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DYNAMIC ANALYSIS OF THE NOVA TARGET
CHAMBER TO ASSESS ALIGNMENT ERRORS
DUE TO AMBIENT NOISE

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ABSTRACT

We performed a study to determine the dynamic behavior of the Nova Target Chamber. We conducted a free vibration analysis to determine the natural frequencies of vibration and the corresponding modeshapes of the target chamber. Utilizing the free vibration results, we performed forced vibration analysis to predict the displacements of the chamber due to ambient vibration. The input support motion for the forced vibration analysis was defined by a "white noise" acceleration spectrum which was based on previous measurements of ground noise near the Nova site. A special purpose computer program was prepared to process the results of the forced vibration analysis. The program yields distances by which the lines of sight of the various laser beams "miss" the target as a result of ambient vibrations. We also performed additional estimates of "miss distance" to provide bounds on the results.

A description of the finite element model of the chamber, the input spectrum, and the results of the analyses are included in this report.

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MASTER

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1.0 Background

1.1 The Nova Target Chamber

The Nova target chamber consists of two hemispherical shells attached to a cylindrical ring (Fig. 1). The chamber is approximately 14 feet in diameter. The hemispheres are constructed of aluminum with a nominal thickness of 5.0 inches. The cylindrical ring, also constructed of aluminum, has a nominal thickness of 3.5 inches. Stiffener rings are located at the cylindrical/spherical interface. The holes in the hemisphere are to accommodate the lens positioners for the laser beams. The lens positioners are quite large and represent a significant portion of the system's mass (4500 lb. per positioner). Figure 2 shows an artist's conception of the target chamber with the lens positioners attached to it. The potassium, dihydrogen, phosphate, (KDP), arrays will attach to the ends of the lens positioners and are not shown. The target chamber is supported on 12 legs which are connected to the Nova space frame (Fig. 3).

1.2 Purpose of Study

The laser beams will pass through the lens positioners into the target chamber and strike the target which is suspended at the center of the chamber. Because the actual target is quite small, misalignment of the laser beams or motion of the lens positioners can lead to a target miss.¹

Nova project engineers were concerned that small ambient vibrations resulting from nearby equipment operation might induce large enough vibration in the target chamber to cause problems with the laser beam/target alignment. There was particular concern about the effects of the large masses of the lens positioners. The purpose of this study was to utilize the existing information to make the best possible estimates of the possible miss distances resulting from the ambient vibration at the Nova site.

¹For the purpose of this study we define target miss as "miss distance". This is equal to the perpendicular distance between the target center and the line of action of the laser beam.

Fig. 1: Nova Target Chamber

Fig. 2: Target Chamber and
Lens Positioners

Fig. 3: Target Chamber
Mounted in Frame

2.0 Analytical Work

In order to estimate the miss distances attributable to ambient vibrations, we proceeded with the following tasks:

- i) A finite element model of the chamber was developed.
- ii) A free vibration analysis of the chamber/lens positioner assembly/KDP array was made to determine the natural frequencies and the corresponding modeshapes.
- iii) An acceleration spectrum was developed to represent the ambient ground noise.
- iv) A forced vibration analysis was performed to estimate the chamber displacements due to support motion.
- v) The structural displacements determined by the forced vibration analysis were post processed to estimate miss distance.

2.1 The Nova Target Chamber Model

We generated the original finite element model of the Nova target chamber using the interactive program SLIC [1]. The model is shown in Fig. 4. The hemisphere and cylindrical ring were modeled with 1,350 shell elements. The lens positioners and attached components were represented by stiff beam elements and lumped masses. The hemisphere-cylindrical ring connection was a continuous connection in the original model. However, inspection of the actual ring-hemi connection led to an uncoupling of the ring and hemi with beam elements used to connect the hemi to the ring. These elements are intended to be representative of actual bolt connections which are at 18° intervals. The actual connectivity between the hemi and ring is somewhere between a continuous connection and the discrete connection which has been modeled, however, treating the connection as merely consisting of the bolts will maximize the flexibility of the system. This, in turn, will maximize the displacements obtained and thus yield a conservative approximation. The "bolts" can be seen in the plot of the displaced chamber in Fig. 5.

For both the free vibration and forced vibration analysis the chamber was pinned (x, y, and z translations prohibited) at the locations indicated in Fig. 5. These are the points at which the support legs connect to the

Fig. 4a: Nova Target Chamber Finite Element Model

Fig. 4b: Nova Target Chamber Finite Element Model (reflected by computer graphics)

Fig. 5: Ring-Hemisphere Connection
in Deformed Position

chamber. By assuming a pinned support the moment resistance provided by the bending stiffness of the legs is neglected. This is another assumption which maximizes flexibility.

The structure was supported at the location where the support legs connect to the chamber because the relative deflections of the chamber/lens positioners were of primary interest.

2.2 Free Vibration Analysis

The chamber was modeled using symmetry considerations. While this drastically reduces the number of elements and thus the cost per computer run, it necessitates more cases which must be run. Four possible sets of boundary conditions exist for the symmetry model (Fig. 6). Each of the combinations must be considered in the forced vibration analysis. Modeshapes for selected modes are shown in Figs. 7 and 8. The results of the free vibration analysis for all the possible boundary conditions are summarized in Table 1. The analysis results were obtained using the GEMINI computer program [2].

Table 1 shows that for two of the boundary condition cases there are modes which have frequencies in the 20 Hz range. Inspection of the modeshapes for these low frequency modes (see Fig. 8) shows that they are associated with deformation of the stiffener ring. These modes are probably fictitious in that the structural model was pinned at the edge of the stiffener ring and the heavy plate which actually extends along the ring (see Fig. 3) at the leg/ring connection was not included. Had the stiffener plate been included these low frequency modes would most likely not be attained.

Fig. 6: Boundary Condition Combinations

Mode #1
 $f_1 = 44.2 \text{ hz}$

Mode #5
 $f_5 = 67.3 \text{ hz}$

Mode #3
 $f_3 = 60.7 \text{ hz}$

Fig. 7: Selected Mode Shapes for Symmetry-Symmetry Boundary Condition

Mode shape is composed of
deformation of stiffening
ring

ig. 8: Mode #1, Antisymmetry - Antisymmetry
Boundary Condition

Table 1: Modal Frequencies (Hz) for First Ten Modes for the
Boundary Conditions Analyzed -- Free Vibration Analysis

Mode	Boundary Condition			
	Symmetry- Symmetry	Symmetry- Antisymmetry	Antisymmetry- Symmetry	Antisymmetry- Antisymmetry
1	44.2	46.5	23.8*	23.8*
2	60.5	50.6	27.3*	49.1
3	60.7	66.0	59.0	60.5
4	64.8	67.7	59.5	68.4
5	67.3	85.3	64.8	80.8
6	74.6	86.6	65.3	84.4
7	81.3	92.6	78.6	92.9
8	118.7	146.0	89.8	123.2
9	141.5	161.7	111.0	150.6
10	173.8	199.1	124.2	202.4

* Modes associated with deformations of the stiffener ring only.

2.3 Forced Vibration - SRSS Displacements

The natural frequencies and modes shapes can be used in a response spectrum dynamic analysis to estimate the deflections of a structure due to support motion. In addition to obtaining the modes shapes and frequencies we must define an acceleration response spectrum which is representative of the motion of the supports of the structure. The Nova space frame and target chamber legs will modify the ground spectrum, amplifying at some frequencies and attenuating at others so that the actual spectrum for the target chamber (i.e., the spectrum defining the motion of the top of the support legs) could be significantly different from the ground spectrum.

Based on measurements made by the Structural Mechanics Group at nearby sites [3], a maximum ground acceleration, due to ambient noise, was estimated to be approximately 0.004g. The corresponding "white noise" spectrum is shown in Fig. 9a. To account for possible amplification by the supporting frame structure (frame and legs) this spectrum was scaled by a factor of 3 to get the in-structure spectrum for the target chamber (Fig. 9b). The scale factor of 3 is not based on analytical results but on experience of amplifications obtained in frame structures.

Fig. 9a: Ground Motion Acceleration Spectrum

Fig. 9b: Target Chamber (in-structure) Spectrum

The 0.012g spectrum was assumed to represent the support motion for all three orthogonal directions. Thus we used this spectrum as input for x, y and z directions simultaneously in the response spectrum analysis.

Because we used the symmetry model we had to decide which boundary conditions were appropriate for each direction of support motion. For example, in the case of the symmetry-symmetry boundary condition (see Fig. 6) careful inspection showed that only a y-direction support excitation could excite the modes defined by this boundary condition. The inclusion of an x or z ground motion for this boundary condition could lead to erroneous results. The other appropriate boundary condition/excitation combinations are shown in Fig. 10 (Note Antisymmetry-Antisymmetry does not contribute).

The displacements of the chamber/lens positioners were determined by making 3 response spectrum runs using GEMINI. The displacements for each direction of excitation were determined by running each of the cases in Fig. 10. The displacements for each case were found using the square root of the sum of the squares (SRSS) modal combination. Finally, the displacements for each of the 3 cases were combined by hand using the SRSS combinations to determine the displacements at important locations e.g., at the ends of the lens positioners.

2.4 Post Processing - Miss Distances

The SRSS displacements of the structure provide useful information on the overall displacements of the structure. However, they do not directly yield what is of primary concern, the distance by which the laser beam misses the center of the target. Miss distances were estimated by three approaches to obtain bounds on the expected results. These methods were as follows:

Method 1: Based on deflection of lens positioner and KDP array.

Method 2: Based on lateral motion of lens positioner only.

Method 3: Based on lateral motion of lens positioner coupled with deflection of target rigidly connected to shell.

Each method and their respective result are summarized below:

Fig 10: Boundary Condition - Excitation Combinations

Method 1

In Fig. 11a P_1 represents the location of the target and P_2 and P_3 represent the location of the ends of a lens positioner. Figure 11b shows the lens positioner location when the SRSS displacements are considered (the target is assumed to remain stationary). The vectors A and B are formed using the Cartesian coordinates of P_1 , P_2 , and P_3 . The cross product, $A \times B$, yields vector C (directed out of plane). Then the cross product, $C \times D$, yields vector D (D lies in the plane defined by P_1 , P_2 , and P_3). The vector D is then "unitized" to get $\hat{D}$; and finally, the dot product, $B \cdot \hat{D}$, yields the desired miss distance.

It should be noted that as a result of using the SRSS modal combination the sense of the displacements at the ends of the lens positioners are lost. Because of this, we assumed that the displacements at the opposite ends of the lens positioners were of opposite sign. For example, if the X-direction displacement of P_2 in Fig. 11b was assumed to be positive, the X-direction displacement of P_3 was assumed to be negative. The computer program (see Appendix) which calculates miss distances requires as input the SRSS displacements of the ends of the lens positioners. For the lens positioner indicated in Fig. 12, the program output is shown. A summary of the miss distances for all the lens positioners is given in Table 2.

The computer output in Fig. 12 shows "node locations prior to adjustment" and "adjusted location of outer point on lens positioner". The locations prior to adjustment are the Cartesian locations of the nodes as defined by the finite element mesh. Since the deflections of the chamber are quite small, it is necessary to have the three points (i.e., target and points on lens positioners) precisely colinear at the outset, or there will be a miss distance even before the vibration displacements are added. The computer program automatically adjusts the location of the outermost node on the lens positioner so that the three points are colinear (at least to machine precision) prior to adding in the displacements.

Fig. 11a: Target and lens positioner location prior to vibration deflections

Miss Distance

Fig. 11b: Target and lens positioner with SRSS displacements added

```

node i = 218      node j = 219

node locations prior to adjustment....

nodal locations :
node = 218  x= 2.746000000e+01  y= -8.451000000e+01  z= 7.466000000e+01
node = 219  x= 4.024290000e+01  y= -1.230500000e+02  z= 1.092700000e+02
target     x=      0.          y=      0.          z=      0.

adjusted location of outer point on lens positioner:

node = 219  x= 4.024292028e+01  y= -1.230803637e+02  z= 1.092606170e+02

locations of nodes after displacements are added in and displacement components

nodal locations :
node = 218  x= 2.746001119e+01  y= -8.450999032e+01  z= 7.466001309e+01
node = 219  x= 4.024290049e+01  y= -1.230504222e+02  z= 1.092604764e+02
target     x=      0.          y=      0.          z=      0.

nodal displacements:
node = 218  x= 1.115100000e-05  y= 4.567000000e-05  z= 1.309100000e-05
node = 219  x= -3.770700000e-05  y= -6.050000000e-05  z= -4.021000000e-05
target     x=      0.          y=      0.          z=      0.

distance by which line of sight of displaced lens positioner misses target = 3.2255409141e-04

```

Fig. 12: Program Output for Miss Distance Calculation

Positioner	Nodes	Miss Distances (in)	Miss Distances (u)*
1	218-219	9.7×10^{-4}	~25
2	618-619	6.2×10^{-4}	~16
3	1225-1226	3.7×10^{-4}	~10

*1u = 1×10^{-6} meter

Table 2: Calculated Miss Distances for Three Lens Positioners by Method 1.

Method 2:

This method assumes that the target remains fixed in space, and the miss distance is based on lateral translation of the lens positioner only. Lens positioner rotation was assumed not to affect the results. We assumed displacement of the lens positioner was orthogonal to the line of site. This is a conservative assumption, since there is also a component along the line of site. The miss distance was then calculated as

$$\text{Miss Distance} = d_l = \sqrt{u_x^2 + u_y^2 + u_z^2}.$$

This is shown schematically in Figure 13.

Figure 13: Miss distance based on translation of lens positioner only.

For the three lens positioners included in the model, miss distances calculated in this manner are tabulated in Table 3.

<u>Positioner</u>	<u>Miss Distances (in)</u>	<u>Miss Distances (μ)</u>
1	1.6×10^{-4}	~ 4.1
2	1.7×10^{-4}	~ 4.3
3	1.8×10^{-4}	~ 4.6

Table 3: Calculated Miss Distances for Three Lens Positioners by Method 2.

Method 3:

This method combines the results from Method 2: d_1 , with a target motion, d_2 , assuming the target is rigidly attached to the shell and its motion is determined from the shell translation and rotation at the attachment point. The translation of the target is assumed to be orthogonal to the laser line of site. The motion of the target and lens positioner are further assumed to be out of phase so the miss distance is calculated as

$$\text{miss distance} = |d_1| + |d_2|.$$

This is shown schematically in Figure 14.

Based on the translations and rotations at the top of the shell the displacement of the target is $\sim 1.9 \times 10^{-4}$ in. Adding this to the miss distances based on lens translation from Method 2, the miss distances tabulated in Table 4 are obtained.

<u>Positioner</u>	<u>Miss Distances (in.)</u>	<u>Miss Distances (μ)</u>
1	3.5×10^{-4}	8.9
2	3.6×10^{-4}	9.1
3	3.7×10^{-4}	9.4

Table 4: Calculated Miss Distances for Three Lens Positioners by Method 3.

Figure 14: Miss Distance Based on Translation of Lens Positioner and Motion of Target.

3.0 Summary of Results

The Nova target chamber and the Nova space frame which supports the chamber constitute a very complicated structural system. A number of simplifying assumptions were required to reduce the problem of obtaining the displacements to one which could readily be solved. Because of this, the calculated miss distances represent, at best, an approximation.

The estimated miss distances by each method range as shown below:

Method 1	$10 \mu \rightarrow 25 \mu$
Method 2	$4.1 \mu \rightarrow 4.6 \mu$
Method 3	$8.9 \mu \rightarrow 9.4 \mu$

We believe Method 1 provides an upper bound and is more conservative than necessary. Method 2 provides a lower bound since target motion is not included, while Method 3 provides a "best estimate" based on data available at this time. We feel miss distances of 10μ should be expected due to ambient vibrations of the target chamber/frame structure. This error is acceptable for Nova Inertial Confinement Fusion target alignment.

The spectrum used to define the ground motion was estimated based on past measurements. Currently, the Structural Mechanics Group is making measurements on the target chamber/frame to verify the level of ambient vibration used in the analysis.

4.0 ACKNOWLEDGEMENT

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APPENDIX "Miss" Program


```

9 form. 10x,"nodal locations :",//,10x,"node =",15,5x,"x=", 1.10,5x
1,"y=",e20.10,5x,"z=",e20.10,/)
10 format(10x,"node =",15,5x,"x=",e20.10,5x,"y=",e20.10,5x,"z=",e20.10,/)
11 format(10x,"nodal displacements:",//,10x,"node =",15,5x,"x=",e20.10,5x
1,"y=",e20.10,5x,"z=",e20.10,/)
12 format(10x,"node =",15,5x,"x=",e20.10,5x,"y=",e20.10,5x,"z=",e20.10,/)
13 format(10x,"distance by which line of sight of displaced lens ",
1"positioner misses target =",e20.10)
14 format(10x,"node locations prior to adjustment....",//)
15 format(10x,"adjusted location of outer point on lens positioner:",//)
16 format(10x,"locations of nodes after displacements are added in ",
1"and displacement components",//)
17 format(10x,"target is hit ..... no miss!!",////)
18 format(10x,"target",10x,"x=",5x,e20.10,"y=",5x,e20.10,"z=",e20.10,////)
19 format(10x,"node =",15,5x,"x=",e20.10,5x,"y=",e20.10,5x,"z=",e20.10,
1"////)
c
c determine how many lenses to consider this run
c
      read(5,1)n1lens
      read(5,2)uxt,uyt,uzt
      read(5,2)duxt,duyt,duzt
      do 50 i=1,n1lens
      read(5,3)nodei(i),nodej(i)
      read(5,4)xloci(i),yloci(i),zloci(i)
      read(5,5)xlocj(i),ylocj(i),zlocj(i)
      read(5,6)uxi(i),uyi(i),uzi(i)
      read(5,7)uxj(i),uyj(i),uzj(i)
50 continue
      do 200 k=1,n1lens

      write(6,8)nodei(k),nodej(k)
      write(6,14)
      write(6,9)nodei(k),xloci(k),yloci(k),zloci(k)
      write(6,10)nodej(k),xlocj(k),ylocj(k),zlocj(k)
      write(6,18)uxt,uyt,uzt

c
c adjust location of outer point for collinearity
c
      t(1)=xloci(k)
      t(2)=yloci(k)
      t(3)=zloci(k)
      d1=xlocj(k)-xloci(k)
      d2=ylocj(k)-yloci(k)
      d3=zlocj(k)-zloci(k)
      dist1=sqrt(t(1)**2+t(2)**2+t(3)**2)
      dist2=sqrt(d1**2+d2**2+d3**2)
      scale=(dist1+dist2)/dist1
      xlocj(k)=t(1)*scale
      ylocj(k)=t(2)*scale
      zlocj(k)=t(3)*scale
      write(6,15)
      write(6,19)nodej(k),xlocj(k),ylocj(k),zlocj(k)

c
c add incremental displacements to coordinates of endpoints
c
      do 100 i=1,n1lens
      xloci(i)=xloci(i)+uxi(i)
      yloci(i)=yloci(i)+uyi(i)
      zloci(i)=zloci(i)+uzi(i)

```



```

        xlocj(1)=xlocj(1)+uxj(1)
        ylocj(1)=ylocj(1)+uyj(1)
        zlocj(1)=zlocj(1)+uzj(1)
188 continue
        uxt=uxt+duxt
        uyt=uyt+duyt
        uzt=uzt+duzt
c
c      form a and b vectors
c
        a(1)=xlocj(k)-xloci(k)
        a(2)=ylocj(k)-yloci(k)
        a(3)=zlocj(k)-zloci(k)
        b(1)=uxt-xloci(k)
        b(2)=uyt-yloci(k)
        b(3)=uzt-zloci(k)
c
c      form c vector
c
        call cross(a,b,c)
c
c      form d vector
c
        call cross(c,a,d)
c
c      unitize d
c
        dmag=sqrt(d(1)**2+d(2)**2+d(3)**2)
        if(dmag .eq. 0.) go to 282
        d(1)=d(1)/dmag
        d(2)=d(2)/dmag
        d(3)=d(3)/dmag
c
c      calculate the miss distance
c
        call dot(d,b,e)
        dist(k)=e
c
c      echo input and write miss distance
c
        write(6,16)
        write(6,9)nodei(k),xloci(k),yloci(k),zloci(k)
        write(6,10)nodej(k),xlocj(k),ylocj(k),zlocj(k)
        write(6,18)uxt,uyt,uzt
        write(6,11)nodei(k),uxi(k),uyi(k),uzi(k)
        write(6,12)nodej(k),uxj(k),uyj(k),uzj(k)
        write(6,18)duxt,duyt,duzt
        write(6,13)e
        do 198 j=1,3
            a(j)=0.
            b(j)=0.
            c(j)=0.
            d(j)=0.
            e=0.
198 continue
208 continue
        if(dmag .ne. 0.) go to 283
282 write(6,17)
283 continue

```

```

        call exit
        end
        subroutine cross(a,b,c)
c
c   this subroutine calculates the cross product of two
c   input vectors (a and b) and puts the components of
c   the resulting vector in c.
c
        dimension a(3),b(3),c(3)
        c(1)=(a(2)*b(3))-(a(3)*b(2))
        c(2)=(a(3)*b(1))-(a(1)*b(3))
        c(3)=(a(1)*b(2))-(a(2)*b(1))
        return
        end
        subroutine dot(a,b,c)
c
c   this subroutine calculates the dot product of two
c   vectors (a and b) and sets the resulting scalar
c   equal to c.
c
        c=(a(1)*b(1))+(a(2)*b(2))+(a(3)*b(3))
        dimension a(3),b(3)
        return
        end

```