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NUMERICAL AND EXPERIMENTAL STUDY FOR THE BURST PRESSURE EVALUATION OF POLYIMIDE PIPELINES USED IN CRYOGENIC ROCKET STAGES FOR OPTIMAL DESIGN

Abstract

The upper stage of most launch vehicles uses cryogenic propellants. The tanks, initially at room temperature will contract while it gets filled with fuel/oxidizer. The fluid lines will be subjected to displacement loading during tank contraction. This calls for a system consisting of flexible elements to reduce the loads at support locations. The flexibility is added by providing polyimide pipeline segments. Polyimide material has low density, high flexibility (attributed to the low value of young's modulus) and high coefficient of thermal expansion which makes it an ideal material for fluid lines.

Estimation of rupture/burst pressure is useful in the design of a polyimide pipeline against effects like water hammer, pressure surge etc. To qualify the workmanship, every pipeline will be subjected to an acceptance pressure test and a sufficient margin on failure is to be ensured. This paper describes a theoretical model, proposed to predict the burst/failure pressure of a bent polyimide pipeline, used in one of the propellant feed system.

The computational domain includes a bend polyimide pipeline with steel end adaptors. Winding of Glass fiber reinforced polymer (GFRP) in helical direction is provided near the end adaptors over polyimide-steel interface. A burst criterion is evolved at, after studying failure of multiple polyimide pipelines in the past, using numerical simulations. Non-linear material models obtained after multiple specimen tests, along with accurate thickness mapping (using ultrasonic inspection) were used to predict the structural response. The results showed that the weakest location is the steel-polyimide interface and design modifications were implemented so that premature-failure at this region for low internal pressure is avoided. The optimal length and thickness of GFRP winding were evaluated after multiple non-linear finite element (FE) simulations using ANSYS. This paper also provides the results from burst tests conducted on three hardware (one without any design modification and two with proposed design changes). Test results are compared with predictions from numerical simulation.

Failure modes in tests were as predicted and results are of high reference value for devising acceptance test plans of polyimide pipelines as well as for design optimization.