Transmissibility of a set of blades

Previous work (T040024) looked at various aspects of blade transmissibility by FEA. Two conclusions from discussion of that work were that the way of implementing damping seemed sensible and the that it would be worth proceeding to analyse a set of blades and combine their transmissibilities to see how that looked. I took as a starting point a set of blade dimensions and masses from the conceptual design. For the time being I ignored the fact that the wires are not vertical and I left all three stages the same length and with the same wire diameter.

I looked at the transmissibility of each blade/mass combination (top, upper intermediate, penultimate) and multiplied the three together. I used ANSYS for all the work, and worked largely using macros so that the results can be reproduced.

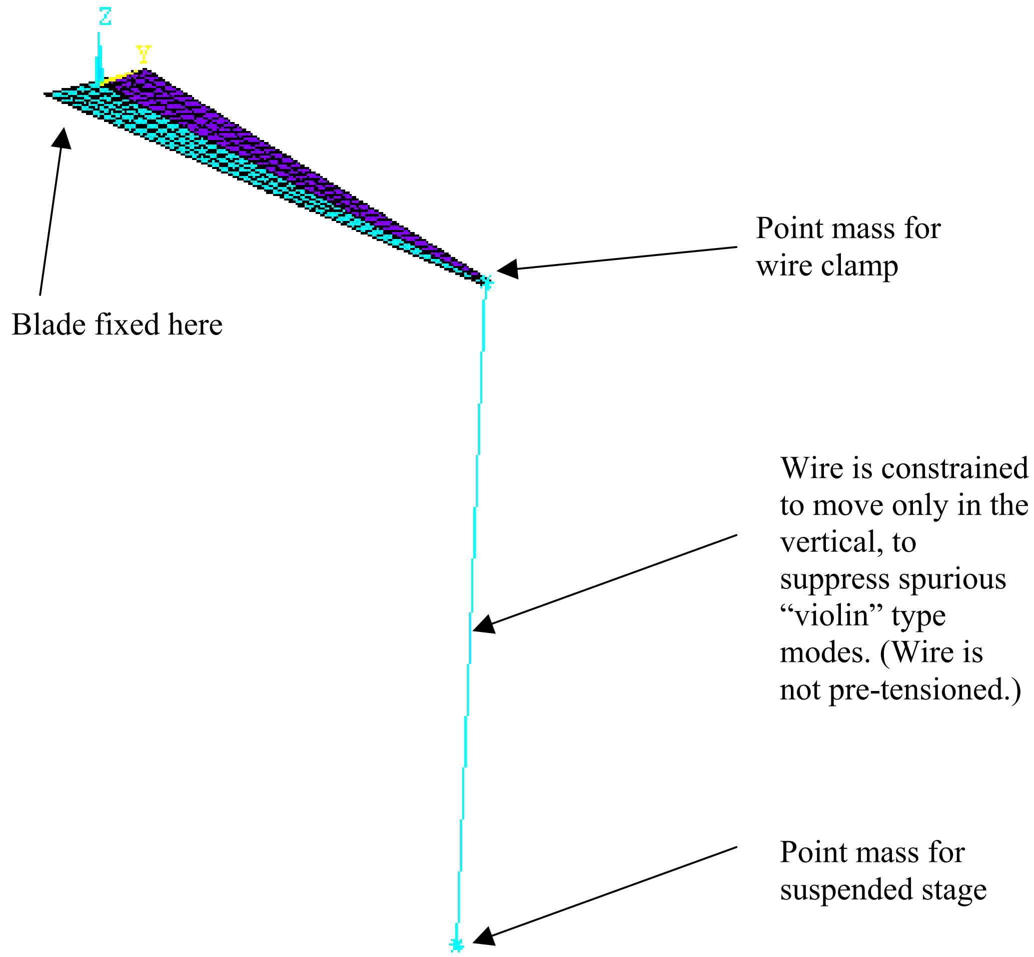
I. Normal modes

To speed the work I wrote a macro that allows the natural frequencies to be calculated. It is called bf1.mac, based on work in T040024 and it takes arguments that define the blade, mass and frequency range of interest. It is reproduced in the appendix.

Extract from bf1.mac:
```
! to use, call
! macroname blength,bthick,rootwidth,tipwidth,nmodes,fstart,fend,tipmass,testmass
!          arg1    2      3         4        5      6      7    8       9
```

The first four arguments define the blade dimensions, the next three the frequency range, and the last two the mass of the wire clamp and the mass of the suspended stage.

Here is a picture of a typical model generated:



For the time being I left the wire diameter and length fixed.

A simple macro called this three times for the three blades I chose to analyse (dimensions taken for a recent conceptual design document, suspended masses approximate).

Bfmany.mac:

```
! to use the bf1 macro to do nat freq of several blades
!
bf1,.48,.0045,.096,.01,20,1,1000,.050,11
bf1,.42,.0049,.058,.01,20,1,1000,.050,11
bf1,.34,.0045,.05,.01,20,1,1000,.050,20
```

The results were

```
 ****  VALUES OF ARGx  *****

  NAME          VALUE                      TYPE

  ARG1     0.480000000                     SCALAR
  ARG2     4.500000000E-03                 SCALAR
  ARG3     9.600000000E-02                 SCALAR
  ARG4     1.000000000E-02                 SCALAR
  ARG5      20.0000000                     SCALAR
  ARG6      1.00000000                     SCALAR
  ARG7      1000.00000                     SCALAR
  ARG8     5.000000000E-02                 SCALAR
  ARG9      11.0000000                     SCALAR


  *****  INDEX OF DATA SETS ON RESULTS FILE  *****
```

```
  SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
    1  2.3937           1          1         1
    2  70.906           1          2         1
    3  213.51           1          3         1
    4  407.38           1          4         1
    5  422.48           1          5         1
    6  538.30           1          6         1
    7  760.67           1          7         1
    8  802.33           1          8         1
    9  984.38           1          9         1

****  VALUES OF ARGx  *****

 NAME          VALUE                       TYPE

 ARG1    0.420000000                       SCALAR
 ARG2    4.900000000E-03                   SCALAR
 ARG3    5.800000000E-02                   SCALAR
 ARG4    1.000000000E-02                   SCALAR
 ARG5     20.0000000                       SCALAR
 ARG6     1.00000000                       SCALAR
 ARG7     1000.00000                       SCALAR
 ARG8    5.000000000E-02                   SCALAR
 ARG9     11.0000000                       SCALAR


 *****  INDEX OF DATA SETS ON RESULTS FILE  *****

  SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
    1  2.6334           1          1         1
    2  99.681           1          2         1
    3  295.52           1          3         1
    4  478.32           1          4         1
    5  667.53           1          5         1
    6  686.72           1          6         1
    7  767.71           1          7         1

****  VALUES OF ARGx  *****

 NAME          VALUE                       TYPE

 ARG1    0.340000000                       SCALAR
 ARG2    4.500000000E-03                   SCALAR
 ARG3    5.000000000E-02                   SCALAR
 ARG4    1.000000000E-02                   SCALAR
 ARG5     20.0000000                       SCALAR
 ARG6     1.00000000                       SCALAR
 ARG7     1000.00000                       SCALAR
 ARG8    5.000000000E-02                   SCALAR
 ARG9     20.0000000                       SCALAR


 *****  INDEX OF DATA SETS ON RESULTS FILE  *****

  SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
    1  2.2121           1          1         1
    2  138.48           1          2         1
    3  390.23           1          3         1
    4  540.91           1          4         1
    5  900.79           1          5         1
    6  931.16           1          6         1
    7  977.18           1          7         1
```

II. Transmissibility

Bt1.mac calculated transmissibility. It is based on work in the previous note T040024 but takes arguments to define a blade and the frequency range of interest.

Extract from Bt1.mac

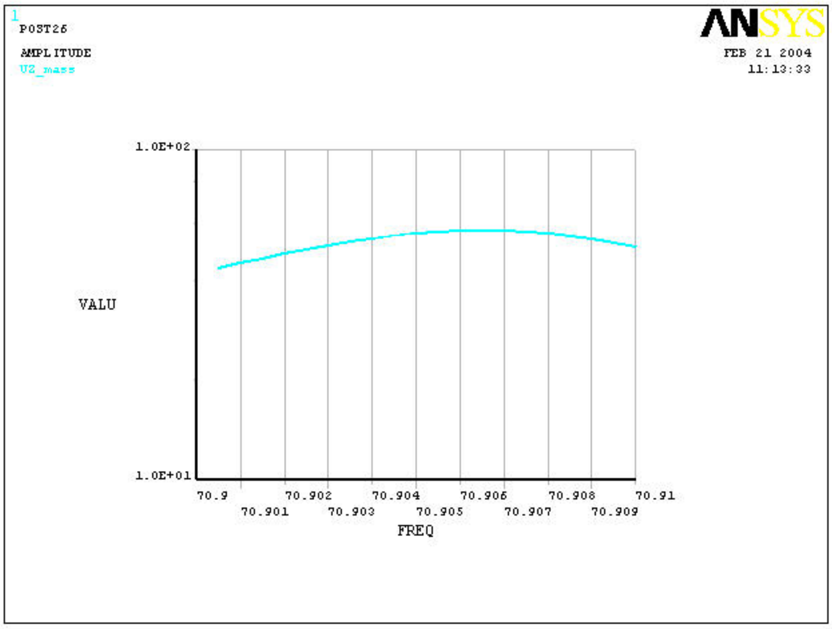
```
! to use, call
! macroname blength,bthick,rootwidth,tipwidth,nsteps,fstart,fend,tipmass,testmass,dmprat
!           arg1    2      3         4        5      6      7    8       9        10
```

!

Knowing the natural frequencies of the three blade systems, I used bt1 repeatedly to determine what frequency range to use to capture the resonant peak for each one.

For example:
bt1,.48,.0045,.096,.01, 20,70.9,70.91,.050,11,1e-4

yields this for the motion at the suspended mass



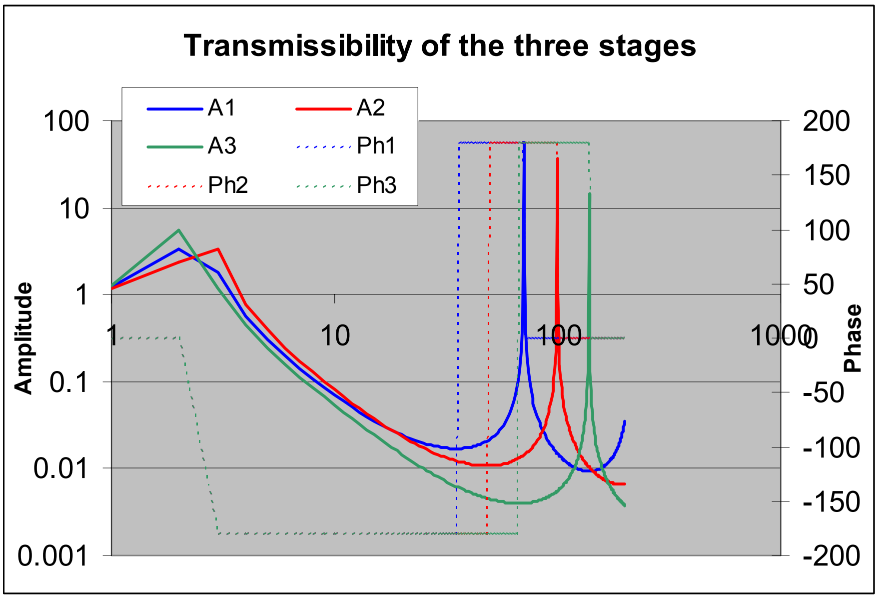
In a similar manner I found the frequency ranges to capture the peaks of the other two blades. Then I wrote a couple more macros to automate the process of getting results in all frequency ranges for all three blades:

Btmany.mac
```
! to use the bt1 macro to do tranmissibility of several blades
! for a given frequency
!
bt1,.48,.0045,.096,.01,arg1,arg2,arg3,.050,11,1e-4
bt1,.42,.0049,.058,.01,arg1,arg2,arg3,.050,11,1e-4
bt1,.34,.0045,.05,.01,arg1,arg2,arg3,.050,20,1e-4
```

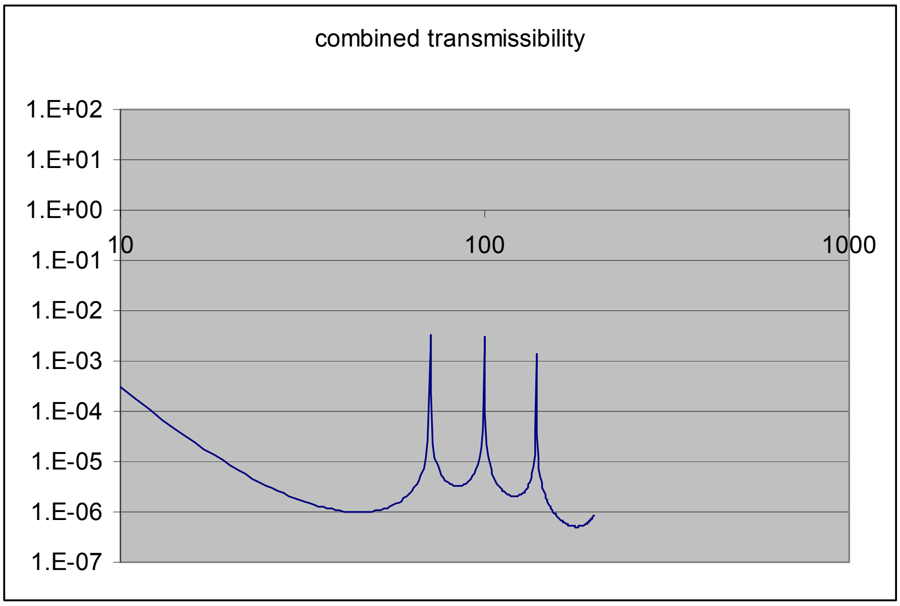
btlots.mac
```
! to use the bt1 macro to do transmissibility of several blades
!
btmany,200,0,200
btmany,20,70.9,70.91
btmany,20,99.67,99.7
btmany,20,138.47,138.49
```

The three figures on the next page show
- The transmissibility of all three blades (amplitude and phase). This is the motion of the test mass at the end of the wire. Note that the fundamental frequency around 2 Hz is not resolved by the 1Hz frequency step.
- The product of the three amplitudes

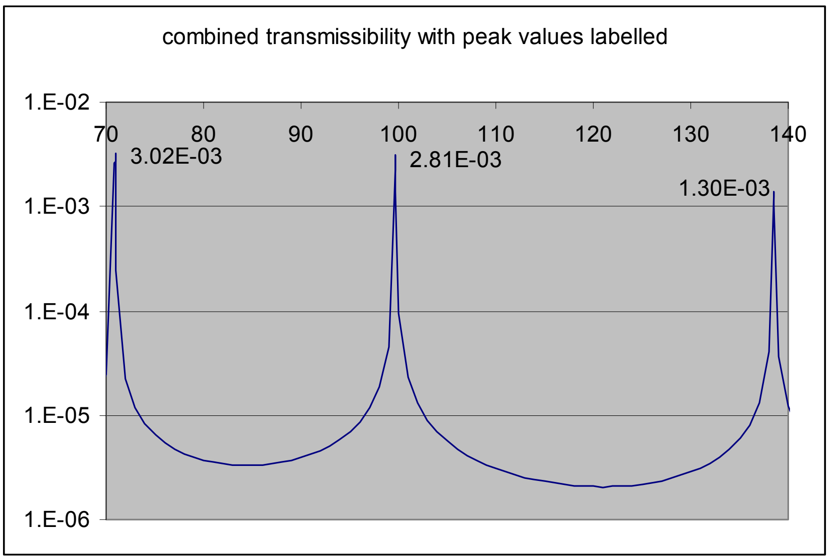
- A close-up of the region where the peaks are. The peaks ARE resolved because the of the addition of the narrow frequency ranges around each peak as explained above.



Transmissibility of the three stages
A1
A2
A3
Ph1
Ph2
Ph3
Amplitude
Phase
100
10
1
0.1
0.01
0.001
1
10
100
1000
200
150
100
50
0
-50
-100
-150
-200



combined transmissibility
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
10
100
1000



combined transmissibility with peak values labelled
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
70
80
90
100
110
120
130
140
3.02E-03
2.81E-03
1.30E-03

APPENDIX – macros.

Bf1.mac

```
! macro to analyse blade natural frequencies
for a given set of dimensions
!
! to use, call
! macroname
blength,bthick,rootwidth,tipwidth,nmodes,fsta
rt,fend,tipmass,testmass
!            arg1    2      3         4
5      6      7    8       9
!
!justin greenhalgh RAL February 2004
!
finish
/CLEAR,START
*abbr,doit,doit
/input,start71,ans,'C:\Program Files\Ansys
Inc\v71\ANSYS\apdl\',,,,,,,,,,,,,,,,1
/PREP7
!*
! values of parameters
!analysis type at is 0 for modal and 1 for
harmonic
at=0
blength=ARG1
bthick=ARG2
rootwidth=ARG3
tipwidth=ARG4
hroot=rootwidth/2
htip=tipwidth/2
maryoung=1.76e11
marpoiss=0.3
mardens=7800
wireyoung=2e11
wirepoiss=0,3
wiredens=7800
!dampratio=1e-4
tipmass=ARG8
wiredia=7e-4*2
wirelen=0.54
testmass=ARG9

!*
ET,1,SHELL93  !for the blade
ET,2,MASS21   !for the clamp and the test
mass
ET,3,LINK8    !for the wire
!*
!*

!*
R,1,bthick, , , , , , !for the blade
R,2,tipmass,tipmass,tipmass,0,0,0 !for the
clamp
R,3,testmass,testmass,testmass,0,0,0 !for the
test mass
R,4,3.14*wiredia*wiredia/4, ,  !for the wire

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,maryoung
MPDATA,PRXY,1,,marpoiss
MPDATA,DENS,1,,mardens

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,wireyoung
MPDATA,PRXY,2,,wirepoiss
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,DENS,2,,wiredens

K, ,0,0,0,
K, ,0,hroot,0,
K, ,0,-hroot,0,
K, ,blength,0,0,
K, ,blength,htip,0,
K, ,blength,-htip,0,
K, ,blength,0,-wirelen

LSTR,       3,       6
LSTR,       6,       4
LSTR,       4,       1
LSTR,       1,       3
LSTR,       4,       5
LSTR,       5,       2
LSTR,       2,       1

AL,4,1,2,3

AL,3,5,6,7
aplot
ESIZE,hroot/4,0
amesh,1,2

!clamp
TYPE,   2
MAT,       1
REAL,       2
kmesh,4

! add wire
lstr,4,7  !line 8

type,3
mat,2
real,4
lmesh,8

!add testmass
type,2
mat,1
real,3
kmesh,7

!constrain the wire
DL,8, ,UX,0
DL,8, ,UY,0

! encaster
DL,4,,all,0
DL,7,,all,0
!next two lines for harmonic analsysis
*if,at,eq,1,then
DL,4,,uz,1  !root displacement
DL,7,,uz,1
*endif
!-------------------------------------------
------------------
*if,at,eq,0,then
! modal analysis
FINISH
/SOL

ANTYPE,2
MSAVE,0
!*
MODOPT,LANB,arg5
EQSLV,SPAR
MXPAND,0, , ,0
LUMPM,0
PSTRES,0

!*
MODOPT,LANB,arg5,arg6,arg7, ,OFF
/STATUS,SOLU
SOLVE
FINISH
/POST1
/output,bf1,out,,append
*Status,argx
SET,LIST
/output
*get,freq1,mode,1,freq
*get,freq2,mode,2,freq
*get,freq3,mode,3,freq
! end modal analysis
!*
!-------------------------------------------
----------------------
*else
! harmonic analysis
FINISH
/SOL
!*
ANTYPE,3
!*
HROPT,FULL
HROUT,ON
LUMPM,0
```

```
DMPRAT,dampratio,
!*
EQSLV,FRONT,0,
PSTRES,0
!*
HARFRQ,0,100
NSUBST,100,
KBC,1
!*
/STATUS,SOLU
SOLVE
/POST26
FILE,'file','rst','.'
NUMVAR,200
SOLU,191,NCMIT
STORE,MERGE
PLCPLX,0
PRCPLX,1
FILLDATA,191,,,,1,1
REALVAR,191,191
!*
NSOL,2,92,U,Z, UZ_tip
nsol,3,421,u,z,uz-mid
STORE,MERGE
/GROPT,LOGX,On
/GROPT,LOGY,ON
XVAR,1
PLVAR,2,3
*endif
```

Bt1.mac

```
! macro to analyse blade natural frequencies
for a given set of dimensions
!
! to use, call
! macroname
blength,bthick,rootwidth,tipwidth,nmodes,fsta
rt,fend,tipmass,testmass
!           arg1    2      3         4
5      6      7    8       9
!
!justin greenhalgh RAL February 2004
!
finish
/CLEAR,START
*abbr,doit,doit
/input,start71,ans,'C:\Program Files\Ansys
Inc\v71\ANSYS\apdl\',,,,,,,,,,,,,,,,1
/PREP7
!*
! values of parameters
!analysis type at is 0 for modal and 1 for
harmonic
at=0
blength=ARG1
bthick=ARG2
rootwidth=ARG3
tipwidth=ARG4
hroot=rootwidth/2
htip=tipwidth/2
maryoung=1.76e11
marpoiss=0.3
mardens=7800
wireyoung=2e11
wirepoiss=0,3
wiredens=7800
!dampratio=1e-4
tipmass=ARG8
wiredia=7e-4*2
wirelen=0.54
testmass=ARG9

!*
ET,1,SHELL93  !for the blade
ET,2,MASS21   !for the clamp and the test
mass
ET,3,LINK8    !for the wire
!*
!*

!*
R,1,bthick, , , , , , !for the blade
R,2,tipmass,tipmass,tipmass,0,0,0 !for the
clamp
R,3,testmass,testmass,testmass,0,0,0 !for the
test mass
R,4,3.14*wiredia*wiredia/4, ,  !for the wire

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,maryoung
MPDATA,PRXY,1,,marpoiss
MPDATA,DENS,1,,mardens

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,wireyoung
MPDATA,PRXY,2,,wirepoiss
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,DENS,2,,wiredens

K, ,0,0,0,
K, ,0,hroot,0,
K, ,0,-hroot,0,
K, ,blength,0,0,
K, ,blength,htip,0,
K, ,blength,-htip,0,
K, ,blength,0,-wirelen

LSTR,       3,       6
LSTR,       6,       4
LSTR,       4,       1
LSTR,       1,       3
LSTR,       4,       5
LSTR,       5,       2
LSTR,       2,       1

AL,4,1,2,3

AL,3,5,6,7
aplot
ESIZE,hroot/4,0
amesh,1,2

!clamp
TYPE,   2
MAT,       1
REAL,       2
kmesh,4

! add wire
lstr,4,7  !line 8

type,3
mat,2
real,4
lmesh,8

!add testmass
type,2
mat,1
real,3
kmesh,7

!constrain the wire
DL,8, ,UX,0
DL,8, ,UY,0

! encaster
DL,4,,all,0
DL,7,,all,0
!next two lines for harmonic analsysis
*if,at,eq,1,then
DL,4,,uz,1  !root displacement
DL,7,,uz,1
*endif
!---------------------------------------------
------------------
*if,at,eq,0,then
! modal analysis
FINISH
/SOL

ANTYPE,2
MSAVE,0
!*
MODOPT,LANB,arg5
EQSLV,SPAR
MXPAND,0, , ,0
LUMPM,0
PSTRES,0
```

```
!*
MODOPT,LANB,arg5,arg6,arg7, ,OFF
/STATUS,SOLU
SOLVE
FINISH
/POST1
/output,bf1,out,,append
*Status,argx
SET,LIST
/output
*get,freq1,mode,1,freq
*get,freq2,mode,2,freq
*get,freq3,mode,3,freq
! end modal analysis
!*
!--------------------------------------------
----------------------
*else
! harmonic analysis
FINISH
/SOL
!*
ANTYPE,3
!*
HROPT,FULL
HROUT,ON
LUMPM,0
DMPRAT,dampratio,
!*
EQSLV,FRONT,0,
PSTRES,0
!*
HARFRQ,0,100
NSUBST,100,
KBC,1
!*
/STATUS,SOLU
SOLVE
/POST26
FILE,'file','rst','.'
NUMVAR,200
SOLU,191,NCMIT
STORE,MERGE
PLCPLX,0
PRCPLX,1
FILLDATA,191,,,,1,1
REALVAR,191,191
!*
NSOL,2,92,U,Z, UZ_tip
nsol,3,421,u,z,uz-mid
STORE,MERGE
/GROPT,LOGX,On
/GROPT,LOGY,ON
XVAR,1
PLVAR,2,3
*endif
```