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Subject: Analysis and Testing of MSC/NASTRAN's New Rotordynamic Capability

## ABSTRACT

Analysis and Testing of MSC/NASTRAN's 2004 new rotordynamic capability was performed and compared with theoretical calculations. The objective of this report is to have MSC/NASTRAN determine critical frequencies, compare with the theoretical Campbell diagram, and check the correlation of bearing loads and run-outs due to an imbalance for a typical rotor as a function of rotor angular speed. A stability analysis is being put together for verification, however, not in time to be included in this report. It will be performed and written under separate cover in the next few months.

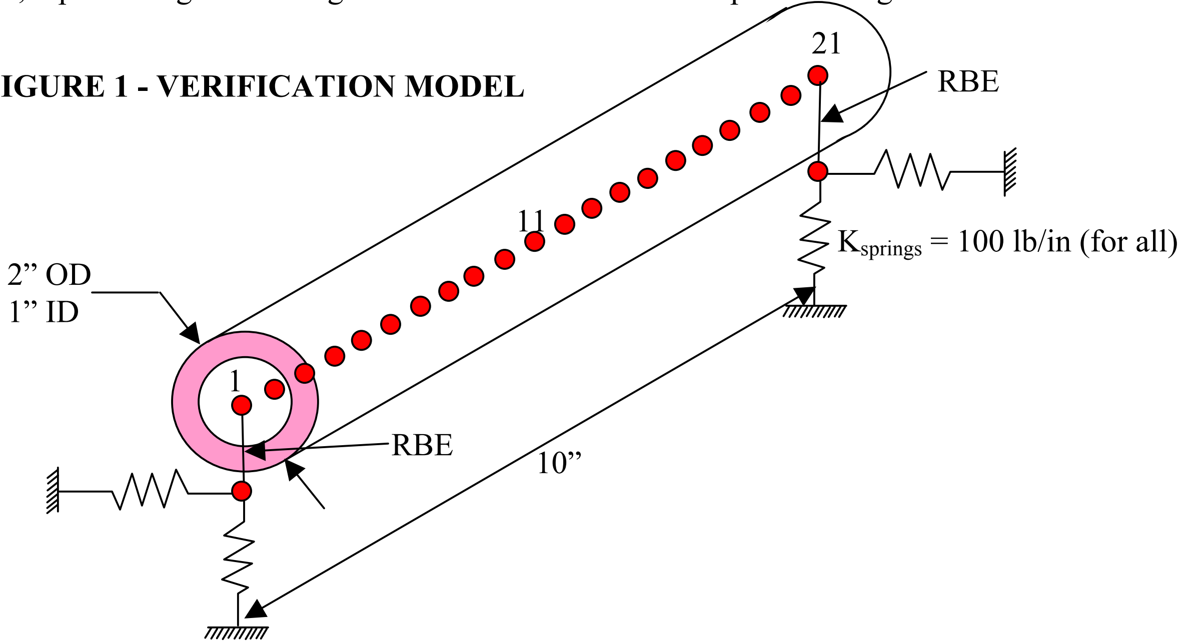
The MSC/NASTRAN results showed excellent correlation with the theoretical Campbell diagram. Comparison of the two is illustrated later on in this report. In addition, the critical speed calculations for the forward cylindrical whirl and the forward conical whirl are in excellent agreement with theory.

Finally, a frequency response analysis was performed using MSC/NASTRAN and compared with theory. The objective was to determine bearing loads, run-outs, and phase when subjected to a 50 inch-gram static imbalance from the rotor. The results show that the MSC/NASTRAN calculated bearing loads and zero-to-peak run-outs at the critical speed of interest were in perfect agreement with theory.

## DISCUSSION

A verification problem was developed that has a closed-form solution including the gyroscopic effects. The problem as stated is a 10" long hollow cylinder, 2" OD and 1" ID, with a 100 lb/in spring stiffness at each end, representing the bearings. A sketch of the model is depicted in Figure 1.

**FIGURE 1 - VERIFICATION MODEL**



The model was developed using 20 CBAR elements. Material properties used in the model are shown below in Table 1.

**Table 1:**
**Material Properties**

| Item | PATRAN Designation | Description | Steel |
|---|---|---|---|
| E (ksi) | $E_1$ | Modulus of Elasticity | 30.E6 |
| NUxy | $NU_{12}$ | Poisson's Ratio in XY-plane | 0.3 |
| Density (lb/in$^3$) | $\rho$ | Density | .2835 |

Using MSC/NASTRAN 2004, the rotor ends are attached to the support bearings via RBE2 elements. Then from there, the bearings are represented by CELAS1 (spring) elements connected to ground. The bearings were assigned a stiffness value of 100 lb/in. In addition, a stiffness of 100 lb/in was also included in the model in the axial direction to represent the connection from the rotor to the stator. This spring element simulates a magnet between the rotor and stator. The bulk data file used to run this case is given in Enclosure (1).

## MODAL ANALYSIS RESULTS

The model was exercised solution sequence (SOL) 107, which is a complex eigenvalue solution. Complex eigenvalue analysis is necessary when the matrices contain unsymmetric terms, damping effects, or complex numbers where real modes analysis cannot be used. It is typically used for the analysis of rotating bodies such as this. The eigenvalue method chosen for this analysis was the complex Hessenberg Method. The solution was run at 0, 10K, 30K, and 50KRPM and the real and imaginary roots were determined without damping. Table 2 below lists the key modes of vibration determined from the MSC/NASTRAN 2004 solution.

**Table 2**

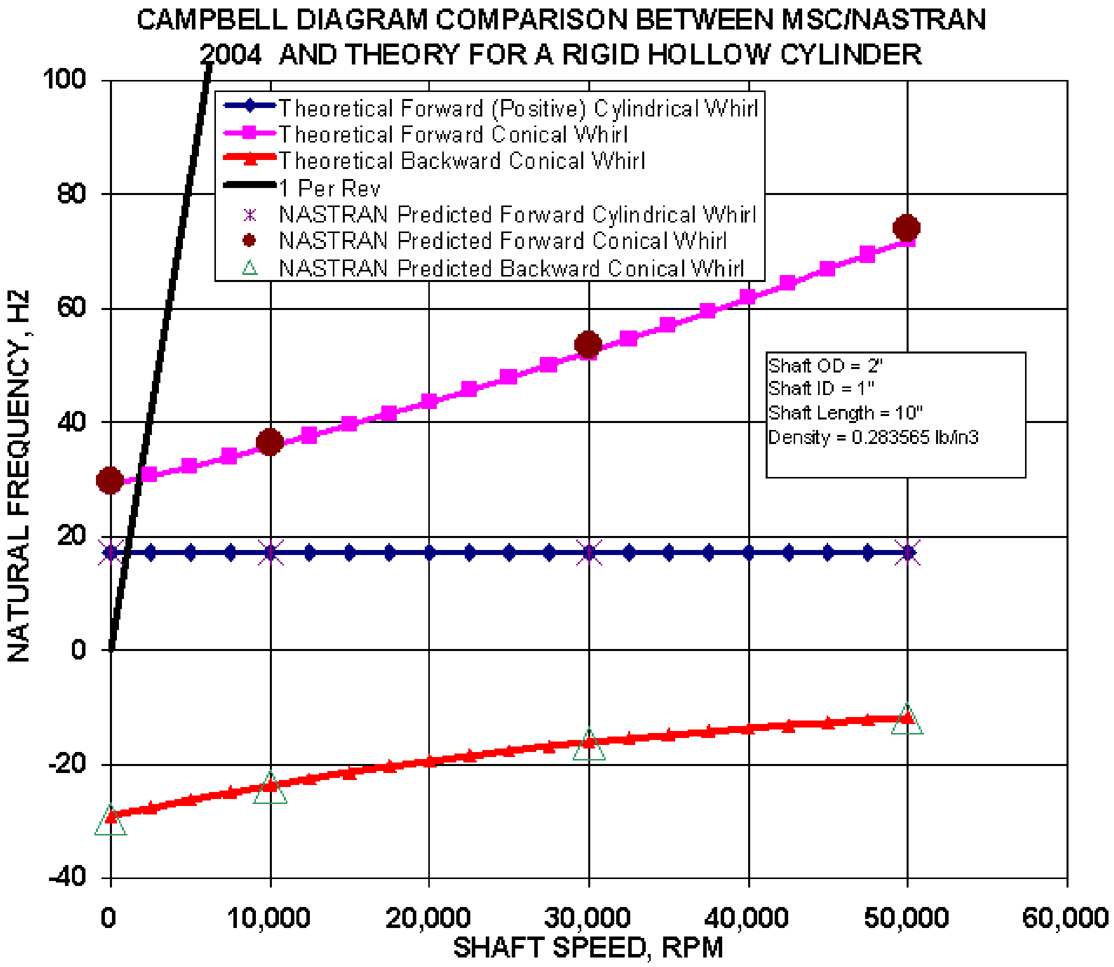
**MSC/NASTRAN 2004 RESULTS**
**Frequencies and Mode Shapes**

| | Forward | | Backward | |
|---|---|---|---|---|
| RPM | Cylindrical | Conical | Cylindrical | Conical |
| 0 | 17.11 | 29.56 | -17.11 | -29.56 |
| 10,000 | 17.11 | 36.43 | -17.11 | -23.99 |
| 30,000 | 17.11 | 53.62 | -17.11 | -16.30 |
| 50,000 | 17.11 | 74.00 | -17.11 | -11.81 |

The cylindrical and conical whirl modes are strictly a function of the bearing stiffness values chosen for this analysis. Note that the cylindrical forward and backward whirl modes are insensitive to the rotor's spin speed.

The theoretical Campbell Diagram is plotted in Figure 2 below, along with the MSC/NASTRAN 2004 results. The results show good correlation with theory.

**FIGURE 2**



One way to obtain the critical speeds is by using the Campbell Diagram. Drawing in a straight line called the “1 per revolution” or “1 per Rev”, the intersection of the 1 per Rev line with the whirl lines determines the critical speeds. In order to get an accurate value, a closer view of the data is given in Figure 3 below. Using this method, the first critical speed (forward cylindrical whirl) occurs at 10 Hz or 600 RPM, the second critical speed (backward conical whirl) at 28.33 Hz or 1,700 RPM, and the third critical speed at 30 Hz or 1,800 RPM (forward conical whirl).

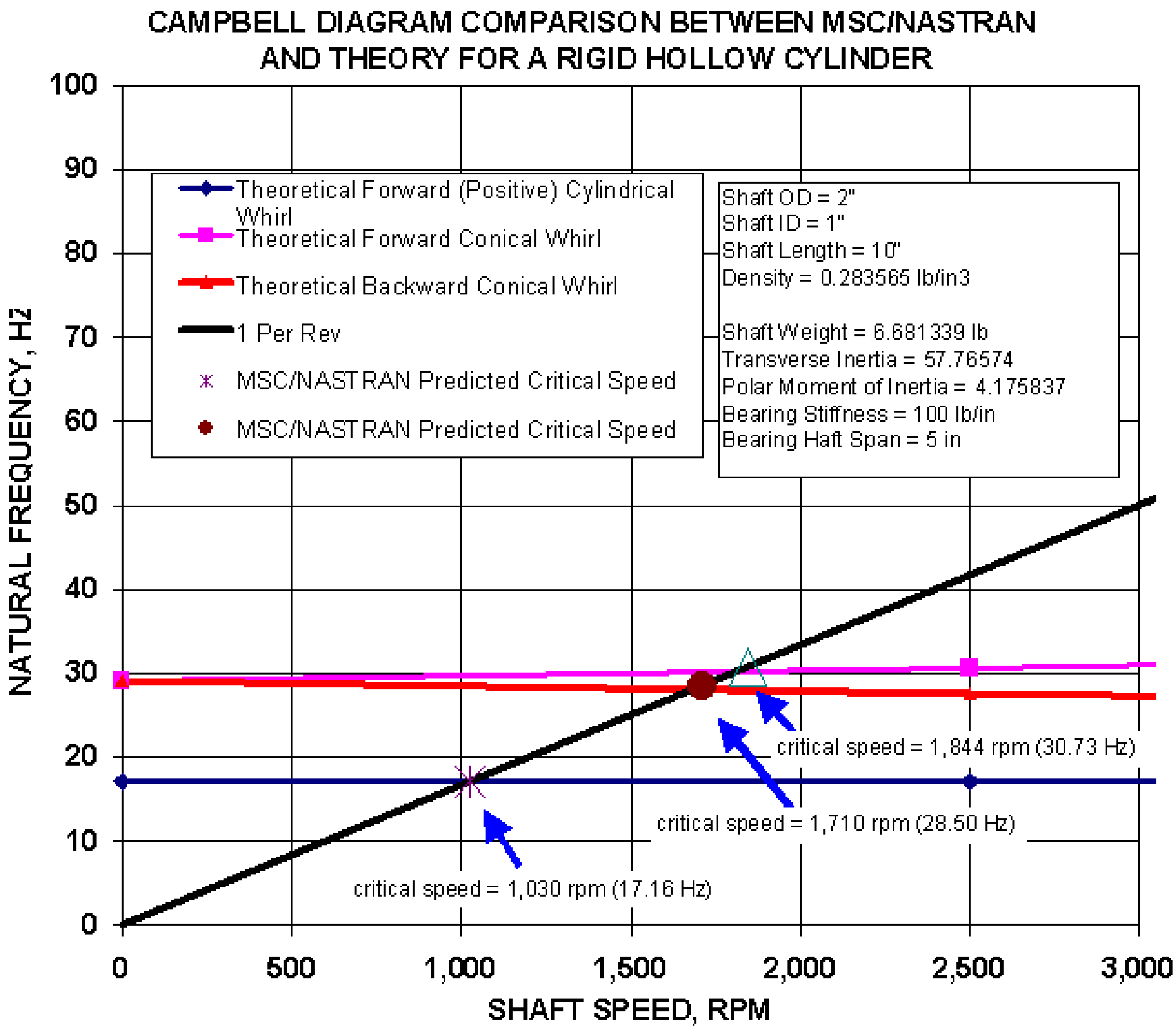
However, a better way is to use MSC/NASTRAN’s 2004 version and have it calculated the critical speeds directly using solution sequence 107. The results of that analysis are given below in Table 3.

## TABLE 3

### MSC/NASTRAN 2004 RESULTS
### Critical Speeds

| Mode | Direction | Theory | MSC/NASTRAN 2004 |
|---|---|---|---|
| Cylindrical | Forward | 17.11 | 17.11 |
| Cylindrical | Backward | 17.11 | 17.11 |
| Conical | Forward | 28.50 | 28.52 |
| Conical | Backward | 30.73 | 30.73 |

FIGURE 3



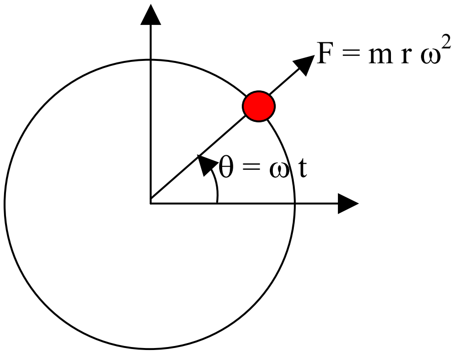
## ROTOR FREQUENCY RESPONSE DUE TO UNBALANCE ROTOR

A rotor imbalance acts as a force synchronous with the rotor speed. Therefore, only forward critical speeds are excited by imbalance forces. Backward critical speeds can be excited by a rotor rubbing against the stator. Since the rotor was connected by spring elements directly to ground, then all calculated eigenfrequencies are critical speeds. If the model of the support structure were included in the analysis, then the critical speed would be intermixed with the modes of the rotor-support structure.

Since the analysis is for a rotating imbalance and the steady-state solution is wanted, Solution Sequence SOL 111 (modal frequency response) will be used for this analysis.

First, the dynamic loading must be defined. The loading is a rotating imbalance acting at frequency ω and may be described as shown in Figure 4.

**Figure 4 – Rotating Load**



$F_x = m\,r\,\omega^2 \cos(\omega t)$
$F_y = m\,r\,\omega^2 \sin(\omega t)$

At any point in time, the force can be described as a combination of the x and y components. In MSC/NASTRAN, the RLOAD1 entries will be used to define each component of the applied loading. The applied load has a constant term (*m r*) and a frequency-dependent term ($\omega^2$). The constant term will be entered by using DAREA entries and the frequency-dependent term will be entered using a TABLED4 entry. The 90-degree phase angle between the x and y-components will be entered using a DPHASE entry. These terms will be combined using a DLOAD entry. The following describes how these entries will be filled out for this problem.

Defining the values for *r* and *m* gives the distance *r* = 1 inches and *m* = 50 grams which gives a 50 inch-gram imbalance. Therefore, mr = 50 will be used on the DAREA entries. As mentioned, the phase angle between the x and y-components is 90 degrees and will be entered on the DPHASE entry.

It should be noted at this point, that the input frequencies are in Hz, not in radians/sec. Therefore, it is necessary to convert the frequencies to radians per second for the equation. This will be done by entering a value of $X2 = (2\pi)^2$ or 39.478.

The load is applied at GRID point 11, which is at the center of the rotor. Using this information, the dynamic load will be entered using the following bulk data entries:

```
$
DLOAD   20      5.705-6 1.0     11      1.      12      1.      13
+DLD1   1.      14
$
RLOAD1  11      601                     800
RLOAD1  12      602             700     800
$
RLOAD1  13      701                     800
RLOAD1  14      702             750     800
$
DPHASE  700     4       3       90.
DPHASE  750     11      3       90.
$
$    ********  50 INCH-GRAMS  *******
$
DAREA   601     4       1       0.
DAREA   602     4       3       0.
$
DAREA   701     11      1       50.
DAREA   702     11      3       50.
$
$
TABLED4   800  0.   1.   0.   1000.
               39.4784   ENDT
```

These bulk data entries are described as follows:

The DLOAD (set 20) instructs the program to apply the loading described by combining RLOAD1 entries 11, 12, 13, and 14, both with a scaling factor of 1.0, but both multiplied by a 5.705E-6 scale factor.

RLOAD1 number 13 applies DAREA 701 (the X load) and uses TABLED4 number 800 to describe the frequency content of the load.

RLOAD1 number 14 applies DAREA 702 (the Y load) with a phase angle of 90 degrees (DPHASE set 750) and also uses TABLED4 number 800 to describe the frequency content of the load.

The frequency range of interest is from 0 to 300 Hz. Since 0 Hz is a static solution (not of interest), we will start at a frequency of 0.20 Hz and perform our analysis using a frequency increment of 0.10 Hz until 416 Hz is reached. The following FREQ1 entry describes this frequency range:

```
$
FREQ1   10      0.2     0.1     2998
$
```

In the interest of efficiency, a modal approach was used for the solution. Modes up to 1,000 Hz were obtained and used in the solution. The following EIGRL instructs the program to find those modes.

```
EIGRL   1       1.      1000.
```

Table 4 below illustrates the key results from the imbalance vibration analysis determined from the MSC/NASTRAN solution.

**TABLE 4**
**MSC/NASTRAN 2004 RESULTS**

| Location | **Force (lbs)** | | **Run-out (mils) zero-to-peak** | |
|---|---|---|---|---|
| | 1,110 rpm (18.5Hz) | 18,000rpm (300Hz) | 1,110 rpm (18.5Hz) | 18,000rpm (300Hz) |
| Top Bearing | 3.18 | 1.65 | 31.8 | 16.5 |
| C.G. | - | - | 31.8 | 16.5 |
| Bottom Bearing | 3.18 | 1.65 | 31.8 | 16.5 |

**TABLE 5**
**THEORETICAL RESULTS**

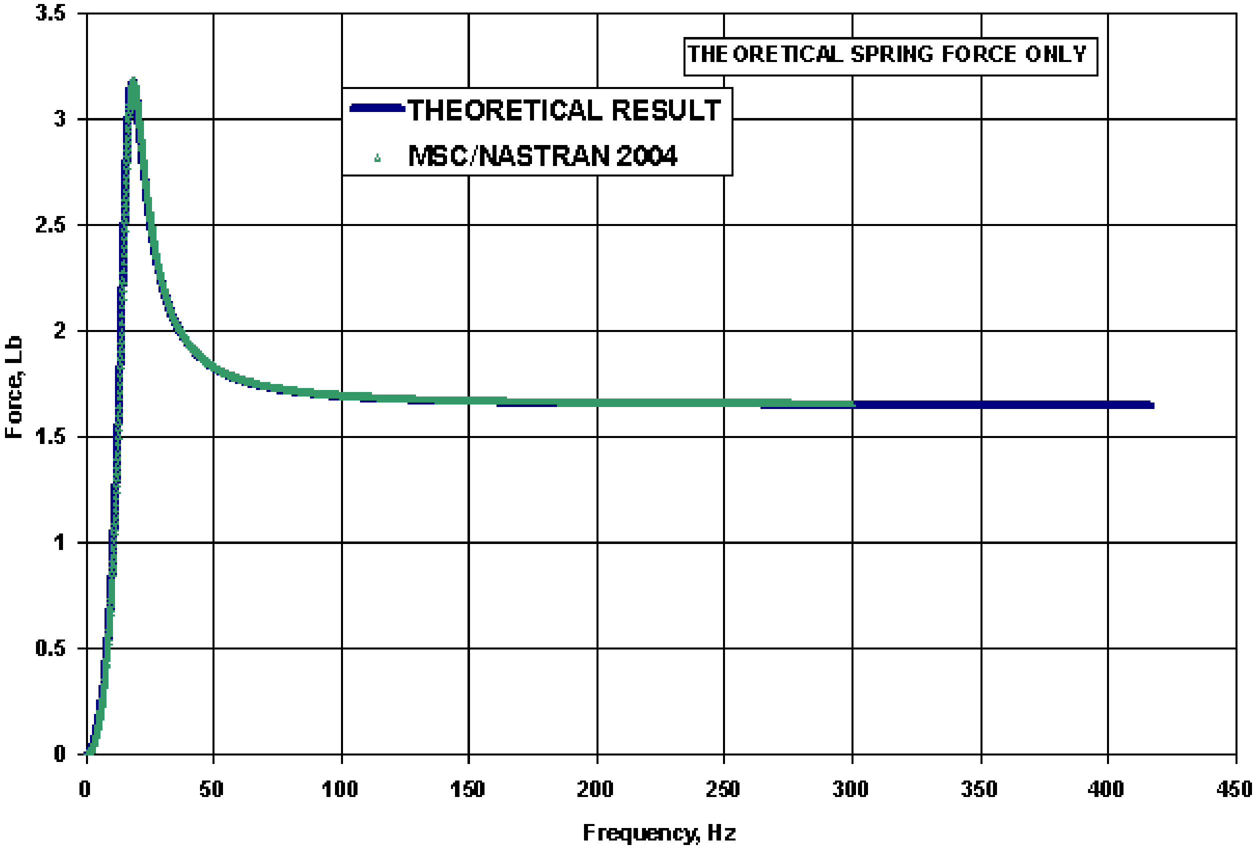
| Location | **Force (lbs)** | | **Run-out (mils) zero-to-peak** | |
|---|---|---|---|---|
| | 1,110 rpm (18.5Hz) | 18,000rpm (300Hz) | 1,110 rpm (18.5Hz) | 18,000rpm (300Hz) |
| Top Bearing | 3.18 | 1.65 | 31.8 | 16.5 |
| Bottom Bearing | 3.18 | 1.65 | 31.8 | 16.5 |

Careful examination of Tables 4 and 5 illustrate excellent correlation between MSC/NASTRAN 2004 and the theoretical values. Indeed, the agreement is exact.

## Bearing Force Plots

A plot of the bearing force in the radial direction, as predicted by MSC/NASTRAN 2004, is provided in Figure 5 along with a comparison with theory. Careful examination of the plot illustrates the excellent agreement between the two.

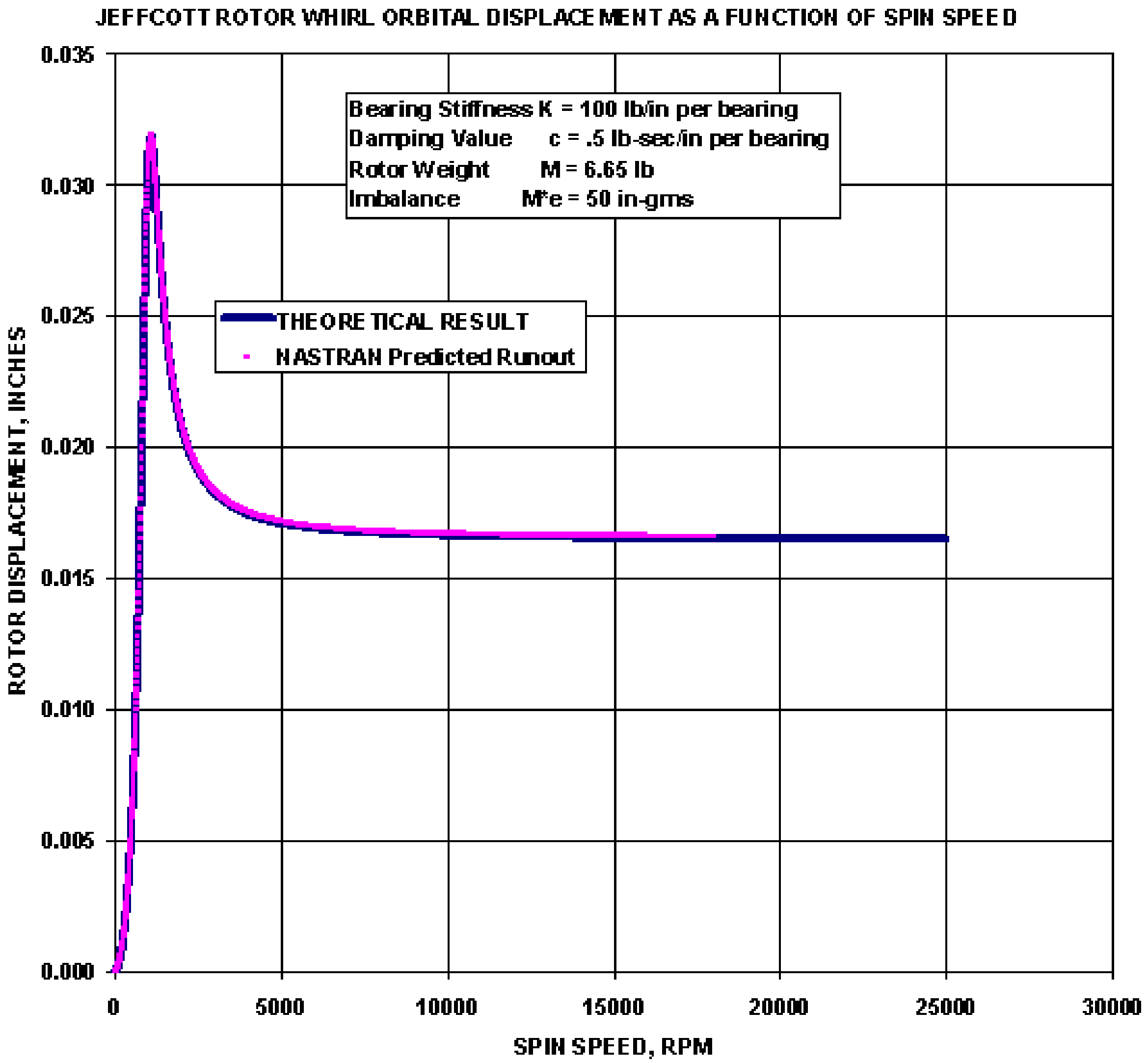
FIGURE 5
THEORETICAL SPRING LOAD VS MSC/NASTRAN 2004 PREDICTION



## Bearing Amplitude

The 0-peak amplitude of vibration for the bearing in the radial axis is illustrated in Figure 6. A comparison with the theoretical bearing run-out is superimposed on top of the MSC/NASTRAN results given in Figure 6. Once again, the results are the same.

## FIGURE 6



## CONCLUSIONS

Analysis and Testing of MSC/NASTRAN's 2004 new rotordynamic capability was performed and compared with theoretical calculations. The MSC/NASTRAN results showed excellent correlation with the theoretical Campbell diagram. In addition, the critical speed calculations for the forward cylindrical whirl and the forward conical whirl are in excellent agreement with theory. A frequency response analysis was also performed using MSC/NASTRAN and compared with theory. The results show that the MSC/NASTRAN calculated bearing loads and zero-to-peak run-outs at the critical speed of interest were in perfect agreement with theory. Finally, a stability analysis is being put together for verification, however, was not in time to be included in this report. It will be performed and written under separate cover in the next few months.

MSC/NASTRAN's version 2004 new rotordynamic has provided a relatively simple method of analyzing rotating structures. The major benefit of this new rotordynamic capability is that it is integrated directly into the dynamic solution sequences while removing the need for DMAP alters which include the elimination of DTI and DMIG cards that are cumbersome and rather awkward to input into a bulk data file. It is of the writer's opinion that this is a major improvement for MSC/NASTRAN since it is the only Finite Element code that can perform 3-dimensional rotordynamic analysis with orthotropic material properties such as in Beacon Power Flywheel systems. This version of MSC/NASTRAN, which previously overwhelmed all other codes, will help distance MSC Software Corporation from their competitors even further. Beacon Power has and will continue to use MSC/NASTRAN as their rotordynamic tool as they continue to research and develop Flywheel systems for their customers.

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Dynamicist
Beacon Power Corp

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11. A. M. Cerminaro and F. C. Nelson, "The effect of Viscous and Hysteretic Damping on Rotor Stability", presented at the ASME Turbo-Expo Conference, May 2000.
12. T. L. C. Chen and C. W. Bert, "Whirling Response and Stability of Flexibly Mounted, Ting-Type Flywheel Systems, Journal of Mechanical Design – Transactions of the ASME v102, April 1980.

## ENCLOSURES

(1) MSC/NASTRAN Bulk Data File For Solution Sequence SOL 107, Complex Eigenvalue Analysis at 10,000 RPM.

(2) MSC/NASTRAN Bulk Data File For Solution Sequence SOL 111, Frequency Response Analysis.

**ENCLOSURE (1):** MSC/NASTRAN Bulk Data File For Solution Sequence SOL 107, Complex Eigenvalue Analysis at 10,000 RPM

```
SOL 107
TIME 600
$ Direct Text Input for Executive Control
$
CEND
SEALL = ALL
SUPER = ALL
TITLE = NASTRAN 2004 TESTING FOR WHIRL FREQUENCIES
SUBTITLE = SPEED:10000 RPM
ECHO = NONE
MAXLINES = 999999999
SUBCASE 1
$ Subcase name : 10000 RPM
   CMETHOD = 1
   SPC = 200
   VECTOR(SORT1,REAL)=ALL
RGYRO = 100
$
$
BEGIN BULK
PARAM    POST    0
PARAM    WTMASS  .00259
PARAM    GRDPNT  0
PARAM,NOCOMPS,-1
PARAM   PRTMAXIM YES
EIGC     1       HESS    MAX
                                                         20
$
RGYRO   100     ASYNC   10      RPM                     10000.
ROTORG  10      1       THRU    21
RSPINR  10      1       2       0.0     RPM     1.
$
$
$
$   ************** SOFT ROTATIONAL STIFFNESS  ***************
$   ******** TO PREVENT RIGID BODY ROTATIONAL MOVEMENT ******
CELAS2  7013    10.     1       4
$
$
SPC1    200     123456  101     102     103     104     105
$
$
$ Nodes of the Entire Model
$
$      ROTOR GRIDS 1-21
$
GRID    1               0.0     0.00    0.00
GRID    2               0.5     0.00    0.00
GRID    3               1.0     0.00    0.00
GRID    4               1.5     0.00    0.00
GRID    5               2.0     0.00    0.00
GRID    6               2.5     0.00    0.00
```

```
GRID    7               3.0     0.00    0.00
GRID    8               3.5     0.00    0.00
GRID    9               4.0     0.00    0.00
GRID    10              4.5     0.00    0.00
GRID    11              5.0     0.00    0.00
GRID    12              5.5     0.00    0.00
GRID    13              6.0     0.00    0.00
GRID    14              6.5     0.00    0.00
GRID    15              7.0     0.00    0.00
GRID    16              7.5     0.00    0.00
GRID    17              8.0     0.00    0.00
GRID    18              8.5     0.00    0.00
GRID    19              9.0     0.00    0.00
GRID    20              9.5     0.00    0.00
GRID    21              10.     0.00    0.00
$
$     GRIDS ON THE GROUND
$
GRID    101             0.0     1.0     0.
GRID    102             10.     1.0     0.
GRID    103             0.0     0.0     1.0
GRID    104             10.     0.0     1.0
GRID    105             10.     0.0     0.0
$
GRID    201             0.      0.      0.              456
GRID    205             10.     0.      0.              456
$
$   BEAM ELEMENTS REPRESENTING THE SHAFT
CBAR    1       1       1       2       0.00    1.00    0.00
CBAR    2       1       2       3       0.00    1.00    0.00
CBAR    3       1       3       4       0.00    1.00    0.00
CBAR    4       1       4       5       0.00    1.00    0.00
CBAR    5       1       5       6       0.00    1.00    0.00
CBAR    6       1       6       7       0.00    1.00    0.00
CBAR    7       1       7       8       0.00    1.00    0.00
CBAR    8       1       8       9       0.00    1.00    0.00
CBAR    9       1       9       10      0.00    1.00    0.00
CBAR    10      1       10      11      0.00    1.00    0.00
CBAR    11      1       11      12      0.00    1.00    0.00
CBAR    12      1       12      13      0.00    1.00    0.00
CBAR    13      1       13      14      0.00    1.00    0.00
CBAR    14      1       14      15      0.00    1.00    0.00
CBAR    15      1       15      16      0.00    1.00    0.00
CBAR    16      1       16      17      0.00    1.00    0.00
CBAR    17      1       17      18      0.00    1.00    0.00
CBAR    18      1       18      19      0.00    1.00    0.00
CBAR    19      1       19      20      0.00    1.00    0.00
CBAR    20      1       20      21      0.00    1.00    0.00
$
$
$                   BEAM PROPERTY CARDS
$                        AREA   I1      I2       J
PBAR    1       1       2.35619 .73631  .73631  1.4726
$
CONM2   2001    1                                                       +CM1
+CM1    .104395
CONM2   2002    2                                                       +CM2
+CM2    .20879
```

```
CONM2   2003    3                                                       +CM3
+CM3    .20879
CONM2   2004    4                                                       +CM4
+CM4    .20879
CONM2   2005    5                                                       +CM5
+CM5    .20879
CONM2   2006    6                                                       +CM6
+CM6    .20879
CONM2   2007    7                                                       +CM7
+CM7    .20879
CONM2   2008    8                                                       +CM8
+CM8    .20879
CONM2   2009    9                                                       +CM9
+CM9    .20879
CONM2   2010    10                                                      +CM10
+CM10   .20879
CONM2   2011    11                                                      +CM11
+CM11   .20879
CONM2   2012    12                                                      +CM12
+CM12   .20879
CONM2   2013    13                                                      +CM13
+CM13   .20879
CONM2   2014    14                                                      +CM14
+CM14   .20879
CONM2   2015    15                                                      +CM15
+CM15   .20879
CONM2   2016    16                                                      +CM16
+CM16   .20879
CONM2   2017    17                                                      +CM17
+CM17   .20879
CONM2   2018    18                                                      +CM18
+CM18   .20879
CONM2   2019    19                                                      +CM19
+CM19   .20879
CONM2   2020    20                                                      +CM20
+CM20   .20879
CONM2   2021    21                                                      +CM21
+CM21   .104395
$
MAT1    1       30.0+6          .3      .2835
$
$
$   ****************************************************************
$   *********** TOP BEARING ELEMENTS  ********************
$   ****************************************************************
$
$       EID     PID     G1      C1      G2      C2
CELAS1  1009    3000    205     2       102     2
CELAS1  1010    3000    205     3       104     3
PELAS   3000    100.
$
$
RBE2    4001    1       123     201
RBE2    4002    21      123     205
$
$   ****************************************************************
$   *********** BOTTOM BEARING ELEMENTS ***************************
$   ****************************************************************
```

```
$
$       EID     PID     G1      C1      G2      C2
CELAS1  2009    2000    201     2       101     2
CELAS1  2010    2000    201     3       103     3
PELAS   2000    100.
$
$
$   ******* REPELLING MAGNET (X-AXIS) *******
CELAS1   46645   10      205     1       105     1
PELAS    10      10.
$
ENDDATA
```

**ENCLOSURE (2):** MSC/NASTRAN Bulk Data File For Solution Sequence SOL 111, Frequency Response Analysis.

```
ID ROTATING SHAFT
DIAG 8
SOL 111
TIME 600
$ Direct Text Input for Executive Control
$
CEND
$
TITLE = FREQUENCY RESPONSE ANALYSIS
SUBTITLE = SOLVING FOR BEARING ZERO-TO-PEAK RUNOUTS (MODAL METHOD)
LABEL = USING A 50 INCH-GRAM STATIC IMBALANCE ON THE SHAFT
$
SEALL = ALL
SUPER = ALL
ECHO = NONE
MAXLINES = 999999999
   FREQUENCY = 10
   DLOAD = 20
   SPC = 200
RGYRO = 100
$
   SET 111 = 1, 20
   DISPLACEMENT(PHASE,SORT2,PLOT) = 111
$
   SET 222 = 1009, 1010, 2009, 2010, 20011, 20012, 30011, 30012
   ELFORCE(PHASE,SORT2,PLOT) = 222
$ Direct Text Input for Global Case Control Data
$
$
SUBCASE 1
METHOD = 1
$ Direct Text Input for this Subcase
$
$
OUTPUT (XYPLOT)
PLOTTER,NAST
CSCALE 2.0
XAXIS = YES
YAXIS = YES
$XLOG = YES
$YLOG = YES
XGRID LINES = YES
YGRID LINES = YES
XTGRID LINES = YES
YTGRID LINES = YES
XBGRID LINES = YES
YBGRID LINES = YES
XPAPER = 28.
YPAPER = 20.
$
XTITLE = FREQUENCY, HZ
YTITLE = TOP BEARING Y FORCE OF ELEMENT 1009 Y-DIR (LB)
```

```
TCURVE = TOP BEARING Y FORCE OF ELEMENT 1009 Y-DIR (LB)
XYPLOT XYPEAK ELFORCE /1009(2)
$
YTITLE = TOP BEARING Z FORCE OF ELEMENT 1010 Z-DIR (LB)
TCURVE = TOP BEARING Z FORCE OF ELEMENT 1010 Z-DIR (LB)
XYPLOT XYPEAK ELFORCE /1010(2)
$
YTITLE = TOP DAMPER FORCE OF ELEMENT 20011 Y-DIR (LB)
TCURVE = TOP DAMPER FORCE OF ELEMENT 20011 Y-DIR (LB)
XYPLOT XYPEAK ELFORCE /20011(2)
$
YTITLE = TOP DAMPER FORCE OF ELEMENT 20012 Z-DIR (LB)
TCURVE = TOP DAMPER FORCE OF ELEMENT 20012 Z-DIR (LB)
XYPLOT XYPEAK ELFORCE /20012(2)
$
YTITLE = BOTTOM BEARING Y FORCE OF ELEMENT 2009 Y-DIR (LB)
TCURVE = BOTTOM BEARING Y FORCE OF ELEMENT 2009 Y-DIR (LB)
XYPLOT XYPEAK ELFORCE /2009(2)
$
YTITLE = BOTTOM BEARING Z FORCE OF ELEMENT 2010 Z-DIR (LB)
TCURVE = BOTTOM BEARING Z FORCE OF ELEMENT 2010 Z-DIR (LB)
XYPLOT XYPEAK ELFORCE /2010(2)
$
YTITLE = BOTTOM DAMPER FORCE OF ELEMENT 30011 Y-DIR (LB)
TCURVE = BOTTOM DAMPER FORCE OF ELEMENT 30011 Y-DIR (LB)
XYPLOT XYPEAK ELFORCE /30011(2)
$
YTITLE = BOTTOM DAMPER FORCE OF ELEMENT 30012 Z-DIR (LB)
TCURVE = BOTTOM DAMPER FORCE OF ELEMENT 30012 Z-DIR (LB)
XYPLOT XYPEAK ELFORCE /30012(2)
$
$
$ytlog = yes
$yblog = no
$
$ ******* TOP BEARING RUNOUT *******
YTITLE = GRID 21 Y-DISPLACEMENT (INCHES)
TCURVE = TOP BEARING RUNOUT 0-PEAK (INCHES) - Y-AXIS GRID 21
XYPLOT XYPEAK DISP /21(T2RM, T2IP)
$
$ ******* TOP BEARING RUNOUT *******
YTITLE = GRID 21 Z-DISPLACEMENT (INCHES)
TCURVE = TOP BEARING RUNOUT 0-PEAK (INCHES) - Z-AXIS GRID 21
XYPLOT XYPEAK DISP /21(T3RM, T3IP)
$
$ ******* BOTTOM BEARING RUNOUT *******
YTITLE = GRID 1 Y-DISPLACEMENT (INCHES)
TCURVE = BOTTOM BEARING RUNOUT 0-PEAK (INCHES) - Y-AXIS GRID 1
XYPLOT XYPEAK DISP /1(T2RM, T2IP)
$
$ ******* BOTTOM BEARING RUNOUT *******
YTITLE = GRID 1 Z-DISPLACEMENT (INCHES)
TCURVE = BOTTOM BEARING RUNOUT 0-PEAK (INCHES) - Z-AXIS GRID 1
XYPLOT XYPEAK DISP /1(T3RM, T3IP)
$
BEGIN BULK
PARAM    POST    0
PARAM    WTMASS  .00259
```

```
PARAM    GRDPNT  0
PARAM,NOCOMPS,-1
PARAM   PRTMAXIM YES
PARAM   DDRMM   -1
EIGRL   1       1.      1000.
$ Direct Text Input for Bulk Data
$
$  ********************************************
$  ****** ROTORDYNAMIC DATA CARDS *************
$  ********************************************
$
RGYRO   100     SYNC    10      RPM     0.0     50000.
ROTORG  10      1       THRU    21
RSPINR  10      1       2       0.0     RPM     1.
$
FREQ1   10      0.2     0.1     2998
$
DLOAD   20      5.705-6 1.0     11      1.      12      1.      13      +DLD1
+DLD1   1.      14
$
RLOAD1  11      601                     800
RLOAD1  12      602             700     800
$
RLOAD1  13      701                     800
RLOAD1  14      702             750     800
$
DPHASE  700     4       3       90.
DPHASE  750     11      3       90.
$
$    ********  50 INCH-GRAMS *******
$
DAREA   601     4       1       0.
DAREA   602     4       3       0.
$
DAREA   701     11      1       50.
DAREA   702     11      3       50.
$
$TABLED1 800                                                             +TBD1
$+TBD1   0.0     1.0     375.    1.0     ENDT
$
TABLED4     800   0.    1.    0.    1000.
                  39.4784     ENDT
$
$
$
$   ************** SOFT ROTATIONAL STIFFNESS  ***************
$   ******** TO PREVENT RIGID BODY ROTATIONAL MOVEMENT ******
CELAS2  7013    10.     1       4
$
$
SPC1    200     123456  101     102     103     104     105
$
$
$ Nodes of the Entire Model
$
$      ROTOR GRIDS 1-21
$
GRID    1               0.0     0.00    0.00
```

```
GRID    2               0.5     0.00    0.00
GRID    3               1.0     0.00    0.00
GRID    4               1.5     0.00    0.00
GRID    5               2.0     0.00    0.00
GRID    6               2.5     0.00    0.00
GRID    7               3.0     0.00    0.00
GRID    8               3.5     0.00    0.00
GRID    9               4.0     0.00    0.00
GRID    10              4.5     0.00    0.00
GRID    11              5.0     0.00    0.00
GRID    12              5.5     0.00    0.00
GRID    13              6.0     0.00    0.00
GRID    14              6.5     0.00    0.00
GRID    15              7.0     0.00    0.00
GRID    16              7.5     0.00    0.00
GRID    17              8.0     0.00    0.00
GRID    18              8.5     0.00    0.00
GRID    19              9.0     0.00    0.00
GRID    20              9.5     0.00    0.00
GRID    21              10.     0.00    0.00
$
$     GRIDS ON THE GROUND
GRID    101             0.0     1.0     0.
GRID    102             10.     1.0     0.
GRID    103             0.0     0.0     1.0
GRID    104             10.     0.0     1.0
GRID    105             10.     0.0     0.0
$
GRID    201             0.      0.      0.              456
GRID    205             10.     0.      0.              456
$
$
$   BEAM ELEMENTS REPRESENTING THE SHAFT
CBAR    1       1       1       2       0.00    1.00    0.00
CBAR    2       1       2       3       0.00    1.00    0.00
CBAR    3       1       3       4       0.00    1.00    0.00
CBAR    4       1       4       5       0.00    1.00    0.00
CBAR    5       1       5       6       0.00    1.00    0.00
CBAR    6       1       6       7       0.00    1.00    0.00
CBAR    7       1       7       8       0.00    1.00    0.00
CBAR    8       1       8       9       0.00    1.00    0.00
CBAR    9       1       9       10      0.00    1.00    0.00
CBAR    10      1       10      11      0.00    1.00    0.00
CBAR    11      1       11      12      0.00    1.00    0.00
CBAR    12      1       12      13      0.00    1.00    0.00
CBAR    13      1       13      14      0.00    1.00    0.00
CBAR    14      1       14      15      0.00    1.00    0.00
CBAR    15      1       15      16      0.00    1.00    0.00
CBAR    16      1       16      17      0.00    1.00    0.00
CBAR    17      1       17      18      0.00    1.00    0.00
CBAR    18      1       18      19      0.00    1.00    0.00
CBAR    19      1       19      20      0.00    1.00    0.00
CBAR    20      1       20      21      0.00    1.00    0.00
$
$
$                           BEAM PROPERTY CARDS
$                                 AREA    I1      I2       J
PBAR    1       1       2.35619 .73631  .73631  1.4726
```

```
$
CONM2   3001    1                                                       +CM1
+CM1    .104395
CONM2   3002    2                                                       +CM2
+CM2    .20879
CONM2   3003    3                                                       +CM3
+CM3    .20879
CONM2   3004    4                                                       +CM4
+CM4    .20879
CONM2   3005    5                                                       +CM5
+CM5    .20879
CONM2   3006    6                                                       +CM6
+CM6    .20879
CONM2   3007    7                                                       +CM7
+CM7    .20879
CONM2   3008    8                                                       +CM8
+CM8    .20879
CONM2   3009    9                                                       +CM9
+CM9    .20879
CONM2   3010    10                                                      +CM10
+CM10   .20879
CONM2   3011    11                                                      +CM11
+CM11   .20879
CONM2   3012    12                                                      +CM12
+CM12   .20879
CONM2   3013    13                                                      +CM13
+CM13   .20879
CONM2   3014    14                                                      +CM14
+CM14   .20879
CONM2   3015    15                                                      +CM15
+CM15   .20879
CONM2   3016    16                                                      +CM16
+CM16   .20879
CONM2   3017    17                                                      +CM17
+CM17   .20879
CONM2   3018    18                                                      +CM18
+CM18   .20879
CONM2   3019    19                                                      +CM19
+CM19   .20879
CONM2   3020    20                                                      +CM20
+CM20   .20879
CONM2   3021    21                                                      +CM21
+CM21   .104395
$
$
MAT1    1       30.0+6          .3      .2835
$
$
$   ***************************************************************
$   *********** TOP BEARING ELEMENTS  ********************
$   ***************************************************************
$
$       EID     PID     G1      C1      G2      C2
CELAS1  1009    3000    205     2       102     2
CELAS1  1010    3000    205     3       104     3
PELAS   3000    100.
$
CDAMP1  20011   99      205     2       102     2
```

```
CDAMP1  20012   99      205     3       104     3
$
$
RBE2    4001    1       123     201
RBE2    4002    21      123     205
$
$
$   **************************************************************
$   *********** BOTTOM BEARING ELEMENTS ***************************
$   **************************************************************
$
$       EID     PID     G1      C1      G2      C2
CELAS1  2009    2000    201     2       101     2
CELAS1  2010    2000    201     3       103     3
PELAS   2000    100.
$
CDAMP1  30011   99      201     2       101     2
CDAMP1  30012   99      201     3       103     3
PDAMP   99      0.5
$
$   ******* REPELLING MAGNET (X-AXIS) *******
CELAS1  46645   10      205     1       105     1
PELAS    10      10.
CDAMP2  90005   1.      205     1       105     1
$
ENDDATA
```