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MECHANICAL RESPONSE OF DT TARGET TO ACCELERATION FOR A LASER POWER PLANT

E. Valmianski[1] and R.W. Petzoldt[2]

[1]*Consultant to General Atomics, P.O. Box 85608, San Diego, California, 92186-5608*
[2]*General Atomics, P.O. Box 85608, San Diego, California, 92186-5608*
valmians@fusion.gat.com

Mechanical response of DT targets to acceleration was analyzed using the finite element method for Inertial Fusion Energy (IFE) targets and for smaller targets that have been proposed for an upcoming Fusion Test Facility (FTF). Analysis was done in the temperature and acceleration regions of interest for Inertial Fusion Energy (14-19 K and 1,000–10,000 m/s^2). In these ranges, von Mises stress distribution, axial deflection, and the minimum value of support membrane attachment angle as well as free vibrations of the target after it leaves the injector were calculated. The role of the outer polymer coating, the support membrane attachment angle and the DT void pressure in the mechanical response of a DT target to acceleration was considered. Analysis shows, assuming that DT mechanical properties are equivalent to D_2, that IFE and FTF targets should withstand acceleration of up to 10,000 m/s^2 with negligible deformation.

I. INTRODUCTION

The ability of the DT target to withstand acceleration during injection is a key issue in the target injector design. Acceleration stress, axial deflection, and free vibration after acceleration directly affect target survivability and limit the required length of the injector.[1-3] The goal of this analysis is to understand the mechanical response of the DT target to acceleration and to give a comprehensive overview of the role of DT void pressure, outer polymer coating, and support membrane attachment angle in this response. Analysis of the mechanical response of the DT target to acceleration and calculations of von Mises stress distribution, axial deflection, and the minimum value of support membrane attachment angle as well as free vibrations were made in temperature and acceleration ranges of 14-19 K and 1,000-10,000 m/s^2.

We evaluated two targets. The baseline direct drive IFE target for the high average power laser program[4] and a much smaller target proposed by the Naval Research Laboratory for the Fusion Test Facility.[5]

II. ANSYS MODEL AND MATERIAL PROPERTIES

The ANSYS software package was used for a two dimensional finite element analyses of the DT target response to acceleration. Because mechanical properties data for DT is not available (measurements of DT ice mechanical properties are planned at Los Alamos National Laboratory), D_2 data[6] was used adjusted for the lower D_2 triple point. Adjusted values of the Young's modulus and yield strength used in these calculations are presented on Fig. 1.

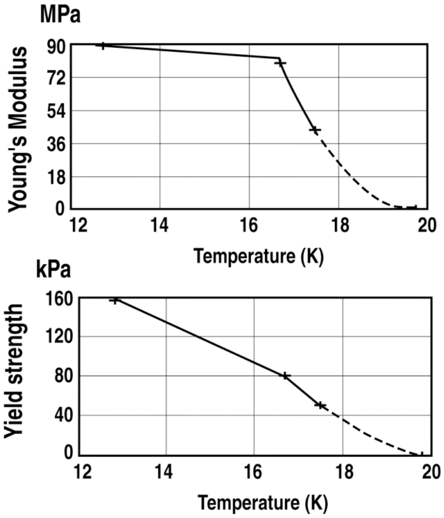

Figure 1. Estimated values of Young's modulus and yield strength in DT (experimental data for D_2 are designated by the symbol +).

It is assumed that the membrane and the outer polymer coating are made of an elastic material with density of 1,000 kg/m^3 and Young's modulus of 5.4 GPa (polystyrene). The values of DT density and Poisson's ratio used in these calculations are shown in Table I.

Table I. DT Mechanical Properties

Temperature (K)	Density (kg/m^3)	Poisson's ratio
14	257	0.311
15	257	0.311
16	256	0.311
17	255	0.312
18	254	0.312
19	253	0.313

Calculations were made for IFE and FTF targets with a support membrane attachment angle of 41° and axisymmetric geometry. In IFE and FTF targets, the outer radii are 2.29 mm and 1.189 mm, while the inner radii are 1.78 mm and 0.899 mm. The thickness of the outer polymer coating for both targets is 5 μm. The targets are assumed to be supported by 5 μm thick membranes departing the target at an angle of φ on which they are free to slide and pull away. The boundary conditions include fixed outer edge of the membrane and fixed boundaries along the symmetry axis.

The ANSYS model used in these calculations is shown on Fig. 2. The DT fuel is divided into 800 elements, as shown in Fig. 3, the outer polymer coating is divided into 100 elements, and the membrane into 195 elements.

III. VON MISES STRESS DISTRIBUTION IN THE ACCELERATING DT TARGET

Von Mises stress, a scalar function of the stress tensor components, is a theoretical measure of stress and is used to estimate the yield failure criteria in ductile materials. In our analysis, we consider von Mises stress as a yield criterion for a DT target during acceleration in the injector. Yielding occurs when von Mises stress exceeds the yield strength in tension. A typical picture of von Mises stress distribution in an IFE target with an outer polymer coating is presented in Fig. 3. It is seen that for a = 6,000 m/s^2 and T = 18 K, von Mises stress varies from 57 Pa to 11.3 kPa in a small area.

To evaluate IFE and FTF targets survivability dependence on outer coating and DT temperature calculations of von Mises stress distribution for different accelerations were made. An example of these calculations for an IFE target with and without a 5 μm outer polymer coating is presented on Fig. 4.

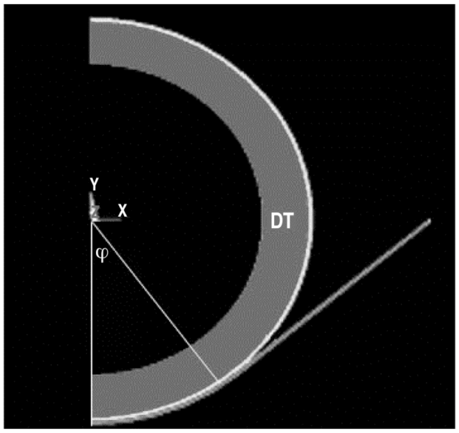

Figure 2. ANSYS model of DT target. The thickness of membrane and shell are not to scale.

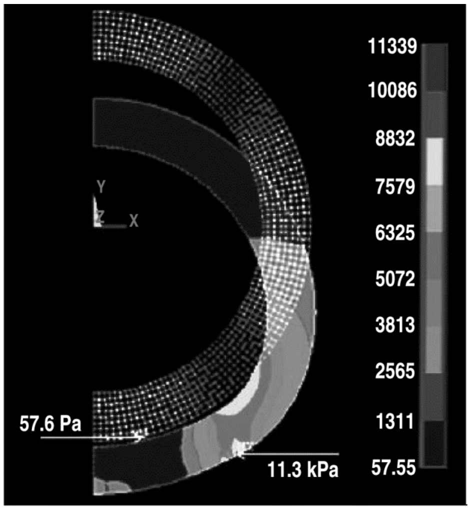

Figure 3. Von Mises stress distribution in DT of IFE target, a = 6000 m/s^2, T = 18 K, estimated yield strength = 35 kPa. Undeformed model and deformed shape scaled by a factor of 450 are presented.

It is seen that the maximum value of the von Mises stress is approximately proportional to the acceleration. Also, the outer polymer coating of 5 μm significantly decreases the von Mises stress. It is especially important in the temperature range of 17.5-19.0 K and acceleration of 10,000 m/s^2 where an IFE target cannot survive without a coating.

Similar calculations show that FTF targets, even without outer polymer coating, can survive acceleration and temperature of up to 10,000 m/s^2 and 18.8 K. With coating, FTF targets can survive at 19 K.

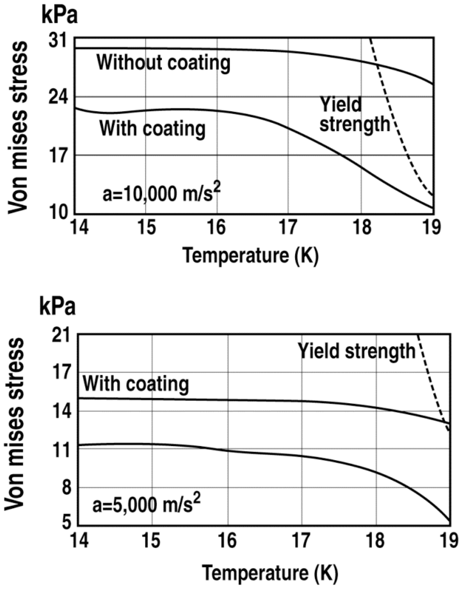

Figure 4. Maximum value of von Mises stress dependence on temperature for an IFE target.

Support membrane attachment angle affects von Mises stress and, thus, the survivability of the target. This issue must be taken into the consideration in the sabot design for a direct drive target. Estimation of the minimum value of the support membrane attachment angle for which the von Mises stress is smaller than the yield strength was made. The minimum values of the support membrane attachment angle at 18 K for IFE and FTF targets in the acceleration range 1,000–10,000 m/s^2 are shown in Fig. 5.

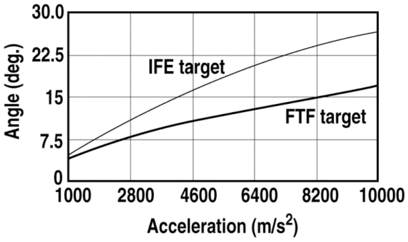

Figure 5. Minimum support membrane attachment angle dependence on target acceleration at T = 18 K.

IV. AXIAL DEFLECTION IN THE ACCELERATING DT TARGET

Axial deflection in an accelerating DT target determines the amplitude of free vibrations of the target the difference between the maximum and minimum values of the displacement in the Y direction at the top and the bottom of the target. Figures 6 and 7 present ANSYS calculations of the axial deflection for the temperature range of 14-19 K at 10,000 m/s^2 acceleration for IFE and FTF targets.

It can be seen from Figs 6 and 7 that in the temperature range of 14-17 K, the influence of the outer polymer coating on the axial deflection is insignificant, but for the temperature range of 17-19 K, the outer polymer coating significantly decreases the axial deflection. For example, at 19 K and acceleration of 10,000 m/s^2, the axial deflection for IFE target with 5 μm outer polymer coating is 10 times less then that of the DT target without an outer polymer coating.

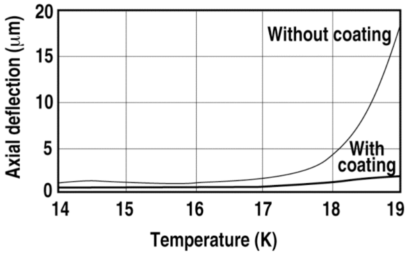

Figure 6. Axial deflection of IFE target dependence on temperature for acceleration of 10,000 m/s^2.

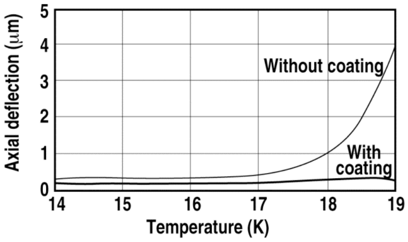

Figure 7. Axial deflection of FTF target dependence on temperature for acceleration of 10,000 m/s^2.

The influence of the DT void pressure on axial deflection was also analyzed. Calculations show that, in the temperature range of 17-19 K, the DT void pressure varies from 4.85 kPa to 7.85 kPa and insignificantly affects the axial deflection for IFE and FTF targets.

V. FREE VIBRATION OF THE DT TARGET

After acceleration in the injector, the target is subject to free vibrations. Considering the DT target as a thick shell,[7] the lowest frequencies of free vibrations can be calculated using:

$$f_{n,k} = \frac{\Omega_{n,k}}{2\cdot\pi}\cdot\sqrt{\frac{E}{a^2\cdot\rho}} \quad . \qquad (1)$$

Where E is the Young's modulus of the shell material, ρ is the density of the shell material, and a is the middle radius of the shell. For $k=1$ and $k=2$ $\Omega_{n,k}$ is given by:

$$\Omega_{n,1} = \frac{1}{2\cdot(1-\mu^2)}\cdot\left(A+\sqrt{A^2-4\cdot m\cdot B}\right) \quad , \qquad (2)$$

$$\Omega_{n,2} = \frac{1}{2\cdot(1-\mu^2)}\cdot\left(A-\sqrt{A^2-4\cdot m\cdot B}\right) \quad . \qquad (3)$$

In formulas (2) and (3) μ is the Poisson ratio, A and B are given by:

$$A = 3\cdot\left(1+\mu\right)+m+\frac{1}{12}\cdot\frac{h^2}{a^2}\cdot\left(m+3\right)\cdot\left(m+1+\mu\right) \quad , \qquad (4)$$

$$B = 1-\mu^2+\frac{1}{12}\cdot\frac{h}{\mu}\cdot\left[\left(m-1\right)^2-\mu^2\right] \quad , \qquad (5)$$

where $m = n\cdot(n+1)-2$, $n = 0,1,2,\ldots$ and h is the thickness of the shell. The branch $\Omega_{n,1}$ is dominant in in-plane motion, and $\Omega_{n,2}$ is dominant in transverse motion.

Influence of temperature on the lowest frequency of transverse vibration for the IFE and FTF targets is presented in Fig. 8.

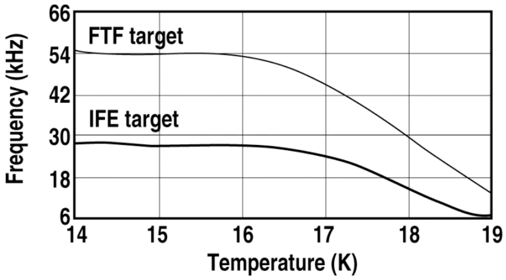

Figure 8. Influence of temperature on the lowest frequency of transverse vibration at acceleration of 10,000 m/s^2.

The amplitude of free vibrations was estimated using ANSYS generated data of axial deflection in the accelerating target. The estimation shows that the amplitude is negligibly small (not more than 0.12 µm for an FTF target and not more than 0.92 µm for an IFE target at 18 K and acceleration of 10,000 m/s^2).

VI. SUMMARY AND CONCLUSION

The mechanical response of IFE and FTF DT targets to acceleration was analyzed in the temperature and acceleration ranges of 14-19 K and 1,000-10,000 m/s^2. It was found that while an outer polymer coating decreases the von Mises stress and axial deflection, DT void pressure has no affect. It was also calculated that, depending on target radius, temperature, and acceleration, there is a minimum value of the support membrane attachment angle needed for target survivability; and free vibrations, even without damping, do not significantly affect the target symmetry.

This analysis allows us to conclude, assuming that DT mechanical properties are equivalent to D_2, that IFE and FTF targets should withstand acceleration of up to 10,000 m/s^2 with negligible deformation.

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