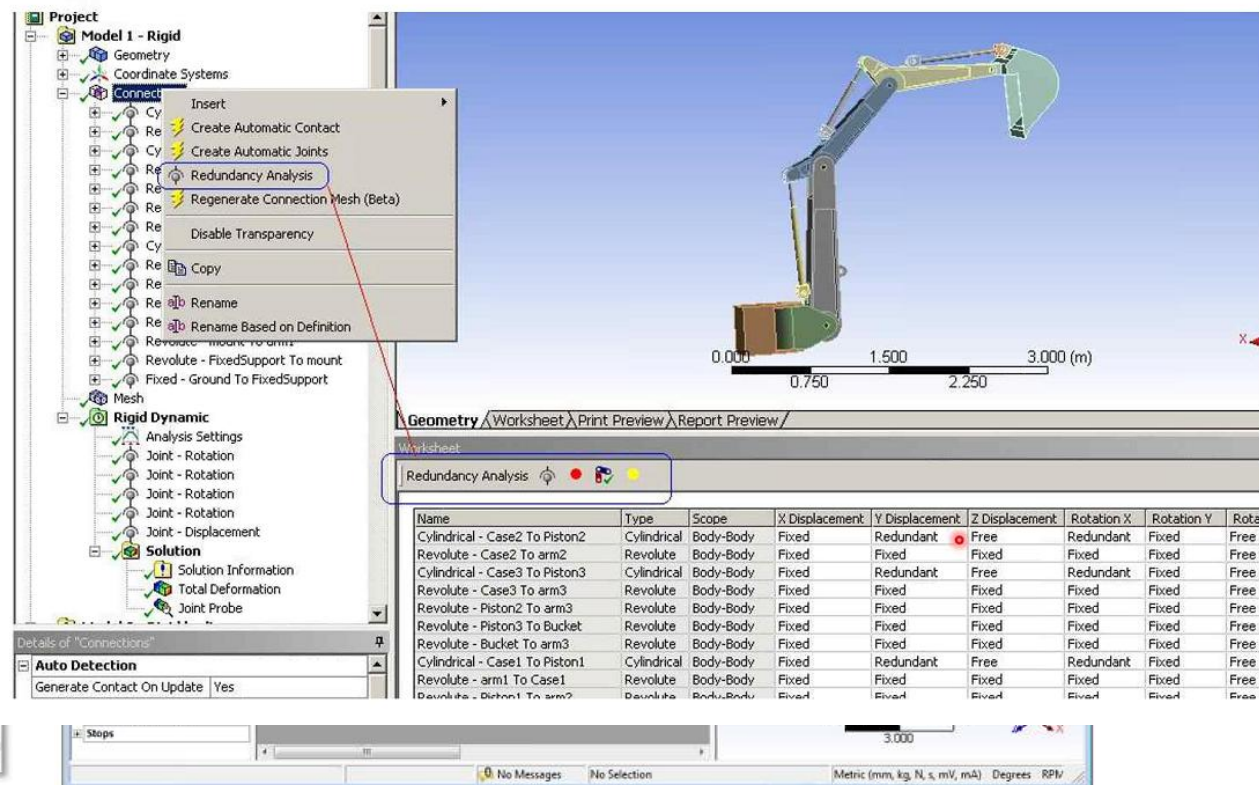
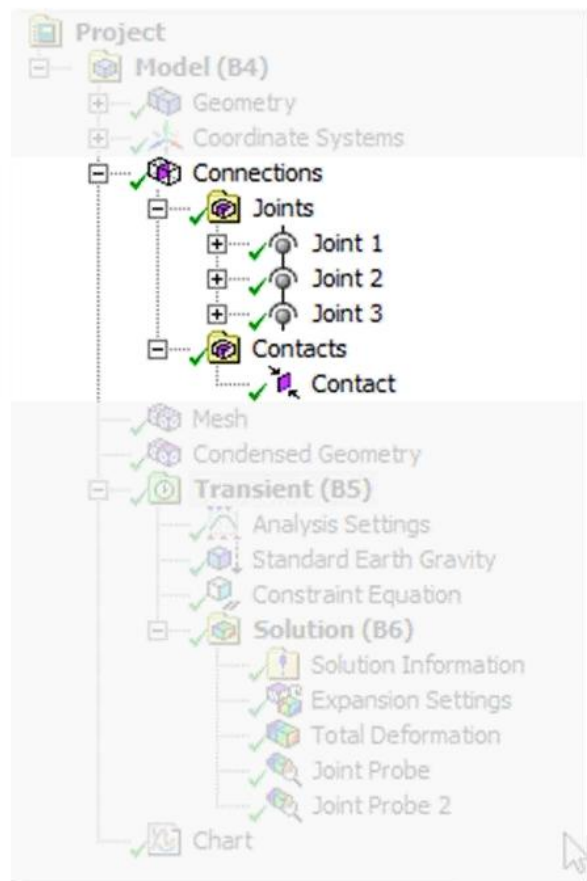




## Step2 : 定义运动副和接触

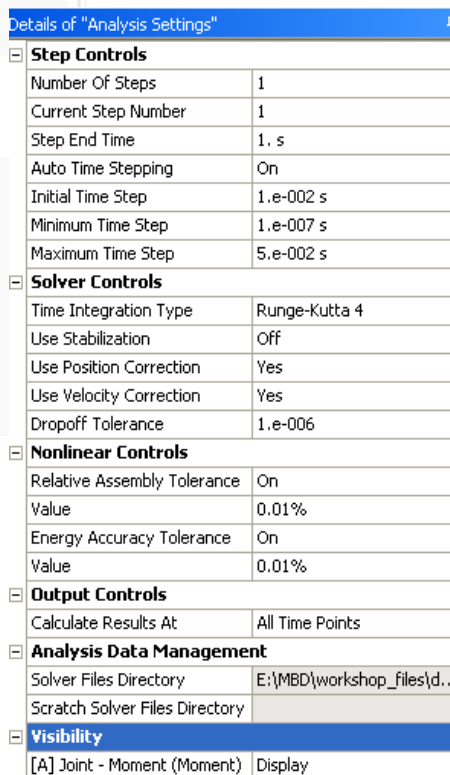
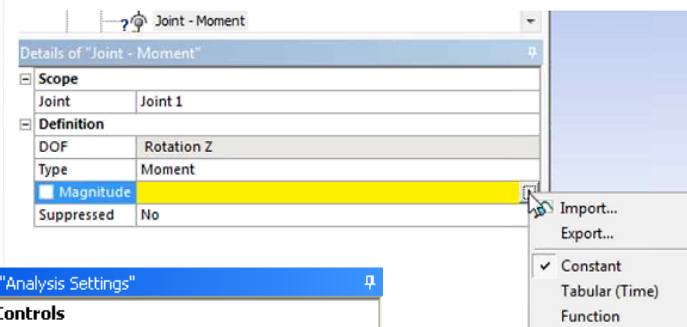
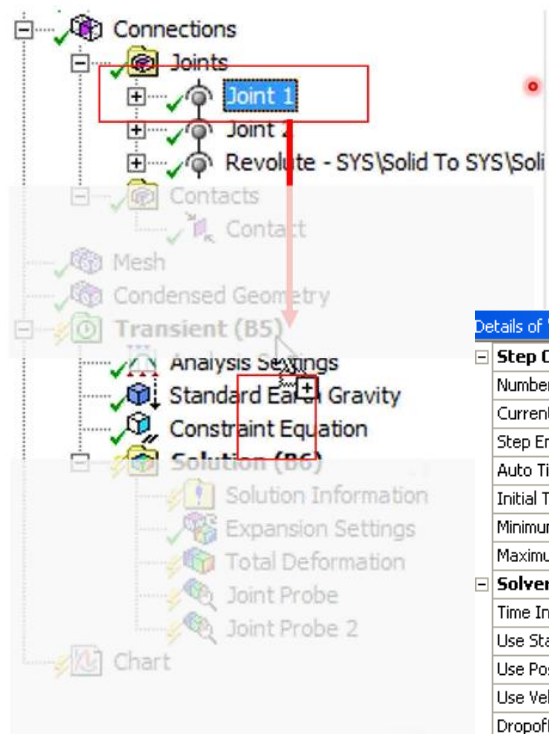
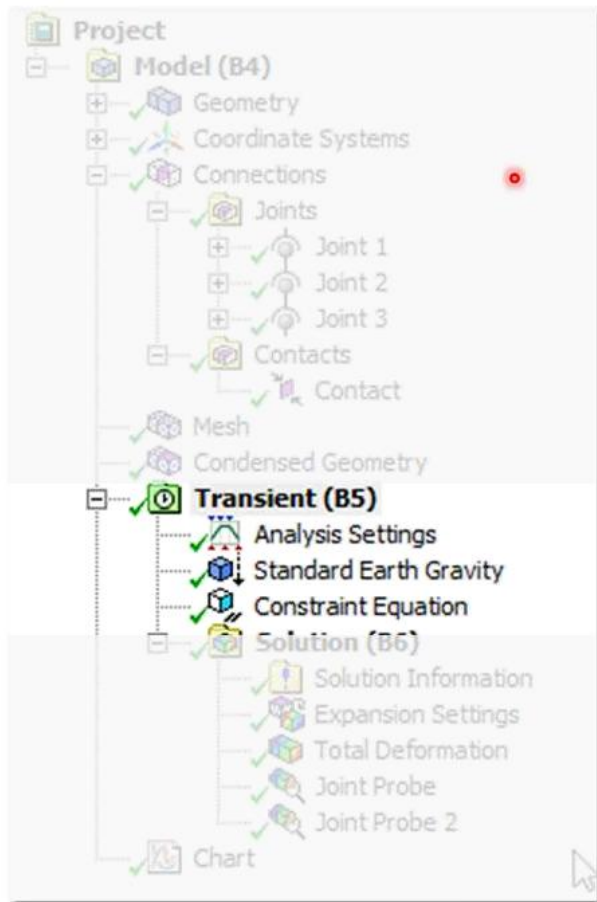
## 使用多窗口工具

## 自由度检查和过约束分析



## Step3 : 加载载荷和边界, 进行分析设置

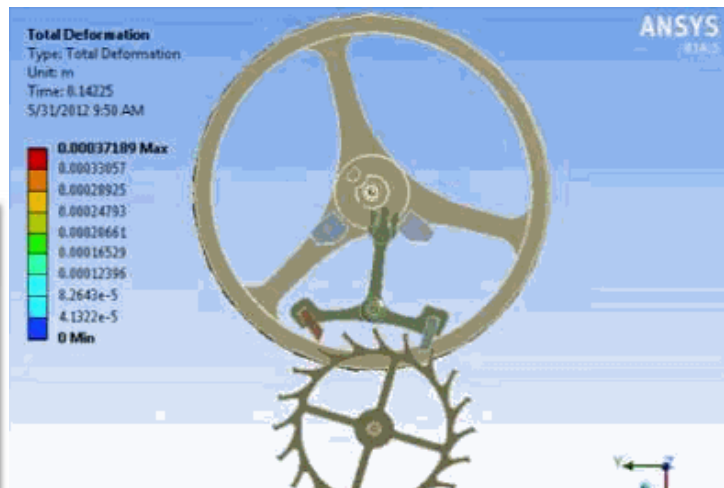
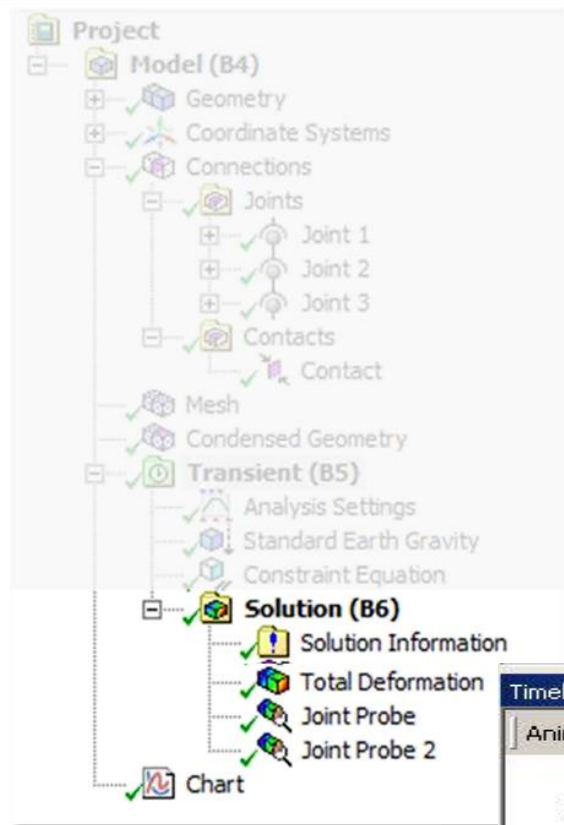
载荷可通过直接拖动运动副形式实现



- 载荷步数目
- 初始、最小、最大时间步
- 输出控制

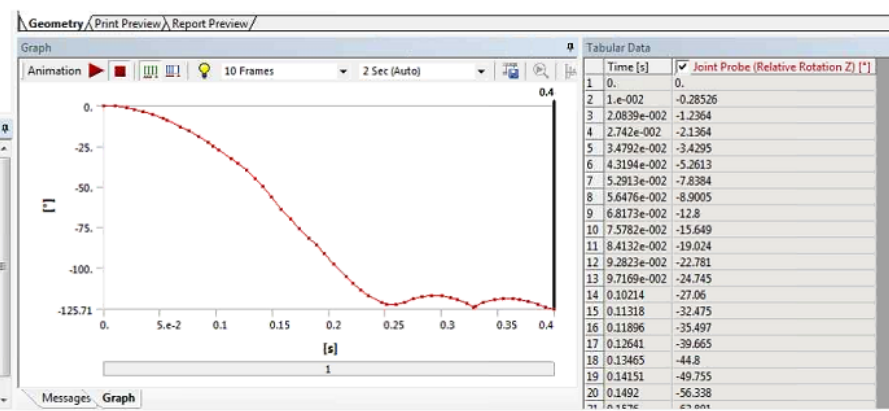


## Step4 : 后处理



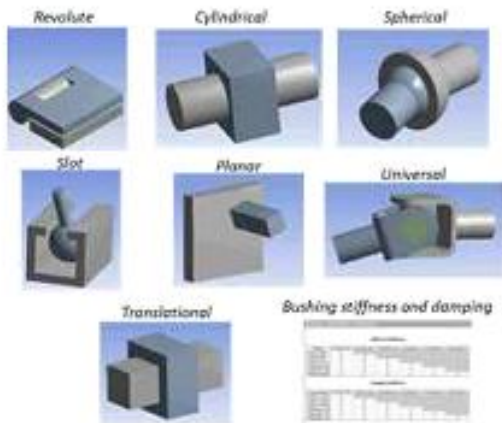
Details of "Joint Probe"

Definition	
Type	Joint Probe
Boundary Condition	Joint 2
Orientation Method	Joint Reference System
Orientation	Reference Coordinate System
Suppressed	No
Options	
Result Type	Relative Rotation
Result Selection	Total Force
Display Time	Constraint Force
	Total Moment
	Elastic Moment
	Damping Moment
Maximum Value Over	Relative Rotation
Z Axis	
Minimum Value Over	Relative Angular Velocity
Z Axis	Relative Angular Acceleration



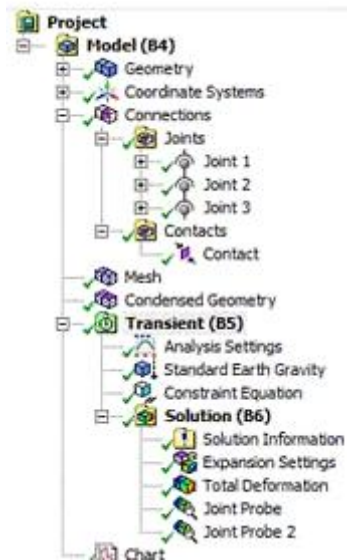
指定时间点输出

# 大纲



## • 多体动力学分析组成

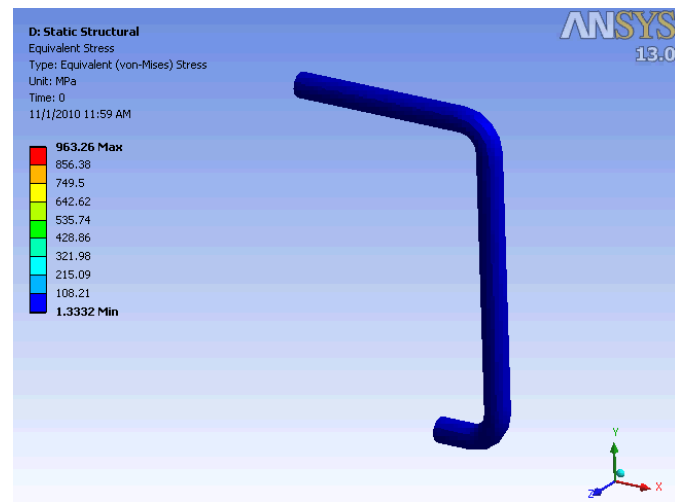
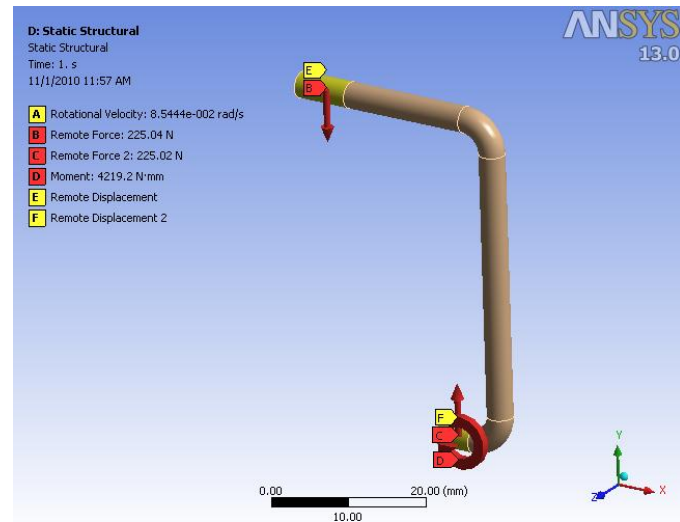
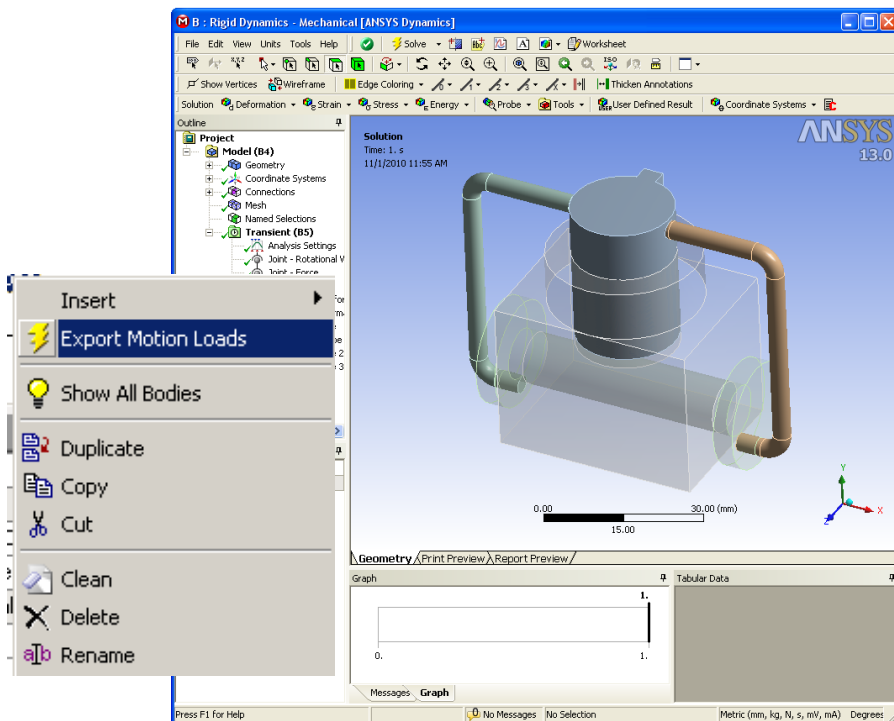
## • 多体动力学分析流程



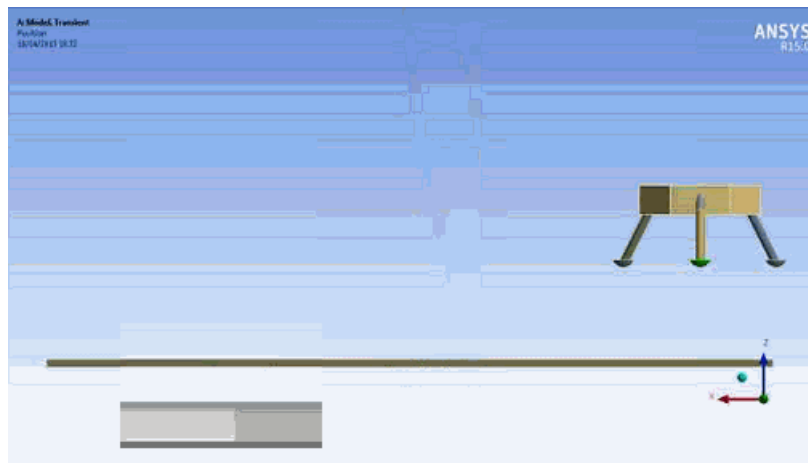
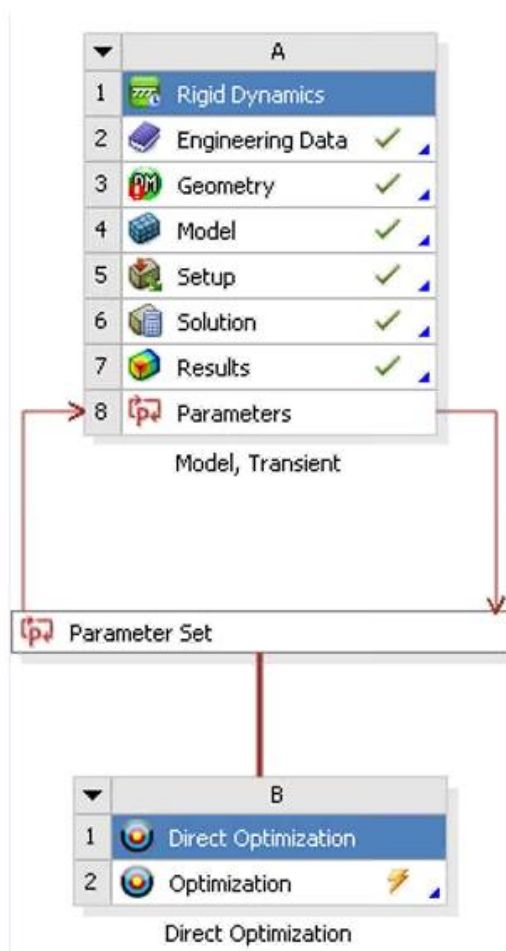
## • 多体动力学和其他模块的连接

# 输出运动载荷进行静力分析

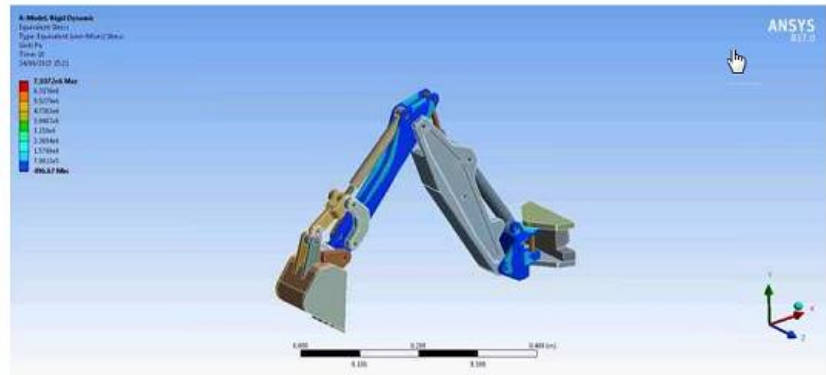
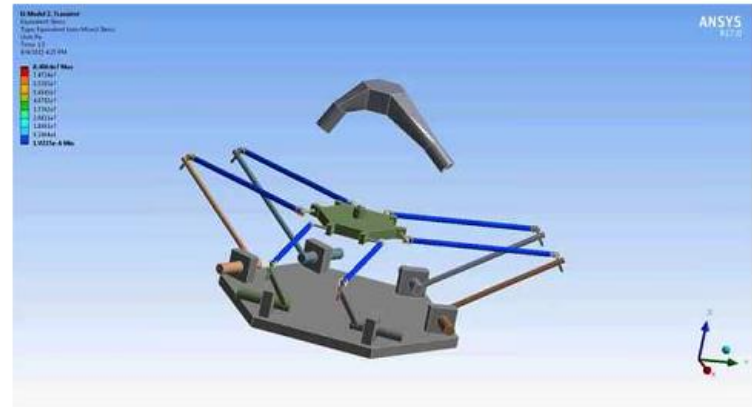
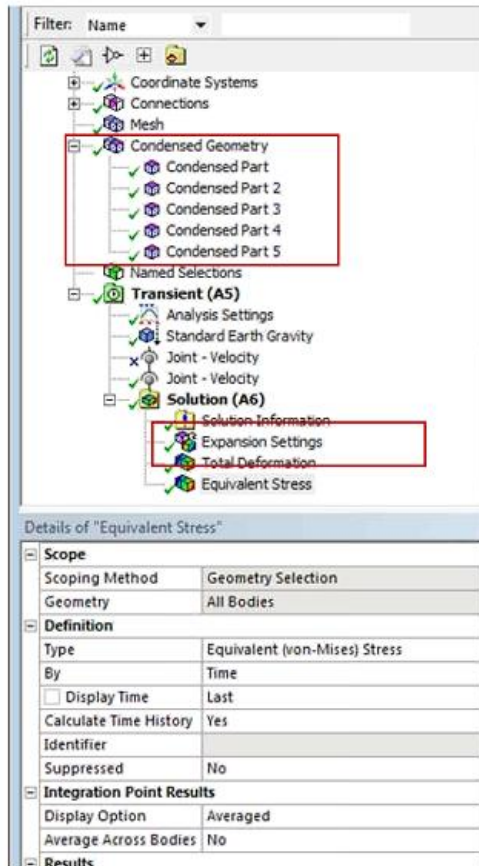
- 针对多体中某个柔性部件输出某个时刻动载荷进行静力分析



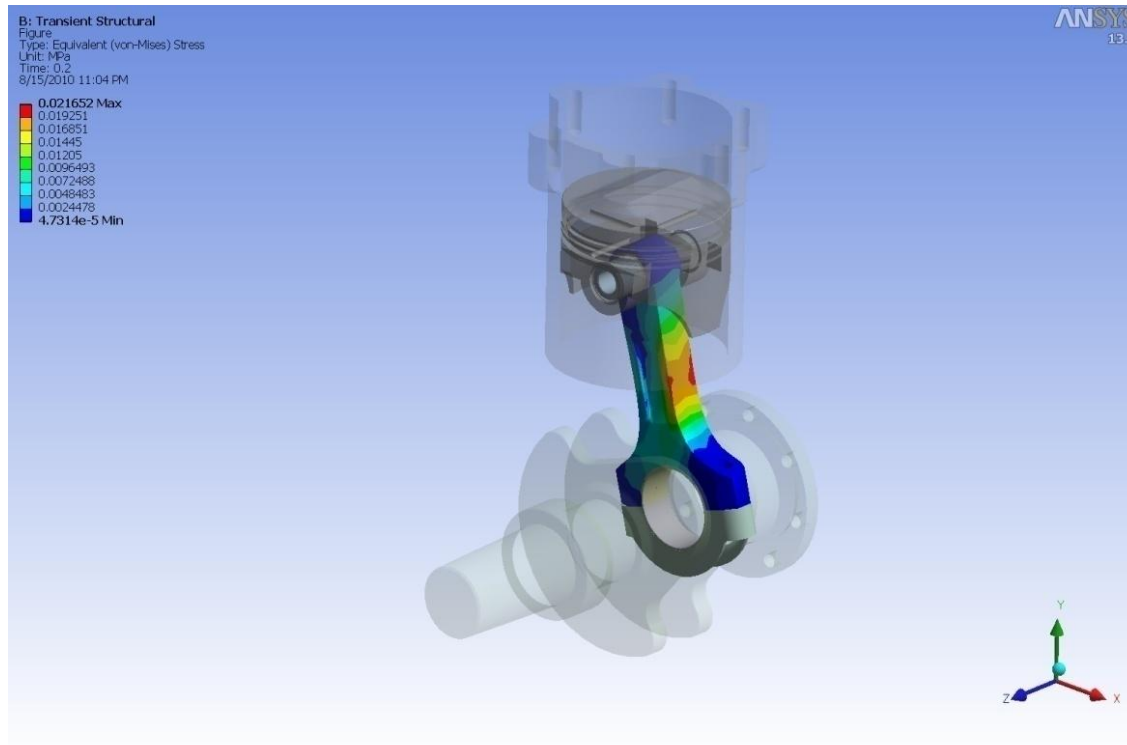
# 连接参数优化模块DX



# 子结构刚柔耦合(NEW)



# Demo





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感谢聆听