Connection Elements and Connection Library

Lecture 2

Overview

• Introduction
• Defining Connector Elements
• Understanding Connector Sections
• Understanding Connection Types
• Understanding Connector Local Directions
• Rotational Degrees of Freedom at Nodes
• Components of Relative Motion
• Connector Local Kinematics
• Summary of Orientations and Local Directions
Introduction

- General characteristics of connector elements
  - Connector elements model discrete (point-to-point) physical connections between deformable or rigid bodies or can be connected to ground.
  - Example: typical connections in automotive suspension systems

Typical connections in automotive suspension:
Introduction

• Connector elements have relative displacements and rotations that are local to the element, which are referred to as components of relative motions (CORM).
  • Connector elements impose kinematic constraints. For example:
    • Door connected to a frame through a hinge
    • Two panels of sheet metal spot welded together
    • Constant velocity joints
  • Connector elements may include (nonlinear) force-versus-displacement (or velocity) behavior in their available components of relative motion.
    • Example: muscle force resisting the rotation of a knee joint in a crash-test occupant dummy model.
  • Connector elements can provide comprehensive kinematic and kinetic output describing the connection.

Introduction

• Connector elements are functionally defined by specifying the connection attributes.
  • Connection types
    • For example: axial, hinge, weld, constant velocity joints, link, beam, etc.
  • Local connector directions
  • Connector behaviors
    • Uncoupled or coupled response
    • Linear or nonlinear response
    • Elasticity and damping
    • Plasticity
    • Friction
    • Damage and Failure
    • Stops and locks

AXIAL connection in a shock absorbing strut uses a variety of connection behaviors, including spring, damping and stop behaviors
Defining Connector Elements

- Connector elements are 2-node elements.
  - Element type:
    - CONN2D2
      - Two-dimensional analysis
      - Axisymmetric analysis
    - CONN3D2
      - Three-dimensional analysis
  - Both types of element have at most two nodes.
  - The position (location, orientation) and motion (displacement, velocity, acceleration) of the second node on the element are measured relative to the first node.
Defining Connector Elements

1. **Defining a connector element – Keywords interface**
   - To connect two points:
     *ELEMENT, TYPE=[CONN2D2 or CONN3D2]
     element number, first node number, second node number
   - Example: Shock absorber
     *ELEMENT, TYPE=CONN3D2
     101, 11, 12

2. **To connect a point to ground:**
   - The ground “node” can be the first or second node on the connector element.
   *ELEMENT, TYPE=name
   element number, node number on the body
   or
   *ELEMENT, TYPE=name
   element number, node number on the body
   - The ground node is fixed.

Simplified connector model of a shock absorber
Defining Connector Elements

- Defining connector geometry – ABAQUS/CAE interface
  - Create **assembly-level wire features** to define connector geometry in the Interaction module.

  - disjoint wires
  - chained wires
  - wires to ground.

- Click **Add** to add points

  - **Tip:** two coincident points can be selected simultaneously by double-clicking on the location of the points

- Click **Delete** to delete the selected point pair.

- Click **Swap** to swap the points of the selected point pair.

  - **Tip:** the point pair needs to be selected by clicking its index number.

Defining Connector Elements

- A geometry **set** including all of the wires can be created when creating the wire feature.
  - The set can be used during the subsequent selection procedures.

  - For example, you can use sets to assign connector sections, request output, or prescribe motions.

  - Note: Multiple sets can be merged into a new **set** using the set merge feature.

- Assembly-level wire features cannot be modified directly once created.

- Wires can be removed by selecting **Remove Wires From Feature**.
Defining Connector Elements

- Example: Truck door hinges
  - In this example, hinge connectors connect a truck door to the truck body.

  Keywords interface
  Define a connector element

  ```
  *ELEMENT, TYPE=CONN3D2, ELSET=CONN_DOOR_HINGE
  620601, 9000009, 9000010
  620602, 9000011, 9000012
  ```

  HINGE connectors at door hinges

Understanding Connector Sections
Understanding Connector Sections

• Connector section defines:
  • The connection type.
  • The local directions associated with the connector’s nodes
  • The connector behaviors.
    • Note: Details of connector behavior will be discussed in lectures 4 and 5.
• Creating a connector section

Keywords interface

*CONNECTOR SECTION, ELSET=name

AB AQUS/CAE interface

Understanding Connector Sections

• Defining the connection type
  • Basic connection components
    • Translations
    • Rotations
  • Assembled connection components
    • Combination of basic connection components

Keywords interface

*CONNECTOR SECTION, ELSET=name

basic connection type, <basic connection type>

OR

*CONNECTOR SECTION, ELSET=name

assembled connection
Understanding Connector Sections

- Example: Truck door hinges – Keywords interface
  - Define and assign a connector section

```plaintext
*ELEMENT, TYPE=CONN3D2, ELSET=CONN_DOOR_HINGE
  620601,9000009,9000010
  620602,9000011,9000012

*CONNECTOR SECTION, ELSET=CONN_DOOR_HINGE
  HINGE

Assembled connection; one can also use basic connection types: JOIN and REVOLUTE.
```

Assembled Hinge connection; one can also use basic connection types: JOIN and REVOLUTE.

No behavior options are specified (default).

Note: Details will be discussed in lectures 4 and 5.
Understanding Connector Sections

1. Assign a connector section
   - Connector section assignment is used to assign a connector section to a region (wires) of the model.

Assign the connection section **DOOR_HINGES** to the wire **Wire-1-DOOR_HINGES**.

Understanding Connection Types
Understanding Connection Types

• Connection types

  • The connection-type library contains:
    • Translational basic connection components, which affect translational DOFs at both nodes and may affect rotational DOFs at the first node of the connector element.
    • Rotational basic connection components, which affect only rotational DOFs at both nodes of the connector element
    • Assembled connections, which are a predefined combination of translational and rotational basic connection components.

  • The above choices determine which element local DOFs exist.
  • Given the number of connection types available, it is clear that connector elements can easily be customized to suit an application.

Examples of translational basic connections:

• AXIAL – Provide a connection between two nodes that acts along the line connecting the nodes.

• CARTESIAN – Provide a connection between two nodes that allows independent behavior in three local Cartesian directions.

• JOIN – Join the position of two nodes.

• ACCELEROMETER – Provide a connection between two nodes to measure the relative acceleration, velocity, and position of a body in a local coordinate system.
  • Available only in 3D analysis in ABAQUS/Explicit.
  • Will be converted internally to a CARTESIAN connector type in ABAQUS/Standard.
Understanding Connection Types

• Examples of rotational basic connections:
  • REVOLUTE – Provides a revolute connection between two nodes.
  • CARDAN – Provides a rotational connection between two nodes parameterized by Cardan angles.
  • EULER – Provides a rotational connection between two nodes parameterized by Euler angles.

Summary of basic connection types

<table>
<thead>
<tr>
<th>Basic translational</th>
<th>Basic rotational</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCELEROMETER</td>
<td>ALIGN</td>
</tr>
<tr>
<td>AXIAL</td>
<td>CARDAN</td>
</tr>
<tr>
<td>CARTESIAN</td>
<td>CONSTANT VELOCITY</td>
</tr>
<tr>
<td>JOIN</td>
<td>EULER</td>
</tr>
<tr>
<td>LINK</td>
<td>FLEXION-TORSION</td>
</tr>
<tr>
<td>PROJECTION CARTESIAN</td>
<td>PROJECTION FLEXION-TORSION</td>
</tr>
<tr>
<td>RADIAL-THRUST</td>
<td>REVOLUTE</td>
</tr>
<tr>
<td>SLIDE-PLANE</td>
<td>ROTATION</td>
</tr>
<tr>
<td>SLOT</td>
<td>ROTATION-ACCELEROMETER</td>
</tr>
<tr>
<td></td>
<td>UNIVERSAL</td>
</tr>
</tbody>
</table>
Understanding Connection Types

- Examples of **assembled** connections:
  - BEAM – provides a rigid beam connection between two nodes (JOIN + ALIGN)
  - HINGE – joins the position of two nodes, and provides a revolute connection between their rotational degrees of freedom (JOIN + REVOLUTE)
  - UJOINT – joins the position of two nodes, and provides a universal connection between their rotational degrees of freedom at the nodes (JOIN + UNIVERSAL)

### Summary of assembled connection types

<table>
<thead>
<tr>
<th>Assembled</th>
<th>Equivalent basic connection components (translational + rotational)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEAM</td>
<td>JOIN, ALIGN</td>
</tr>
<tr>
<td>BUSHING</td>
<td>JOIN, PROJECTION CARTESIAN, PROJECTION FLEXION-TORSION</td>
</tr>
<tr>
<td>CVJOINT</td>
<td>JOIN, CONSTANT VELOCITY</td>
</tr>
<tr>
<td>CYLINDRICAL</td>
<td>SLOT, REVOLUTE</td>
</tr>
<tr>
<td>HINGE</td>
<td>JOIN, REVOLUTE</td>
</tr>
<tr>
<td>PLANAR</td>
<td>JOIN, REVOLUTE</td>
</tr>
<tr>
<td>TRANSLATOR</td>
<td>JOIN, ALIGN</td>
</tr>
<tr>
<td>UJOINT</td>
<td>JOIN, UNIVERSAL</td>
</tr>
<tr>
<td>WELD</td>
<td>JOIN, ALIGN</td>
</tr>
</tbody>
</table>

Flexible Multibody Systems with ABAQUS
Copyright @1987-2006, Inc.
Understanding Connection Types

- More advanced connection types, such as FLOW-CONVERTER, RETRACTOR and SLIPRING, are also available.
  - These connectors are special pulley-type connectors used to model seatbelt kinematics.
  - These connection types will not be discussed here but are discussed further in Appendix 1.
  - Example: Three-point belt model with retractor and pretensioner.

Understanding Connector Local Directions
- Understanding connector local directions
  - Orientations are used to define local directions for connection types that use local directions (local directions may be required or optional)
    - The local directions are defined by reference to a local orientation or coordinate system.
    - Example: HINGE connector requires an orientation to be associated with the first node \( \text{a} \).
      - The hinge axis is aligned with the orientation \( X \)-direction.

- Not all connection types require the local directions (e.g. LINK).
- In some cases, default local directions are chosen (e.g. CARTESIAN).
- Local directions at the second node are not used by all connection types.
- Example: SLOT connection
  - The line of the slot is defined by the first local direction at node \( \text{a} \) and the initial position of node \( \text{b} \). (fig. a)
  - The SLOT connection constrains the position of node \( \text{b} \) \( (x_b) \) to remain on the line of the slot.
    - Note: different results would be obtained if different orientations are used for the local directions. (figs. b, c)
Understanding Connector Local Directions

- The default directions at the second node are the local directions at the first node.
- It may be necessary to define local directions at the second node to model the mechanism correctly, e.g. UJOINT.
- In geometrically nonlinear analyses, the element local directions associated with the nodes rotate with the rotational degrees of freedom at the nodes.
- A summary of connector local directions will be in the section “Summary of Orientations and Local Directions” in this lecture.

Defining connector orientation

Example: Truck door hinges

Keywords interface
Define orientation using a datum coordinate system

*ORIENTATION, NAME=ORI_CONN_DOOR
0.,0.,1., 1.,0.,0.
3,0

ABAQUS/CAE interface
Define orientation using a datum coordinate system
Understanding Connector Local Directions

- Example: Truck door hinges

Keywords interface

*ORIENTATION, NAME=ORI_CONN_DOOR
0.,0.,1.,1.,0.,0.
3,0
*ELEMENT, TYPE=CONN3D2, ELSET=CONN_DOOR_HINGE
620601,9000009,9000010
620602,9000011,9000012
*CONNECTOR SECTION, ELSET=CONN_DOOR_HINGE
HINGE
ORI_CONN_DOOR

Specify local orientations for the endpoints of the wires – ABAQUS/CAE interface.

- Connector section assignment is used to specify local orientations for the endpoints of the wires.

- Example: Truck door hinges
Rotational Degrees of Freedom at the Nodes

• Overview
  • In geometrically nonlinear analyses, the element local directions associated with the nodes rotate with the rotational degrees of freedom at the nodes.
    • In linear or perturbation analyses, the element local directions remain fixed.
  • In cases where an orientation definition is permitted for defining connection directions (either required or optional), the connector element will activate rotational degrees of freedom at the nodes if they do not exist already.
    • The only exception is JOIN (will be discussed later).
Rotational Degrees of Freedom at the Nodes

- Example: The BEAM connection activates rotational degrees of freedom. The solid elements do not provide rotational stiffness at these DOFs; the connector does NOT transmit rotation into the solid.

- Other connections where an orientation definition is permitted activate rotational degrees of freedom (e.g. BEAM, ...):
  - If local directions are used and either the element's nodes do not possess rotational DOFs or if rotational constraints such as,
    - Equations
    - Multi-point constraints
    - Boundary conditions
  are not applied to the nodes, numerical singularities associated with unconstrained degrees of freedom will exist.
  - Solutions:
    - Attach the connector element to a structural element.
    - Add rotational boundary conditions.
    - Use coupling constraints (Recommended)
Rotational Degrees of Freedom at the Nodes

• JOIN connection does NOT activate rotational degrees of freedom
  • This allows the user to define a join constraint between two solids expressed only in terms of translations.
  • Example 1: Two deformable solids connected by the JOIN connection type rotate under certain loading and boundary conditions.
    • Orientation at node a does not rotate with the rotation of the deformable body since the solid element does not have rotational DOFs active.

Note: The examples discussed here and the next two slides consider geometric nonlinearity.

Rotational Degrees of Freedom at the Nodes

• Example 2: Make one solid in Example 1 rigid.
  • Orientation at node a rotates with the rotation of the rigid body since the rigid body has rotational DOFs.
  • Node b will move accordingly with node a.
Rotational Degrees of Freedom at the Nodes

- **Example 3**: Define a surface-based coupling constraint on the surface of one of the deformable solids in **Example 1**; choose the reference point of the surface-based coupling constraint as node a.
  - Orientation at node a rotates with the rotation of the deformable body since the coupling constraint activates rotational DOFs.
  - Node b will move accordingly with node a.

**Components of Relative Motion**
Components of Relative Motion

• Components of relative motion
  • Connector elements have internal DOFs that do not exist at any node, but are a part of the connector element itself.
  • The connector local degrees of freedom, that is, the three translations and three rotations relative to the connector element local coordinate system (in three dimensions), are called the components of relative motion (CORM).
    • The three translations are in the element local coordinate directions.
    • The three rotations are angular quantities that depend on the specific connection definition and may or may not be rotations about orthogonal directions.
  • All components of relative motion are either constrained or available.
    • The definitions of constrained and available components of relative motion will be discussed in next two slides, respectively.

Components of Relative Motion

• Constrained components of relative motion
  • Constrained components of relative motion are displacements and rotations that are fixed by the connector element.
  • ABAQUS/Standard uses Lagrange multipliers to enforce the kinematic constraints.
    • The constraint forces and moments carried by the element appear as additional solution variables.
  • ABAQUS/Explicit uses an augmented Lagrange technique to enforce the kinematic constraints.
  • Constrained components of relative motion are measured by reaction forces and moments.
  • The kinematic constraint is equivalent to forcing one or more of the components of relative motion to behave according to some predefined relationship.
Components of Relative Motion

- Available components of relative motion
  - Available components of relative motion are displacements and rotations that are not constrained kinematically.
  - Available components of relative motion can be used for
    - Defining material-like behavior (discussed in lectures 4 and 5).
    - Specifying connector actuation (discussed in lecture 6).
      - Time-dependent motion
      - Applying loading
    - Assigning complex interactions, such as contact or friction (discussed in lecture 4).

Examples:

<table>
<thead>
<tr>
<th>Connection types</th>
<th>Kinematic constraints</th>
<th>Available components</th>
</tr>
</thead>
<tbody>
<tr>
<td>AXIAL</td>
<td>0: u1 \neq 0</td>
<td>1: u1</td>
</tr>
<tr>
<td>CARTESIAN</td>
<td>0:</td>
<td>3: u1, u2, u3</td>
</tr>
<tr>
<td>JOIN</td>
<td>3: u1=0, u2=0, u3=0</td>
<td>0:</td>
</tr>
<tr>
<td>REVOLUTE</td>
<td>2: e1=e2=e3=0</td>
<td>1: ur1</td>
</tr>
<tr>
<td>CARDAN/EULER</td>
<td>0:</td>
<td>3: ur1, ur2, ur3</td>
</tr>
<tr>
<td>BEAM</td>
<td>3+3: u1=0, u2=0, u3=0</td>
<td>0:</td>
</tr>
<tr>
<td>HINGE</td>
<td>3+2: e1=e2=e3=0</td>
<td>1: ur1</td>
</tr>
<tr>
<td>U-JOINT</td>
<td>3+1: u1=0, e1=e3=0</td>
<td>2: ur1, ur2</td>
</tr>
</tbody>
</table>
There are many different kinematic quantities used to describe a connector element:

- Position
- Displacement
- Velocity
- Acceleration
- Reference position for defining constitutive response
- Constitutive displacements (essentially material strains)

All these quantities provide useful information regarding the connector element.
Connector Local Kinematics

• In three dimensions each of the above kinematic quantities requires six components to completely define it.
  • Three components in two dimensions.
  • For example, in three dimensions, a position requires
    • Three generalized coordinates to identify the location of the second node relative to the first.
    • Three angles to identify the orientation of the second node relative to the first.
  • In two dimensions, a position requires
    • Two generalized coordinates to identify the location of the second node relative to the first.
    • One angle to identify the orientation of the second node relative to the first.

Connector Local Kinematics

• Displacement, velocity, acceleration
  • These quantities are derived from position:
    • Displacement = change in position
    • Velocity = rate of change of position
    • Acceleration = rate of change of velocity
  • The reference position for constitutive response and constitutive displacements is relevant only for material behavior and will be discussed in Lecture 4.
Connector Local Kinematics

• Translations:
  • With the exception of RADIAL-THRUST, BUSHING, PROJECTION CARTESIAN and AXIAL, all the connections use Cartesian coordinates to locate the second node relative to the first.
    • For translations the second node’s position, displacement, velocity, etc. are identified by three Cartesian components relative to local directions at the connector element’s first node.
  • RADIAL-THRUST uses a cylindrical coordinate system with origin at the first node.
  • BUSHING and PROJECTION CARTESIAN use an orthonormal system that follows the systems at both nodes in the connection.
  • AXIAL does not use a coordinate system. The CORM is measured along the line separating the two nodes in the connection.

Connector Local Kinematics

• Rotations:
  • Describing directions at the second node relative to directions at the first node is much more complicated.
  • Example: REVOLUTE

• Several different rotation parameterizations are used.
  • Cardan angles and Euler angles are successive rotation parameterizations. Examples:
    • Spinning top = EULER angles (precession, nutation, and spin).
    • Airplane attitude = CARDAN angles (roll, pitch, and yaw).
Connector Local Kinematics

- The rotation vector is a parameterization similar to the nodal rotational degrees of freedom in ABAQUS.
  - Example: Instantaneous angular velocity
- FLEXION-TORSION has rotation parameterization angles consisting of total flexion, torsion, and sweep.
- PROJECTION FLEXION-TORSION connection has rotation parameterization angles consisting of two component flexion angles and a torsion angle.
  - Example: Head position on the shoulders in a crash test dummy model.
- Different rotation parameterizations are analogous to different coordinate systems (Cartesian versus cylindrical versus polar, etc.).
  - Use the one that makes the most sense for a particular application.

Summary of Orientation and Local Directions
## Summary of Orientation and Local Directions

### Local Directions at Connector Nodes – Basic Translational

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>1st node</th>
<th>2nd node</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCELEROMETER</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>AXIAL</td>
<td>Optional**</td>
<td>Optional**</td>
</tr>
<tr>
<td>CARTESIAN</td>
<td>Optional</td>
<td>Ignored</td>
</tr>
<tr>
<td>JOIN</td>
<td>Optional</td>
<td>Ignored</td>
</tr>
<tr>
<td>LINK</td>
<td>Ignored</td>
<td>Ignored</td>
</tr>
<tr>
<td>PROJECTION CARTESIAN</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>RADIAL-THRUST</td>
<td>Required</td>
<td>Ignored</td>
</tr>
<tr>
<td>SLIDE-PLANE</td>
<td>Required</td>
<td>Ignored</td>
</tr>
<tr>
<td>SLOT</td>
<td>Required</td>
<td>Ignored</td>
</tr>
</tbody>
</table>

*Rotational dofs are not activated. If rotational dofs do not exist, the local coordinate system does not co-rotate and fixed directions are used.

**Optional only at a ground node. Otherwise, ignored.

### Local Directions at Connector Nodes – Basic Rotational

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>1st node</th>
<th>2nd node</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALIGN</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>CARDAN</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>CONSTANT VELOCITY</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>EULER</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>FLEXION-TORSION</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>PROJECTION FLEXION-TORSION</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>ROTATION</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>REVOLUTE</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>ROTATION-ACCELEROMETER</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>UNIVERSAL</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>FLOW-CONVERTER</td>
<td>Required</td>
<td>Ignored</td>
</tr>
</tbody>
</table>
Summary of Orientation and Local Directions

Local Directions at Connector Nodes – Assembled

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>1st node</th>
<th>2nd node</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEAM</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>BUSING</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>CVJOINT</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>CYLINDRICAL</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>HINGE</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>PLANAR</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>TRANSLATOR</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>UJOINT</td>
<td>Required</td>
<td>Optional</td>
</tr>
<tr>
<td>WELD</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>SLIPRING</td>
<td>Ignored</td>
<td>Ignored</td>
</tr>
</tbody>
</table>

Example: the definitions of orientation and local directions in UJOINT

Unit angular velocity at node 1 about shaft 1 axis, what is shaft 2 rotation after 1 sec?

*ELEMENT, TYPE=CONN3D, ELSET=UJOINT_EL 3,2,3
*CONNECTOR SECTION, ELSET=UJOINT_EL UJOINT, ORI_SHAFT_1, ORI_SHAFT_2
*ORIENTATION, NAME=ORI_SHAFT_1 0.0,0.0,1.0, 0.0,0.0,0.0
*ORIENTATION, NAME=ORI_SHAFT_2 0.0,0.0,1.0, 0.937,0.342,0.0
*TRANSFORM, NSET=NODE4 0.937,0.342,0.0, -0.342,0.937,0.0

*BOUNDARY, TYPE=VELOCITY 1.4,1.0
*MOTION, NSET=MODE4, GLOBAL=NO U in local coord. system is 0.971 (Note: arctan[cos(20°) tan(1.4+1.0)]=0.971 O.K.)

UJOINT: if drive shaft moves at constant angular velocity, for \( \beta \neq 0 \), driven shaft moves with uneven angular velocity (it “wobbles”) driven twist angle = \( \alpha_2 = \arctan[\cos(\beta) \tan(\omega_1 t)] \)

Local 2 axes along shaft axes

Align local 1 direction at node 4 with shaft 2 axis

Step time = 1.0 sec

Step time = 1.0 sec
### Example: the definitions of orientation and local directions in CVJOINT

Unit angular velocity at node 1 about shaft 1 axis, what is shaft 2 rotation after 1 sec?

- **ELEMENT, TYPE=CONN3D2, ELSET=CVJOINT_EL 3,2,3**
- **CONNECTOR SECTION, ELSET=CVJOINT_EL CVJOINT, ORI_SHAFT_1,ORI_SHAFT_2**
- **ORIENTATION, NAME=ORI_SHAFT_1 0.0,0.0,1.0, 0.0,-1.0,0.0**
- **ORIENTATION, NAME=ORI_SHAFT_2 0.0,0.0,1.0, 0.342,-0.937,0.0**
- **TRANSFORM, NSET=NODE4 0.937,0.342,0.0, -0.342,0.937,0.0**
- **BOUNDARY, TYPE=VELOCITY 1,4,4,1.0**
- **NODE PRINT, GLOBAL=NO U, \( \beta = 20^\circ \)**

**Shaft 1**

1 2 3

**Shaft 2**

1' 2' 3'

Local 3 axes (=1 \times 2) must be along shaft axes

- **CVJOINT:** if drive shaft moves at constant angular velocity, driven shaft moves with same angular velocity (no "wobble")
- driven shaft twist angle = \( \alpha = \omega t \)

**Step time = 1.0 sec**

UR, in local coord. system is 1.0 (Note: \( \omega t \approx 1.8 \approx 1.8 \), O.K.)