Dynamic Stress Analysis of Light Ion Fusion Target Development Facility Reaction Chambers

E.G. Lovell and R.L. Engelstad

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DISCLAIMER

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DYNAMIC STRESS ANALYSIS OF LIGHT ION FUSION TARGET DEVELOPMENT FACILITY REACTION CHAMBERS

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ABSTRACT

Preliminary structural analysis and design is presented for the reaction chamber of a preconceptual light ion beam target development facility (TDF). The chamber consists of a capped, reinforced cylindrical shell submerged in a water shield. Axisymmetric response is determined for blast waves generated by target ignition. From the analysis, design curves are developed for dynamic displacements and flexural stresses of the shell wall. It is shown that the added mass effect of the water can substantially reduce the response and that a practical design is possible for a range of geometric parameters and materials.

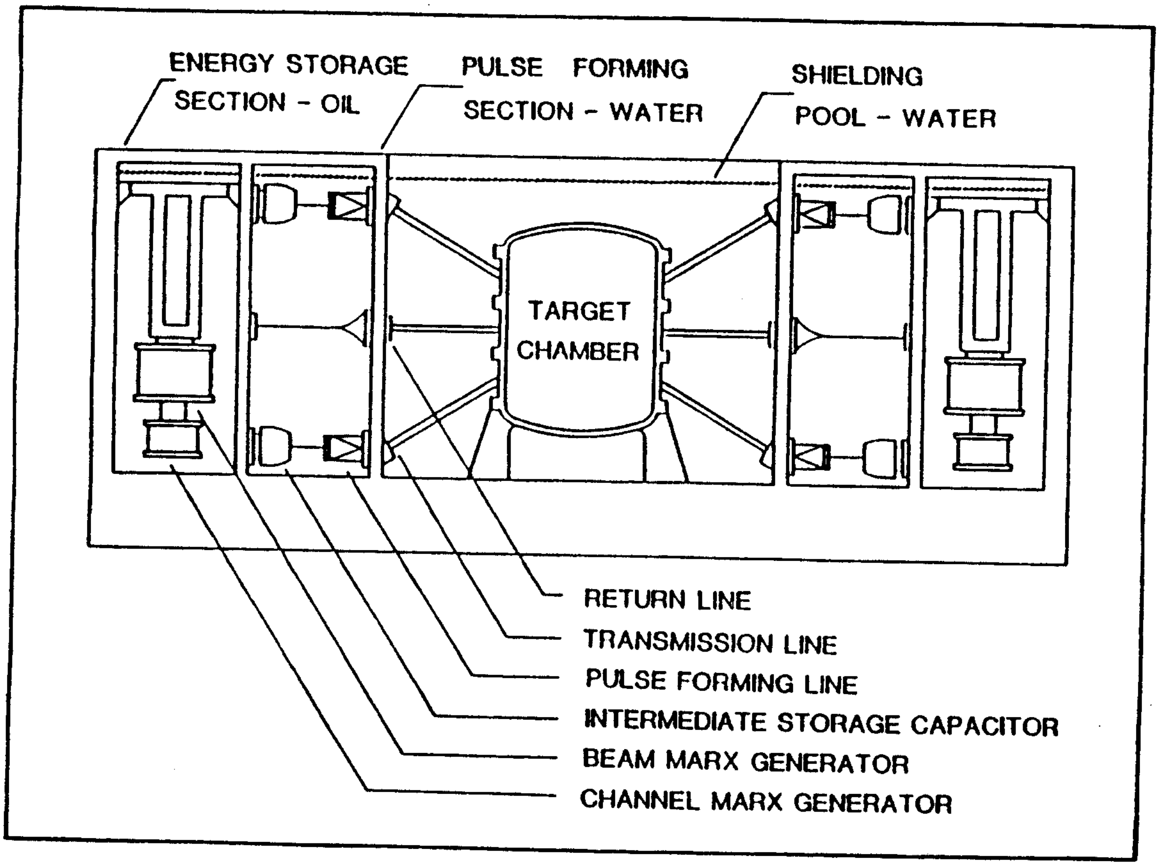

Fig. 1. Conceptual light ion fusion target development facility.

INTRODUCTION

A preconceptual design study of a light ion fusion target development facility has been initiated by Sandia National Laboratories (SNL). An overview and progress report on the study has been presented by Moses.[1] Figure 1 shows a schematic diagram of the TDF, having an annular configuration and pulsed power system similar to the SNL-PFBA-I facility. The reaction chamber is a capped cylindrical shell with a 6 meter height and diameter. For shielding purposes, it is submerged in a water pool, the surface of which can be lowered for access to the chamber. It has also been proposed that a screen of air bubbles be continuously generated in the water to absorb shocks originating at the chamber wall. A number of structural materials have been considered for the chamber[2] including Al 6061 and 5086, 304 SS, HT-9, Ti-6Al-4V, Cu-Be C17200 and C17600. Of these, the aluminum alloys have the best combination of high strength-to-weight, low cost, good thermal shock resistance and low induced activity.

The strongest influence on the mechanical design is the blast wave produced by target ignition. Earlier mechanical designs were based upon a cylindrical shell reinforced by a system of mutually orthogonal ribs and stringers.[3] Individual wall components were modeled as plates and dynamic stresses and deflections were determined on this basis. In this paper, an alternative, but similar design is considered in which the basic shell is reinforced by rings equally spaced at 2 meter intervals.

SHELL ANALYSIS

A schematic representation of the chamber alone is shown in Fig. 2. For relatively stiff rings, each shell section may be considered independently, with end conditions characterized by zero displacement and slope. Maximum static or dynamic flexural stress occurs at the ends in the axial direction as shown in Fig. 3. The displacement profiles are generally uniform over a considerable portion of the length with high gradients near the ends, as in Fig. 4, in which w, p, R and E denote displacement, pressure, radius and elastic modulus, respectively.

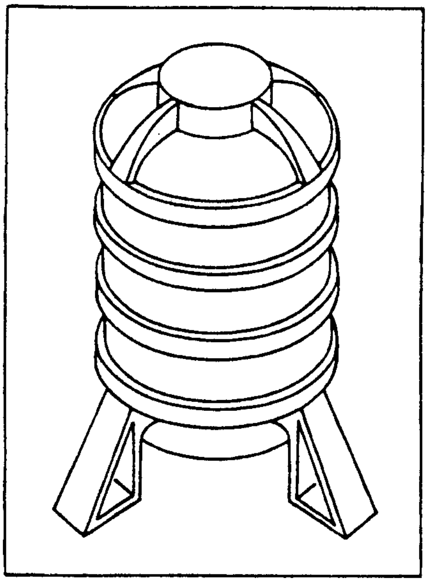

Fig. 2. Schematic diagram of target chamber.

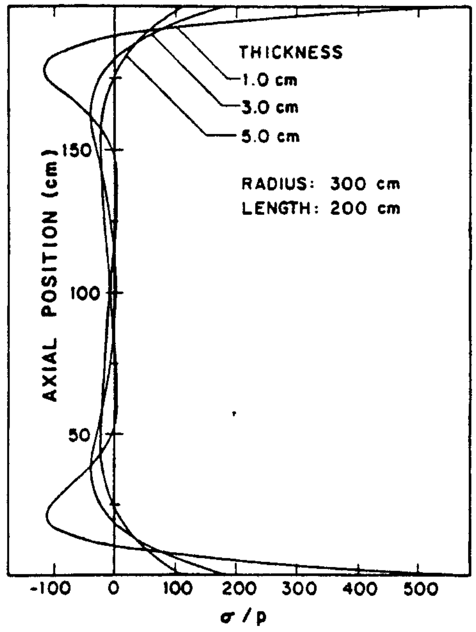

Fig. 3. Dimensionless static stress vs. axial position.

The dynamic response of the shell sections can be determined by multiplying quasi-static displacements and stresses by modal dynamic load factors (i.e., dynamic load functions). Solution accuracy increases with the number of modes included, but few are needed for axisymmetric cases. The dynamic loading is characterized as the product of an amplitude F_{max} and a time-dependent forcing function f(t). The blast wave can be represented by a linear ramp with rise time t_r and an exponential function with decay constant k. Analytical representations of such dynamic load factors are rather complex, particularly with damping, and have been summarized by Engelstad and Lovell.[4]

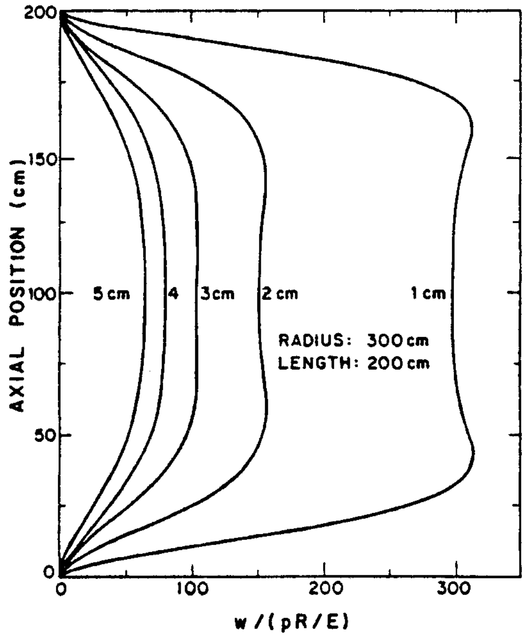

Fig. 4. Dimensionless static deflection vs. axial position.

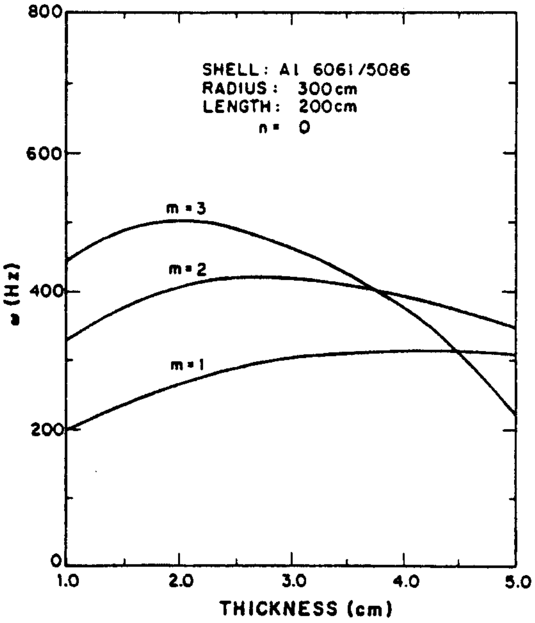

Fig. 5. Fundamental, second and third harmonic frequencies vs. thickness for a shell in water.

For design purposes, it is necessary to determine vibration frequencies of the shell. Typical results are shown in Fig. 5 for axisymmetric modes ($n = 0$) with 1, 2 and 3 axial half-waves. Dynamic overpressures are obtained from fireball code calculations such as the extreme case shown in Fig. 6.[5] As indicated by Fig. 7, maximum dynamic load factor values depend strongly upon both the vibration frequency and the level of damping.

PARTICULAR RESULTS

The extreme case considered for dynamic overpressure corresponds to a 200 MJ target yield in 70 torr of xenon, with peak amplitude of 1.71 MPa and t_r and k equal to 0.14 ms and 3432/sec, respectively (Figs. 6 and 7). Maximum dynamic flexural stress and deflection based on the fundamental frequency and a conservative damping level of 2.5% critical are shown in Fig. 8. The corresponding stress and deflection history for a 3 cm wall appears in Fig. 9. Peak stress amplitudes for 3 and 4 cm thicknesses are 182 and 140 MPa, approximately 66 and 51 percent of the yield stress.

From the displacement results, the velocity history can be determined as shown in Fig. 10. These results are used for determining pulse propagation from the chamber wall into the water shield.[6]

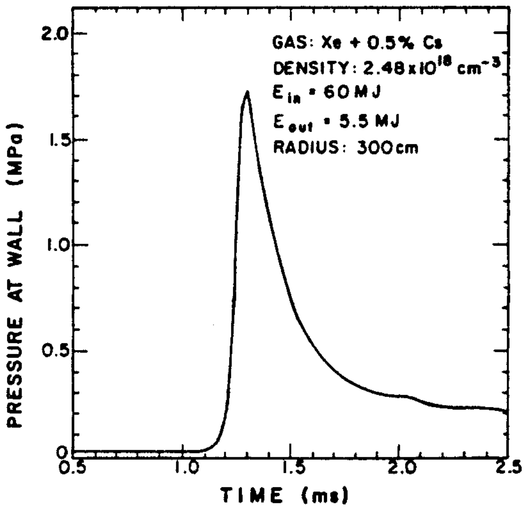

Fig. 6. Dynamic overpressure at the first wall for 200 MJ target yield.

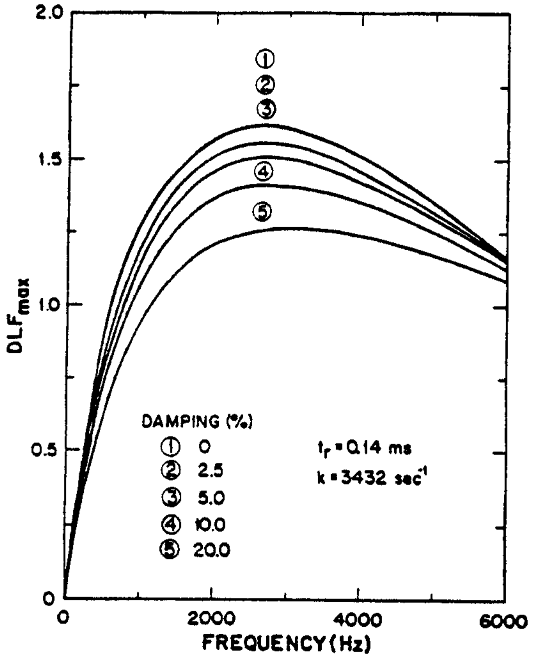

Fig. 7. Maximum dynamic load factor vs. fundamental frequency.

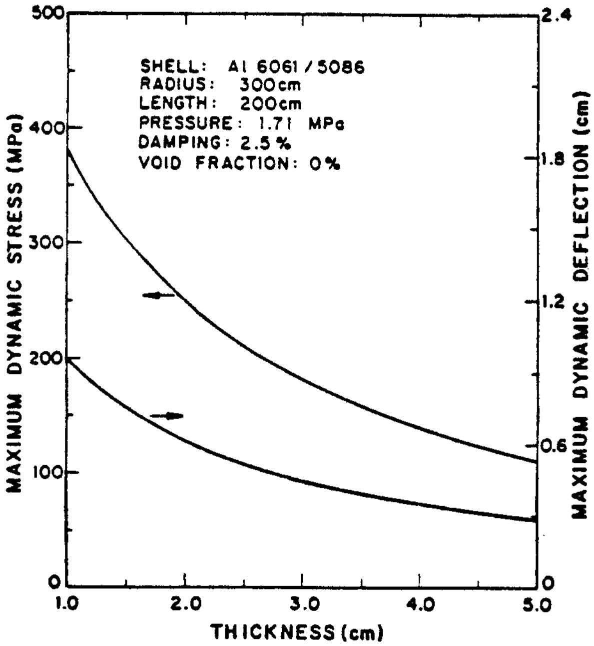

Fig. 8. Maximum dynamic stress and deflection based on fundamental frequency vs. shell thickness.

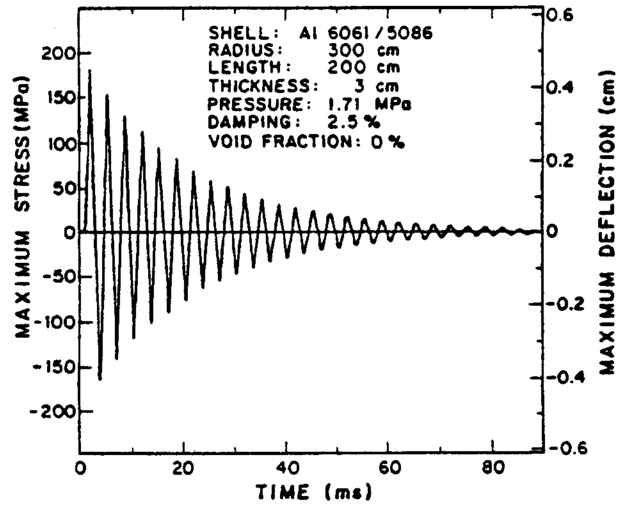

Fig. 9. Maximum stress and deflection vs. time.

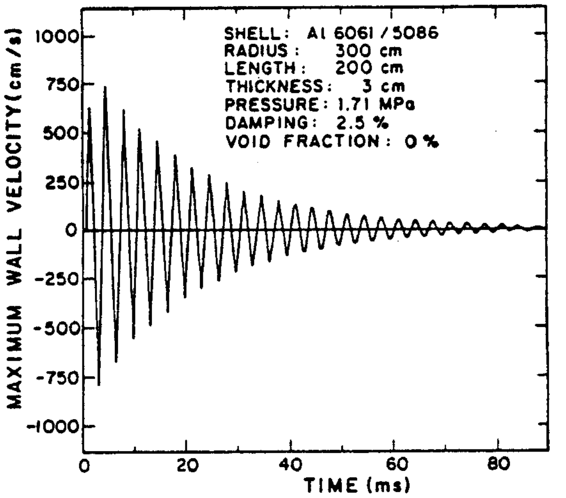

Fig. 10. Maximum wall velocity vs. time.

CONCLUSIONS

Procedures using modal analysis and dynamic load factors are convenient for estimating dynamic stresses and deflections in conventional structural systems. Such techniques have been applied to the analysis of the shell wall of a preconceptual design for a light ion fusion target development facility. In particular it is shown that acceptable stresses and deflections are possible for an Al 6061 chamber with a radius of 300 cm and thickness greater than 3 cm, loaded by the predicted blast wave from a 200 MJ target in 70 torr of xenon cavity gas.

ACKNOWLDEGMENT

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