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Thermal Stress Relievers in Internal Insulation of Solid Rocket Motor

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Abstract:
Solid Rocket Motor (SRM) is designed with very few moving parts for consistent performance and longer shelf life, making it attractive choice for missiles, heavy-lift applications and boosters for satellite launchers. This paper discusses the Solid Rocket Motor configuration and its processing, in brief. During its processing and operation, SRMs experience thermal stress at various stages, which, if left unrelieved, become detrimental to the operation of SRM. This paper presents the details of thermal stress relievers in the internal insulation of metallic case SRMs and composite case SRMs. Also, the challenges faced during processing of SRMs with thermal stress relievers and the improvements incorporated to overcome them, which were successfully tested in flights, are discussed in detail.

***Index Terms* – Solid Rocket Motor, Thermal stress reliever, Loose flap, Loose flap venting scheme.**

I. INTRODUCTION

Rocket uses jet propulsion, where a reaction force is imparted to a vehicle by the momentum of ejected matter. The energy source most commonly used in rocket propulsion is chemical combustion of propellants. Propellant constitutes fuel and oxidizer, stored within the rocket motor without depending on the surrounding atmosphere. A solid rocket motor (SRM) uses solid propellant for generating the required thrust.

SRM has simple design with very few moving parts, quick deployment capability, consistent performance and longer shelf life making it attractive choice for missiles, heavy-lift applications and boosters for satellite launchers.

II. SOLID ROCKET MOTOR

1. Solid Rocket Motor Configuration:

Solid Rocket Motor consists of an outer case made of high specific strength material like Mar aging Steel, D6AC, 15CDV6, Kevlar fibre, Carbon fibre etc., to contain the solid propellant in a defined geometry to achieve the desired ballistics during the motor operation. Flame inhibitor coating is applied on propellant grain surface for restricting the initial burning surface, aiding controlled burning of propellant grain to achieve desired thrust profile. SRM case is assembled with nozzle along with thrust vector control for generating controlled thrust during flight. And, in order to maintain the SRM case temperature within structural limits during the motor operation, the case is lined with internal insulation. Internal insulation being an elastomer also buffers transmission of case strain into the propellant.

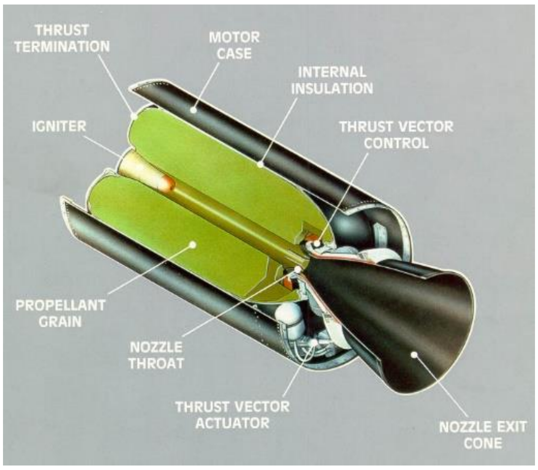

Figure 1: Solid Rocket Motor Configuration [1]

2. Solid Rocket Motor Processing

Solid Rocket Motor can be monolithic or in segments based on the size, propellant loading, processing ease, handling, maintenance and storage conditions. SRM processing involves the following steps

2.1. *SRM case preparation and testing:* SRM case can be of either metal or composite. Metallic rocket motor case is usually fabricated by plate rolling followed welding or flow forming. Composite case is made by epoxy coated composite fibres. Fabricated SRM case is pressure tested and then cleared for further processing.

2.2. *Surface preparation of SRM case before internal insulation lining:* Qualified SRM case is cleaned to remove any contamination usually by grit blasting and solvent cleaning. Cleaned surface is coated with primer and adhesive before lining the insulation.

2.3. *Lining of internal insulation on SRM case:* Prepared motor case is lined with insulation. The thickness of the insulation varies across the motor case. The variation in exposure time to the propellant combustion products, local heat flux and particle-impingement effects and desired downstream flow patterns dictates the thickness of insulation at particular zone inside the motor case. In case of SRMs of ISRO, insulation is NBR based and lined in un-vulcanized state. Upon completion of lining the case to desired profile, Vulcanization is carried out to develop insulation-case interfacial properties and insulation mechanical properties. Subsequently, insulation lined SRM is prepared for propellant casting.

2.4. *Casting & Curing of the SRM propellant:* Solid propellant is a mixture of oxidizer, fuel along with cross linking agents, anti-oxidant, burn rate modifier and process aids. Propellant is prepared in mixers and cast into the insulation lined SRM case using various casting techniques. One of the most prevalent solid propellant casting technique is vacuum casting. Feed rate of propellant during casting is an important parameter that influences the uniformity of the composition of cast propellant and density which is vital for safe and effective operation of SRM. Now, the SRM case filled with propellant is subjected to thermal cycling for propellant curing to achieve desired mechanical properties of the propellant and interfacial properties between insulation – propellant. SRM case with cured propellant is machined to designed grain shape and based on the required thrust profile, specific surface area of machined SRM is coated with inhibition material for controlled burning. During propellant curing process, SRM with insulation and propellant is subjected to thermal load and in case-bonded SRMs, stress is generated due to wide variation in thermal coefficients of SRM case material, insulation and propellant.

III. THERMAL STRESS RELIEVERS IN SRMs

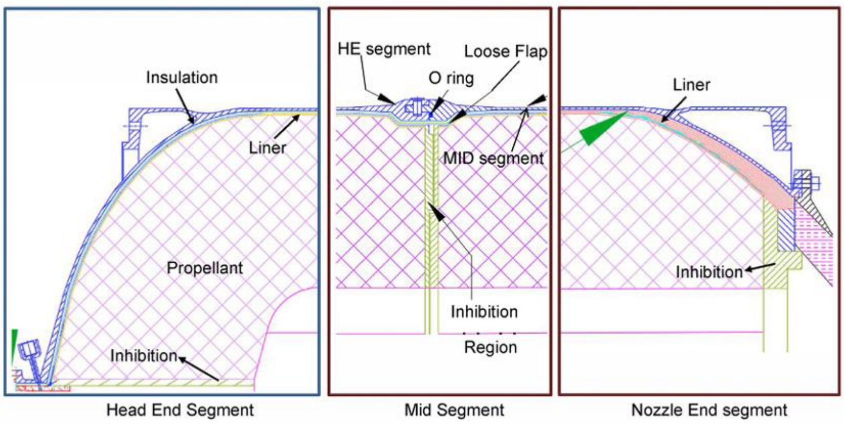

Figure 2: SRM configuration with Loose flap [3]

Thermal stress relieving is prominent aspect of solid rocket motor design and operation. The thermal stress relieving mechanism mitigates the effect of the thermal stresses generated during processing or operation of SRMs enhance the structural integrity and shelf life of the motor.

These stress relieving systems incorporate various designs such as slotted propellant grain geometry to take care the thermal stresses developed during SRM operation and free or loose members eliminate stress developed during SRM processing within its structure and components [2].

In order to accommodate the thermal stresses developed during SRM processing, thermal stress relievers are incorporated in insulation design.

In general, articulated member called free flap or loose flap is incorporated in insulation design at the ends of the motor in case of metallic case and throughout the motor length in case of composite case. Loose flap or free flap is a layer of insulation that is left un-bonded to fixed insulation. This thermal stress relieving mechanism should be active till the completion of propellant curing process. Subsequently, the free flap is filled with resin to maintain structural integrity during SRM handling and operation.

IV. LOOSE FLAP VENTING SCHEME FOR SRMS

During propellant casting of SRM, free flap at both the ends of the motor should be secured in position to avoid propellant entrapment between the loose flap and the fixed insulation while maintaining the flexibility of the member. Also, care should be envisaged during vacuum casting for evacuation of air between the loose flap and fixed insulation while the loose flap is secured at the ends. To mitigate with the requirement, a proper loose flap venting scheme should be adopted throughout the propellant casting and curing phase of SRM. Otherwise, propellant entrapped between loose flap and fixed insulation cause undesired burning during motor operation leading to disturbance in thrust-time profile. And, improper loose flap evacuation leads to voids in propellant due to the escape of entrapped air into the propellant slurry during casting along with propellant level fall at vacuum break at the end of casting leading to a defective propellant grain.

1. **Loose Flap Venting mechanism for metallic SRM case:** Prevalent loose flap venting mechanism on casting bottom side of metallic SRM case is to secure the loose flap to fixed insulation with a V-shaped bellow arrangement and to puncture or slit the loose flap for about 10 to 20 mm at the centre to evacuate the entrapped air between the loose flap and fixed insulation. And on casting top side, loose flap is secured by extending it to handling ring while maintaining vent paths at equi-spaced locations with breathing material. However, this scheme has some limitations. As the propellant level rises to the loose flap puncture or slit location, loose flap is in elongation conforming to the contour of the fixed insulation profile. This enables the slits in loose flap to allow the propellant between loose flap and fixed insulation zone. Also, as the propellant level rises beyond the loose flap slit location, there is no scope for loose flap venting and the minor amount of entrapped air will result in propellant voids after vaccum break. These limitations are dominating in domed metallic cases.
2. **Loose Flap Venting scheme for composite SRM case:** Loose Flap Venting in composite case of SRM is relatively critical as the loose flap is present throughout the length of the case. Following the prevalent practice, loose flap is punctured or slit at equally spaced locations circumferentially and as a part of securing the loose flap, cast bottom side loose flap is bonded to fixed insulation with a V- shaped bellow and loose flap is extend on casting top. However, it was observed that evacuation of air entrapped between loose flap and fixed insulation is not effective, leading to the bulging of loose flap when in vacuum and consequent propellant level fall after vacuum break at the end of casting.

V. IMPROVEMENTS IN LOOSE FLAP VENTING SCHEME FOR SRMS

1. **Improvement in Loose Flap Venting mechanism of metallic SRM case:** In order to over come this limitation, loose flap venting scheme which allows continuous evacuation of loose flap through out casting is required. For this, instead of puncturing the loose flap, V-bellow is punctured at circumferentially equally spaced locations. Number of puncturing locations depend on the volume of the zone between the loose flap and fixed insulation. This improvement in loose flap venting scheme alleviated the propellant entrapment between loose flap and fixed insulation and also aids for effective continuous evacuation of zone under the loose flap.
2. **Improvement in Loose Flap Venting mechanism of composite SRM case:** In order to over come the effect of improper evacuation of air entrapped between loose flap and fixed insulation, a continuous vent path that can evacuate the zone below the loose flap throughout the casting is required. For this, a continuous vent path thorough out the length of the composite case is created under the loose flap alleviating the need for loose flap puncturing. These vent paths are connected to the V shaped bellow bonded to loose-flap end and fixed insulation at casting bottom and to the vent paths under the extended loose flap on the casting top side. Now, the vent holes provided on the bellow and the vent paths under the extended loose flap will allow the effective evacuation of the air under loose flap continuously throughout the casting eliminating the loose flap bulging and thus reducing the propellant level fall.
3. **Separator between Loose flap and Fixed insulation:** In cases with higher L/D ratio SRM where the mandrel rests on the insulation imparting higher load intensity, cold bonding is observed between loose flap and fixed insulation. In order to overcome the effect of cold bonding, alternative casting setup where mandrel is supported from bottom instead of resting completely on the insulation is incorporated. Also, talc as a separator is smeared on contact surfaces of the loose flap and fixed insulation as a part of Loose flap venting scheme, to aid the functionality of loose flap.

VI. CONCLUSION

Solid rocket motor configuration and various stages involved in the processing of SRMs are presented in this paper. Thermal stresses are developed in internal insulation during processing of SRMs. It is essential to relieve these thermal stresses for defect-free propellant grains. Various loose flap venting schemes with improvements, pertaining to metal & composite case SRMs are presented in this paper, which were successfully implemented and tested in ISRO LVM3, PSLV & SSLV flights.

VII. ACKNOWLEDGEMENT

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