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Large Angle Transient Dynamics (LATDYN) Demonstration Problem Manual

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Large Angle Transient Dynamics (LATDYN) Demonstration Problem Manual

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Example 1 Symmetrical Rigid Top with One Point Fixed

Description:

In this example, LATDYN is used to simulate the motion of a symmetrical rigid top in a uniform gravitational field when one point on the axis of symmetry fixed in space. The mass of the top is 1.0 and principal moments of inertia are (0.1875, 0.1875, 0.3) and are defined with respect to a reference frame located at the C. G. Initially, the top lies in the global y-z plane and is tilted 30 degrees from the global Z-axis as shown in Fig. 1.1. Location of the C.G. in global coordinates is (0.0, -0.5, 0.8660254). The top is given an initial angular velocity of 35.0 rad/sec about its axis of symmetry and released to start the motion.

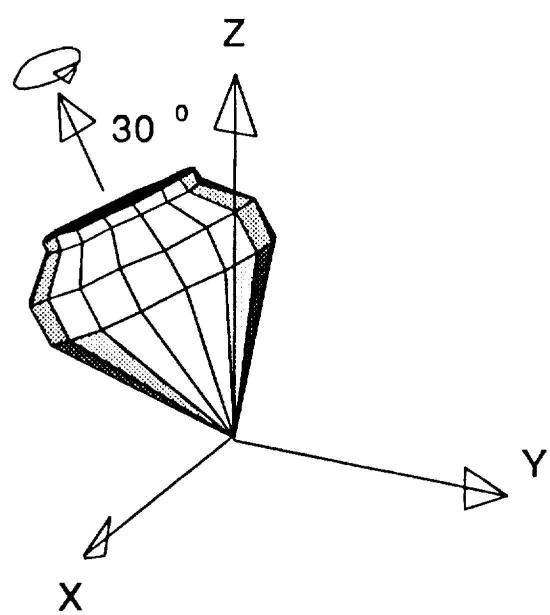

Figure 1.1 Rigid Top in Uniform Gravity Field

Modeling:

A LATDYN model of the top is shown in Fig. 1.2. The rigid top is modeled using the RBODY command with the OFFSET option. Since the linear displacement of one point of the top is fixed, it can be modelled using three SDFC commands or a BALLJOINT command.

The latter, however, requires an addition grid point to be defined and six SDFCs to ground it, therefore it is not recommended for this case. After a rigid body is defined using the RBODY command, MASSPROP and ADMASS commands must be given to add a mass property to the system. If the mass property are not included, a non-positive definite matrix will be created on execution and a run time error will occur.

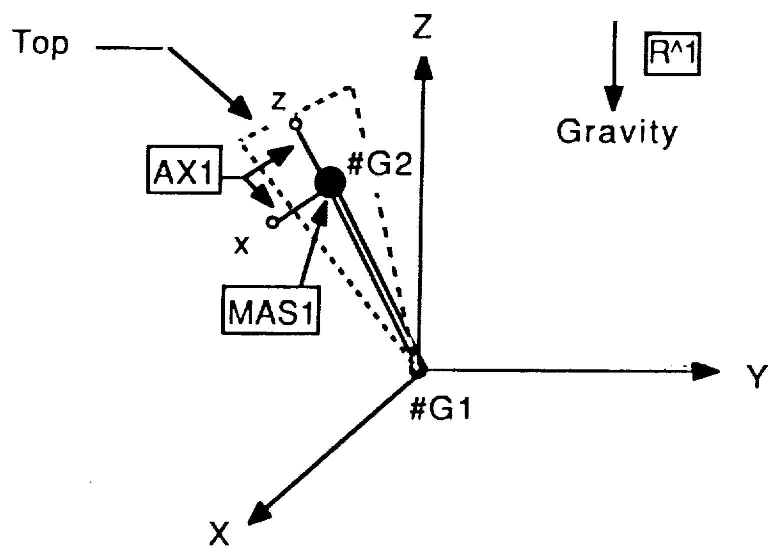

Figure 1.2 LATDYN Model of The Top

Input Data File:

```
TITLE: SPINNING RIGID TOP IN UNIFORM GRAVITY FIELD
$
$ Define simulation control parameters
$
INTEG:      EXPLICIT(0.5)
TIMESPAN:      0.0      6.0
TIMESTEP: 5.0E-4
PRINT: STEP(50 GLOBAL  50 GLOBAL  0  0  0)
PLOT: STEP(10)
$
$ Define global position of grid points
$
GRIDPT: #G1   0.0   0.0   0.0
GRIDPT: #G2   0.0   -0.5  0.866025403
```

```
$
$ Define rigid body and its mass properties
$
RBODY: TOP #G1 #G2 OFFSET
MASSPROP: MAS1  1.0 0.0 0.0 0.0  0.1875 0.1875 0.3 0.0 0.0 0.0
AXES: AX1 ORIGIN(0.0,-0.5,0.866025403) &
AXPTS(X,1.0,0.5,0.866025403,Z,0,-1,1.732050808)
ADMASS: #G2  MAS1  AX1
$
$ Define constraints to fix the translational motion of the TOP
$
SDFC: FIX1 #G1 X 0.0
SDFC: FIY1 #G1 Y 0.0
SDFC: FIZ1 #G1 Z 0.0
$
$ Define initial conditions
$
VELOCITY: #G2  0.0 0.0 0.0 0.0 -17.5 30.31088913
$
$ Define a gravity field
$
REFVECT:R^1,RCOORD(0,0,-1,GLOBAL),FIXGLO
GRAVITY: CONSTANT(9.8065,R^1)
```

Results:

Selected simulation results are displayed in Figs. 1.3-1.5 Figure 1.3 shows the trajectory of the C. G. on X-Y plane. Figure 1.4 shows the Z location history of the C. G. The results are compared with exact solutions (shown in dotted line) obtained by solving the governing ordinary differential equation. Figure 1.5 shows the angular velocity of the top about the Z axis.

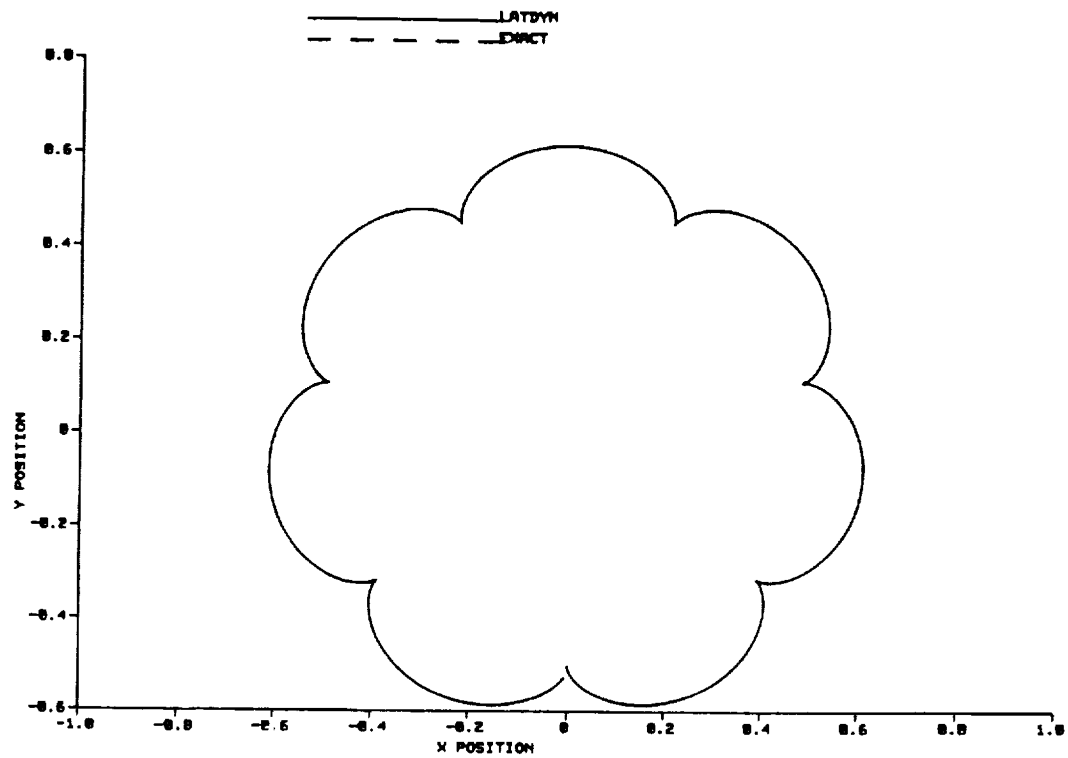

Figure 1.3 C. G. Trajectory on the X-Y Plane

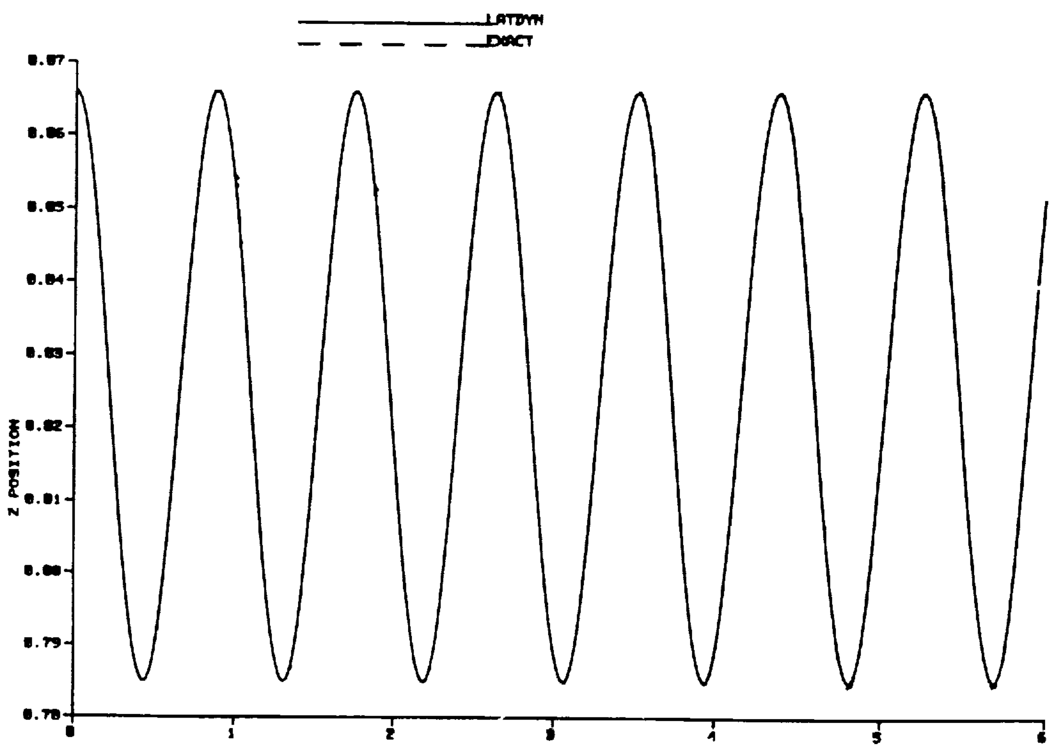

Figure 1.4 Location of C. G. In the Z direction

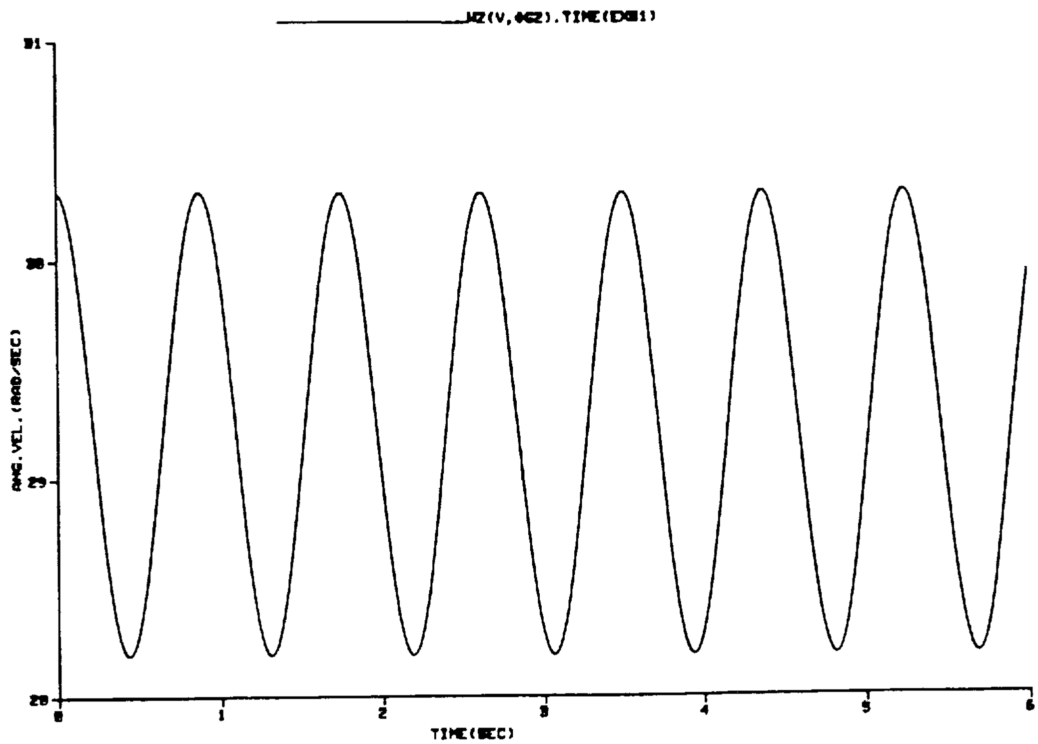

Figure 1.5 Angular Velocity in the Z Direction

Example 2 Rigid Slider-Crank Mechanism

Description:

The slider-crank mechanism shown in Fig. 2.1 consists of four components, the crank, the connecting rod, the slider and the ground body. The mechanism set in the x-y plane. Three one degree-of-freedom hinges are used to connect the ground body and the crank, the crank and the connecting rod, and the connecting rod and the slider. The slider is constrained to translate only in the x direction. Initially, both the crank and the connecting rod are horizontal and the crank is given an initial angular velocity of 124.8 rad/sec (about 1200 rpm).

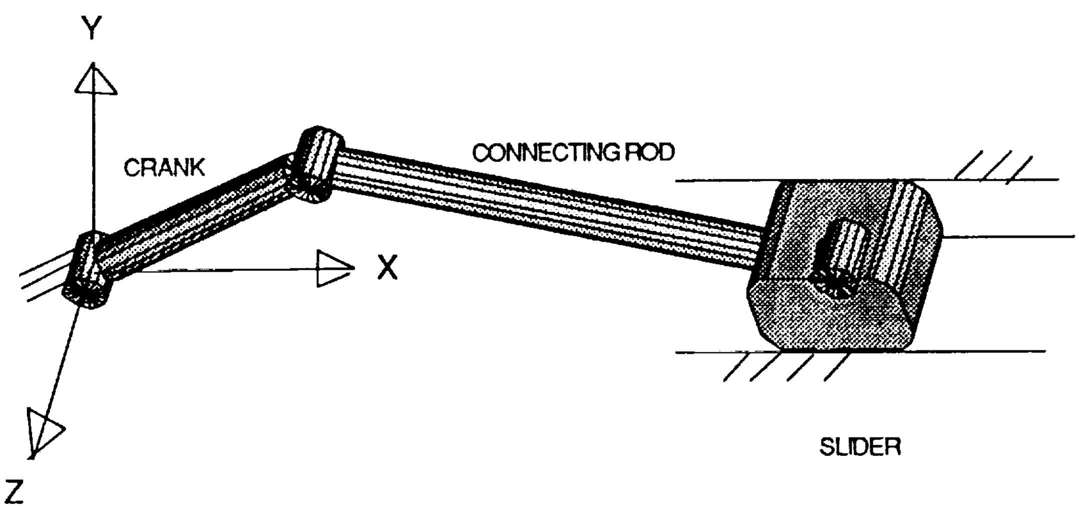

Figure 2.1 A Slider-Crank Mechanism

Modeling:

A LATDYN model of the rigid slider-crank mechanism is shown in Fig. 2.2. Six grid points are defined. Both the crank and the connecting rod are modeled using RBODY commands each with two grid points, while both the slider and the ground bodies are each defined using one grid point. The ground body is constrained using the FIX command. Three revolute joints are defined to connect bodies. Masses are added to each moving rigid body using ADMASS command.

Since both the crank and the connecting rod are modeled as rigid bodies, the system has only 1 degree-of-freedom. By modeling the hinges as revolute joints and constraining the motion of the slider using a translational joint, there are a total of 26 constraint equations in the system (5 constraints for each revolute and translational joints). On the other hand there are 24 generalized coordinates (6 for each component) in the system. This implies that there are 3 redundant constraint equations among those defined. In the simulation, LATDYN detects and removes the 3 redundant constraints at the begining of the simulation.

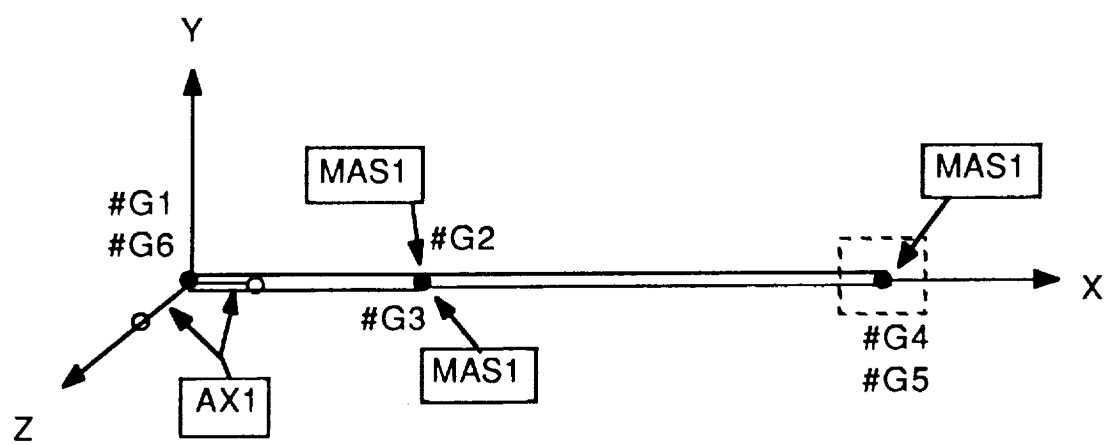

Figure 2.2 LATDYN model of the Rigid Slider-Crank Mechanism

Input Data File:

```
TITLE: RIGID SLIDER-CRANK MECHANISM
$
$ Define simulation control parameters
$
INTEG:     EXPLICIT(0.5)
TIMESPAN:     0.0     0.2
TIMESTEP: 1.0E-4
PRINT: STEP(20 GLOBAL  20 GLOBAL 0 0 0)
```

```
PLOT: STEP(10)
$
$ Define global position of grid points
$
GRIDPT: #G1  0.0   0.0  0.0
GRIDPT: #G2  6.0   0.0  0.0
GRIDPT: #G3  6.0   0.0  0.0
GRIDPT: #G4  18.0  0.0  0.0
GRIDPT: #G5  18.0  0.0  0.0
GRIDPT: #G6  0.0   0.0  0.0
$
$ Define rigid body and its mass properties
$
RBODY: CRANK #G2 #G1 OFFSET
RBODY: ROD   #G3 #G4 OFFSET
MASSPROP: MAS1  1.0 0.0 0.0 0.0  1.0 1.0 1.0 0.0 0.0 0.0
AXES: AX1 ORIGIN(0.0,0.0 0.0) AXPTS(X,1.0,0.0,0.0,Z,0,0.0,1.0)
ADMASS: #G2  MAS1  AX1
ADMASS: #G3  MAS1  AX1
ADMASS: #G5  MAS1  AX1
$
$ Define reference points
$
REFPT: #R1  6.0 0.0 1.0 GLOBAL
REFPT: #R2  18.0 0.0 1.0 GLOBAL
REFPT: #R3  0.0 0.0 1.0 GLOBAL
$
$ Define constraints between rigid bodies
$
HINGEJOINT: HINGE1  #G2 #G3  POINT(#R1)
HINGEJOINT: HINGE2  #G4 #G5 POINT(#R2)
HINGEJOINT: HINGE3  #G1 #G6  POINT(#R3)
TRANSJOINT: TRANS1  #G5 #G6
FIX: FIX6  #G6
$
$ Define initial conditions
$
VELOCITY: #G2  0.0  748.8 0.0 0.0 0.0 124.8
VELOCITY: #G3  0.0  748.8 0.0 0.0 0.0 -62.4
```

Results:

Figures 2.3-2.5 show the plotted results of the simulation at the slider, comparing with the results from the DADS codes[1]. Identical results would be obtained if revolute joint between the crank and the connecting rod, and the joint between the connection rod and the slider were modeled as a cylindrical joint and balljoint, respectively. However, in this case the model doesn't form a redundant constraint system.

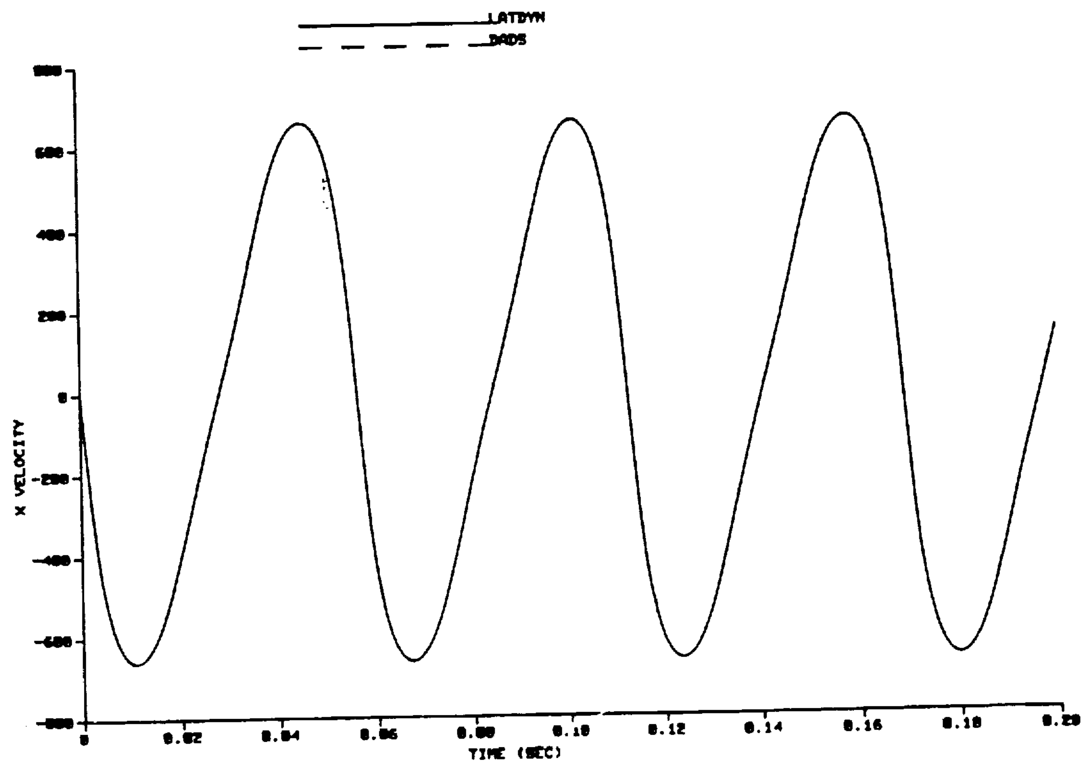

Figure 2.3 Displacement of the Slider

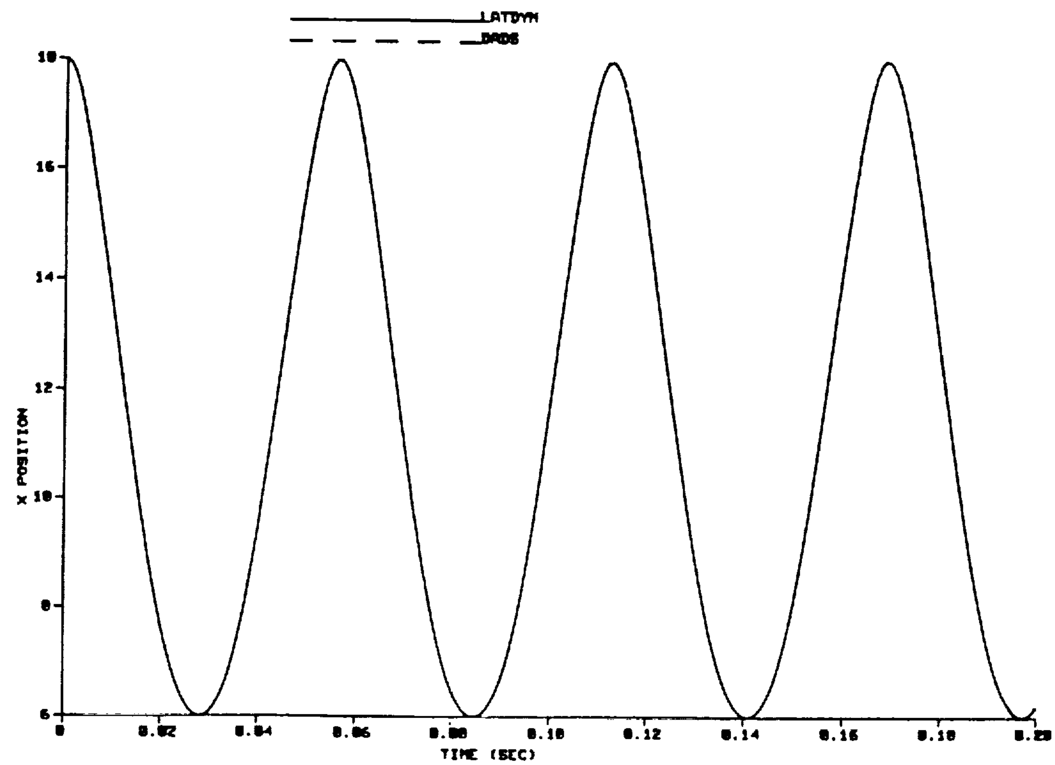

Figure 2.4 Velocity of the Slider

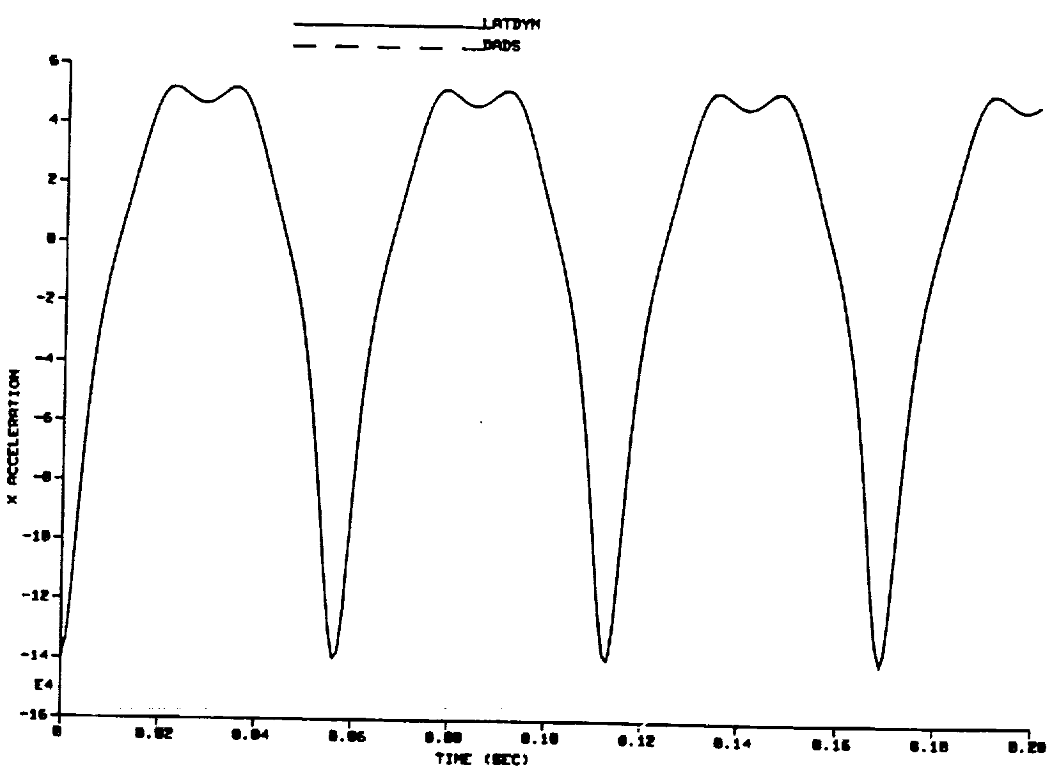

Figure 2.5 Acceleration of the Slider

Reference:

1. DADS User's Manual, Computer Aided Design Software, Inc., P. O. Box 203, Oakdale, Iowa 52319, 1987.

Example 3 Rigid Governor Mechanism

Description:

The governor mechanism shown in Fig. 3.1 is composed of a shaft, 2 balls, 2 arms, 2 couplers and a collar, not including ground. Arms that are attached to the balls are connected to the shaft through revolute joints whose axes are perpendicular to the shaft and parallel to each other. The collar is connected to the shaft by a translational joint that it can slide along the shaft. Couplers that connect the ball arm and the collar are modeled as massless rigid links. The shaft is connected to the ground body by a revolute joint whose hinge axis is along the y axis, thus allowing the shaft to rotate. Initially, the mechanism is given an angular velocity of 4 rad/sec.

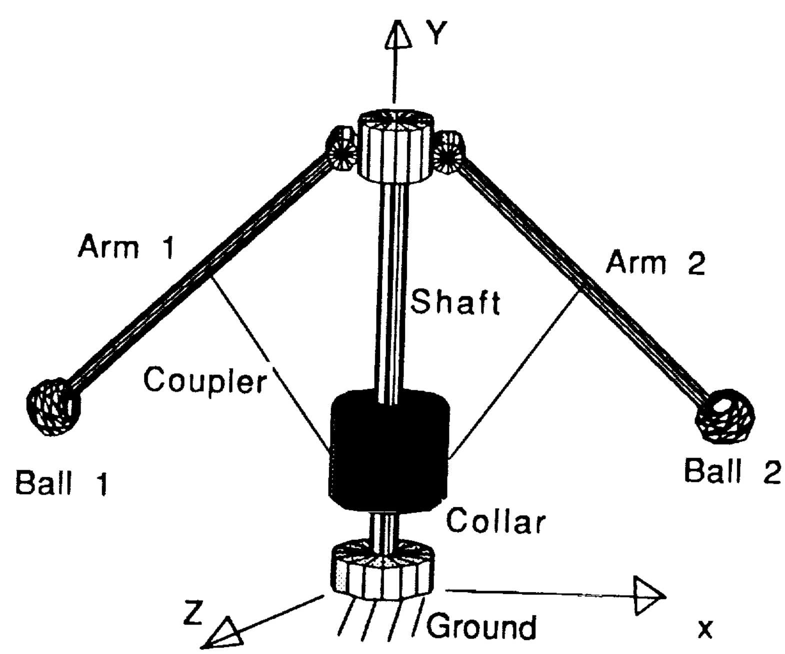

Figure 3.1 A Governor Mechanism

Modeling:

A LATDYN model is shown in Fig. 3.2. All the rigid bodies are modeled using the RBODY command with the OFFSET option. Bodies denoted as BALL 1 and BALL 2 each consist of a ball and an arm combination having three grids, one at the ball, one at the other end of the arm and one at the coupler to arm connection point. To properly define the moments of inertia for each body, an AXES command is used to define the principal axes. ADMASS commands are then used to give mass property to the bodies. Massless coupler constraints between the BALLs and the collar are imposed using the DISTLINK commands.

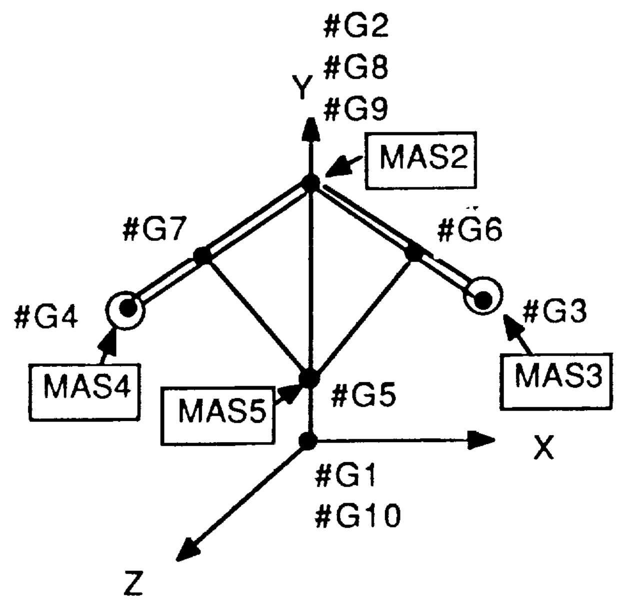

Figure 3.2 LATDYN model of the Governor

<u>Input Data File:</u>

TITLE: GOVERNOR MECHANISM
$
$ Define simulation control parameters
$
INTEG: EXPLICIT(0.5)
TIMESPAN: 0.0 6.0
TIMESTEP: 1.0E-2
PRINT: STEP(5 GLOBAL 5 GLOBAL 0 0 0)
PLOT: STEP(1)
$
$ Define global position of grid points
$
GRIDPT: #G1 0.0 0.0 0.0
GRIDPT: #G2 0.0 0.2 0.0
GRIDPT: #G3 0.11314 0.08686 0.0

```
GRIDPT: #G4   -0.11314 0.08686 0.0
GRIDPT: #G5  0.0      0.05    0.0
GRIDPT:  #G6   0.0565685 0.1434315  0.0
GRIDPT:  #G7  -0.0565685  0.1434315  0.0
GRIDPT: #G8 0.0        0.2       0.0
GRIDPT: #G9 0.0        0.2       0.0
GRIDPT: #G10  0.0      0.0       0.0
$
$ Define rigid body and its mass properties
$
RBODY: ARM2  #G8  #G6  #G3 OFFSET
RBODY: ARM1  #G9  #G7  #G4 OFFSET
RBODY: SHAFT  #G2  #G10    OFFSET
MASSPROP: MAS1   1.0 0.0 0.0 0.0   1.0 1.0 1.0   0.0 0.0 0.0
MASSPROP: MAS2   200.0 0.0 0.0 0.0   25.0 50.0 25.0   0.0 0.0 0.0
MASSPROP: MAS3   1.0 0.0 0.0 0.0     0.1   0.1   0.1   0.0 0.0 0.0
MASSPROP: MAS4   1.0 0.0 0.0 0.0     0.1   0.1   0.1   0.0 0.0 0.0
MASSPROP: MAS5   1.0 0.0 0.0 0.0     0.15 0.125 0.15   0.0 0.0 0.0
AXES:  AX1  ORIGIN(0.0,0.0,0.0)  AXPTS(X,1.0,0.0,0.0,Z,0,0.0,1.0)
AXES:  AX2  ORIGIN(0.0,0.2,0.0)  AXPTS(X,1.0,0.2,0.0,Z,0,0.2,1.0)
AXES:  AX3  ORIGIN(0.11314,0.08686,0.0)&
AXPTS(X,1.0,0.08686,0.0,Z,0.11314,0.08686,1.0)
AXES:  AX4  ORIGIN(-0.11314,0.08686,0.0)&
AXPTS(X,1.0,0.08686,0.0,Z,-0.11314,0.08686,1.0)
AXES:  AX5  ORIGIN(0.0,0.05,0.0)  AXPTS(X,1.0,0.05,0.0,Z,0,0.05,1.0)
ADMASS: #G1   MAS1   AX1
ADMASS: #G2   MAS2   AX2
ADMASS: #G3   MAS3   AX3
ADMASS: #G4   MAS4   AX4
ADMASS: #G5   MAS5   AX5
$
$ Define reference points
$
REFPT: #R1 0.0 1.0 0.0
REFPT: #R2 0.0 0.2 1.0
$
$ Define constraints between bodies
$
HINGEJOINT: HIN1  #G1  #G10  POINT(#R1)
HINGEJOINT: HIN2  #G2  #G8   POINT(#R2)
HINGEJOINT: HIN3  #G2  #G9   POINT(#R2)
TRANSJOINT: TRAN1  #G5  #G2
DISTLINK: DIS1  #G5  #G7
```

```
DISTLINK: DIS2  #G5  #G6
FIX: FIX1  #G1
$
$ Define initial conditions
$
VELOCITY: #G2  0.0   0.0 0.0 0.0 4.0 0.0
VELOCITY: #G8  0.0   0.0 0.0 0.0 4.0 0.0
VELOCITY: #G9  0.0   0.0 0.0 0.0 4.0 0.0
VELOCITY: #G5  0.0   0.0 0.0 0.0 4.0 0.0
```

Results:

Partial results of the simulation are shown in Figs. 3.3-3.5. Figure 3.3 shows the x coordinate of ball 1, Figs. 3.4 and 3.5 show the displacement and acceleration of the collar. Identical results are obtained with the DADS codes[1].

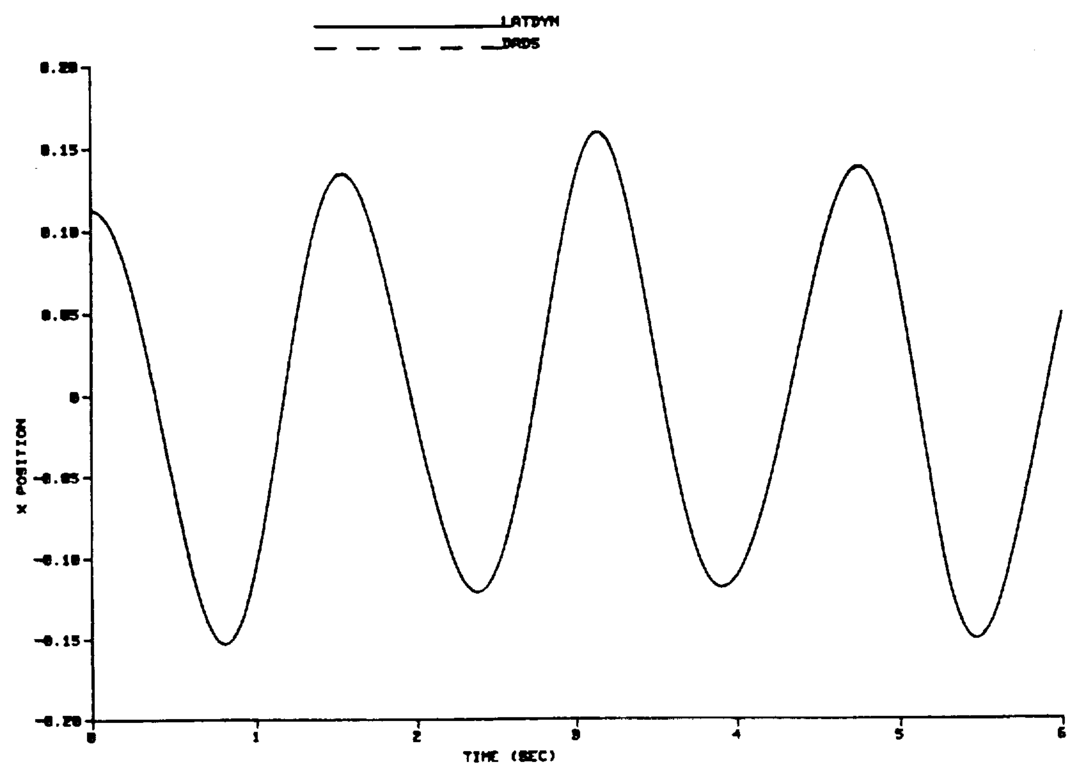

Figure 3.3   X coordinate of Ball 1

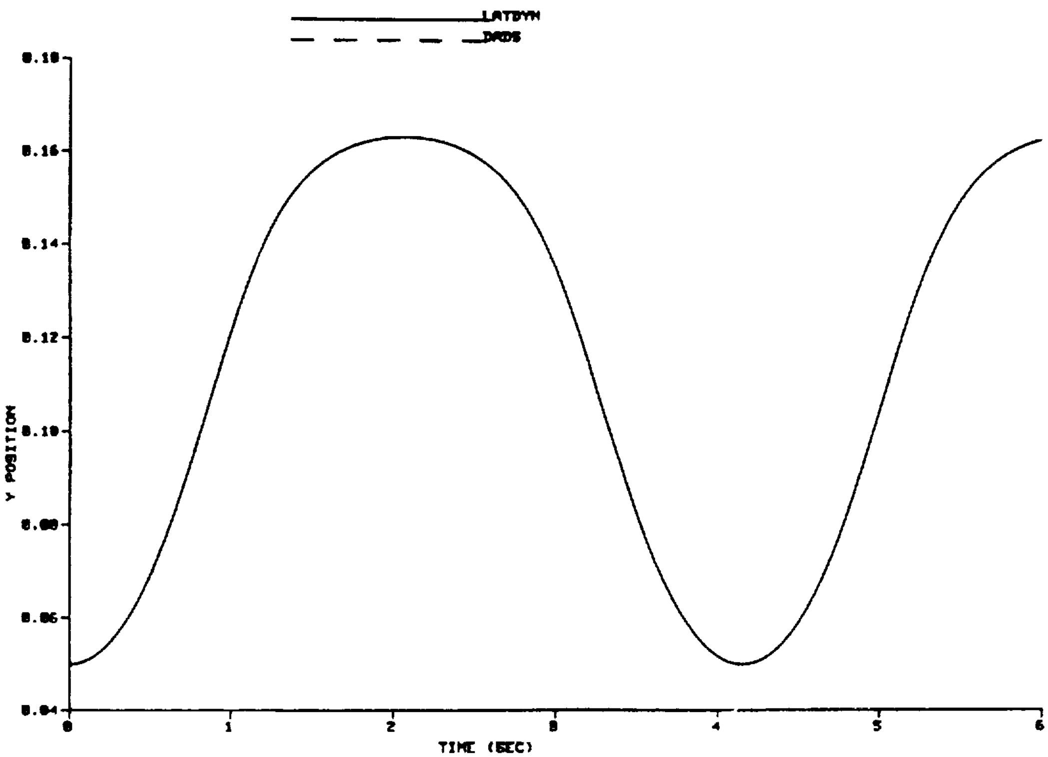

Figure 3.4 Displacement of the Collar

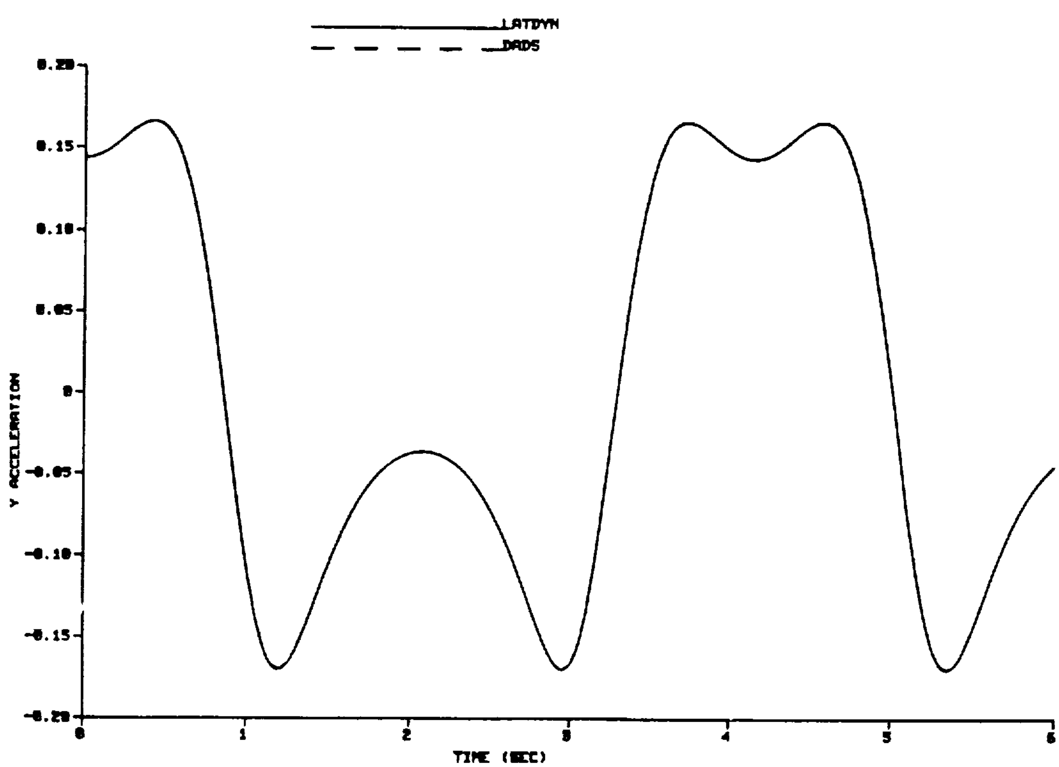

Figure 3.5 Acceleration of the Collar

Reference:

1. DADS User's Manual, Computer Aided Design Software, Inc., P. O. Box 203, Oakdale, Iowa 52319, 1987.

Example 4 Spin-up Beam

Description:

Mathematical modeling of spinning elastic bodies is usually simplified to a cantilever beam built into a rigid base that moves and rotates with a specific motion. To represent the flexiblity of the beam, deformation modes from linear finite element analysis are used. In linear theory, transverse vibration of a beam is calculated without considering axial forces. In some cases, it is not possible to ingore the effect of axial forces on bending vibration of beams. When the beam is spinning, so called geometric stiffening effects that are due to the presence of axial (centrifugal) forces come into play. Coupling between centrifugal forces and bending moment makes a rapidly spinning beam stiffer than is predicted by linear theory. Experience has shown that linear analysis techniques are inaccurate for predicting deflection of such spinning beams.

In this example, a slender beam with length 8.0 meter, is spin-up from rest to a constant angular velocity in the x-z plane. The function to spin-up the beam is written as

$$Q=\frac{\omega_s}{T_s}[1.0-\cos\ (\frac{2\pi t}{T_s})],\ t<T_s$$

$$Q=0.0,\quad t\geq T_s$$

where ω_S is the final angular velocity, T_S is the time to reach the velocity, and Q is the angular acceleration of the hinge. T_S and ω_S are taken as 15.0 and 4.0 in the example.

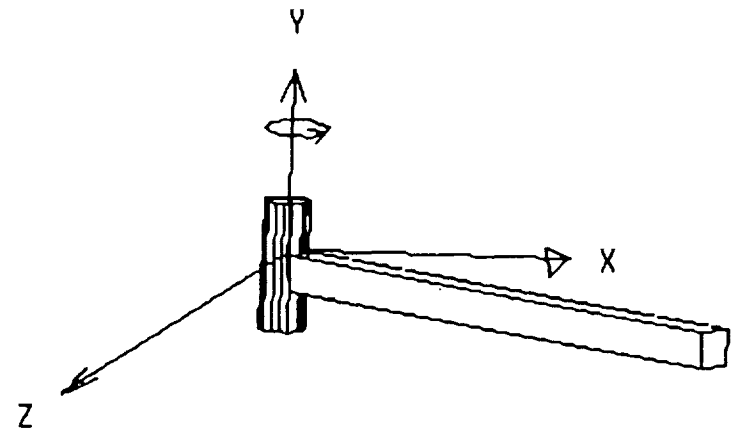

Figure 4.1 A Spin-Up Beam

Modeling:

A LATDYN model of the spin-up beam is shown in Fig. 4.2. The beam is modeled with two beam elements. Two conditions are defined to switch on/off the constraint on angular acceleration of grid point 1 in the y direction. Variables Q1 to Q8 are used to calculate the flexural deflection of the beam, (measured with respect to the rigid body configuration, as shown in Fig. 4.3). Q11 and Q12 are defined as the value of Q when t is less than and greater than 15, respectively.

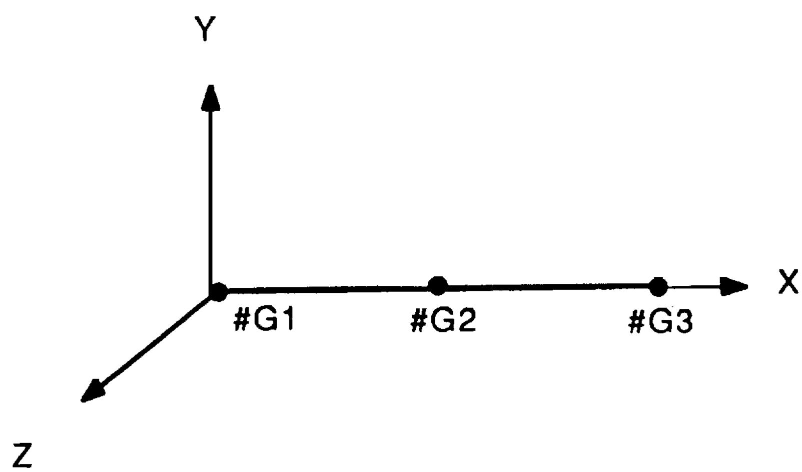

Figure 4.2 LATDYN model of the Spin-up Beam

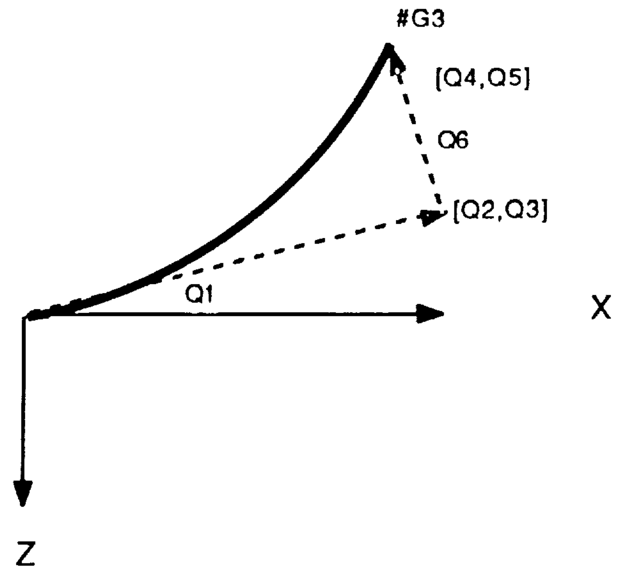

Figure 4.3 Calculation of Tip Deflection

Input Data File:

```
TITLE: SPIN-UP BEAM
$
$ Define simulation control parameters
$
INTEG:      EXPLICIT(0.5)
TIMESPAN:      0.0       25.0
TIMESTEP: 5.0E-4
PRINT: STEP(100 GLOBAL  100 GLOBAL  0  0 0)
PLOT: TIME(2.0E-2)
CHKGYR: ON
$
$ Define global position of grid points
$
GRIDPT: #G1  0.0   0.0  0.0
GRIDPT: #G2  4.0   0.0   0.0
GRIDPT: #G3  8.0   0.0   0.0
$
$ Define reference point
$
REFPOINT:#R2  0.0       1.0       0.0
$
$ Define beam properties
$
```

```
MATPROP: MAT      6.895E10      2.6519E10    2766.67
BEAMPROP: BEAM MAT 73E-6  8.2181E-9 8.2181E-9 1.6436E-8
$
$ Define beam element
$
FMEMBER:#M1   SINGLE(#G1,#G2) POINT(#R2) BEAM
FMEMBER:#M2   SINGLE(#G2,#G3)  POINT(#R2) BEAM
$
$ Define constraints
$
SDFC: FIX #G1 X 0.0
SDFC: FIY #G1 Y 0.0
SDFC: FIZ #G1 Z 0.0
SDFC: FWX #G1 WX 0.0
SDFC: FWZ #G1 WZ 0.0
$
$ Define Q variable and condition labels
$
SET:  Q11=(4./15.)*(1.-COS(2.*3.14159*T/15.))
SET: Q12=0.
C1: T.LT.15.
C2: T.GE.15.
$
$ Constrain angular acceleration of grid point 1
$
SDFC: FWY1 #G1 WY Q11 ? C1
SDFC: FWY2 #G1 WY Q12 ? C2
$
$ Define Q variables to calculate tip deflection
$
SET: Q1=YAW(#G1)
SET: Q2=8.0*COS(Q1)
SET:  Q3=-8.0*SIN(Q1)
SET: Q4=Q2-XLOC(#G3)
SET: Q5=Q3-ZLOC(#G3)
SET: Q6=SQRT(Q4*Q4+Q5*Q5)
SET: Q7=-Q2*Q5+Q3*Q4
SET:  Q8=-SIGN(1.0D00,Q7)*Q6
```

Results:

Figure 4.4 show the angular acceleration of the beam at the root, which is constrained in the simulation. Figure 4.5 shows the flexural deflection of the beam tip, comparing with result from Ref. 1. Figure 4.6 shows the bending moment of the beam at its mid-point.

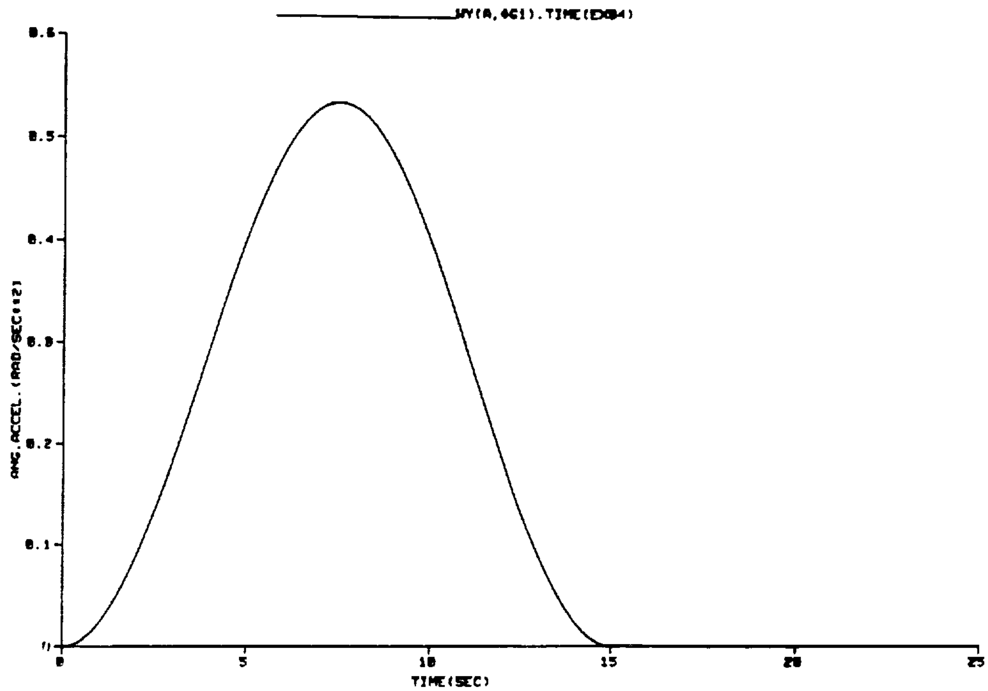

Figure 4.4 Angular Acceleration of the Beam at the Root

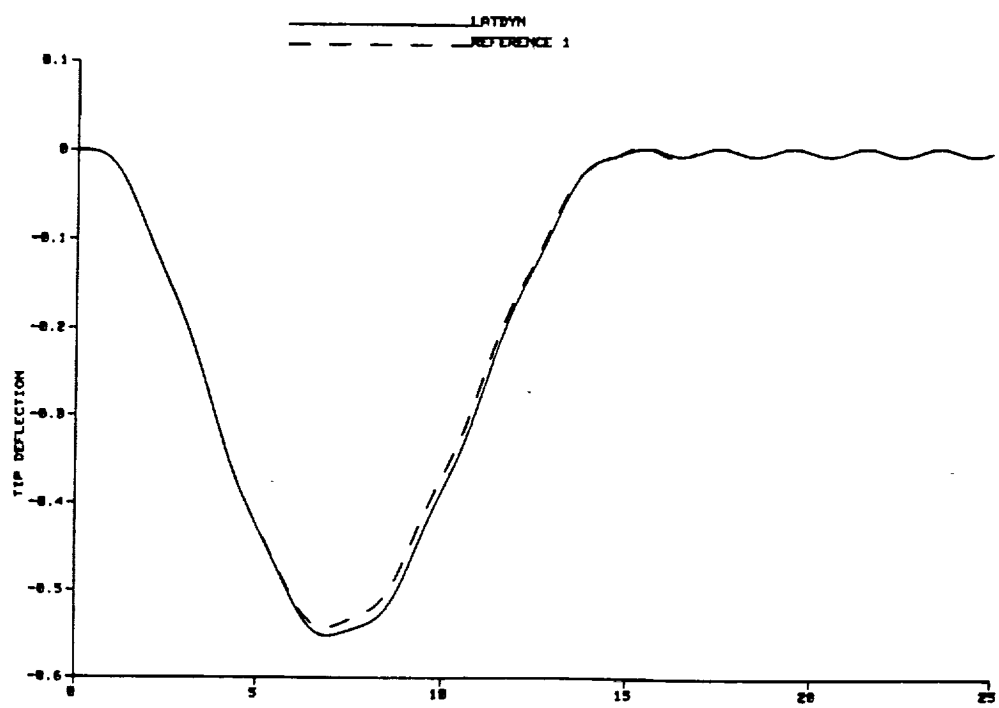

Figure 4.5 Tip Flexural Deflection of the Beam

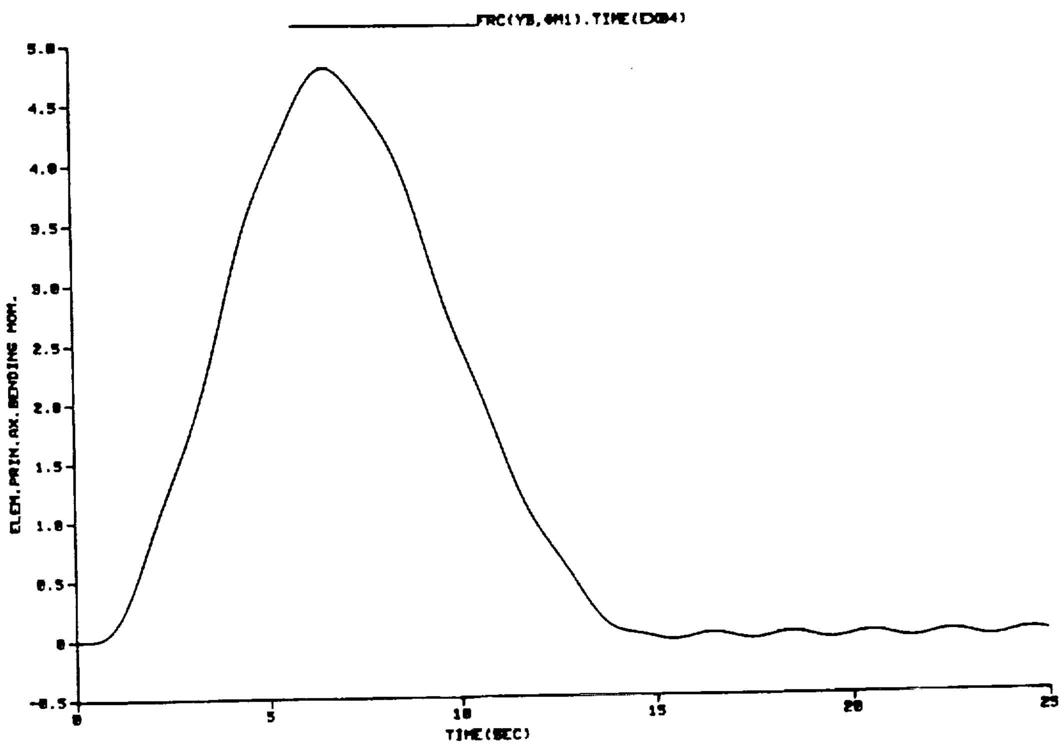

Figure 4.6 Bending Moment of the Beam at Its Mid-point

Reference:

1. Wu, S. C. and Haug, E. J.," Geometric Nonlinear Substructuring for Dynamics of Flexible Mechanical System", International Journal for Numerical Methods In Engineering, Vol. 26, No. 10, pp. 2211-2226, 1988.

Example 5 Planar Space Crane with Two Booms

Description:

A space crane is assumed to operate in a plane and consist of two truss booms joined to each other at a hinge. The actuators capable of driving the crane were located so as to provide a torque about the hinge. A schematic diagram of the set-up is shown in Fig. 5.1. In the LATDYN model, the booms are modeled as continuous beams. Each boom is represented by one beam finite element. The torque actuation is represented by two linear actuators supplying a force at a points offset from the neutral axis of the equivalent beam. The beams are hinged together at an offset point as well. Element ab (see Fig. 5.1) is modeled as a rigid member. In the simulation, one of the linear actuators supplies a constant force of 200N for 5 seconds while the second actuator is inactive and modeled as a linear spring.

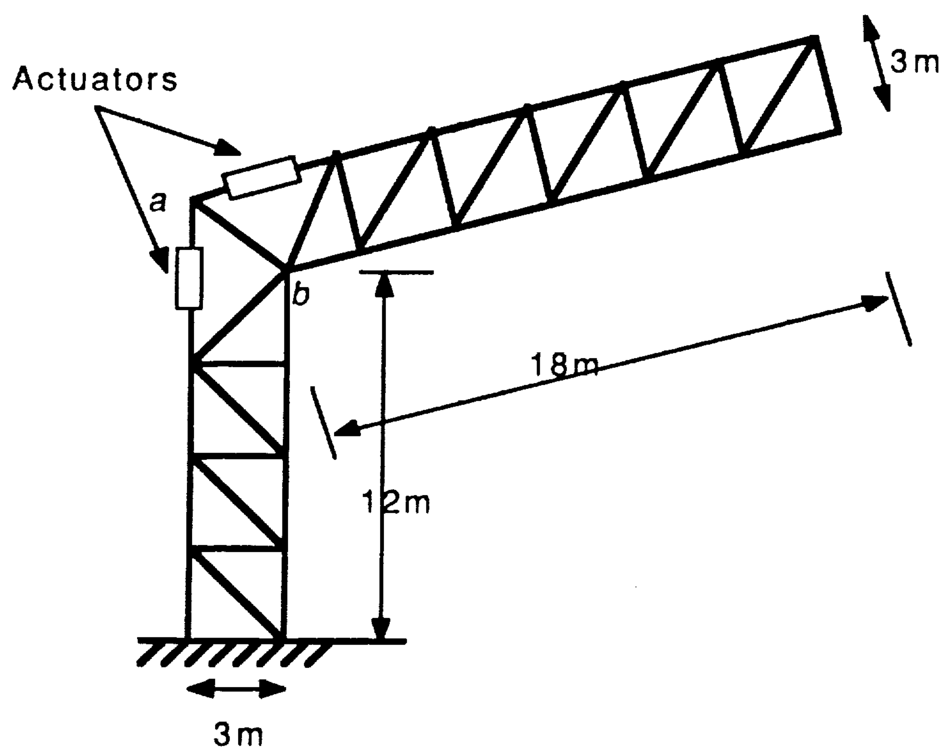

Figure 5.1 Two Booms Space Crane

Modeling:

A LATDYN model of the crane system is shown in Fig. 5.2. The model consists of three bodies, two flexible booms and one rigid element- Element ab in Fig. 5.1. The three bodies are jointed together at one point, #G3(or #G9,#g10), by two revolute joints. Each boom is modeled using one beam element. Section contains grids #G2, #G3, and #G4 is assumed rigid, comparing with the length of the booms. Similarly for section contains grids #G5, #G9, and #G7. A small mass is asumed for element ab and is lumped at #G8.

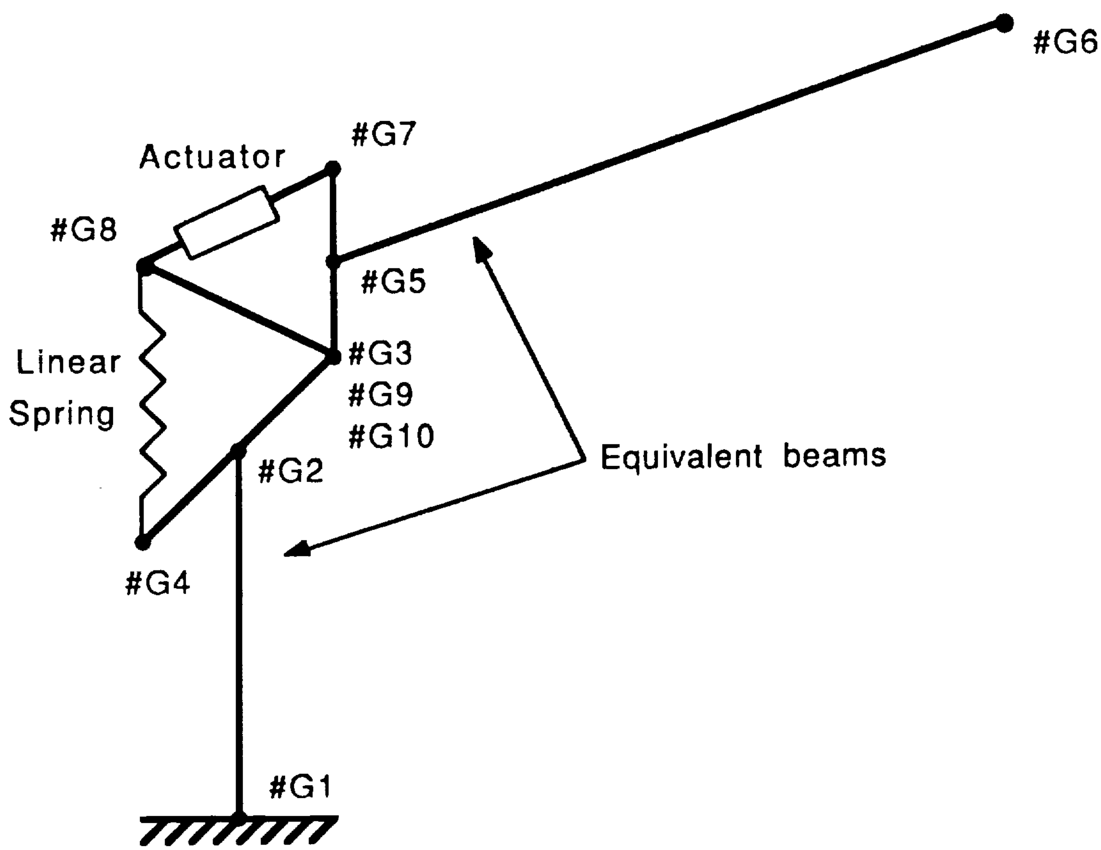

Figure 5.2 LATDYN Model of Space Crane

Input Data File:

TITLE: LINEAR-ACTUATOR-DRIVEN TWO BOOM SPACE CRANE
$
$ Define simulation control parameters
$
INTEG: EXPLICIT(0.5)
TIMESPAN: 0.0 5.0
TIMESTEP: 1.0E-3

```
PRINT: STEP(10 GLOBAL  10 GLOBAL  0  0  0)
PLOT: STEP(10)
$
$ Define global position of grid points
$
GRIDPT: #G1   0.0    0.0    0.0
GRIDPT: #G2   0.0    10.5   0.0
GRIDPT: #G3   1.5    12.0   0.0
GRIDPT: #G4  -1.5     9.0   0.0
GRIDPT: #G5   1.5    14.2   0.0
GRIDPT: #G6  11.6    25.8   0.0
GRIDPT: #G7   1.5    16.4   0.0
GRIDPT: #G8  -1.5    13.24  0.0
GRIDPT: #G9   1.5    12.0   0.0
GRIDPT: #G10  1.5    12.0   0.0
$
$ Define rigid body and its mass properties
$
RBODY: BOD1 #G2 #G3 #G4 OFFSET
RBODY: BOD2 #G5 #G9 #G7 OFFSET
RBODY: BOD3 #G8 #G10   OFFSET
MASSPROP: MAS1  1.0 0.0 0.0 0.0  1.0 1.0 1.0  0.0 0.0 0.0
AXES: AX1 ORIGIN(-1.5,13.24,0.0) AXPTS(X,0.5,13.24,0.0,Z,-
1.5,13.24,1.0)
ADMASS: #G8  MAS1  AX1
$
$ Define reference points
$
REFPT: #R1 1.0 0.0 0.0
REFPT: #R2 1.5 12.0 1.0
$
$ Define constraints between bodies and invoke constraint
$ stabilization technique
$
FIX: FIX1  #G1
HINGEJOINT: REV1 #G3 #G10 POINT(#R2)
HINGEJOINT: REV2 #G3 #G9  POINT(#R2)
ABSTB: 5.0 5.0
$
$ Define beam element and its material properties
$
MATPROP: MAT       3.0290E7   3.6808E6   2.5148
BEAMPROP: BEAM MAT 1.0 1.78 1.78 3.56
```

```
FMEMBER:#M1   SINGLE(#G1,#G2) POINT(#R1) BEAM
FMEMBER:#M2   SINGLE(#G5,#G6)  POINT(#R1) BEAM
$
$ Define force elements
$
LINSPRING: SPRING #G4 #G8 18.0E5 0.0
LINACTUATOR: ACTUATOR #G8 #G7  200.0
```

Results:

Figure 5.3 shows the trajectory of the tip, due to the constant actuator. Figure 5.4 shows the x displacement at the upper end of the vertical boom, while Fig. 5.5 shows the bending moment of the same boom at the clamped end.

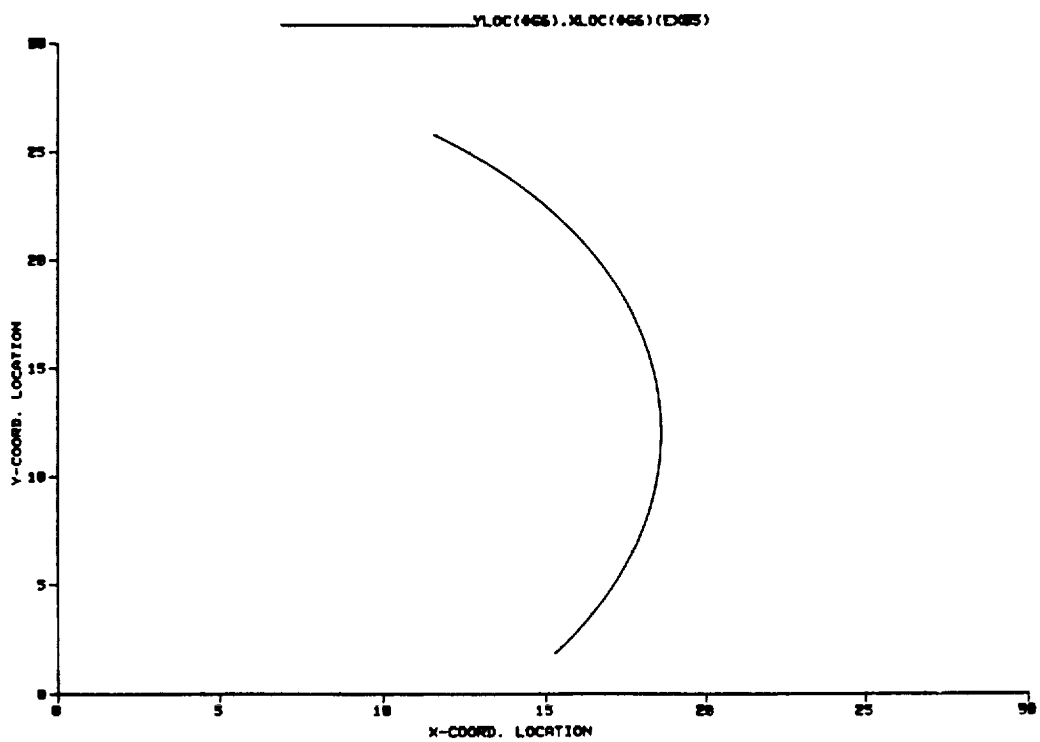

Figure 5.3 Trajectory of the Tip

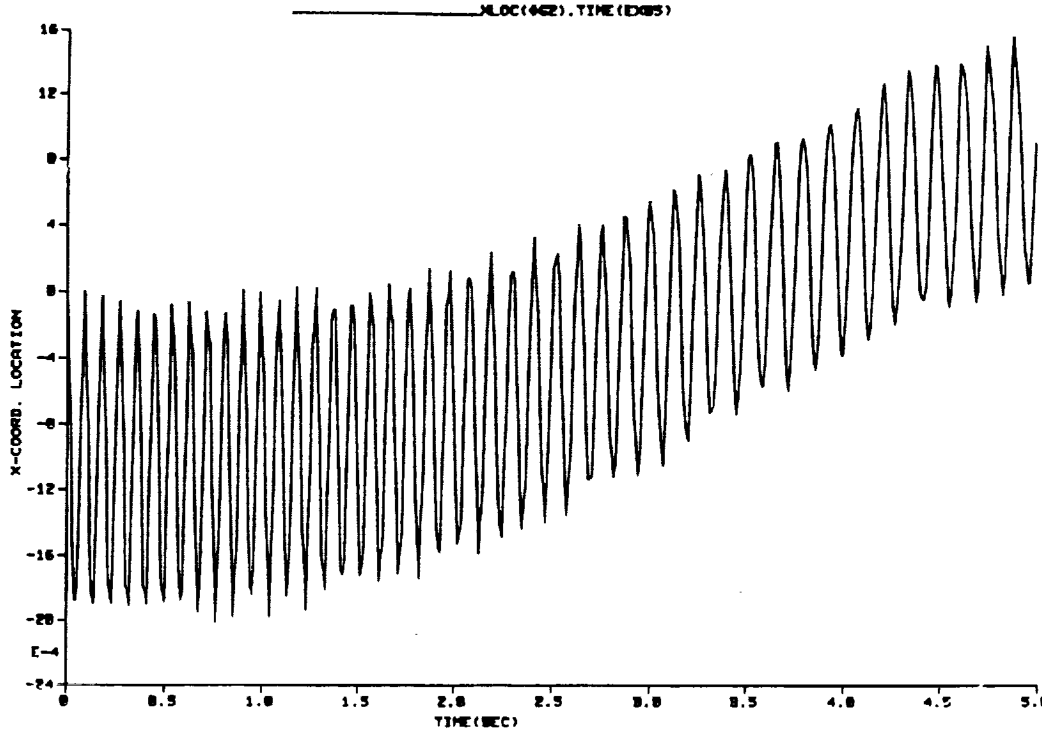

Figure 5.4 X Displacement at Upper End of Vertical Boom

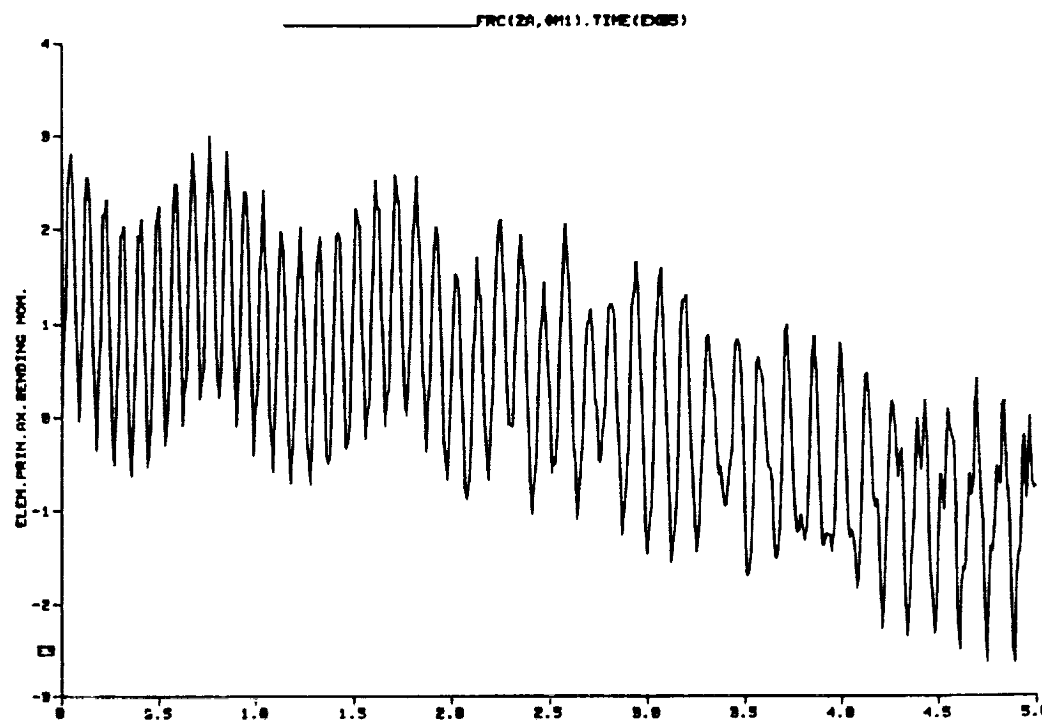

Figure 5.5 Bending Moment of Vertical Boom at Root

Example 6 Flexible Slider-Crank Mechanism

Description:

This problem is similar to that of Example 2. However, instead of modeling the connecting rod as a rigid body, it is modeled as a flexible body.

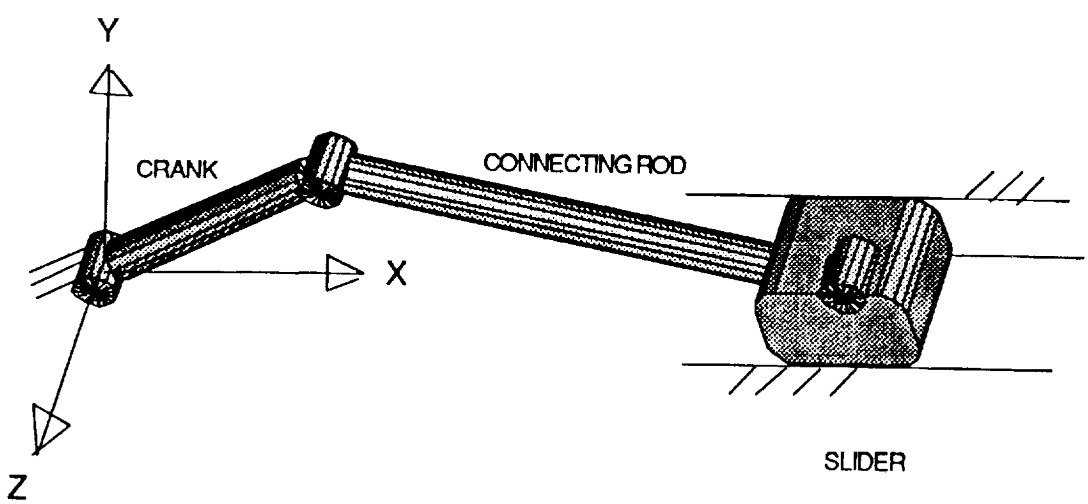

Figure 6.1 A Slider-Crank Mechanism

Modeling:

A LATDYN model of the flexible slider-crank mechanism is shown in Fig. 6.2. Two beam elements are used to model the flexible connecting rod. Totally five grid points are defined in the model. Grid point 1 and 2 are on the same rigid body- the crank. A revolute joint is defined between grid point 1 and 5, while grid point 5 is grounded. Grid point 4 represents the slider which is constrained to move in the x direction using a TRANSJOINT command. Hinges at both ends of the connecting rod are defined using HINGEPT commands, with reference points defining the orientation of the hinge axes. Q variables are used to calculate the deflection of the rod at its midspan.

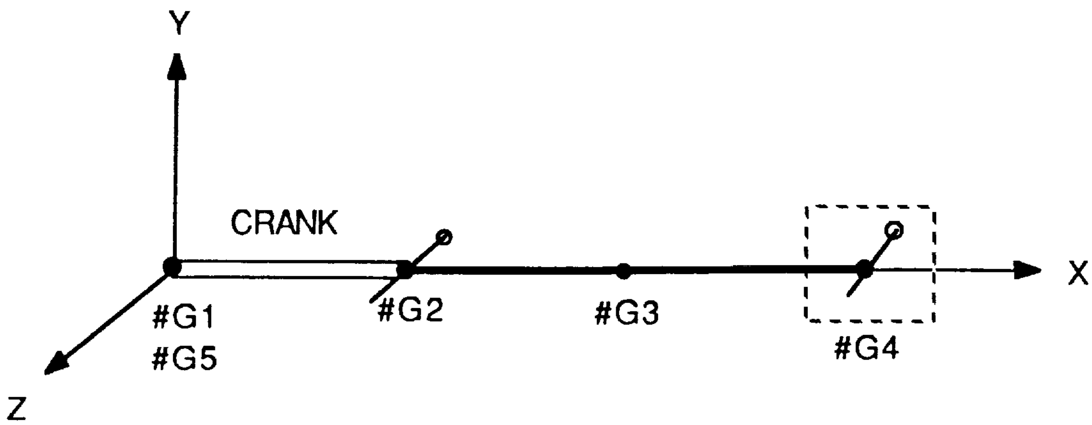

Figure 6.2 LATDYN model of the Flexible Slider-Crank Mechanism

Input Data File:

```
TITLE: PLANAR SLIDER CRANK MECHANISM
$
$ Define simulation control parameters
$
CHKGYR:ON
INTEG:EXPLICIT(.5)
TIMESPAN: 0. , .06
TIMESTEP:0.200E-4
PRINT: STEP( 100   GLOBAL  100  GLOBAL   0 0  0)
PLOT: STEP(20)
$
$ Define global position of grid points
$
GRIDPT: #G1, 0. ,0. ,0.
GRIDPT: #G2, 6. ,0. ,0.
GRIDPT: #G3, 12. , 0. ,0.
GRIDPT: #G4, 18. , 0., 0.
GRIDPT: #G5, 0. ,0. ,0.
$
$ Define reference points
$
REFPOINT:#R1, 6.,0.,1.,GLOBAL,FIXGLO
REFPOINT:#R2, 18.,0.,1.,GLOBAL,FIXGLO
REFPOINT:#R3, 6.,1.,0.,GLOBAL,FIXGLO
```

```
REFPOINT:#R4, 12.,1.,0.,GLOBAL,FIXGLO
REFPOINT:#R5, 0.,0.,1.,GLOBAL,FIXGLO
$
$ Define hinges
$
HINGEPT:#G2H1,0.,POINT(#R1)
HINGEPT:#G4H1,0.,POINT(#R2)
$
$ Define beam element and its material properties
$
MATPROP: FLEXMAT, 3.0E7,1.15E07,7.331E-4
BEAMPROP:FLEXBM,FLEXMAT,.049087385,1.91747E-4,1.91747E-4,3.83494E-4
FMEMBER:#M1,SINGLE(#G2H1,#G3),POINT(#R3),FLEXBM
FMEMBER: #M2,SINGLE(#G3,#G4H1),POINT(#R4),FLEXBM
$
$ Define initial conditions
$
VEL:#G1,0..0.,0.,0.,0.,1.248E+02
VELHINGE:#G2H1,-187.2
VEL:#G3,0.,374.4,0.,0.,0.,-62.4
VELHINGE:#G4H1,-62.4
$
$ Define rigid body and its mass properties
$
RBODY:CRANK,#G1,#G2,OFFSET
$
$ Define constraints
$
SDFC:FIXINX #G5 ,X , 0.
SDFC:FIXINY #G5 ,Y , 0.
SDFC:FIXINZ #G5 ,Z , 0.
SDFC:FIXINWX #G5 ,WX , 0.
SDFC:FIXINWY #G5 ,WY , 0.
SDFC:FIXINWZ #G5 ,WZ , 0.
SDFC:FIXINWZ1 #G1 ,WZ , 0.
TRANSJOINT: TR1, #G4,#G5
HINGEJOINT:TESTJOINT,#G1,#G5,POINT(#R5)
$
$ Define Q variables to calculate deflection at midspan of the
$ connecting rod
$
SET: Q21=XLOC(#G2)
SET: Q22=YLOC(#G2)
```

```
SET: Q31=XLOC(#G3)
SET: Q32=YLOC(#G3)
SET: Q41=XLOC(#G4)
SET: Q42=YLOC(#G4)
SET:  Q51=0.5*(Q21+Q41)-Q31
SET:  Q52=0.5*(Q22+Q42)-Q32
SET:  Q53=DSQRT(Q51*Q51+Q52*Q52)/12.
CL1: Q52.GT.0.
SET:  Q53=-Q53 ? C1
```

Results:

Figure 6.3 shows the deflection of the connecting rod at its midspan, normalized with respect to its length. Similar result is obtained as reported in Ref. 1. Figure 6.4 shows the bending moment of the connecting rod at its midspan. Figure 6.5 show the acceleration of the slider.

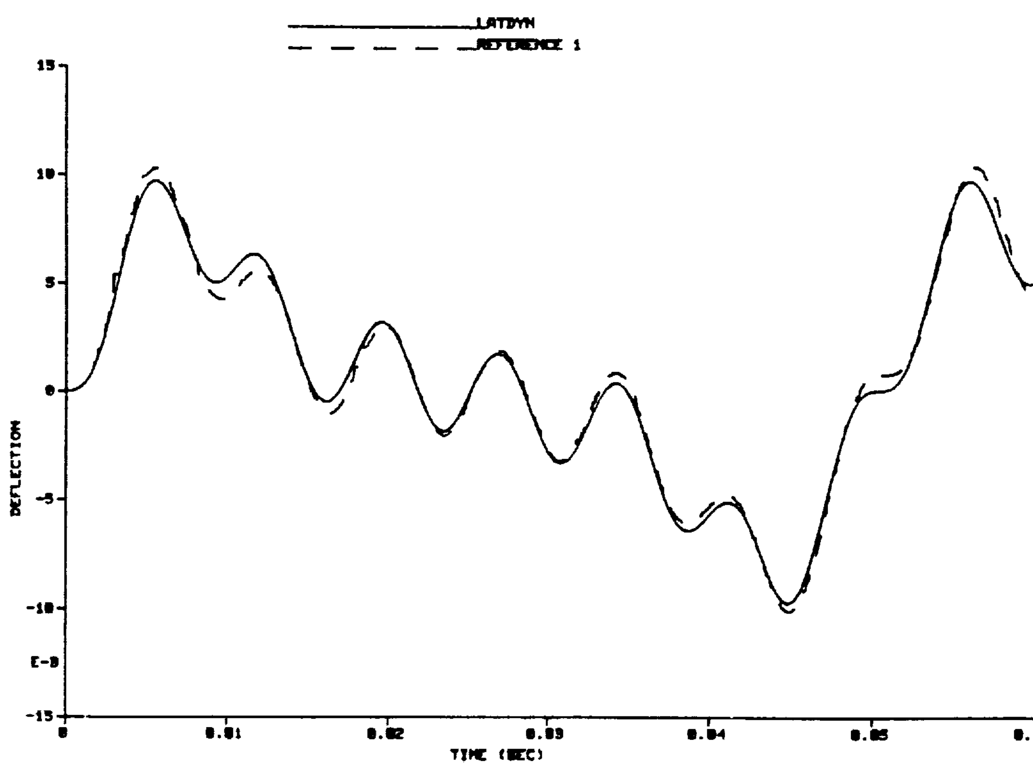

Figure 6.3   Normalized Deflection

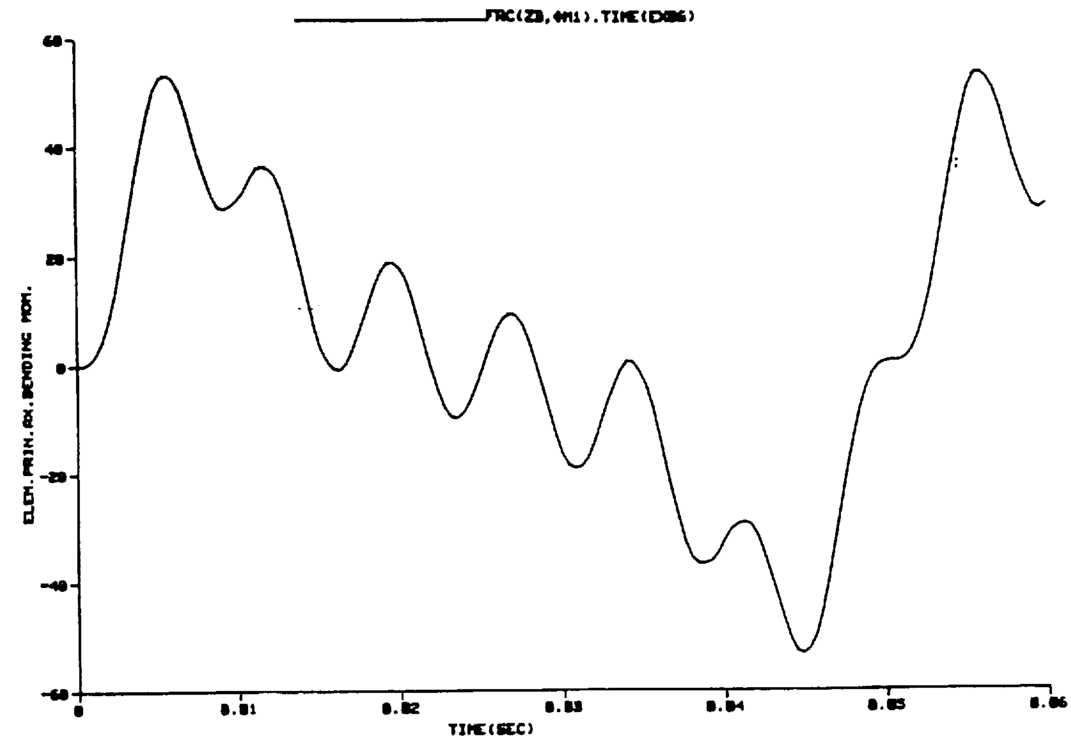

Figure 6.4 Bending Moment at Midspan

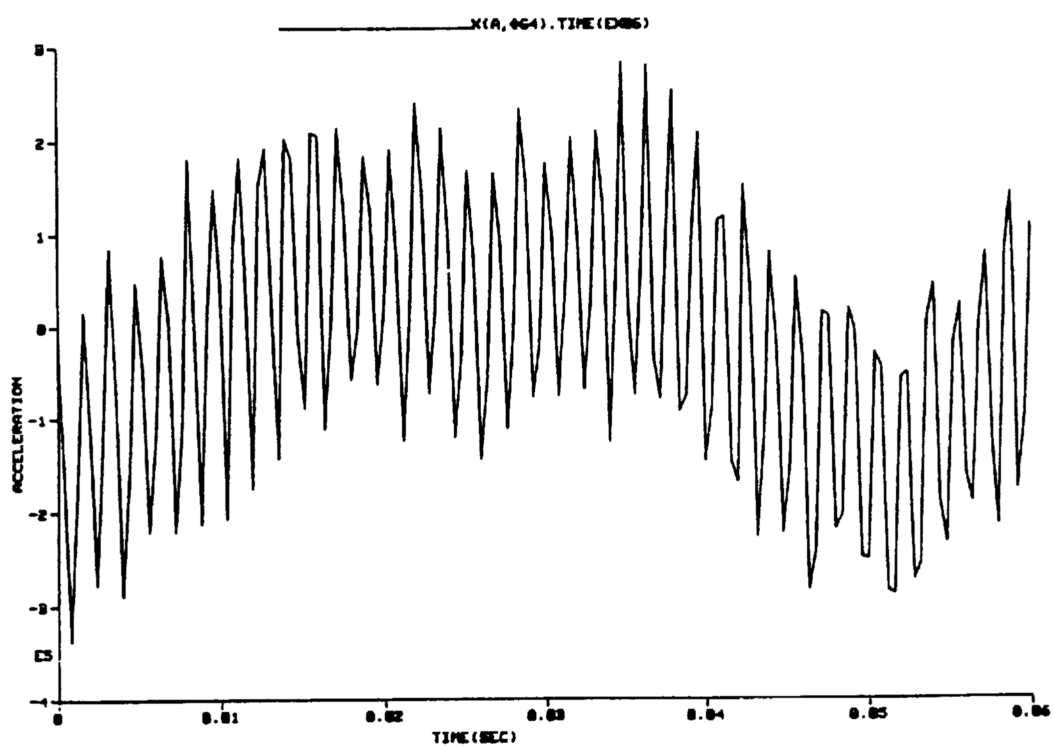

Figure 6.5 Acceleration of the Slider

Reference :

1. Shabana A. and Wehage, R. A., "Variable Degree-of-Freedom Component Mode Analysis of Inertia Variant Flexible Mechanical Systems", ASME Journal, 82-DET-93.

Example 7 Robot Constrained to Follow a Square Trajectory

Description:

The end of a grounded two-arm robot system is constrained to follow a square trajectory as shown in Fig. 7.1. Both arms are modeled as flexible bodies. The system is driven such that the end starts from rest at one corner and moves to and stops at an adjacent corner. Therefore, constraints on the end are different for all sides of the trajectory. The acceleration of the end along one side of the square is

$$Q=\frac{L}{T}[t-\frac{T}{2\pi}\sin\left(\frac{2\pi t}{T}\right)],\ t<T$$

where L is the length of a side and T is time to move along one side.

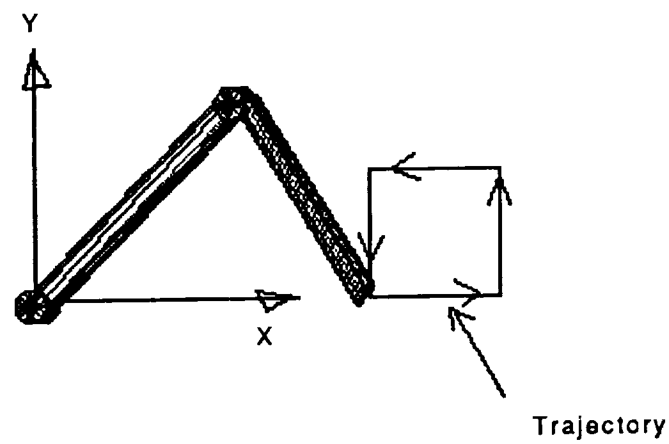

Figure 7.1 A Two-Arm Robot

Modeling:

A robot model is shown in Fig. 7.2. Each robot arm is modeled as one beam element. Two hinges are defined to model the joints of the robot, by using the HINGEPT commands. Four conditions are defined using CL command to impose constraints for moving the end about the square trajectory.

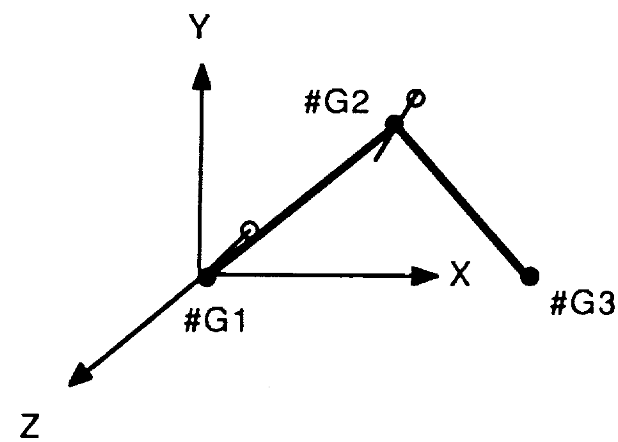

Figure 7.2 LATDYN model of the Robot System

Input Data File:

```
TITLE: A ROBOT ARM CONSTRAINED TO FOLLOW A SQUARE TRAJECTORY
$
$ Define simulation control parameters
$
INTEG:      EXPLICIT(0.5)
TIMESPAN:   0.0     4.0
TIMESTEP: 1.0E-3
PRINT: STEP(100 GLOBAL  100 GLOBAL  0  0  0)
PLOT: STEP(10)
$
$ Define global position of grid points
$
GRIDPT: #G1  0.0   0.0  0.0
GRIDPT: #G2  2.0   2.0  0.0
GRIDPT: #G3  2.818   0.0  0.0
$
$ Define reference points
$
REFPOINT:#R1 0.0     0.0     1.0
REFPOINT:#R2 2.0     2.0     2.0
REFPOINT:#R3 0.0     1.0     0.0
$
$ Define hinges
$
HINGEPT:#G1H1  0.0  POINT(#R1)
HINGEPT:#G2H1  0.0  POINT(#R2)
$
```

```
$ Define beam element and its material properties
$
MATPROP: MAT      70000E5     27300E6    2700
BEAMPROP: BEAM MAT 3.008575657E-4 3.45932434E-8 &
3.45932434E-8  6.918648679E-8
FMEMBER:#M1   SINGLE(#G1H1,#G2) POINT(#R3) BEAM
FMEMBER:#M2   SINGLE(#G2H1,#G3) POINT(#R3) BEAM
$
$ Define constraints to fix grid point 1
$
SDFC: FIX #G1 X 0.0
SDFC: FIY #G1 Y 0.0
SDFC: FIZ #G1 Z 0.0
SDFC: FWX #G1 WX 0.0
SDFC: FWY #G1 WY 0.0
SDFC: FWZ #G1 WZ 0.0
$
$ Define constraints to move the robot system follow the square path
$
SDFC: Q1X #G3 X  Q1   ?C1
SDFC: Q1Y #G3 Y  0.0  ?C1
SDFC: Q2X #G3 X  0.0  ?C2
SDFC: Q2Y #G3 Y  Q2   ?C2
SDFC: Q3X #G3 X  Q3   ?C3
SDFC: Q3Y #G3 Y  0.0  ?C3
SDFC: Q4X #G3 X  0.0  ?C4
SDFC: Q4Y #G3 Y  Q4   ?C4
$
$ Define Q variables and condition lables
$
SET:  Q1=(2.0*PI*1.0/(1.0*1.0))*SIN(2.0*PI*T/1.0)
SET:  Q2=(2.0*PI*1.0/(1.0*1.0))*SIN(2.0*PI*T/1.0)
SET:  Q3=(2.0*PI*(-1.0)/(1.0*1.0))*SIN(2.0*PI*T/1.0)
SET:  Q4=(2.0*PI*(-1.0)/(1.0*1.0))*SIN(2.0*PI*T/1.0)
CL1: T.LT.1.0
CL2: T.GE.1.0  .AND. T.LT.2.0
CL3: T.GE.2.0  .AND. T.LT.3.0
CL4: T.GE.3.0  .AND. T.LT.4.0
```

Results:

Figure 7.3 displays the prescribed trajectory of the end of the robot arm, while figures 7.4 and 7.5 display the angular displacements of hinge 1 and hinge 2 with the time.

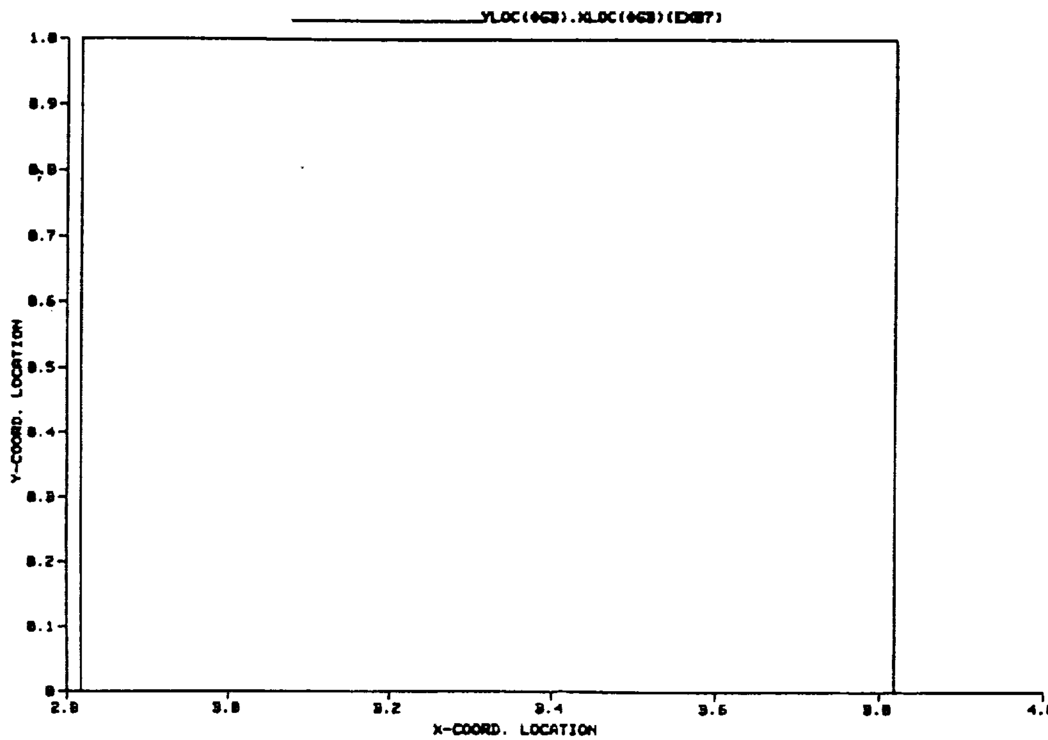

Figure 7.3 Trajectory of End

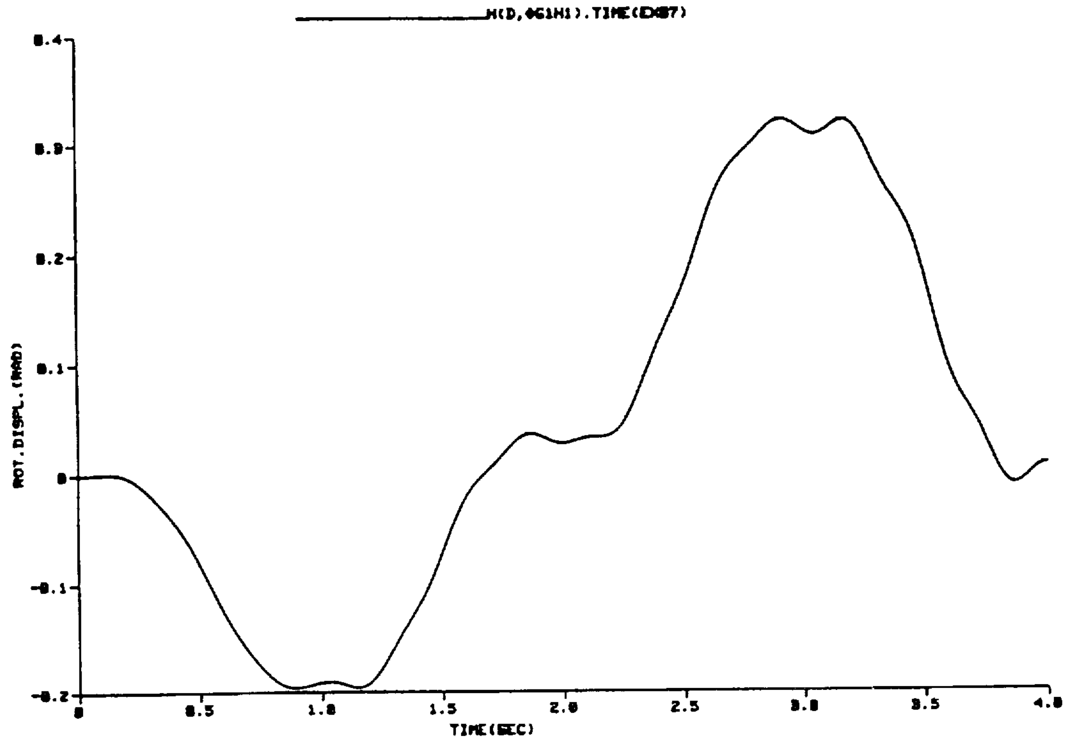

Figure 7.4 Angular Displacement of Hinge 1

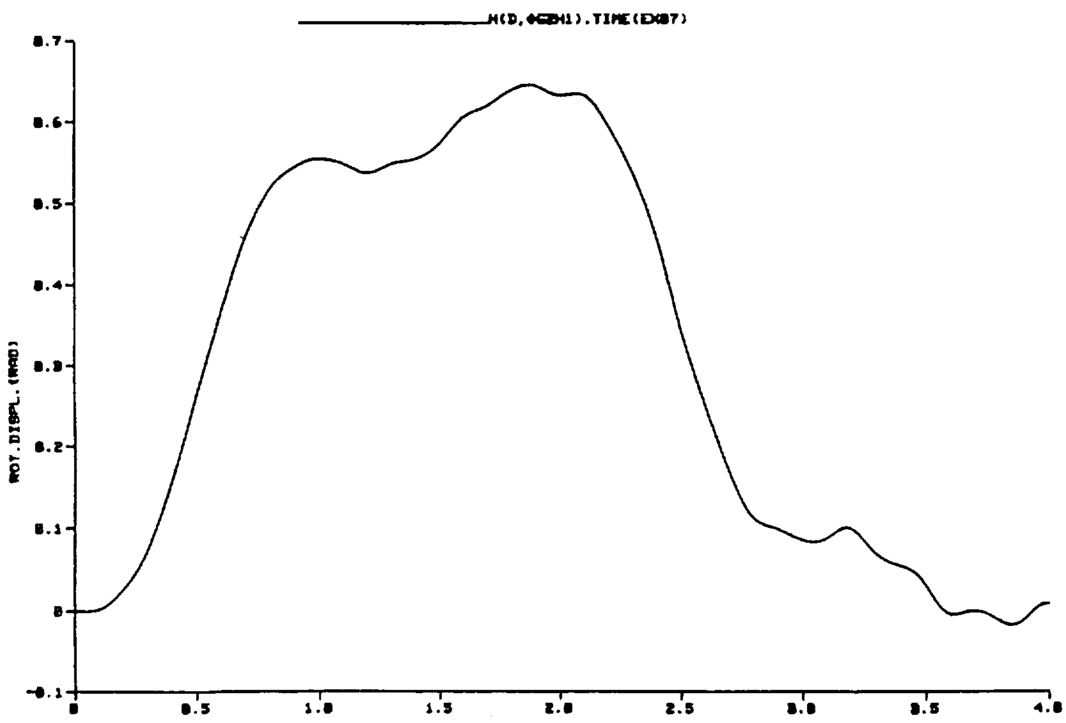

Figure 7.5 Angular Displacement of Hinge 2

Example 8 Slewing Control Analysis of a Flexible Steel Beam

Description:

A flexible steel beam slewing through a 45 degrees while simultaneously suppressing vibration motion is modeled. The slewing motion and vibration suppresion of the system is provided by a torque motor located at the root of the beam. The design of an active controller of such a system has been on reported by Juang, Horta and Robertshaw in Ref. 1. Their design attempts to suppress vibrations by the completion of the maneuvor. The torque , as stated in [1], is a function of the slewing angle, the bending strain in the beam, and the root slewing angular velocity and acceleration. The angular velocity and acceleration is included to model the actuator dynamics. The feedback controller uses bending strain at three positions along the beam (root, 22% and 50% of the beam length), and the root angular position, and angular velocity.

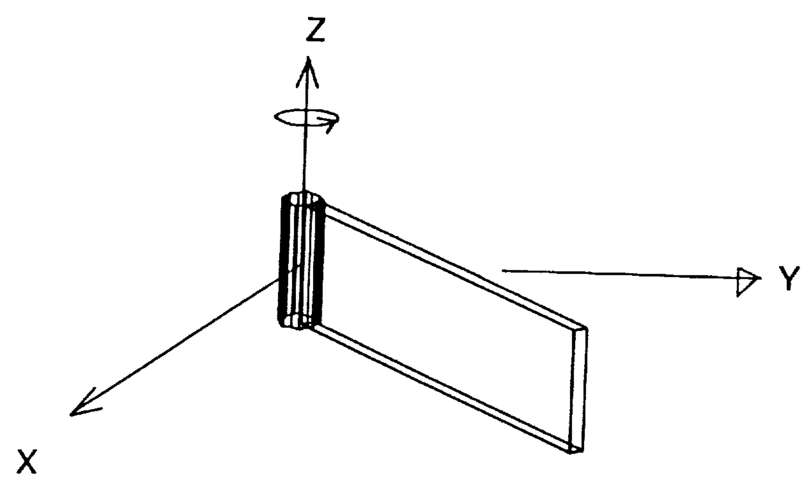

Figure 8.1 A Slewing Steel Beam

Modeling:

A LATDYN model of the slewing beam is shown in Fig. 8.2. Two finite elements are used to model the steel beam. A hinge is defined at the root, grid point 1, using the HINGPT command. Q variables are used to define the control law through the use of SET command. A block diagram of the control law is shown in Fig. 8.3. Variables Q1 to Q4 are defined as the feedback gains for slewing angular position and bending strains at the root, 22% and 50% of the beam length. Variables Q5 and Q6 are defined as scaling factors, while Q7 is defined as half the beam thickness. Variables Q8 to Q10 are defined as bending strains at the three measured locations. The slewing angular position and the three strains are converted to output voltage, which gives variables Q11 to Q14. Variable Q15 is the input signal to the motor, which is the summation of the feedback gains times output voltages. Variables Q16 to Q19 are defined as motor constants. Variable Q20 is defined as the net motor torque applied to the beam. The ROTACTUATOR command apply the torque at the root hinge. The second terms on the right-hand-side of Q20 comes from motor dynamics. As given in Ref. 1 the actuator dynamics has two parts, one which depends on the motor angular velocity and the other which depends on the angular acceleration. The second part is not included in Q20, but is accounted for by modifying the system's mass matrix through the ADMASS command.

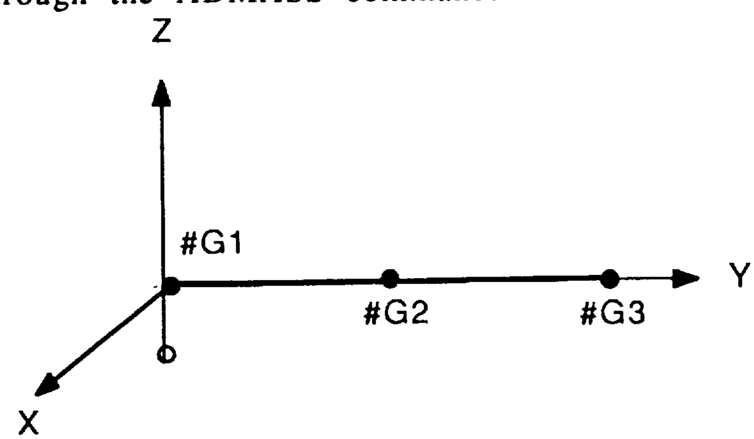

Figure 8.2 LATDYN model of the Slewing Beam

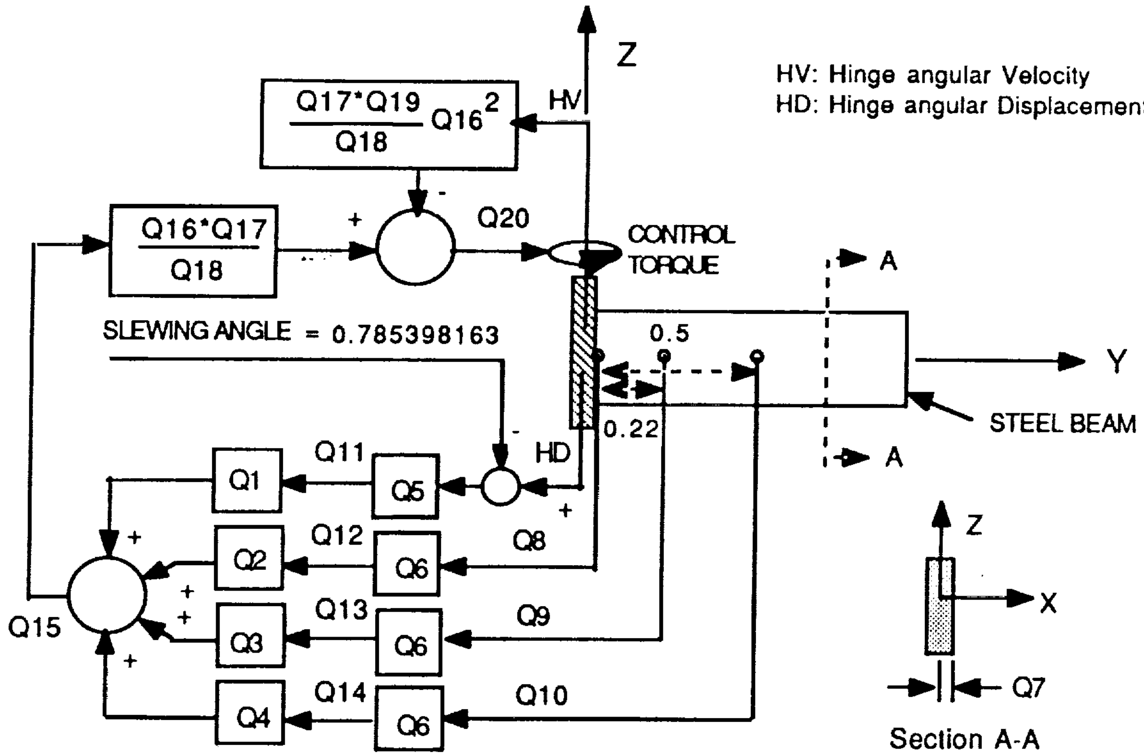

Figure 8.3 Block Diagram of the Control Design

Input Data File:

```
TITLE: SLEWING STEEL BEAM
$
$ Define simulation control parameters
$
INTEG:      EXPLICIT(0.5)
TIMESPAN:     0.0       5.0
TIMESTEP: 5.0E-5
PRINT: STEP(100 GLOBAL  100 GLOBAL  0  0  0)
PLOT: STEP(100)
CHKGYR: ON
$
$ Define global position of grid points
$
GRIDPT: #G1  0.0   0.0   0.0
GRIDPT: #G2  0.5   0.0   0.0
GRIDPT: #G3  1.0   0.0   0.0
$
$ Define reference points
```

```
$
REFPOINT:#R1  0.0      0.0     1.0
REFPOINT:#R2  0.0      1.0     0.0
$
$ Define hinges
$
HINGEPT:#G1H1   0.0   POINT(#R1)
$
$ Define beam element and its material properties
$
MATPROP: MAT      2.191E11 10.0 7886.17
BEAMPROP: BEAM MAT 6.0759E-5  2.9210E-8 3.2405E-12  2.9210E-8
FMEMBER:#M1   SINGLE(#G1H1,#G2) POINT(#R2) BEAM
FMEMBER:#M2   SINGLE(#G2,#G3)  POINT(#R2) BEAM
$
$ Define constraints
$
SDFC: FIX #G1 X 0.0
SDFC: FIY #G1 Y 0.0
SDFC: FIZ #G1 Z 0.0
SDFC: FWX #G1 WX 0.0
SDFC: FWY #G1 WY 0.0
SDFC: FWZ #G1 WZ 0.0
$
$ Define motor moment inertial and add it to left-hand-side of the
$ equation
$
MASSPROP:  MASS1  0.0  0.0 0.0 0.0 0.0 0.0 3.5596 0.0 0.0 0.0
ADDMASS: #G1H1  MASS1  GLOBAL
$
$ Define Q variable to calculate strains and feedback signal
$
SET: Q1= -14.82
SET: Q2= 185.20
SET: Q3= 44.99
SET: Q4= -25.43
SET: Q5= 0.17*27.0
SET: Q6= 2.64*27.0
SET: Q7= 0.04E-2
SET: Q8= Q7*((-4.0+6.0*0.0)*DEF(ZA,1)+(6.0*0.0-2.0)*DEF(ZB,1))/0.5
SET: Q9= Q7*((-4.0+6.0*0.44)*DEF(ZA,1)+(6.0*0.44-2.0)*DEF(ZB,1))/0.5
SET: Q10= Q7*((-4.0+6.0*1.0)*DEF(ZA,1)+(6.0*1.0-2.0)*DEF(ZB,1))/0.5
SET: Q11= Q5*( HINGE(D,#G1H1)-0.785398163 )
```

```
SET: Q12= Q6*Q8
SET: Q13= Q6*Q9
SET: Q14= Q6*Q10
SET: Q15= Q1*Q11+Q2*Q12+Q3*Q13+Q4*Q14
SET: Q16= 941.0
SET: Q17= 0.023
SET: Q18= 3.7
SET: Q19= 0.031
SET: Q20= (Q16*Q17/Q18)*Q15-(Q17*Q19/Q18)*Q16*Q16*HINGE(V,#G1H1)
SET: Q21= (Q16*Q17/Q18)*Q15
ROTACTUATOR: TOR1 UX(#G1H1) Q20
```

Results:

Figure 8.4 shows the strain at the root of the beam, while Fig. 8.5 shows the angular position of the beam root. Results from Ref. 1 are also shown in the figures. The control torque is shown in Fig. 8.6.

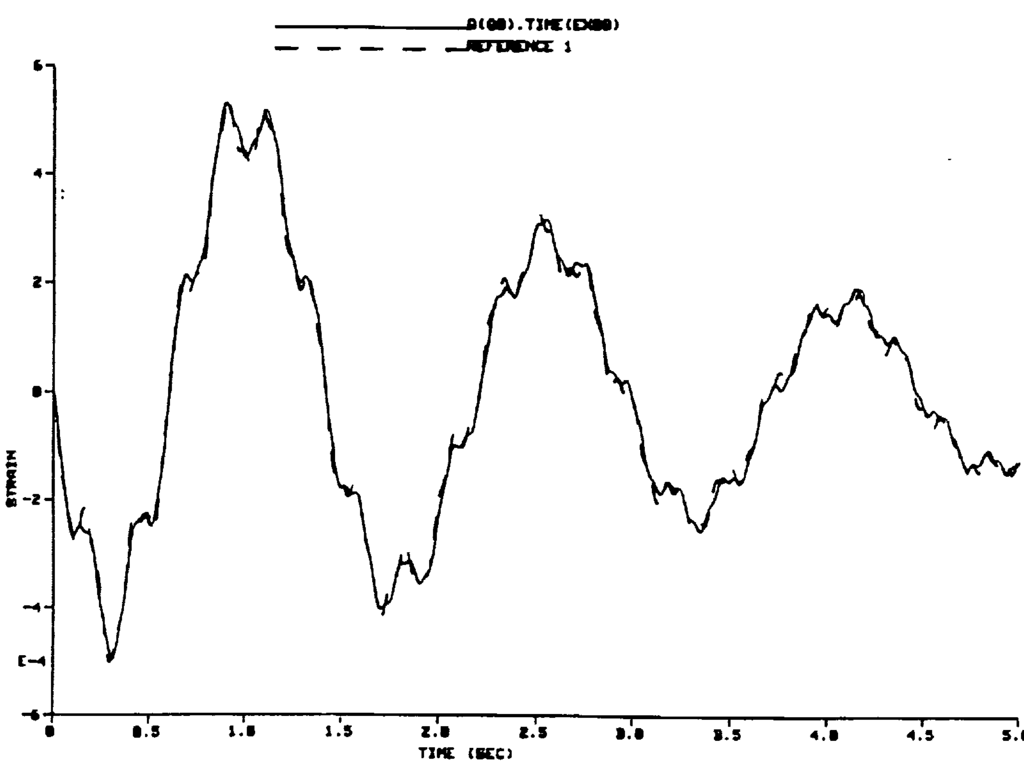

Figure 8.4 Strain At the Root

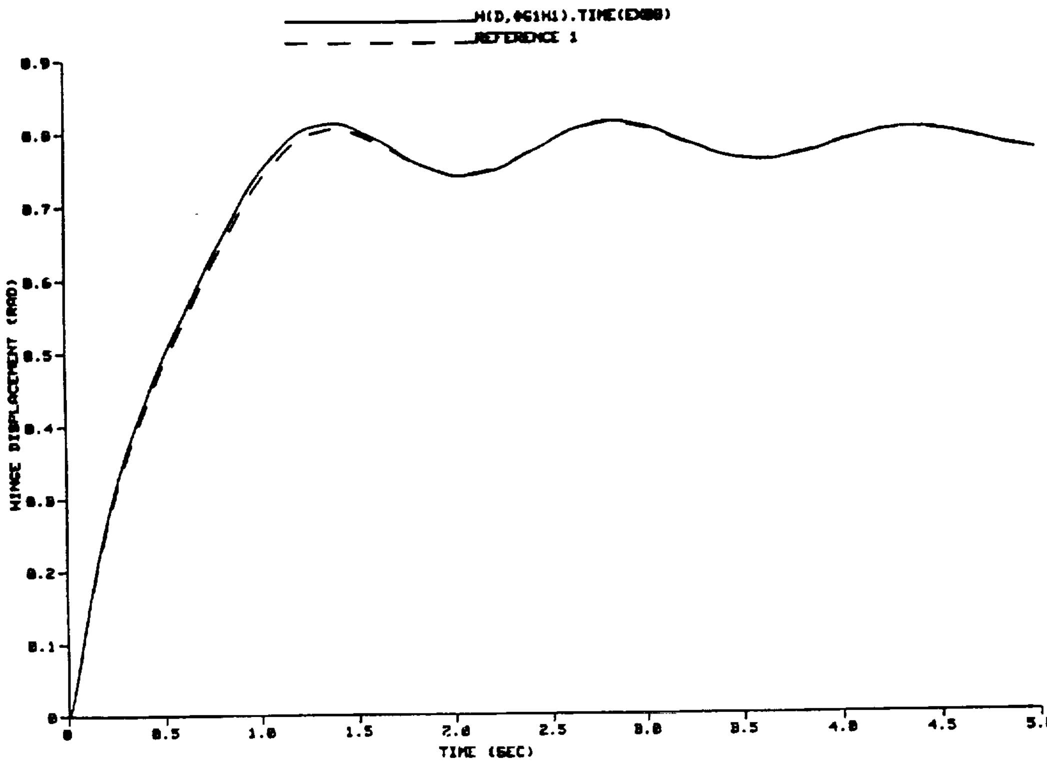

Figure 8.5 Angular Displacement of The Beam

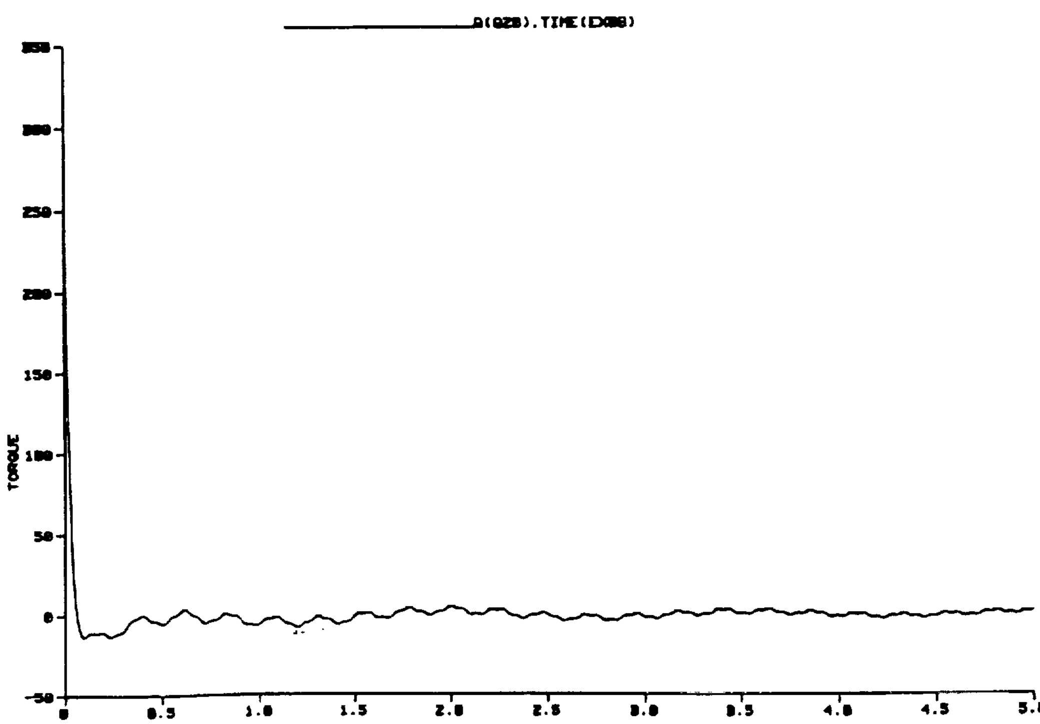

Figure 8.6 Torque Applied to the Beam

Reference:

1. Juang, J. N., Horta, L. G., and Robertshaw, H. H., "A Slewing Control Experiment for Flexible Structures", Vol. 9, Journal of Guidance, Control and Dynamics, 1986, pp. 599-607.

Example 9 Flapping Blade

Description:

A number of problems arise which make it necessary to study the effects of flexibility on blade motion. This example involves the affect of flexible motion on the performance, stresses occur in the deformed blade, and interactions between the rotational speed and the natural frequencies of the flexible blade. A simplified version of an articulated blade is shown in Fig. 9.1. Initially, the blade is straight and tilted 0.157 radians (9 degrees) from the horizontal, and rotates at a constant speed. As the blade rotates, it starts to flap up and down due to centrifugal effects. An additional complicating factor is that due to the stiffening effect of centrifugal force, natural frequencies of the blade vary with the blade rotational speed.

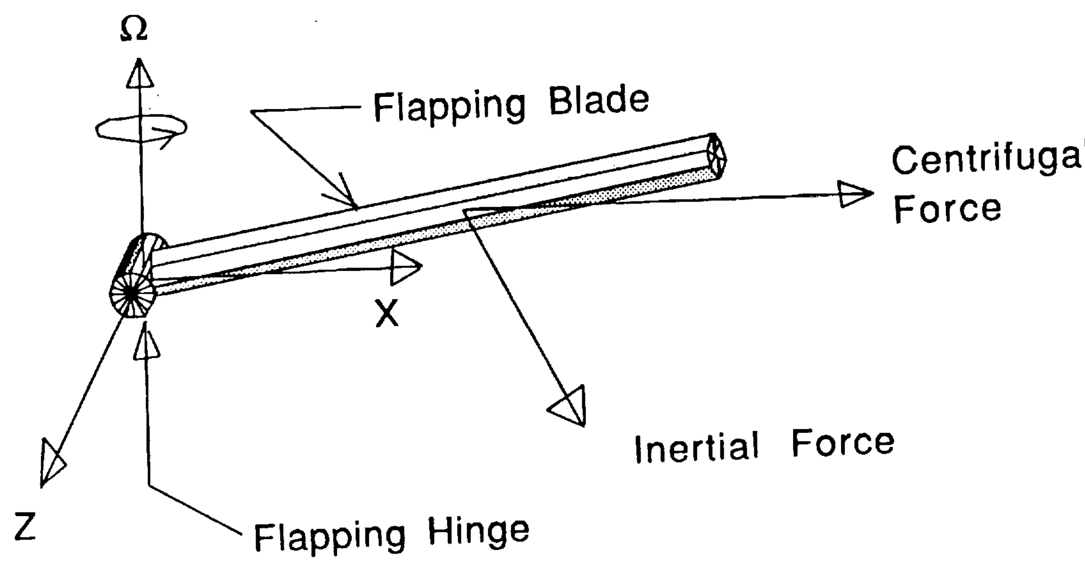

Figure 9.1 A Flapping Beam

Modeling:

A LATDYN model of the flapping blade is shown in Fig. 9.2. Four elements are used to model the blade flexibility. The flapping hinge is defined at grid point 1, by using a HINGEPT command. Initial orientation of the hinge axis is parallel to the global z axis, as defined by the reference point in the HINGEPT command. The constant rotational speed of the blade is imposed by constraining the angular acceleration of grid point 1 using an SDFC command and by giving an initial angular velocity using the VELOCITY command.

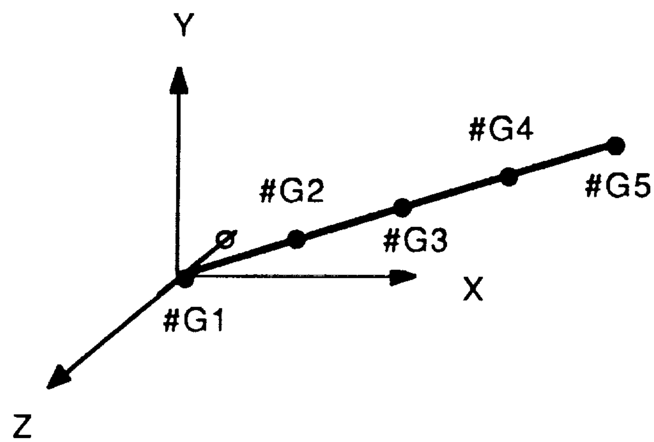

Figure 9.2 LATDYN Model of the Flapping Blade

Input Data File:

```
TITLE: FLAPPING BLADE
$
$ Define simulation control parameters
$
INTEG:      EXPLICIT(0.5)
TIMESPAN:      0.0      5.0
TIMESTEP: 1.0E-4
PRINT: STEP(100 GLOBAL  100 GLOBAL  0  0  0)
PLOT: STEP(100)
CHKGYR: ON
$
$ Define global position of grid points
$
GRIDPT: #G1  0.00000000  0.00000000  0.00000000
GRIDPT: #G2  1.97540159  0.31271162  0.00000000
GRIDPT: #G3  3.95080318  0.62542325  0.00000000
GRIDPT: #G4  5.92620477  0.93813487  0.00000000
```

```
GRIDPT: #G5   7.90160636    1.25084650    0.00000000
$
$ Define reference points
$
REFPOINT:#R1  0.0      0.0      1.0
REFPOINT:#R2  0.0      1.0      0.0
$
$ Define hinge
$
HINGEPT:#G1H1   0.0   POINT(#R1)
$
$ Define beam element and its material properties
$
MATPROP: MAT      6.895E10     2.6519E10     2766.67
BEAMPROP: BEAM MAT 73E-6   8.2181E-9 8.2181E-9 1.6436E-8
FMEMBER:#M1   SINGLE(#G1H1,#G2) POINT(#R2) BEAM
FMEMBER:#M2   SINGLE(#G2,#G3)  POINT(#R2) BEAM
FMEMBER:#M3   SINGLE(#G3,#G4)  POINT(#R2) BEAM
FMEMBER:#M4   SINGLE(#G4,#G5)  POINT(#R2) BEAM
$
$ Define constraints
$
SDFC: FIX #G1 X 0.0
SDFC: FIY #G1 Y 0.0
SDFC: FIZ #G1 Z 0.0
SDFC: FWX #G1 WX 0.0
SDFC: FWY #G1 WY 0.0
SDFC: FWZ #G1 WZ 0.0
$
$ Define initial conditions
$
VELOCITY: #G1  0.0   0.0   0.00000000   0.0   5.0   0.0
VELOCITY: #G2  0.0   0.0  -9.87700795   0.0   5.0   0.0
VELOCITY: #G3  0.0   0.0 -19.75401590   0.0   5.0   0.0
VELOCITY: #G4  0.0   0.0 -29.63102384   0.0   5.0   0.0
VELOCITY: #G5  0.0   0.0 -39.50803179   0.0   5.0   0.0
```

Results:

In the flapping blade simulation, rotational speed of the blade is kept constant in each simulation and gradually increased in succeeding simulations, starting with 1 rad/sec and going up to 9 rad/sec. Frequencies are calculated from the transient response of the simulation using a Fast Fourier Transform(FFT). Figure 9.3 shows the flapping bending moment of the blade at the middle of the blade when it rotates at 5 rad/sec. Figure 9.4 shows the frequency results from an FFT of the same blade for different rotation speeds, compared to the solutions derived by Southwell. Excellent agreement between the LATDYN results and the Southwell solution is shown.

Also shown (straight lines) in Fig. 9.4 are different harmonics of the rotor speed. As shown, the natural frequency of the first mode intersects with the third harmonic around 8 rad/sec, fourth harmonic around 4 rad/sec ,fifth harmonic around 3 rad/sec, and so on for higher harmonics. A resonance may then occur when the blade speed near these harmonics. Figure 9.5 shows that the bending moment of the blade, when it rotates at 8 rad/sec, is increasing with time. The frequency of the blade is about three times the rotational speed. The magnitude of the response in Fig. 9.5 may not increase indefinitely, but may represent a beating phenomenon with the period of the beat depending on the closeness of 8 rad/sec to the intersection point.

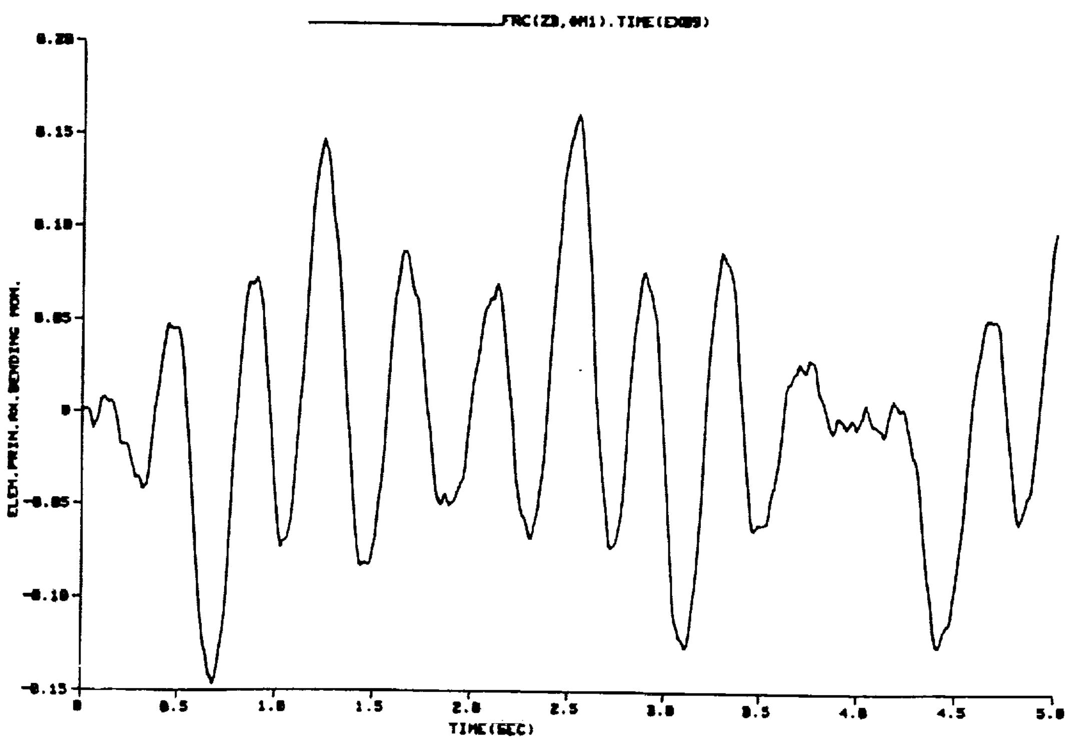

Figure 9.3 Angular Rotation speed = 5.0 rad/sec

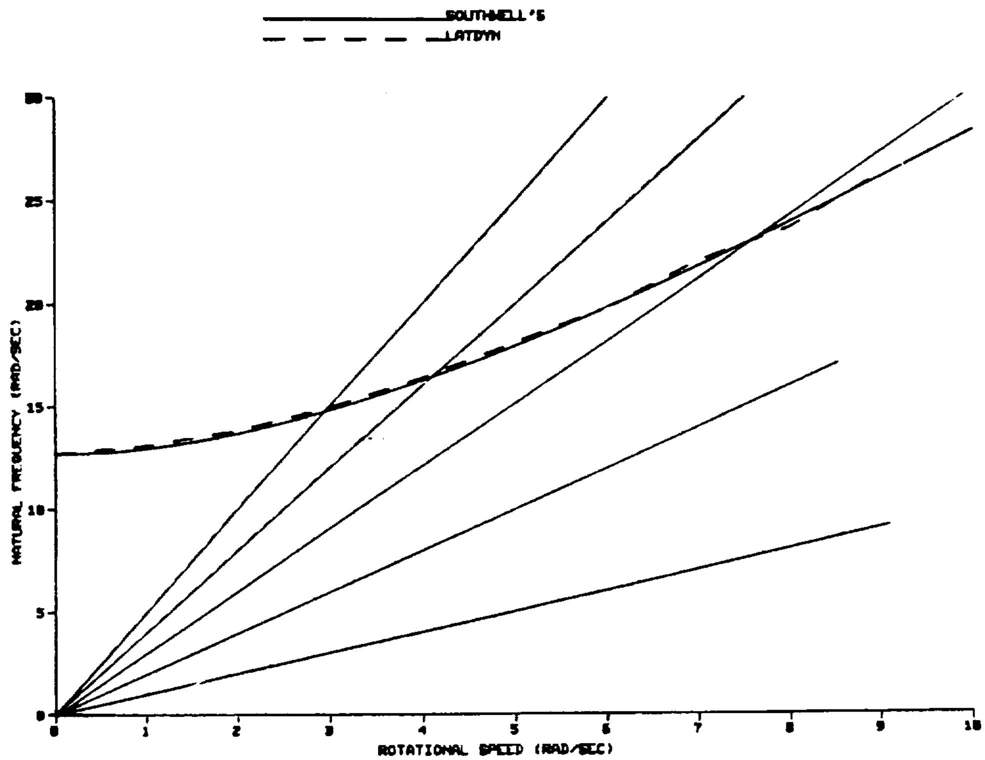

Figure 9.4 Frequency Results

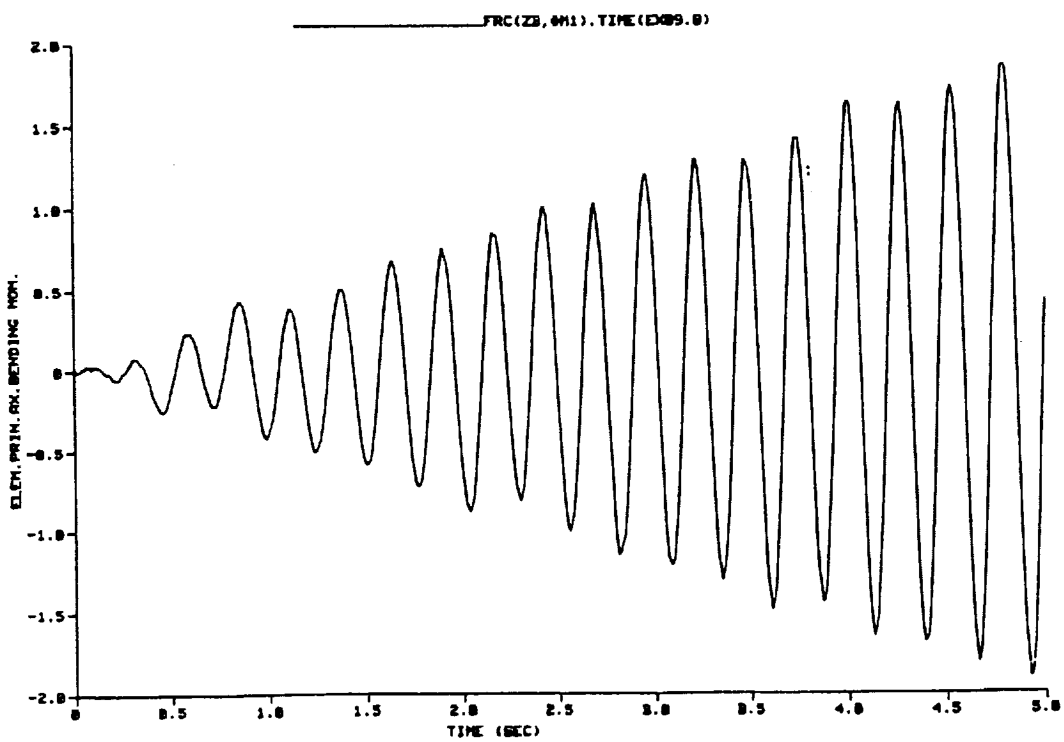

Figure 9.5 Angular Rotation Speed = 8.0 rad/sec

Example 10 Truss Deployment

Description:

One bay of a three longeron truss beam (Longerons A_1B_1, A_2B_2, and A_3B_3 as shown in Fig. 1) with two batten triangles is shown in its packaged state in Fig. 10.1 and in its deployed state in Fig. 10.2.(Lower Batten Triangle $A_1A_2A_3$ and Upper Batten Triangle $B_1B_2B_3$). The triangular cross-section of the bay fits inside a 1.4 m diameter circle. The longerons are connected to batten triangles at each corner (three corner bodies are built into each corner of the batten triangles) by hinges. In the model, longerons are treated as flexible while both batten triangles are assumed rigid. Initially, the system is in its fully packaged position, as shown in Fig. 10.1. The lower triangle is grounded and the upper triangle is constrained to move only in the z direction and rotate about the z axis. The truss is deployed by driving the upper triangle in the longitudial direction without constraining its rotation along the same axis. The driving constraint is

$$\ddot{z}=\frac{L}{T}[t-\frac{T}{2\pi}\sin\left(\frac{2\pi t}{T}\right)],\ t<T$$

where L is length of the longeron, T is total deployment time, and $\ddot{z}$ is the acceleration of the upper triangle in the z direction. Figure 10.2 shows the system in its fully deployed configuration.

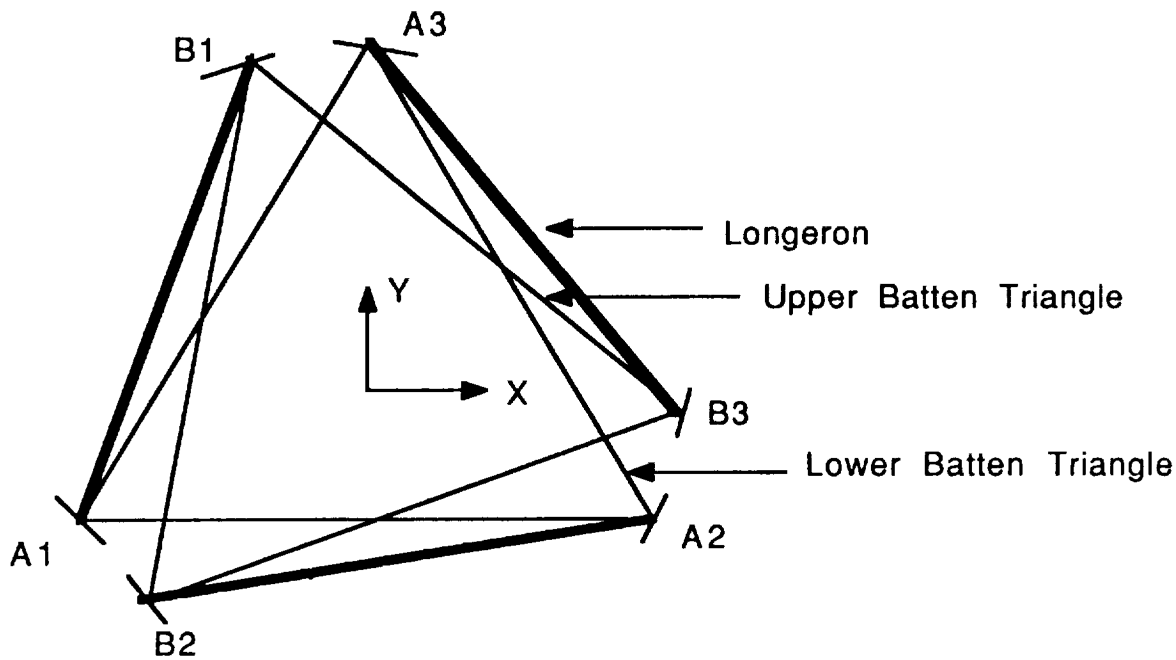

Figure 10.1 Fully Retracted Truss Structure (Top View)

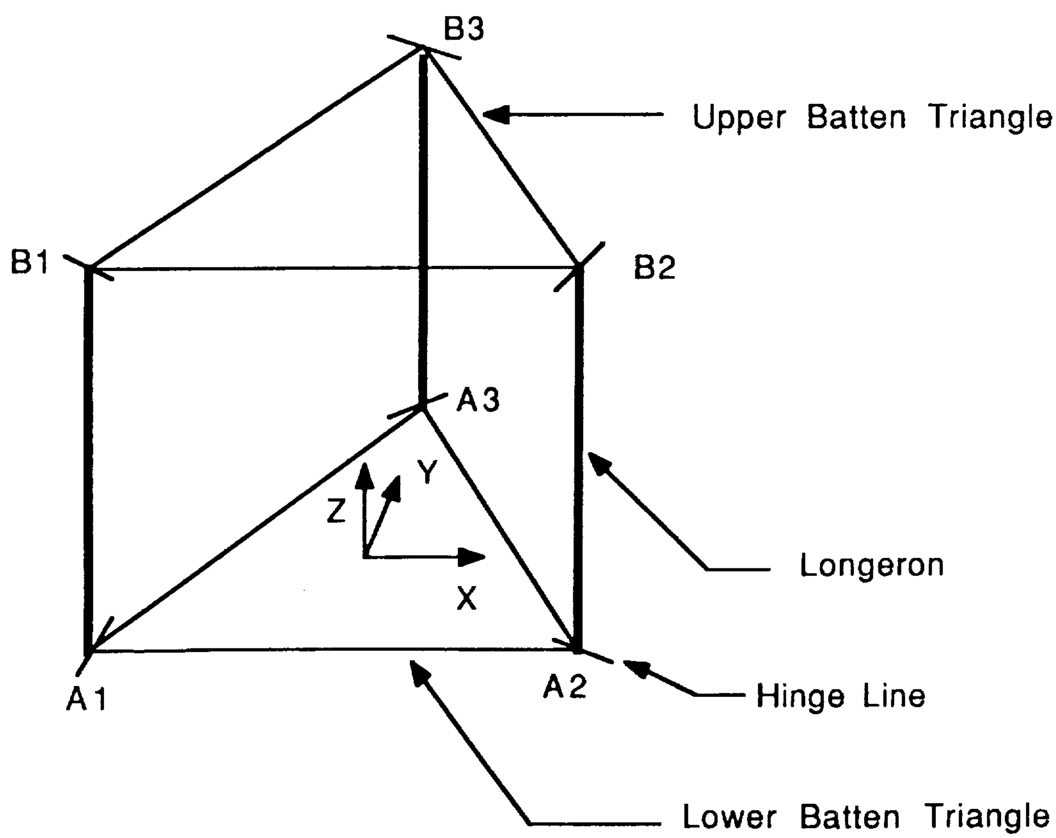

Figure 10.2 Fully Deployed Truss Structure

Modeling:

A model of the packaged truss is shown in Fig. 10.3. By modeling each longeron with one beam element, a total of eight grid points are defined. The batten triangles are modeled as rigid bodies. Grid points 1, 3, 5, and 7 are on the same rigid body- the lower batten triangle, while grid points 2, 4, 6, and 8 are on the same rigid body- the upper batten triangle. For grid point at the corner of batten triangles, a hinge is defined using a HINGEPT command with a reference point used to define the orientation of the hinge axis. Flexible longerons are defined using FMEMBER commands. Six SDFCs are used to ground the lower batten triangle and five SDFCs constrain the upper so that batten triangle can only rotate about the z axis. Translational motion of the batten in the z direction is constrained by a Q variable which is defined as shown above. The mass of the upper batten triangle is lumped at the center of the triangle and added to the system by using ADMASS command.

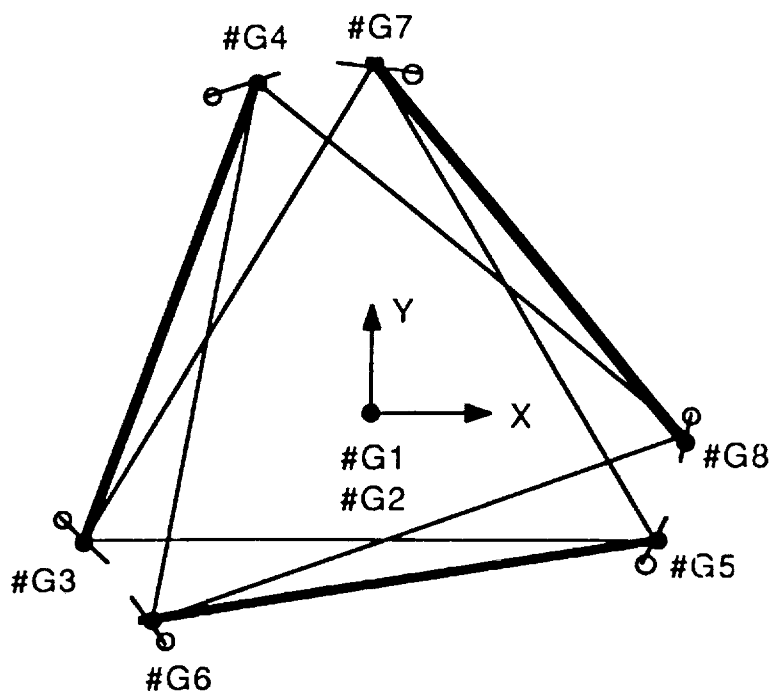

Figure 10.3 LATDYN Model of One Bay of the Truss Structure

Input Data File:

```
TITLE: DEPLOYING OF A TRUSS STRUCTURE
$
$ Define simulation control parameters
$
INTEG:      EXPLICIT(0.5)
TIMESPAN:    0.0       1.0
TIMESTEP: 1.0E-4
PRINT: STEP(100  GLOBAL   100  GLOBAL   0   0  0)
PLOT: STEP(100)
$
$ Define global position of grid points
$
GRIDPT: #G1   0.0        0.0         0.0
GRIDPT: #G2   0.0        0.0         0.0
GRIDPT: #G3   -0.606      -0.34987426  0.0
GRIDPT: #G4   -0.233578   0.65961961  0.0
GRIDPT: #G5   0.606      -0.34987426  0.0
GRIDPT: #G6   -0.454457  -0.532095    0.0
GRIDPT: #G7   0.0        0.699749    0.0
GRIDPT: #G8   0.688037  -0.127522    0.0
$
$ Define reference points
$
REFPOINT:#R1  0.0        0.0         0.0
REFPOINT:#R3  0.311134    -0.2716553    0.390828
REFPOINT:#R4  0.413006     0.00449861  -0.390828
REFPOINT:#R5  0.0796924   0.405278     0.390828
REFPOINT:#R6 -0.210400    0.355424    -0.390828
REFPOINT:#R7  -0.390827   -0.133624     0.390828
REFPOINT:#R8 -0.202605   -0.359924    -0.390828
$
$ Define hinges
$
HINGEPT:#G3H1   0.0   POINT(#R3)
HINGEPT:#G4H1   0.0   POINT(#R4)
HINGEPT:#G5H1   0.0   POINT(#R5)
HINGEPT:#G6H1   0.0   POINT(#R6)
HINGEPT:#G7H1   0.0   POINT(#R7)
HINGEPT:#G8H1   0.0   POINT(#R8)
$
```

```
$ Define beam element and its material properties
$
MATPROP: MAT      1.956E+11  6.830E+9     1.606E+3
BEAMPROP: BEAM     MAT   0.2937E-3    1.232E-8 1.232E-8    2.464E-8
FMEMBER:#M1   SINGLE(#G3H1,#G4H1) POINT(#R1) BEAM
FMEMBER:#M2   SINGLE(#G5H1,#G6H1) POINT(#R1) BEAM
FMEMBER:#M3   SINGLE(#G7H1,#G8H1) POINT(#R1) BEAM
$
$ Define rigid body and its mass properties
$
RBODY:B1  #G1  #G3  #G5  #G7  OFFSET
RBODY:B2  #G2  #G4  #G6  #G8  OFFSET
MASSPROP:  MASS1  0.3029  0.0 0.0 0.0 0.5567E-1 0.1854E-1&
0.7421E-1  0.0  0.0  0.0
ADDMASS: #G2  MASS1  GLOBAL
$
$ Define constraints
$
SDFC: FIX #G1 X 0.0
SDFC: FIY #G1 Y 0.0
SDFC: FIZ #G1 Z 0.0
SDFC: FWX #G1 WX 0.0
SDFC: FWY #G1 WY 0.0
SDFC: FWZ #G1 WZ 0.0
SDFC: IX  #G2 X  0.0
SDFC: IY  #G2 Y  0.0
SDFC: IZ  #G2 Z  Q1
SDFC: WX  #G2 WX 0.0
SDFC: WY  #G2 WY 0.0
$
$ Define Q variable to deploy the system
$
SET:  Q1=(2.0*3.141596*1.076/(1.0*1.0))*SIN(2.0*3.141596*T/1.0)
```

Results:

Figures 10.4-10.5 show bending moments of the longeron in the y and z direction at the lower end connecting with the lower triangle, with the z displacement of the upper triangle. Figure 10.6 show the twisting moment of the longeron.

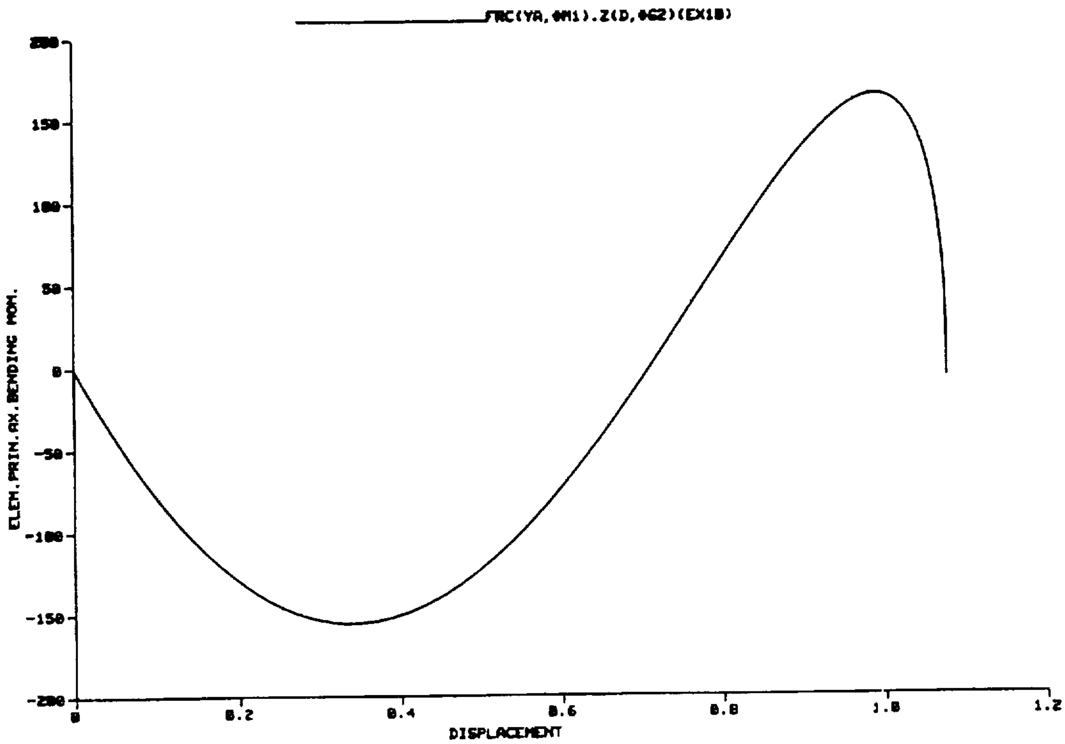

Figure 10.4 Longeron Bending Moment in the y Direction

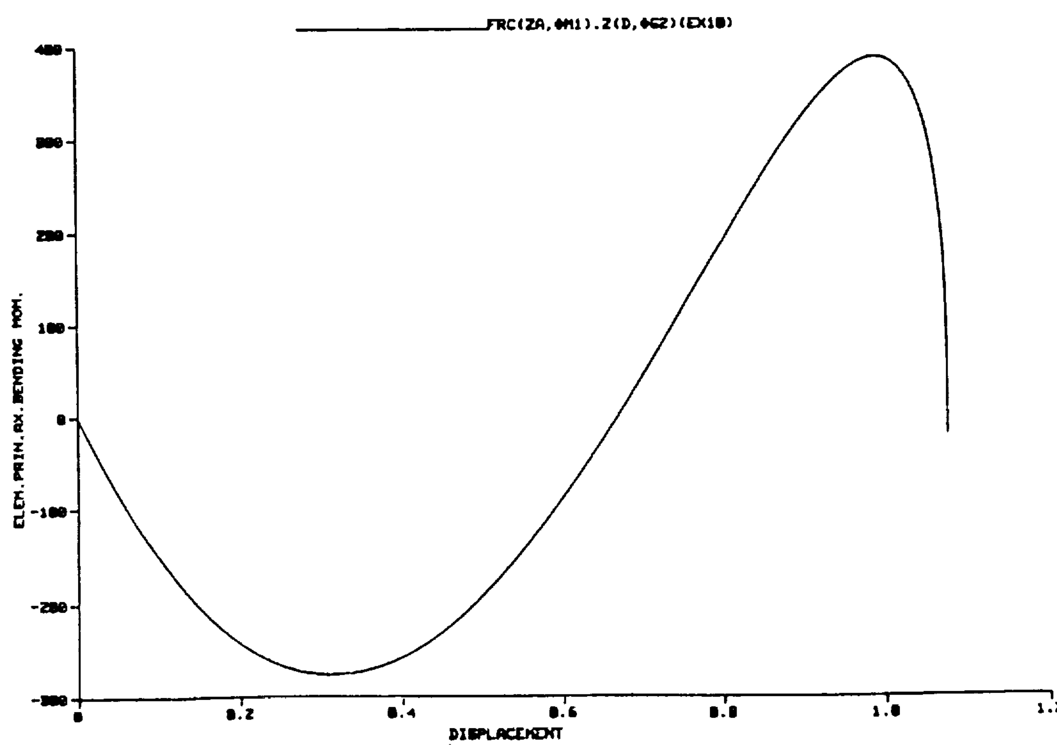

Figure 10.5 Longeron Bending Moment in the z Direction

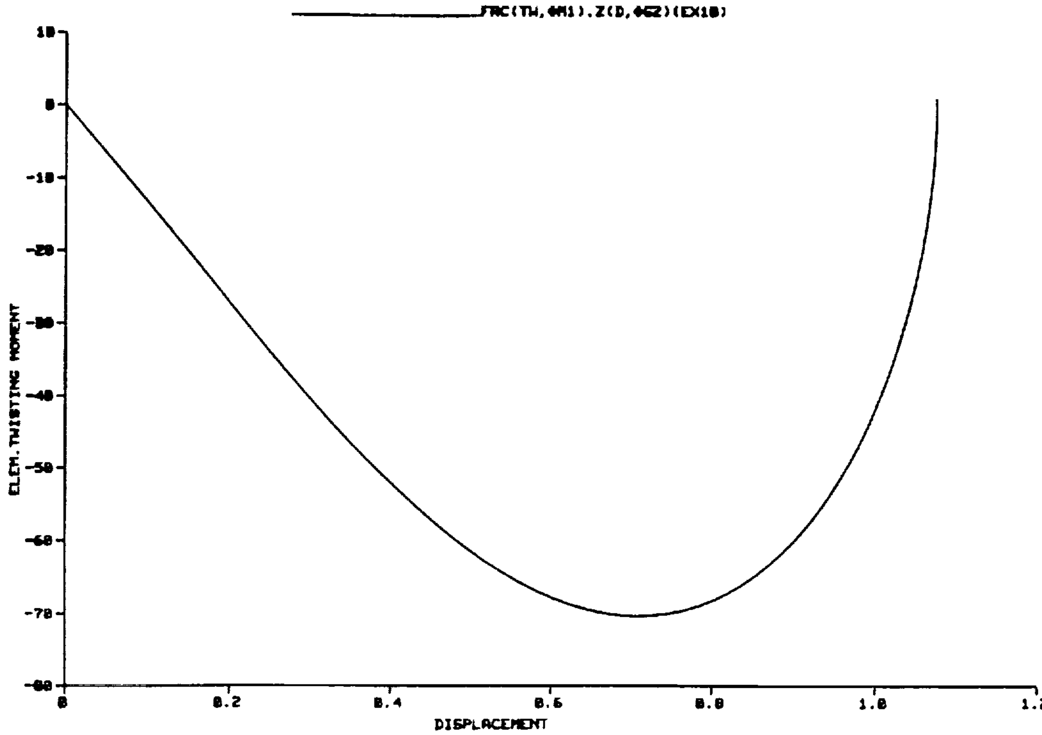

Figure 10.6 Twisting Moment of the Longeron

Report Documentation Page

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16. Abstract

"LATDYN" is a computer code for modeling the Large Angle Transient DYNamics of structures. The objective in developing the code was to investigate new techniques for analysing flexible deformation and control/structure interaction problems associated with large angular motions of spacecraft. Such motions may consist of pointing the entire spacecraft or articulation of individual components, events which occur frequently during construction, operation, and maintaince of large spacecraft.

This type of analysis is beyond the routine capability of conventional analytical tools without simplifying assumptions. In some instances the motion may be sufficiently slow and the spacecraft (or component) sufficiently rigid to simplify analyses of dynamics and controls by making psuedo-static and/or rigid body assumptions.

LATDYN introduces a new approach to the problem by combining finite element structural analysis, multi-body dynamics, and control system analysis,.in a single tool. It includes a new type of finite element that can deform and rotate through large angles at the same time, and which can be connected to other finite elements either rigidly or through mechanical joints. LATDYN also provides symbolic capabilities for modeling control systems which are interfaced directly with the finite element structural model.Thus, the non-linear equations representing the structural model are integrated along with the equations representing sensors, processing and controls as a coupled system.

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