Influence of Viscoelastic properties of Solid Propellants on Starting Transient of Solid Rocket Motors

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Abstract

Launch vehicle propellant grain, in general, is a thick-walled hollow cylinder made of viscoelastic materials bonded on its outer periphery to a thin cylindrical case. Viscoelasticity effects are manifested by the phenomena of creep under constant stress and stress relaxation under constant strain. In most of the analyses, during the starting transient simulation of solid rocket motors (SRMs), the internal flowfield geometry is held fixed. Since grain deformation can significantly alter the internal geometry, and since there is a rapid increase in the pressure load on the propellant at this time, certain SRMs may exhibit strongly time-dependent internal flowfield geometry due to the viscoelastic properties of propellant, during the starting / ignition transient. Literature review reveals that *a prior* knowledge of the grain deformation during the starting transient period of operation of high-performance solid rocket motor with complex port geometry is of topical interest.

Sanalkumar [1] one of the authors of this paper reported that the tubular test appears to be a more acceptable test than uniaxial and strip biaxial tests for characterizing solid propellants because it is more realistic method for predicting relaxation-modulus values of solid propellants and has great potential for characterizing propellants in general. Sanal Kumar [1] further reported that one possible cause of ignition peak in high velocity transient (HVT) motor is grain deformation. It may be important to note that in practical situations, if the structural response time of the propellant (time required to deform the grain) is higher than the starting transient time, then one can rule out the possibility of internal grain deformation being a cause for high ignition peak. Therefore the ballistician should have an *a priori* knowledge about the grain deformation at multi-axial stress conditions. In the design of SRMs, the

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relaxation modulus plays a key role. Propellant with higher relaxation modulus will develop crack on the surface of the grain during the actual firing condition. For those with low relaxation modulus, the grain will deform during demoulding and storing periods. It will also cause the change in shape of the inner surface of the grain during the storing periods. The configuration of the inner surface of the grain is determined mainly by ballistic considerations. Hence more realistic predictions of relaxation modulus values of solid propellants are essential for accurately evaluating the burning surface area during the starting transient period of operation of SRMs.

Sanal Kumar and Raghunandan [3] reported that relaxation modulus values of HTPB based propellant is more strongly affected change in temperature than by change in time. In a typical case, a solid propellant with 18 % metal and 86 % solid loading, we have inferred that its mechanical response time is in the order of seconds. In the actual case, ignition peak is attained within a fraction of a second and the total duration of starting transient in a solid rocket motor is in the order of milli-seconds (50 – 200 ms). Hence one can safely conclude that grain deformation will not take place during the starting transient of solid rocket motors using such propellants. However, there are many propellants which exhibit strain rate effect rapidly under transient load conditions similarly like ignition peak load. An accurate description of such deformation at multiaxial stress conditions, essentially for dual-thrust motors with complex grain geometry for high-performance rockets is of topical interest.

During the development phase, at the Indian industry, many solid rocket motors with non-uniform ports are known to have experienced abnormal high ignition peak often in the order of five times the steady state value [2]. Various measures were taken to eliminate the ignition peak, but none of the conventional remedies seemed to help. One of the flight motors with non-uniform port also experienced an ignition peak in the order of 1.8 times the steady state value. In addition, large dispersion in ignition peak behaviour is also reported for same grain configuration, nozzle throat area and propellant formulation. Although these values are within the design limit, it is desirable, in principle to eliminate the ignition peak or to ensure that the selected grain will withstand the load during flight operation without any deformation or crack.

The results of Chu, Hung-Ta, and Chou, Jung-Hua [4] show that the effect of the Poisson ratio can be significant on stress behavior of propellant grains under ignition loading. In most cases, both the maximum effective stress and the maximum principal stress exhibit a large change when the value of the Poisson ratio changes from 0.497 to 0.499 with a large reduction in the value of the compressive stress. The conventional approach of assuming the Poisson ratio of $\nu = 0.5$ (incompressible) for solid propellant grains will underestimate the stress levels of SRMs, as the compressibility has a large effect on the transient stress behavior when $\nu < 0.5$ (compressible). Admittedly, the assessment of the viscoelastic properties of propellants at flight operating conditions (multi-axial stress) and incorporating it in the models for predicting the propellant surface area and the volume (i.e., predicting the grain deformation / crack, if any, subjected to transient load) are inevitable for the accurate prediction of starting transient of SRMs.

In this paper an idealized cylindrical grain with HTPB based propellant is used for case study. Numerical studies have been carried out to estimate the radial expansion at different internal pressure and propellant properties using viscoelastic theory. Through the parametric analytical studies we have estimated the pressure limit for deformation at different propellant properties and surface temperatures of various grains. Accordingly design curves have been generated. At different pressure levels internal flow simulation of SRMs, with time dependant port geometry, also carried out using properly validated 3D k-omega turbulence model. We concluded that the fluid-structural interactive studies have great potential for the accurate performance prediction of high-performance solid propellant rockets essentially during the starting transient phase.

References

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